ABSTRACT OF THESIS

THE ANALYTICAL METHOD VERSUS THE TRADITIONAL METHOD OF TEACHING THE ELECTRICAL THEORY OF DIRECT CURRENT MOTORS

Submitted by
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In partial fulfillment of the requirements
for the Degree of Master of Science
Colorado State College
of
Agriculture and Mechanic Arts
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ABSTRACT

Conferences with employers and with evening extension students at Dunwoody Institute revealed several years ago, that both felt there was a very definite need for men who would be able to apply their training in the theory of electricity to the field of "trouble shooting" in electrical equipment. In an effort to solve this problem the writer has been experimenting for the past four years with new methods of presenting and explaining the theory of electricity. The analytical approach to the subject and the use of boxheads, diagrams, and skeleton arrangements found considerable favor among both trade preparatory and extension students.

Since the method was new this question naturally was: What is the effectiveness of the analytical method of presentation compared with the traditional method of teaching the theory of direct current motors? In order to evaluate the two methods the problem was set up as a scientific study. This procedure led to the following problem analysis:

1. What is the analytical method?

    a. How is it organized?

b. How is it presented?

c. How does it differ from the traditional method?

2. How are the test groups organized?

3. How are the results of the two evaluated?

4. What are the results shown by the analytical approach?

Answers to question two and three were found in the literature reviewed in Chapter II. Authorized procedures were found for setting up and checking the equivalency of the personnel in two sections used for conducting an experimental study similar to this one. Methods for evaluating the results obtained were also found and outlined in the same study.

Data for this study were obtained from the following four sources:

1. Test items were selected from the course on direct current motors given at Dunwoody Industrial Institute. The background for much of this was provided by American Electricians Handbook, Electrical Machinery by Croft, and electrical equipment bulletins provided by manufacturers.

2. The 120 test items were validated by 50 men from the St. Paul, Minnesota, Electrical Workers Union No. 110.

3. The questions set up from the test items were

checked and highly approved by four people with both trade and school experience.

4. Ten sections of electrical students were selected from the classes at Dunwoody Institute during the past four year period to receive experimental instruction.

The pursuit of the problem required the use of two teaching methods in order that data might be available for a statistical comparison of the effectiveness of the analytical procedure.

All sections covered the same shop jobs and devoted the same periods to job report "writeups" and discussion. Both groups did the same shop work and discussed shop jobs and shop procedure in class. Only in the presentation of the theory of direct current motors did the methods differ.

The traditional method used in this study presented the essential theory of direct current motors from a standard text book. Students were assigned sections from the text. After these had been studied, class discussions were held using charts, models, blackboard diagrams, and real pieces of equipment. Problems from the text were then used to insure a more complete analysis of the various situations. Sometimes these problems were worked in class; sometimes they were used as home assignments.

Such terms as terminal voltage, field flux, armature current, torque, load, speed, counter-electromotive force, and armature circuit resistance were very carefully covered and stressed in the class discussion.

On the other hand the method which was stressed in the experimental classes was a departure from the conventional procedures. Lessons were never given as memory assignments but work of such a nature was provided that the student obtained his understanding by filling in boxheads, analyzing the information in the boxheads while making immediate relations charts, and following out the relative or intermediate effects existing among the operating factors of load, speed, torque, counter-electromotive force, armature circuit resistance, and terminal voltage.[1/]

This teaching procedure developed cause and effect thinking and at the same time associated the necessary items for understanding motor operation into a skeleton framework of ideas. Such a diagrammatic arrangement through association helped the students to a concrete understanding of electric motors and enabled them to do a better job of analytical thinking as is revealed in the test results shown in the summary table (Table 10).

1./ See Appendix A.

Table 9.--COMPARATIVE RESULTS ON THE EQUIVALENCY OF GROUPS AND THE RELATIVE EFFECTIVENESS OF THE TEACHING METHODS

Criteria of equivalency	Control group (58 cases)			Experimental group (58 cases)			Difference
	Mean	S.D.	$Se\bar{x}_C$	Mean	S.D.	$Se\bar{x}_E$	t
Chronological age in months	252.327	21.382	2.81	254.172	22.970	3.01	.448 not significant
Months in Dunwoody - -	10.64	1.69	.222	11.12	1.74	.229	1.504 not significant
Shop grades in percentage -	77.707	5.908	.774	78.026	4.795	.628	.3445 not significant
Previous school years	12.02	.438	.0575	11.67	2.125	.286	.322
First administration of test	9.017	3.59	.470	7.693	3.56	.466	1.99 significant
Second administration of test	29.052	5.31	.698	31.569	4.71	.618	2.69 significant

This summary table showed the groups used in this experiment to be equal on the basis of age, previous schooling, number of months in Dunwoody Institute, and shop marks on a percentage basis for the shop time. None of these criteria exceeded the critical ratio two set up as the point of significance for this experiment.

There were certain variables in gathering the data for this report over which the experimenter had no control. The small number of classes required alternating the methods from month to month over a considerable period of time. This arrangement introduced seasonal conditions; for interest is always more keen when job prospects are good. The physical condition of the instructor might also be a variable factor.

The test developed to check the relative effectiveness of the two methods of teaching the theory of direct current motors proved to be excellent. The coefficient of reliability was .99 which is high enough for excellent individual diagnosis--something rarely found in tests unless a great deal of work has been done with them. Such a reliable instrument enhances the value of the findings shown in Table 9.

The results of this study indicate that the analytical method was superior to the traditional procedure for teaching the theory of direct current motors, at least under the conditions of this experiment. In view of the fact that the control group was significantly superior to the experimental group at the start and that the latter completed the work of the experiment with a significant difference of 2.69 over the control group, would seem to prove fairly conclusively that visual aids together with the analytical presentation provide learning experiences which are superior to those which have been used heretofore.

THESIS

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AGRICULTURE AND MECHANIC ARTS

AUGUST 1, 1941

I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY **LEON R. DRINKALL**

ENTITLED **THE ANALYTICAL METHOD VERSUS THE TRADITIONAL METHOD OF TEACHING THE ELECTRICAL THEORY OF DIRECT CURRENT MOTORS IN DUNWOODY INSTITUTE**

BE ACCEPTED AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF **SCIENCE**

MAJORING IN **TRADE AND INDUSTRIAL EDUCATION**

CREDITS **3.5**

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Permission to publish this thesis or any part of it must be obtained from the Dean of the Graduate School.

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Chapter I

INTRODUCTION

All the large manufacturers of electrical equipment maintain extensive laboratories to carry on experimental work with various materials used in making electrical devices. Here defective materials and faulty points in the design usually show up before the piece of equipment is put into industrial use. This practice and procedure make it possible for the manufacturer to put a product on the market with the defects largely eliminated. Even with equipment made as scientifically as these laboratory practices make possible, there still remains much for the practical man to do in the way of care, installation, repair, maintenance, and operation of these pieces of equipment in the field.

Unforeseen difficulties arise in the performance of the device as it operates day after day on the job. It is the responsibility of the "trouble-shooter" to discover faulty parts and machines that do not operate efficiently, and to make the necessary repairs. He is the one who knows the sources of these troubles and how to remedy them. To him is delegated the responsibility for making the machines operate.

The man responsible for keeping the wheels of industry turning has a job of considerable importance. This work of the "trouble-shooter" requires analytical thinking of a high order. He must seek the causes of most of his troubles among unseen circuits and working parts hidden from view.

The Twin City Area has a number of diversified industries, among the more important of which are milling, mining, and farm machinery manufacturing. Dunwoody Institute trains a great many mechanics who find employment in these industries. A part of these men are in the electrical field. Minnesota employers of electrical helpers trained in the school reported that these employees seemed to know the theory of electricity satisfactorily, but lacked the ability to "shoot trouble". This fact indicated they have not had enough training in the practical application of technical knowledge. For this work it is not enough merely to know the facts. Ability to use them and to apply correct methods of analysis is required of the successful "trouble shooter".

Zeleny (27:336-7) of the University of Minnesota, in an article published in Science Magazine, October 14, 1932, advocated the logical teaching of electricity in preference to the historical treatment:

The logical presentation outlined attempts to completely coordinate the well-established major phenomena in electricity and magnetism.

The logical method is held in high esteem by a large number of educators in the electrical field. Zeleny stated in the article mentioned in the previous paragraph:

> Mathematical equations giving quantitative relationships without rational concepts do not and can never fully satisfy.

This question raised by Zeleny also concerned another authority in the electrical field. Singe (21:128), in his article, "Missing Link", said, "Reduction of a physical problem to mathematics forms a bridge that many cannot cross".

Both of these scientists held similar opinions regarding the use of mathematics for training people in electrical engineering education. They agree that additional aids are needed for interpreting mathematical formulae in terms of everyday problems.

Draffin (6:728), discussing laboratory instruction in engineering education, said, "Laboratory work provides proper ways of analyzing data and reaching conclusions". Shop and laboratory are a necessary part of the work in any training course for both engineering and trade education. In this same article (6:730) in Journal of Engineering Education, June, 1935, he also made the following comments:

> Education consists in the growth of the thinking processes. For this growth to take place the student must have <u>something</u> to think <u>about</u>, he must have a scheme or manner of thinking and he must reach some kind of a <u>conclusion</u>.

If, as Draffin said, some plan or pattern of ideas is necessary to proper mental growth, why not use such a diagram or scheme in presenting these ideas to the student during the learning process?

Roys (16:511), in the April, 1938, issue of the same magazine, said, "There should be better correlation between scientific thought and practical application".

The statements of both Draffin and Roys establish a need for a better connecting link between the electrical theory as taught and practical application of this knowledge demanded on the job. Additional thought patterns and visual aids are needed to make the technical material more workable and understandable for the man whose job it is to keep electrical devices operating satisfactorily.

The early historical method, by which teaching material was presented in a chronological order, seemed to place too much dependence upon mathematical formulae. When the mathematical presentation is used, recourse to additional aids must be made in interpreting formulae into physical experiences which the practical-minded man understands. Both the historical and the mathematical methods of teaching have been almost entirely superceded by the logical arrangement explained by Zeleny.

A logical presentation attempts completely to coordinate all well-established facts and theories about any one particular subject or field of endeavor.

Rogers (15:924) called attention to the fact that how we teach is important in emphasizing the process of effective thinking. Only a few students discover basic principles of technical material unless the teacher uses his ingenuity in presenting them in such a manner that they cannot be misunderstood or overlooked.

Employers when interviewed on electrical help unanimously agree that years of experience are required before an electrician is considered to be an expert "trouble-shooter". This leads to the conclusion that the mastery of the ability to apply electrical theory in terms of practical machine operation comes slowly to the man on the job. Road maps, machine drawings, building plans and many other types of drawings and diagrams are used in many lines of endeavor as aids to an understanding of practical problems. This plan adapts the same idea to teaching the theory of electricity applied to direct current motors, in which analytical diagram is used to show the various items functioning in motor performance and aid in establishing a mental picture of the relationships of all items involved.

The elements that made up the method used with the experimental group in this study were taken from the suggestions discussed above. The two elements are the logical presentation of facts and their interpretation by students through the making of analytical diagrams. The ideas were arranged into a pattern or plan which would guide the student in his thinking and assist in drawing conclusions. The analytical diagram serves a dual purpose. In the first instance it enables the student to master the theory, and in the second it becomes a set of directions to be followed in "trouble-shooting".

The chart shows among other things the relationships among torque, load, and speed. If the torque in a direct current motor increased and the load demand upon the motor remained the same, this extra torque would pass along the line (see diagram, Appendix A) to speed, which would increase. The line in the chart from speed to load would indicate that the motor output would be raised when the speed increased. In like manner all operating conditions which affect the motor may be traced, using the chart as a guide.

The problem of applying theories and principles learned in school to actual situations in life is of real concern to sociologists, scientists, politicians, citizens, and school children. In fact, it is a universal problem. Zeleny, Roys, Singe, and Creasey (3) have studied the methods of teaching the applications of electrical principles in practical situations, while others have investigated phases of this same subject. Their suggestions have formed the basis for the major problem in this study, which stated in question form is:

> What is the effectiveness of the analytical method as compared to the traditional method of teaching the theory of direct current motors?

An analysis of this problem reveals the following subordinate questions:

1. What is the analytical method?
   a. How is it organized?
   b. How is it presented?
   c. How does it differ from the traditional method?

2. How are the test groups set up?

3. How are the results of the test evaluated?

4. What are the results shown by the analytical approach?

Some evidence relating to the problem of teaching the theory and application of principles of generators and motors is available in the research literature on the subject and provides partial answers to the subordinate questions. The review of literature follows.

Chapter II

REVIEW OF RESEARCH

The results of extensive experimentation carried on in research laboratories of large manufacturing concerns are usually made available in special reports, or the information may be found in technical papers and magazines which make this material readily available. The same is true of experimentation that has been carried on in the field of education. The research findings that relate to question two, "How are the test groups organized?", and three, "How are the results of the test evaluated?", follow:

An objective examination on electrical conduit wiring of 225 items in six groups having exceptionally high statistical ratings was prepared and evaluated by Senes (20) at the Joliet Township High School, Joliet, Illinois, during the year 1939. This work was scientifically approached and followed through with meticulous care. The coefficient of reliability for this test was .96.

The test items were selected from well-recognized sources and submitted to the opinion of two teachers, two contractors, and two journeymen electricians, following the rule laid down by Turney (24) for establishing validity. His statement for checking this most important item used in evaluating materials for test purposes follows:

> Validity is by its very nature determinable by no other means, and the only statistical treatment which is essential to the establishment of validity is that which will refine or assist in the consensus of expert opinion.

Two hundred and twenty-five items were selected in this manner, and test questions were formulated according to the method suggested by Ruch (18). A rough draft of the question was drawn upon a 3 x 5 inch card with one or two correct answers as well as several possible or probable ones; on the final draft of the test only the more suitable responses were written into the examination. As an additional check on this matter of validity the "discrimination" criterion used by Pintner, Maller, Forlono, and Axelrod (14) and supported by the work of Swineford (22) was applied. Those items of the test in which the percentage of "failure" was more than 95 percent and less than 5 percent were eliminated because they were considered as not sufficiently discriminative. This left in the test only those questions which had a reasonable probability of being valid (18:163-164). Reliability of the test developed in this work was established by the following procedures: The test was administered to 628 pupils and the results were tabulated, which revealed that items within the several groups would have to be shifted if they were to appear in an increasing order of difficulty. This shift was made, and from the results obtained all questions having little probable testing value were eliminated. The objectivity for this work was obtained by using answer keys, following the suggestion made by Odell (13), who said that whenever persons are able to score tests with a general agreement prevailing among them as to the correctness or incorrectness of all the possible answers, objectivity is present.

In order to compute the coefficient of reliability, a scatter diagram and correlation chart was prepared following the procedure used by Garrett. Data for the diagram were obtained from the scores of 628 pupils on an odd-even basis. This method provided a system of desirable cross checks. Anastasia (1) found from research that the odd-even method of calculating this coefficient was the most reliable of any of the three ordinarily used for the purpose. Garrett furnished the formula for the actual calculation work. The Spearman-Brown formula and the appropriate P E formula derived by Shen are the ones used to determine the reliability coefficient for the whole test. Actual computations of the coefficient of correlation resulted in a value of .96 for r with a probable error of +.0016, which Ruch rates as extremely high unless tests have been long and carefully standardized.

ized.

Aside from meeting the requirements of a standardized test this work might well serve the following purposes: (1) formulation of essential topics of information required by conduit electricians; (2) elimination of subjective grades; (3) improvement of instruction by making it conform more closely to job requirements; (4) development of interest among other workers in the field of objective testing. The procedure used by Senes (20:22-32) for selecting test items, setting up the test questions, validating the material, checking the reliability, and determining the coefficient of reliability offered many suggestions which were followed in making the comparison between two methods of teaching the theory of direct current motors.

During the year 1940, Josserand (9) carried out a study for the evaluation of a method of teaching ninth grade general drafting in the East Moline, Illinois, High School. In this experiment, one hundred and ten people were used, from whom 29 matched pairs were selected to form the groups. This work appears to have been carefully done and the statistical procedure used in equating groups and evaluating the method were very carefully handled. The results show definitely from the statistics that the method of making shop models in wood and paper combined with freehand sketching produces superior performance ability in the students when tested with Fischer's Mechanical Drawing Tests.

The content for this drawing course was taken from the following sources: (a) Van Deventer's survey of mechanical drawing courses in Illinois high schools; (b) the Wisconsin Industrial Arts Association Survey; (c) the investigation made in the state of Illinois of courses of study, current textbooks, and social and economic situations of high school students; (d) Hale's study; Walsh's investigation; (f) Cleveland's analysis; and (g) Honrehammer's study of current newspapers and periodicals. In addition to these sources, 100 responsible people interested in properly trained employees were personally consulted to obtain their criticism and suggestions. Also 150 workmen employed in drafting rooms in the immediate vicinity were interviewed in order to find if possible, just what was needed in a drawing course of this kind.

For the authority in comparing and equating the two groups used in this experiment, the following research studies are quoted: (1) Kruger's study to determine the significance of group influence upon Otis S.-A. test scores; (b) Babcock and Emerson's study of the MacQuarrie test for mechanical ability; (c) Bingham's report of Pond's study to determine the relationship of a person's true score and his obtained score; (d) Fischer's study of his own mechanical drawing tests; (e) Gates and Taylor's techniques for equating groups;

(f) Englehart's analysis of techniques; and (g) Anibel's methods of pairing students.

Equivalency of the two groups set up for this study was determined by using for comparison the chronological age, the previous school work, the intelligence quotients (from the Otis test), and grades received on the MacQuarrie Mechanical Ability Test. No significant differences were found in the equivalency from using the general formula. Fischer's mechanical drawing tests part I and part II are recognized as being valid and reliable for testing drawing proficiencies. Part I was given at the start of the course to determine the group abilities, and part II was administered at the completion of the work to measure achievement. The statistical figures showed definite superior drawing ability when models and freehand drawing were used.

It was suggested that the procedure carried out in this experiment should be handled by a number of teachers and should be tried out over a period of three years so that larger numbers could be used. Wider distribution might show whether locale had any effects on the results.

In a study entitled The Relationship between Industrial Arts Courses and Occupational Choices, covering 160 cases drawn from the 1938-39 student body of Dunwoody Institute, Minneapolis, Minnesota, Miller (10) reported that the students who had taken industrial arts work in high school were able to make more reliable occupational choices than those who had not had such experience. The findings from two groups of matched pairs used in this study tend to indicate also that industrial arts courses have helped the students to some extent in discovering and developing their occupational interests and aptitudes.

Before one could state authoritatively that interests and aptitudes had been definitely discovered and developed by industrial arts experiences, a follow-up study would be necessary after the individuals had been out on the job for several years.

Several sources of information and a variety of facts were enumerated at the beginning of this study. Some of the more interesting ones are given. Porter collected 194 questionnaires from high school boy and girl graduates of three northern Colorado counties. The high school subjects considered most helpful were commercial courses, English, and mathematics. Kennedy, using 515 individuals from Lane Technical High School of Chicago, Illinois, found that 52.2% of all Lane graduates engage in technical and industrial occupations and that 47.8% of all graduates enter occupations for which the curriculum does not aim to provide proper training; Campbell collected 187 questionnaires which indicated that high school industrial arts helped 80% of the workers in their vocations, and a like percentage used this training as recreation; Clodfelter made an occupational survey of the graduates of Dewey High School in Dewey, Oklahoma. He found that the high school courses prepared the students for college, but only 18% of the boys and 17% of the girls go either to college or to business college.

This information used in Miller's study was obtained from the following sources: personal interviews with the student, questionnaires, and office records of Dunwoody Institute.

The factors used by Miller (10) to check group equivalency were chronological age, school attendance, number of months at Dunwoody, and the average shop grade obtained from the numerals 1, 2, 3, 4, and 5 used as shop ratings.

Dunwoody ratings are given as numerals 1, 2, 3, 4, and 5, and have percent equivalents as shown below.

1 = 90 % to 100 % inclusive; average = 95.00%

2 = 80 % to 89 % inclusive; average = 84.50%

3 = 70 % to 79 % inclusive; average = 74.50%

4 = 60 % to 69 % inclusive; average = 64.50%

5 = Failure

The method used by Josserand (9:34-48) and Miller (10:20) for setting up and checking group equivalency offered the writer very material aid. Because of the similarity of the procedure and the fact that the problem had to be solved by the experimental method, the same sources used by these men could be employed by the writer for this part of the problem. Both used matched pairs of individuals in forming the personnel of the groups; the same factors, chronological age, previous school work, number of months in Dunwoody Institute, and the shop grades used by Miller (10:20) for checking the equivalency of the groups, were employed in this study, but the statistical procedure used by Josserand (9:36) formed the basis for the conclusions reached on this item.

The procedure followed by Senes (20:25-32) in the preparation and validation of the test of 225 items on electrical conduit wiring provided the writer with many valuable suggestions. As it was necessary in this study as well as in the one just mentioned to prepare and validate a test, the recognized method of selecting and validating the list of items was used. The methods used in preparing test questions, securing validity, and insuring reliability, outlined in this work, were followed in detail, and question number two has been answered by the research literature.

The research methods outlined by Josserand (9:49-73), which he followed in pursuing and evaluating data for two methods of teaching drawing, furnished the entire plan required for answering question number three in this experiment.

The following abstract of a study made in 1924 at the University of Pittsburgh by Crawford (2) on the subject, "Effect of Visual Aids, Additional to text, on Learning in Technical Electrical Theory", has an interesting bearing on this experiment.

It is acknowledged by educators that visual aids, where theory gets too difficult or abstract, are a great help to the student. After he learns the facts and masters the skill involved, such as square root or the trigonometric functions, he can use them as tools. But it is often desirable to perform the operation needed and investigate the tools at a later time, especially in a vocational or technical high school. In such a class as advanced electrical theory, without the advantages of individual laboratory work, it is advisable to have the student grasp the over-all vein of the subject matter and later develop the technical formulae he already has learned to use. One way to do this is to have the boy use simple visual mechanical devices to perform for him the task yet outside his technical ability range. Incidentally, he will after a time want to know why the device he has used functions as it does; and then he, as an individual or as a member of the class, will be taught the necessary mathematics or science involved. Usually, however, he will of his own accord learn the needed technicalities out of sheer interest aroused by the ingenuity of the device itself. Occasionally, such devices or mechanisms may even inspire a student to develop other such aids to his own thinking, thus furthering his power of analysis and constructive thought at a rapid pace. This ability after all is the main aim of all education.

This particular research carried out on a statistical basis permits the following inferences to be stated:

(a) Where a good visual-mechanical device was used by the student, even without any special classroom mention or discussion, an appreciable increment in better learning of the subject matter involved resulted.

(b) Where classroom stress was given to use of the device, a still greater increment resulted.

(c) Were such mechanisms made and attached to textboods to be copied or used by the student, many parts of technical material now left out or merely skimmed could be adequately handled and mastered by the student, even though he had not yet mastered the usually requisite technical mathematics.

(d) The use of such devices would appreciably cut down the time given to lengthy book and classroom discussion of data as well as the usual trying repetition of data.

In many cases, in which even laboratory exercises would not fully acquaint the student with all the facts of a technical situation in an electrical problem, all possible avenues should be set up and used as byways toward a fuller and more analytical understanding. Among these methods is the use of visual aids.

Additional evidence supporting the findings of Crawford was also found in a study carried out by Haynes

(8) at the University of Chicago, Chicago, Illinois, on the subject, "Pupil Self-Rating Scales in Applied Electricity". Construction of three rating scales in electricity used in classrooms to determine effect on the learning process, using a control and experimental group, showed the following results:

Pupils profited by the use of scales; groups using scales made more gain on making joints than groups not using scales.

Walters (26) developed a manual of experiments in direct and alternating current electricity at the University of California in 1929. This manual is comprised of 50 experiments of a semi-professional level. It should be helpful in organizing a shop and laboratory course for students taking work of less than college grade-A level of the work at Dunwoody Institute where trade and industrial education is stressed.

Norton (12), in <u>Education</u> <u>for</u> <u>Work</u>, written for the Regents' Inquiry, 1938, found some very interesting facts in the survey made of the schools in New York State. Some of the more pertinent ones bearing on this study are quoted:

> Skill requirements in many lines of activity are in a constant process of alteration. (12:4)

> Continued technological change means that any training program may be subject to modification, and school administrators, therefore, must keep abreast of current developments. (12:8)

> With the increasing importance of technically trained men in industry, it is becoming more difficult for men to rise from the factory floor. (12:15)
>
> The major objective of the unit technical course is vocational, the preparation of pupils for employment in industrial occupations requiring technical skill, that is in fields where knowledge of processes or methods is of more importance than skill of hand. The attempt is made to have the fundamentals of science, mathematics, drawing, shop work, and technical information thoroughly mastered by having a closely integrated program in which each part relates to the whole. (12:41)
>
> There is greater need for the use of objective measurements. (12:60)
>
> Lack of facilities in most schools makes it virtually impossible to give an adequate test of shop work. The analytical method employs certain aids to visualization along with a definite method of presentation. (12:167)

The summary of these research findings reveals that these diagrams help the learner relate to the learning in a visual way. Crawford (4) points out the need for visual aids in technical subjects and shows that positive benefits to the learner occur when use is made of them. The findings in the study of Haynes (8) corroborated those of Crawford showing that visual aids provide a positive advantage to the student.

This review of the literature has left unanswered, questions one and four:

1. What is the analytical method?
   a. How is it organized?
   b. How is it presented?
   c. How does it differ from the traditional method?

4. What are the results shown by the analytical approach?

In an attempt to find the answers, further pursuit of the problem will be made in the following chapters.

Chapter III

SOURCES OF MATERIALS

In addition to the material included in the review of literature just outlined, reference was made to a few recognized standard works having a bearing on this study in order to assure authentic sources of material as well as approved methods of procedure. There were four sources drawn upon by the writer in securing data for this study:

(1) A group of four experts in the field of electrical education.

(2) A group of fifty competent tradesmen.

(3) A short list of recognized sources of electrical information.

(4) Ten classes of students from the electrical department of Dunwoody Institute.

The first source was a committee (see Appendix B) made up of the following persons: a teacher-trainer with 15 years of electrical experience, an electrical contractor who was also on the Minnesota State Board of Electricity, a teacher of electricity who was a journeyman electrician six years in Minnesota, and an electrical instructor of eleven year's experience as a teacher in addition to thirteen years in the trade as a journeyman electrician on heavy electrical machinery maintenance. All of these were people with wide experience in electricity who had had much contact with examination questions. For these reasons they were considered thoroughly competent to pass expert opinion on the clarity and understandability of the test questions.

The second source likewise was a group of people considered competent to pass judgment on the validity of a list of items from which the objective examination for this study was drawn. This committee consisted of 50 members of the St. Paul Electrical Workers' Local Number 110. Copy of the names of the men who served in this capacity may be found in Appendix B.

The following works--American Electricians' Handbook (4), Electrical Machinery by Croft (5), National Electric Code (11), 1937 Edition, bulletins of electrical equipment manufacturers, and the job sheets used for the shop work on direct current motors and control apparatus at Dunwoody Institute--were used to supply the test items (see Appendix C) which made up the third source of information in this experiment.

The fourth and last source from which data were collected in carrying out this work consisted of ten sections of students taking the electrical course at Dunwoody Institute. These groups were tested at various times over a period of three and one half years to obtain information used later in this study for data with which to compare the analytical with the traditional method of teaching direct current motor theory.

MATERIALS

Job sheets

All the technical information given to students in Dunwoody centers around the shop job. Since these, then, are necessary for one to obtain a complete picture of its scope and content, a set of the regular job sheets used for this experiment are shown in section D the appendix. The form used for these was laid out by Dr. C. A. Prosser, Director of Dunwoody Institute. After 30 years of trade experience and teaching background, the electrical instructors have set up these jobs as a reasonable requirement for one month devoted to a shop course on direct current motors.

The shop work

The shop work, covering care, maintenance, installation, operation, and repair of direct current motors and control apparatus, was arranged so that it could be covered in 18 jobs of three hours each. Twelve jobs must be done to meet the minimum requirements. This arrangement of the work made it possible for the more able and ambitious students to do an extra job or two each month repairing shop equipment or building some piece of shop apparatus. The latter jobs were classed as production and carried credit the same as a regular shop job for each three hours of shop time, provided of course, that the results accomplished warrant the credit. This arrangement increased both the incentive and the reward for the ambitious student with ability.

The related class work

The information necessary for a course of this type was taught under three separate headings: (1) specific information about the shop jobs called in this experiment shop knowledge (S.K.), on which classes were held one period each day; (2) job report write-up and discussion also held one period daily. For both (1) and (2) the questions on the job sheets formed the basis for much of the discussion in these classes. (3) The third type of related class work was general theory, referred to in this paper as trade knowledge (T.K.). This class on electrical theory T.K., as applied to general problems concerning motors and control apparatus, was taught on alternate days three periods per week. This schedule of time for trade preparatory classes conforms to Smith-Hughes requirements where federal aid is provided to vocational schools. It is the general theory class with which this study deals in comparing the traditional method of teaching with the analytical procedure.

METHODS

The traditional method

The steps in the method that was used in teaching the theory of direct current motors and control apparatus to the control group were arranged in the following manner.

Twenty shop knowledge periods were used entirely for discussing shop jobs, answering from the job sheets, and solving any other problems relating to a shop course about which students inquired.

Twelve job reports on 12 different jobs were written by students and discussed during the 20 periods devoted to this phase of the instruction.

In the theory class (T.K.), particular attention was paid to such items as load, speed, field excitation, armature current effects, counter-electromotive force, terminal voltage, and armature circuit resistance, since they are the important factors affecting motor operation. The purpose was to give all students a thorough understanding of these items and to include such other items as was listed in Appendix C. All of these, from the standpoint of theory, were covered in the twelve allotted periods. In other words the usual procedure for teaching electrical theory was followed.

It consisted of making assignments in standard textbooks on the subject covering symbols, wiring diagrams, mathematical problems, and items on the theory of direct current motors and starting devices. After these assignments were studied, class discussion using charts, models, pieces of equipment, and blackboard sketches were carried on under the guidance of the instructor. To insure comparable results, in using this method all students used the same text material.

This procedure with a class, carefully and thoroughly followed, in presenting theory along with a shop or laboratory experience had produced satisfactory results in the past; but cannot more effective teaching procedures and more efficient approaches be developed?

Roys (16:511) in an article on "The Fundamental Philosophy of Method" said:

> The deductive method, which has many advantages in way of orderliness, comprehensiveness, ease of correlation, ease of learning, and ease of administration, is not the natural way but the inductive method of going from the concrete to the abstract is more natural and although slower and harder to administer, productive of better results in the long run.
>
> There should be better correlation between scientific thought and practical application.

Draffin (6:730) writing on "Laboratory Instruction in Engineering Education," made the following statements:

> Laboratory work provides proper ways of analyzing data and reaching conclusions. . . . . . Education consists in the growth of the thinking processes. For this growth to take place the student must have <u>something to think about</u>, he must have a <u>scheme or manner of thinking</u>, and he must reach some kind of <u>a conclusion</u>.

It was with the idea of correlating the scientific with the practical application mentioned by Roys and of providing the student with a scheme or manner of thinking, which Draffin showed to be so necessary, that the writer developed what has been called the analytical method of teaching the theory of direct current motors. This method was used with the experimental group.

The analytical method, described fully in Section A of the Appendix, is a departure from the traditional method. Students were not required to memorize information but were given assignments or jobs to do in which a knowledge and understanding of the facts were necessary before the task could be accomplished. A complete and thorough analysis of the subject must be made by the instructor before this method can be put into use. All basic or fundamental items used in explaining the operation of the machine or device should be selected by the teacher at the outset. The entire procedure explained under the analytical method was presented to and worked out by the student during the twelve class periods devoted to theory (T.K.) instruction.

The analytical method

The necessary items for explaining the operation of direct current motors are: (1) terminal voltage, (2) field or pole flux, (3) armature current, (4) torque, (5) load, (6) speed, (7) counter-electromotive force, (8) armature-circuit resistance. These were given to the student, who was then asked to complete a boxhead analysis calling for the following information on each item: (1) the usual symbol or abbreviation used; (2) the unit of measurement; (3) a brief statement of what the item is; (4) what the item does; (5) what item or items it has an immediate effect upon. (Appendix A)

Any good textbook or other source of material on direct current motors will yield the necessary information required to complete the box-head analysis. In many cases the student found he had already learned a considerable amount of this knowledge from other sources.

The next step in the procedure consisted of studying, in a preliminary way, the relationships which exist among the eight items listed in the preceding paragraph. A 64-section chart eight spaces high and eight spaces wide similar to a baseball playing schedule is arranged for this part of the work. (See Appendix A)

The relation among the eight items, terminal voltage, field flux, armature current, torque, load, speed, counter-electromotive force, and armature circuit resistance, were then classified into three groups, as follows: (1) those which have an immediate effect on the others indicated in the chart with the symbol Y, for example, terminal voltage has an immediate effect on field flux (See Appendix A); (2) those which have no effect on the other members of the group shown by 0 in the same chart, for example, terminal voltage has no effect on armature circuit resistance; and (3) those which have a relative effect on the other items. A relative or intermediate effect is defined as one in which the action passes through one or more other members of the group, before it reaches the one affected. This relationship is indicated on the chart by ____. Terminal voltage affects torque but only through field flux or armature current.

The third phase of the class instruction using the analytical procedure helps the student develop these intermediate relations or effects. Taking the example of terminal voltage effect on torque used in the preceding paragraph, the following directions should make clear how the third group of relations was found from the chart. Start at the top of the chart (Figure 7, Appendix A) at the column headed torque. Drop down vertically in this row until Y is reached; then allow the eye to travel horizontally to the left side of the chart, where field flux is found. Now again start at the top in the field flux column and drop down to Y. Follow this Y to the left as before; this points to terminal voltage, which shows that torque is affected by field flux, and is affected in turn by terminal voltage.

In other words the analysis proceeds by beginning with torque, then moving back to field flux, thence to terminal voltage. This shows that changes in terminal voltage affect torque through field flux. It must be recognized that there are two circuits through which the torque in a shunt motor can be changed. They are through the field and through the armature. The use of the chart in determining the change in torque produced by a change in field has just been described. The chart also is used in determining the change in torque produced by a change in armature current. This time the analysis proceeds by moving back to armature current, and thence to terminal voltage.

Working out all of the intermediate or relative effects in this manner provides the student with enough repetition and thinking drill to establish fairly well the necessary thought pattern in his mind. A complete list of these secondary or relative effects is given in Appendix A.

The final step in the preliminary development work required in this method consisted of finding a satisfactory arrangement showing a diagrammatic plan of these eight items and their immediate relations to each other. This should be done with lines conveniently straight and all crossing lines eliminated if possible. A clear-cut plan or organized drawing is desirable, for this so-called skeleton diagram serves as a guide in the next steps of the analysis. (See Fig. 9 Sec. A.) Appendix. The skeleton diagram is the device that bridges the gap between theory and practice. Through its use principles can be applied in locating and diagraming motor troubles. Here effects of increase and decrease in load on the shunt motor, and the ways in which the various factors are affected, are shown. Strong and weak fields are analyzed, as well as the resistance effects in the armature circuit. Finally the changes that high and low voltage make in motor operation are discussed.

To make the picture complete all that remains is to fit other items classified in this work as "detail items" into the general scheme of things. A few of these are listed as follows: dirt, rough commutator, poor brush fit, and shorted field coils. Analysis of these items show that they have effects on some one or more of the eight factors used in the skeleton diagram. A shorted coil will affect the pole flux, and dirt or poor brush fit causes increased resistance of the armature circuit.

One method followed by the writer was to ask the students to make a list of all items found during the early part of the month which they feel influence motor operation in any way. The ones which were new to the student were analyzed with the same boxhead form as was used for the eight basic or fundamental factors. The last two or three periods were used in class discussion to clear up any doubts or misunderstanding with regard to these items.

When search was made for some means of evaluating the relative merits of the analytical and the traditional methods used in teaching the theory of direct current motors, none was readily available. This made it necessary to prepare a test for this purpose: The Theory Test on Direct Current Motors.

The first step in the preparation of the test used for conducting this study was the selection of the test items. Following the procedure outlined by Senes (20:26-29), recommended by Ruch (18:153-154), more items were selected from the course content than were required for the examination. These were submitted to the committee of 50 qualified electrical workers to determine validity. See Senes (20:25). Ruch (17:13). A complete list of these approved items is given in Appendix C. Green and Jorgenson (7:73) also approved this method of validating material used for this prupose. These questions were drawn from the approved list of selected items and treated as explained in the following paragraphs.

Since the objective type test was the type used by Josserand (9:50-64) in a similar problem and is at present recognized by a majority of the more progressive people in educational work as one of the best examining devices so far developed, this form was selected for this work. Because the theory of electric motors is basically a technical subject, which lends itself to a cause and effect analysis, each test question was made to consist of two parts. Such an arrangement practically eliminates guessing the right answer.

Tyler (25:24-32) recommended the use of objective test questions for scientific subjects consisting of two parts similar to the above arrangement.

Questions of this type require the student to choose the correct answer from a number of possible answers. The student was required to choose from a number of possible reasons the one that explains correctly why the answer he has chosen is the correct answer to the question. The following is an example.

1. The three-point starting box provides a shunt motor with:
    1. no voltage release.
    2. overload protection.
    3. underload protection.
    -4. no field protection.

because:

(a) the holding coil is across the line.
(b) the holding coil is protected by starting resistance.
-(c) the shunt field is in series with the holding coil.
(d) a holding coil resistor protects the holding coil.
(e) the voltage across the coil will be low.

In drawing up the preliminary draft, each question was placed on a separate slip of paper and many possible responses were listed. (20:27-28). In the final arrangement of the question, however, only the most appropriate answers were used. A complete set of these test questions appears in Appendix D. In order to proceed with this study in a scientific manner, the test questions required validation.

Validity

Validity of the questions was obtained by following the method used by Senes (20:12), recommended by Watson and Forlano (27), and suggested by Ruch (17:20). Validity was determined by submitting the test to the opinion of experts. A group of four competent people passed favorably on this part of the work, as may be seen from the comments in Appendix B. The clarity and understandability of the questions were unchallenged by anyone in this group of experts.

Reliability

According to the authorities previously mentioned the reliability of an objective type test depends upon a number of conditions, such as relative difficulty, discriminatory powers, and objectivity. The relative difficulty of these test questions was obtained from a graph showing the number of times each question was answered incorrectly when 188 students were examined. Rank order shows both the relative difficulty and the discriminatory powers of the questions (Table 1). This diagram provided the means for arranging the questions, as the easy ones came first and gradually increased in difficulty until

Table 1.--TEST QUESTION ERRORS (188 cases)

Question	Number of times missed	Rank order	Question	Number of times missed	Rank order
* 1	9	1	* 27	184	38
2	48	11	28	32	7
3	110	29	29	92	24
4	42	8	30	99	25
5	45	9	31	84	22
6	141	33	32	49	12
7	103	27	33	52	13
8	49	12	34	64	18
9	115	30	35	70	20
10	64	18	36	107	28
11	138	32	37	12	2
12	49	12	38	129	30
13	59	15	39	151	34
14	64	18	40	56	14
15	20	3	41	47	10
16	160	36	42	64	18
17	62	16	43	52	13
18	45	9	44	80	21
19	134	31	45	59	15
20	22	4	46	151	34
21	84	22	47	23	5
22	163	37	48	155	35
23	65	19	49	169	37
24	32	7	50	141	33
25	25	6	51	85	23
26	85	23	52	101	26
			53	64	18
			54	80	21

* Questions 1 and 27 were omitted in odd-even correlation Table 2.

the hardest ones were last Table II. From inspection those questions were found which had been missed less than five percent of the time and also those which 95 percent or more failed to answer. Elimination of top and bottom questions falling outside the prescribed limits were made to increased reliability. See questions marked * in Table I. See Senes (20:40,50). Objectivity, another phase of reliability, was obtained by the use of an answer key.

After the mathematical treatment just explained had been applied to the test questions, the coefficient of reliability was calculated by means of the odd-even method of split halves which, according to Anastasi (1:321-325), is the most accurate way of determining this quantity. The formula recommended by Treloar (23:184), employed here for calculating the coefficient of reliability for this test, is given as follows:

$$r = \frac{\frac{\Sigma(xy)}{N} - \overline{x}\,\overline{y}}{\sigma x \cdot \sigma y}$$

In this formula r represents the degree of correlation which exists between x and y. $\overline{x}$ and $\overline{y}$ = the averages of the samples and σx and σy are the standard deviations of the means. From the statistical treatment of the date shown in Table 2, a coefficient of correlation of .99265 $\pm$ 0015, which is exceptionally high for group association studies

Table 2.--TEST ERRORS FOR ODD AND EVEN QUESTIONS

Odd questions	Number of times missed	Even questions	Number of times missed
1	12	2	20
3	22	4	23
5	25	6	32
7	32	8	42
9	45	10	45
11	47	12	48
13	49	14	49
15	49	16	52
17	52	18	56
19	59	20	59
21	62	22	64
23	64	24	64
25	64	26	64
27	65	28	70
29	80	30	80
31	82	32	82
33	33	34	85
35	92	36	99
37	101	38	103
39	107	40	110
41	115	42	129
43	134	44	139
45	141	46	141
47	151	48	151
49	155	50	160
51	163	52	169

CALCULATIONS MADE IN DETERMINING COEFFICIENT OF RELIABILITY FOR THE TEST

$\bar{x}_o = 78.962$ $\qquad$ $\bar{x}_E = 82.154$

$\Sigma x^2 = 208,679$ $\qquad$ $\Sigma x_E^2 = 222,620$

$\frac{\Sigma x^2}{N} = 8026.11538$ $\qquad$ $\frac{\Sigma x_E^2}{N} = 8562.38461$

$\bar{x}_o = 6234.92320$ $\qquad$ $\bar{x}_E^2 = 6749.11541$

$\sigma x_o^2 = 1791.19218$ $\qquad$ $\sigma x_E^2 = 1813.26920$

$\sigma x = 42.322$ $\qquad$ $\sigma x_E = 42.580$

$r_{xy} = .99265 \pm .0015$ $\qquad$ $SE_r = \frac{1 - r^2}{\sqrt{N}} = .0015$

and also excellent for individual prediction purposes, is obtained. From the correlation chart Treloar (23:58) this coefficient has an individual prediction index of approximately .85.

Group equivalency

Another factor in carrying out an experimental study of this kind which must receive careful consideration is the choice of the individuals making up the groups to be used. They should be selected so that the two groups are as nearly alike as possible. There was a total of 165 individuals in the ten sections from which 58 matched pairs were selected. Josserand (9:34). Among the more important characteristics usually considered for matching groups are the following, according to Miller (10:20), Josserand (9:34): chronological age, previous school experience, results of carefully administered, reliable new-type examinations, special experiences, such as the number of months of some special training, or the school marks given over a definite period of time in some particular line of activity, such as shop grades.

Since the groups were selected from a carefully chosen student body similar to those used by Miller (10:20), the same factors, chronological age, previous school training, number of months in

Dunwoody, and the shop marks are the criteria which have been used to determine group equivalency in this experiment. Because the mean is a true statistic in which all values weigh according to their magnitude, its use is advisable for statistical purposes. See Treloar (23:11). This arithmetical average was suitable in a similar situation; so for this reason it was employed in this problem.

The groups used in this experiment were very similar in their previous years of school experience, as will be seen from the data in Table 3. Against a total of 697 years in school for the control group, the experimental group shows 690½. The difference in favor of the control section was seven and one half years or one per cent, which is not significant; therefore these groups were considered equivalent on the basis of this criterion.

The second criterion considered in dealing with the group equivalency was the number of months in Dunwoody Institute. Miller (10:18) pointed out the fact that the length of time in a specialized course of training such as is offered at this Institute might have considerable influence upon student ratings. The following facts are cited to show that no apparent difference existed in this training time for these groups.

Table 3.--COMPARISON OF GROUPS C AND E ON THE BASIS OF THE NUMBER OF YEARS OF PREVIOUS SCHOOLING

Years of school completed	Number in control group	Total for each year	Number in experimental group	Total for each year
9	0	0	2	18
10	2	20	0	0
11	0	0	2	22
12	52	684	51	672
12½	0	0	1	12½
13	3	39	2	26
14	1	15	0	0
Total	58	697	58	690½

Difference between total school years for the control and experimental groups amounts to 6½ years, or only one percent.

The total months in attendance, shown in Table 4, for the control group were 617, and for the experimental 645, a difference of 28 months in favor of the latter. The averages for this training were 10.64 months for the former and 11.12 months for the latter. The standard deviations were 1.69 and 1.74 with standard errors of the means of .222 and .229 respectivly.

When the foregoing values are substituted in the formula where $t = \dfrac{\bar{x}_c - \bar{x}_e}{\sqrt{SE\,\bar{x}_c^{\,2} + SE\,\bar{x}_e^{\,2}}}$ Treloar in the Outline of Biometric Analysis (23:29) the value of <u>t</u> was found to be 1.504, which is <u>not significant</u>.

This showed the group equivalent within the limits of the errors due to random selection of individuals on the basis of this criterion. Two groups having a value of t less than 2 are probably alike as differences less than this amount are likely due to sampling errors. Treloar (23:25) shows that a value of <u>two</u> will make the errors of random sampling less than one in twenty when this formula is used for determination of probability. Therefore any value greater than <u>two</u> practically eliminates sampling errors.

The third factor used for checking group

Table 4.--COMPARISON OF GROUPS C AND E ON THE BASIS OF THE NUMBER OF MONTHS IN DUNWOODY INSTITUTE

Student pairs	Group		Student pairs	Group	
	Control	Experim'tl		Control	Experim'tl
1	16	14	30	11	11
2	14	14	31	11	11
3	14	14	32	11	11
4	14	14	33	10	11
5	13	13	34	10	11
6	13	13	35	10	11
7	13	13	36	10	11
8	13	13	37	10	11
9	13	13	38	10	11
10	13	13	39	10	11
11	12	13	40	10	11
12	12	13	41	10	11
13	12	13	42	10	11
14	12	13	43	9	11
15	12	12	44	9	10
16	11	12	45	9	10
17	11	12	46	9	10
18	11	12	47	9	10
19	11	12	48	9	10
20	11	12	49	9	9
21	11	12	50	8	9
22	11	12	51	8	9
23	11	11	52	8	9
24	11	11	53	8	9
25	11	11	54	8	9
26	11	11	55	8	9
27	11	11	56	8	8
28	11	11	57	7	8
29	11	11	58	7	7

$$t = \frac{\bar{x}_c - \bar{x}_E}{\sqrt{(SE_{\bar{x}_c})^2 + (SE_{\bar{x}_e})^2}} = 1.504$$

$\sigma_{\bar{x}_c} = .222$

$\bar{x}_E = 11.22$

$\bar{x}_c = 10.64$

$\sigma_{x_E} = 1.74$

$\sigma_{x_c} = 1.69$

$\sigma_{\bar{x}_E} = .229$

equivalency was the average shop ratings received for the months in training at Dunwoody Institute. These marks are based on the number of jobs satisfactorily completed each month and hence correspond very closely to a performance test rating. In fact they may be better than the actual rating on a performance test because of the lack of facilities in many shops for setting up satisfactory procedures for carrying out the tests (12:167).

The results of computations from the tabulated data shown in Table 5 gave the control group an average percentage grade of 77.707 per cent, and the experimental group was slightly higher with 78.026 per cent, with standard deviations of these distributions 5.908 and 4.795, and standard errors of the means, $\pm$.776 and $\pm$.629 respectively. By substituting in the formula t was found to be .3445, which according to Treloar (23:25) is not significant but is very likely due to errors of random sampling. Therefore the experimental and control groups are considered similar on the basis of this criterion.

The fourth and last criterion selected for checking these groups was chronological age stated in months. From Table 6 a total of 14,635 and 14,742 months for the control and experimental groups respectively with averages of 252.327 $\pm$ 2.81 and

Table 5.--COMPARISON OF GROUPS C AND E ON THE BASIS OF SHOP GRADES AT DUNWOODY

Student pairs	Group		Student pairs	Group	
	Control	Experim'tl		Control	Experm'tl
1	92.6	89.4	30	76.4	77.2
2	89.4	88.6	31	76.3	77.1
3	89.4	88.1	32	76.3	77.0
4	88.1	86.0	33	76.3	76.0
5	86.2	84.7	34	76.3	75.9
6	86.0	84.5	35	76.3	75.9
7	85.5	84.0	36	76.1	75.6
8	84.6	83.8	37	75.8	75.4
9	84.6	83.8	38	75.7	75.3
10	82.7	83.8	39	75.6	75.3
11	82.0	83.8	40	75.5	74.5
12	80.9	83.8	41	75.3	74.5
13	80.8	83.6	42	74.5	73.8
14	80.8	83.6	43	74.5	73.7
15	79.5	83.4	44	74.4	73.6
16	79.5	83.2	45	73.7	73.3
17	79.4	83.1	46	73.6	72.8
18	78.5	81.7	47	73.6	72.5
19	78.4	81.7	48	73.4	72.2
20	78.3	81.3	49	73.4	72.0
21	78.2	81.2	50	73.2	72.0
22	78.0	80.9	51	73.0	71.6
23	77.5	79.0	52	72.6	71.2
24	77.5	77.7	53	72.2	70.6
25	77.5	78.7	54	72.0	70.5
26	77.2	78.5	55	71.8	70.5
27	77.2	78.2	56	71.3	69.9
28	77.0	77.8	57	70.9	69.9
29	76.9	77.2	58	70.8	69.1

$$t = \frac{\bar{x}_C - \bar{x}_E}{\sqrt{SE^2_{x_C} + SE^2_{xE}}} = .3445$$

$SE_{xC} = .774$

$\bar{x}_E = 78.026$

$\bar{x}_C = 77.707$

$\sigma_E = 4.795$

$\sigma_c = 5.908$

$SE_{\bar{x}_E} = .628$

Table 6.--COMPARISON OF GROUPS C AND E ON THE BASIS OF AGES IN MONTHS

Student pairs	Groups		Student pairs	Group	
	Control	Experim'tl		Control	Experm'tl
1	320	332	30	248	246
2	299	301	31	248	246
3	298	300	32	248	246
4	298	298	33	248	245
5	288	291	34	247	245
6	287	288	35	246	245
7	283	284	36	244	244
8	280	281	37	243	244
9	275	276	38	243	243
10	274	275	39	243	241
11	271	274	40	243	241
12	270	272	41	243	241
13	269	272	42	240	240
14	268	269	43	240	238
15	266	266	44	238	237
16	257	264	45	236	235
17	256	263	46	235	234
18	256	263	47	235	234
19	255	260	48	235	233
20	255	260	49	232	233
21	254	259	50	231	233
22	253	258	51	231	232
23	253	258	52	230	232
24	253	257	53	226	231
25	250	256	54	225	231
26	250	256	55	223	227
27	249	255	56	221	227
28	249	249	57	221	227
29	248	247	58	217	207

$$t = \frac{\bar{x}_c - \bar{x}_E}{\sqrt{(SE_{\bar{x}_E})^2 + (SE_{\bar{x}_c})^2}} = .448$$

$SE_{x_c} = 2.81$

$\bar{x}_E = 254.172$

$\bar{x}_c = 252.327$

$\sigma_E = 22.970$

$\sigma_c = 21.382$

$SE_{x_E} = 3.01$

254.172 $\pm$ 3.01 and standard deviations of 21.382 and 22.970 calculations revealed t to be .448 which is not considered significant but is probably due to sampling errors. Hence on the basis of this criteria the groups are considered to be equivalent.

The groups on the basis of the above four criteria, previous schooling, number of months in Dunwoody, percentage ratings for the shop work and chronological ages were not proven statistically different and therefore may be considered equivalent for this experiment.

PROCEDURE

The shop work

All shop work for the entire experiment was taught by the writer. Each student's daily progress was recorded on a chart posted in the shop. A total of sixty hours of shop work was given in this unit of instruction. The control and experimental groups in this study were both taught shop work in the same manner.

The class work

A total of 12 hours was devoted, by the writer, to teaching the shop knowledge classes and these classes were conducted in the same manner throughout the study.

The interest factor for both methods appeared to be equal, but the writer had no way of knowing how much home work was done by the students with either procedure.

The trade knowledge was the work around which this experiment centered. As explained before, these classes met three times each week on alternate days. The control group received instruction in the traditional manner, as explained on pages 2 - 5, while the experimental class work was conducted following the analytical method, as explained on pages 6 - 11.

Test administration

The theory (T.K.) test used in this study was given within the first two days of the school month and again on the fourth Wednesday of the month. One period of 45 minutes was allowed the groups for the first trial and two periods or an hour and a half for the final rating. The results obtained from the first administration of this examination were used to check upon the previous knowledge the students in the groups had regarding direct current motors and control apparatus. Josserand (9:50). The final data were used in measuring the comparative achievements of the two groups, by means of the statistical formula recommended by Treloar (23:29) for this purpose.

$$t = \frac{\overline{X}c - \overline{X}E}{\sqrt{(SE\overline{x}_c)^2 + (SEx_e)^2}}$$

The preliminary work in carrying out this experimental study has all been done with care and according to the approved procedures found suitable by others doing a similar type of work.

Answers have been found in this chapter to the following previously unanswered questions:

1. What is the analytical method?
   a. How is it organized?
   b. How is it presented?
   c. How does it differ from the traditional method?

Question number four, 4. What are the results?, still remains unanswered. The answer to this question will be found by application of formulae presented in Chapter III to the results obtained from the administration of the theory test.

Chapter IV

FINDINGS AND DISCUSSION

The procedure for selecting test items, organizing test questions, validating test items and questions, and establishing the reliability described in Chapter III, were found satisfactory for this experiment in evaluating the analytical and traditional methods of teaching direct current motor theory. The fact that Senes (20:22-32) used the same steps in organizing and validating a test for conduit electricians at Joliet Township High School, Joliet, Illinois, with excellent results established the precedent for this part of the work.

The information on the reliability of the test was obtained from the response data accumulated when the questions were given to 188 electrical students over a three and one-half year period.

Table 1, column 1 shows the number of the question, column 2 the number of wrong responses obtained from the results, and column 3 the rank order. All omitted responses were included with the incorrect answers. Rank order was found by placing the easiest question first, i.e. the one which the largest number answered correctly, and proceeding with the more difficult ones until the one missed the greatest number of times was last on the rank list. Senes (20:40) stated that a test arranged in rank order had better reliability than an unranked test.

In ranking the test questions the writer followed the procedure set up by Pintner (14) for determining discrimination:

> Those items of a test in which the percentage of "failure" was more than 95 percent and less than 5 percent were eliminated because they were considered as not sufficiently discriminative.

Five percent of 188 is 9. Thus any question that was missed less than ten times and more than 178 times was eliminated. Inspection of column 3 in Table 1 shows that the first question was missed only nine times, and question 27 was missed 184 times. In order to increase the reliability of this test questions 1 and 27 (marked with an *) were eliminated, and the data used in this experiment were accumulated from the remaining 52 questions. Using the odd-even halves method with the formula given in Chapter III the coefficient of reliability was found to be .99265 ± .0015.

This direct current motor theory test, checked for both validity and reliability, was given to all classes at the beginning of the experiment. 1/ This procedure was followed to ascertain any significant

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1/ See Appendix D.

differences in the knowledge these groups might have had before the work was given (9:49). Results of this test on the two groups, each consisting of 58 matched pairs, are shown in Table 7.

The data secured from administering the test were treated by using the formulae recommended by Treloar (23:29). They yielded the following facts concerning the previous information these people had regarding direct current motors. The average for the control group was 9.017 and for the experimental group 7.693, a difference of 1.324 in favor of the control group. The standard deviation of the distribution was $\sigma c = 3.59$ and $\sigma e = 3.56$ with standard error of the means having values of .470 and .466 respectively.

The value of <u>t</u> was found to be 1.99. Since it was found to be 1.99 it may be concluded that there was a significant difference in favor of the control group in respect to their knowledge of motor theory and control devices at the beginning of the experiment.

To determine the relative effectiveness of teaching the theory of direct current motors by the experimental method and the traditional method the direct current motor theory test was given to all students at the end of the experiment.

Table 7.--COMPARISON OF GROUPS C AND E ON THE BASIS OF THE FIRST ADMINISTRATION OF THE TEST

Student pairs	Group		Student pairs	Group	
	Control	Experim'tl		Control	Experm'tl
1	15	15	30	9	7
2	15	15	31	8	7
3	15	14	32	8	7
4	15	14	33	8	7
5	15	13	34	8	7
6	15	13	35	8	7
7	14	13	36	8	7
8	14	13	37	8	7
9	14	13	38	8	7
10	14	12	39	8	6
11	13	11	40	7	6
12	13	11	41	7	6
13	13	11	42	7	5
14	12	11	43	7	5
15	12	10	44	7	5
16	12	9	45	6	5
17	12	9	46	5	5
18	11	9	47	5	4
19	11	9	48	5	4
20	11	9	47	5	4
21	10	8	50	5	4
22	10	8	51	4	3
23	10	8	52	4	3
24	10	8	53	4	3
25	10	8	54	4	3
26	9	8	55	3	3
27	9	8	56	3	2
28	9	8	57	3	2
29	9	8	58	2	2

$$t = \frac{\bar{x}_c - \bar{x}_E}{\sqrt{SE^2_{\bar{x}_c} + SE^2_{\bar{x}_E}}} = 1.99$$

$SE_{\bar{x}_c} = .470$

$\bar{x}_c = 9.017$

$\bar{x}_E = .7693$

$\sigma_{x_E} = 3.56$

$S_{x_c} = 3.59$

$SE_{\bar{x}_E} = .466$

It was found that the control group had a mean score of 29.052, and the experimental group received an average of 31.569. This showed an advantage of 2.52 for the experimental section. The standard deviations of the distribution of these means were $\sigma_{\bar{x}_c} = 5.31$ and $\sigma_{\bar{x}_e} = 4.71$. It was found that t was 2.69. Since any value over 2. shows the difference in means to be real, and not due to errors of random sampling, it is safe to say that the knowledge of the theory of direct current motors shown by the experimental group was definitely superior to the knowledge of the control group.

Because this test was carefully formulated according to approved methods and drawn from recognized sources of properly validated material, with the coefficient of reliability being .99, the assumption may be safely made, that any results revealed by its use are dependable when they are above the significant figure 2. The difference in the knowledge of the theory of direct current motors and control apparatus that had been gained by the experimental group as compared with the control group seems to be more significant than was indicated by the value of t which was 2.69.

This conclusion is based on the fact that at the beginning of the experiment recording to the first administration of the test, the control group had a greater knowledge of the subject than did the experimental

Table 8.--COMPARISON OF CONTROL AND EXPERIMENTAL GROUPS ON THE BASIS OF THE FINAL TEST

Student	Group		Student	Group	
	Control	Experim'tl		Control	Experm'tl
1	41	40	30	30	32
2	37	40	31	30	31
3	36	39	32	30	31
4	35	39	33	30	31
5	35	39	34	30	31
6	35	38	35	30	31
7	35	37	36	29	30
8	34	37	37	29	30
9	34	37	38	28	30
10	34	36	39	28	30
11	33	35	40	28	30
12	33	35	41	28	30
13	33	35	42	27	30
14	32	35	43	27	30
15	32	35	44	27	29
16	32	35	45	27	29
17	32	35	46	26	29
18	32	35	47	26	29
19	32	35	48	26	29
20	32	34	49	26	28
21	31	34	50	25	27
22	31	34	51	24	27
23	31	34	52	24	27
24	31	33	53	23	26
25	31	33	54	22	26
26	30	33	55	22	25
27	30	33	56	21	24
28	30	33	57	20	23
29	30	33	58	19	23

$$t = \frac{\bar{x}_c - \bar{x}_E}{\sqrt{SE_{\bar{x}_c} + SE_{\bar{x}_E}}} = 2.69$$

$\bar{x}_c = 29.0517$

$\sigma_c = 5.31$

$\sigma_{\bar{x}_c} = .698$

$\bar{x}_E = 31.5689$

$\sigma_E = 4.711$

$\sigma_{\bar{x}_E} = .618$

group. The value of t at the beginning of this experiment was found to be 1.99 and to be in favor of the control group. Therefore the analytical method of teaching the theory of direct current motors to electrical students has proven superior to the traditional method of presenting the same material. Question 4, What are the results shown by the analytical approach? has been answered.

Discussion

Question 1, What is the analytical method? was answered in Chapter III. A complete explanation of the analytical method for teaching theory of direct current motors is given in Appendix A.

Questions 2 and 3, How are the test groups set up? and How are the results of the test evaluated? were answered in Chapter II.

Question 4, What are the results shown by the analytical approach? was answered above by a statistical analysis of test data.

The results of the final testing of these groups showed definitely a greater increment in achievement for the experimental group taught by the analytical procedure than was made by the control group taught by the traditional method. This conclusion was reached from the results obtained when the difference between the means for the final test was found to be significant

2.69.

Because the difference between the means for the final test revealed the significant figure of 2.69 the conclusion was drawn that the chance for errors due to random sampling was less than one in one hundred (23:25), and that the superiority of the traditional group over the control group was due solely to method.

Thus once more the effects of visual aids, along with an organized thinking procedure, have proven superior to less systematic though perhaps equally logical presentation of the same facts. These findings bear out the conclusions reached by Crawford, Haynes, and Norton in their research reviewed in Chapter II; namely, that the increment of learning is greater when visual aids are used in giving instruction. The findings also confirm the opinions of such men in the field of education as Zeleny, Draffin, Roys, Rogers, and Creasey, as well as many others, that technical and scientific subjects need additional visual aids and organized thinking procedures in order to interpret theory and apply it in concrete situations of every day life.

This method of teaching the theory of direct current motors has not only been applied to one electrical device but the theory of direct current generators, transformers, magnetism, and alternating current motors, has been presented to groups of trade preparatory and extension students during the past four years with satisfactory results. Many of the young men in these classes stated that this method provided them with "something with which to think" and was much more satisfactory than the usual procedure followed in learning the theory of electricity.

The writer of this experiment also tried out the analytical method and this direct current motor theory test with a group of evening school students in trade extension work during the winter of 1940-41. Practically every man in the group of 20 expressed very favorable reactions. A number of extension students who were employed in concerns doing electrical maintenance reported the skeleton diagram enabled them to find motor troubles readily. One man was so enthusiastic about the diagram that he said it was worth $200 to him on his work of direct current motor maintenance and operation.

The work in this experiment required two major things to be done: A suitable testing instrument for measuring the achievement of the students working under the different methods, and the analytical teaching procedures had to be developed. The analytical method of presenting the theory of direct current motors had to be organized and explained in a thorough understandable way. Both of these tasks have been accomplished with sufficient accuracy and care to produce results which were significant when treated statistically as the figures in Table 9 show.

Table 9.--COMPARATIVE RESULTS ON THE EQUIVALENCY OF GROUPS AND THE RELATIVE EFFECTIVENESS OF THE TEACHING METHODS

Criteria of equivalency	Control group (58 cases)			Experimental group (58 cases)			Difference t
	Mean	S.D.	$Se\bar{x}_C$	Mean	S.D.	$Se\bar{x}_E$	
Chronological age in months	252.327	21.382	2.81	254.172	22.970	3.01	.448 not significant
Months in Dunwoody - -	10.64	1.69	.222	11.12	1.74	.229	1.504 not significant
Shop grades in percentage -	77.707	5.908	.774	78.026	4.795	.628	.3445 not significant
*Previous school years	12.02	.438	.0575	11.67	2.125	.286	.322
First administration of test	9.017	3.59	.470	7.693	3.56	.466	1.99 significant
Second administration of test	29.052	5.31	.698	31.569	4.71	.618	2.69 significant

Additional work remains to be done on this problem. The analytical method should be tried in other schools teaching the theory of electricity where other teachers with larger numbers of students may experiment with it. If the method were used in presenting the theory of other electrical devices such as the transformer, direct current generator, and the alternating current motor under controlled conditions, additional evidence would be made available on the range of electrical devices to which the analytical method could be successfully applied.

Other problems for further study

1. The effectiveness of the experimental method and the control method in helping men recall and associate the knowledge of the theory of direct current motor and control apparatus should be evaluated at the end of a 2-year period.

2. Experienced electricians should check the usefulness of the diagrams as trouble-shooting devices on the job.

3. A variety of other new type scientific tests of this nature should be constructed for measuring the effectiveness of teaching and learning the application of electrical theories to other devices.

The solution of the foregoing problems should extend the body of scientific knowledge upon which the method of teaching the application of electrical theories to vocational students are based.

Chapter V

SUMMARY

Conferences with employers and with evening extension students at Dunwoody Institute revealed several years ago, that both felt there was a very definite need for men who would be able to apply their training in the theory of electricity to the field of "trouble shooting" on electrical equipment. In an effort to solve this problem the writer has been experimenting for the past four years with new methods of presenting and explaining the theory of electricity. The analytical approach to the subject and the use of boxheads, diagrams, and skeleton arrangements found considerable favor among both trade preparatory and extension students.

Since the method was new this question naturally was: What is the effectiveness of the analytical method of presentation compared with the traditional method of teaching the theory of direct current motors? In order to evaluate the two methods the problem was set up as a scientific study. This procedure led to the following problem analysis:

1. What is the analytical method?

   a. How is it organized?

b. How is it presented?

c. How does it differ from the traditional method?

2. How are the test groups organized?

3. How are the results of the two evaluated?

4. What are the results shown by the analytical approach?

Answers to question two and three were found in the literature reviewed in Chapter II. Authorized procedures were found for setting up and checking the equivalency of the personnel in two sections used for conducting an experimental study similar to this one. Methods for evaluating the results obtained were also found and outlined in the same study.

Data for this study were obtained from the following four sources:

1. Test items were selected from the course on direct current motors given at Dunwoody Industrial Institute. The background for much of this was provided by <u>American Electricians Handbook</u>, <u>Electrical Machinery</u> by Croft, and electrical equipment bulletins provided by manufacturers.

2. The 120 test items were validated by 50 men from the St. Paul, Minnesota, Electrical Workers Union No. 110.

3. The questions set up from the test items were

checked and highly approved by four people with both trade and school experience.

4. Ten sections of electrical students were selected from the classes at Dunwoody Institute during the past four year period to receive experimental instruction.

The pursuit of the problem required the use of two teaching methods in order that data might be available for a statistical comparison of the effectiveness of the analytical procedure.

All sections covered the same shop jobs and devoted the same periods to job report "writeups" and discussion. Both groups did the same shop work and discussed shop jobs and shop procedure in class. Only in the presentation of the theory of direct current motors did the methods differ.

The traditional method used in this study presented the essential theory of direct current motors from a standard text book. Students were assigned sections from the text. After these had been studied, class discussions were held using charts, models, blackboard diagrams, and real pieces of equipment. Problems from the text were then used to insure a more complete analysis of the various situations. Sometimes these problems were worked in class; sometimes they were used as home assignments.

Such items as terminal voltage, field flux, armature current, torque, load, speed, counter-electromotive force, and armature circuit resistance were very carefully covered and stressed in the class discussion.

On the other hand the method which was stressed in the experimental classes was a departure from the conventional procedures. Lessons were never given as memory assignments but work of such a nature was provided that the student obtained his understanding by filling in boxheads, analyzing the information in the boxheads while making immediate relations charts, and following out the relative or intermediate effects existing among the operating factors of load, speed, torque, counter-electromotive force, armature circuit resistance, and terminal voltage.[1]

This teaching procedure developed cause and effect thinking and at the same time associated the necessary items for understanding motor operation into a skeleton framework of ideas. Such a diagrammatic arrangement through association helped the students to a concrete understanding of electric motors and enabled them to do a better job of analytical thinking as is revealed in the test results shown in the summary table (Table 9).

1./ See Appendix A.

Table 9.--COMPARATIVE RESULTS ON THE EQUIVALENCY OF GROUPS AND THE RELATIVE EFFECTIVENESS OF THE TEACHING METHODS

Criteria of equivalency	Control group (58 cases)			Experimental group (58 cases)			Difference
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Second administration of test	29.052	5.31	.698	31.569	4.71	.618	2.69 Significant

This summary table showed the groups used in this experiment to be equal on the basis of age, previous schooling, number of months in Dunwoody Institute, and shop marks on a percentage basis for the shop time. None of these criteria exceeded the critical ratio two set up as the point of significance for this experiment.

There were certain variables in gathering the data for this report over which the experimenter had no control. The small number of classes required alternating the methods from month to month over a considerable period of time. This arrangement introduced seasonal conditions; for interest is always more keen when job prospects are good. The physical condition of the instructor might also be a variable factor.

The test developed to check the relative effectiveness of the two methods of teaching the theory of direct current motors proved to be excellent. The coefficient of reliability was .99 which is high enough for excellent individual diagnosis--something rarely found in tests unless a great deal of work has been done with them. Such a reliable instrument enhances the value of the findings shown in Table 9.

The results of this study indicate that the analytical method was superior to the traditional procedure for teaching the theory of direct current motors, at least under the conditions of this experiment. In view of the fact that the control group was significantly superior to the experimental group at the start and that the latter completed the work of the experiment with a significant difference of 2.69 over the control group, would seem to prove fairly conclusively that visual aids together with the analytical presentation provide learning experiences which are superior to those which have been used heretofore.

APPENDIX

Appendix A

THE ANALYTICAL METHOD OF TEACHING

THE THEORY OF DIRECT

CURRENT MOTORS

SECTION I

The plan of organization for this material is shown by the following nine steps:

1. Select Basic or Fundamental Principles for Each Machine Analysis.

2. Explain these Facts by Using the Following Box Head:

a. Basic factor	d. Unit of measurement
b. Symbol	e. What it does
C. What it is	f. What it primarily affects

3. Make a Rectangular Chart of Direct Relations.

4. Develop Indirect Relations.

5. Check with Circle Arrangement Diagram.

6. Develop Skeleton Diagram.

7. Analyze all Usual Conditions with Skeleton Diagram.

8. Make List of All Other Items Affecting Operation of Machine. Use Box Head under 2.

9. Connect Them in Their Proper Relation to Essential Factors in the Skeleton Diagram.

This arrangement provides the learner with a progressive order for accumulation of information and is the means by which he is enabled to do something with the facts he is learning. It challenges his analytical ability at every step and at the same time provides a mechanical arrangement which greatly aids his thinking and keeps his interest keenly alive. When he has lived through these nine steps, he not only knows the theory of the principles involved but also he knows he can use what he has learned and can reach logical conclusions in his reasoning.

DIRECT CURRENT MOTORS

All the operating characteristics of the three types of direct current motors can be satisfactorily explained by the use of eight basic or fundamental concepts. These are: motor terminal voltage, field flux, armature current, torque, load, speed, counterelectromotive force, and resistance in the armature circuit. With a clear understanding of these factors in all their relationships the reasoning necessary to reach logical conclusions can be easily and correctly followed.

The first task for the beginner is to become thoroughly familiar with these eight basic items individually as well as in all their relationships to each of the others. The next few pages attempt to set up this material so as to direct the learner in a logical and progressive order of analysis. The first task is to learn about each of the eight items. When this material is organized in a box-head as shown on page 15, the direct relationships are determined. After the direct relations are tabulated, the indirect ones can be found from the chart. Now the learner is ready to make the skeleton diagram which serves as a chart for all analysis work pertaining to the operation of the motors themselves.

After a thorough knowledge of the operation of each of the three types of direct current motors is obtained by this process, the effects of the many minor items may be studied. If the item requires search for the information, the next step is to make a boxhead for it in the same way as was done for the basic factors. This will show what the detail primarily affects and where it works into the skeleton diagram. Tracing its effects on the motor operation now becomes routine.

A brief explanation of the eight basic factors or fundamental principles used in this study of direct current motors follows. The next few pages are devoted to an explanation of:

1. Terminal voltage
2. Pole flux
3. Armature current
4. Torque
5. Load
6. Speed
7. Counter-electromotive force
8. Armature circuit resistance

MOTOR TERMINAL VOLTAGE

The voltage at the motor terminals or the voltage at the motor end of the line is called the motor terminal voltage. No one thing is more important in obtaining satisfactory motor performance than the correct operating voltage. If this is more than ten percent above name-plate rating, the speed will be high and the fields may be subject to excessive heating. On the other hand, if the applied voltage is more than ten percent below normal, the speed will be too low and the armature current excessive. This additional current on the line will cause more line drop and aggravate a situation which is already bad.

Besides the motor current, the other things which tend to lower motor terminal voltage are size, material, and length of wire used for motor installation. Under extremely adverse conditions temperature must be given consideration. The National Electrical Code and Local Ordinances require that nothing below a certain minimum size of wire be used with various sizes, types, and motor voltages for installation purposes. These requirements afford some measure of protection to the manufacturer and purchaser of the motor, but by no means solve the problem of motor installation.

Another condition which may cause the motor user trouble with motor terminal voltage is the line or supply voltage. If the voltage regulation of the power company lines is poor because of inadequate regulating equipment, trouble may result for the motor user. This often occurs in small plants where there are a few users of power having large machines. Too long lines for the transmission voltage used will also cause low voltage at the motor. Load conditions on the line will affect this valve as well as any variations in the generated electr-motive force. All the line drop between the motor and the source of electro-motive force taken from the generated voltage will give the terminal voltage available for the motor. If a motor is to have the right terminal voltage, the proper amount of copper must be installed to keep the line drop within definite limits and sufficient electro-motive force must be generated.

All good designs of motors provide for satisfactory operation of the machine with a change of ten percent either over or under the name-plate voltage. However, it is always good practice as well as economy to stay considerably above the low limit. Good engineering and economical production require that motors operate at the proper voltage, that is, the name-plate rating.

It is also essential that once the line voltage is established there should be only a limited variation in the supply. If there is a condition in which large fluctuations in load must be met, expensive regulating equipment must be provided. This can be afforded only by large power companies because of the initial investment costs for generating capacity and transmission lines as well as for the regulating equipment itself.

FIELD OR POLE FLUX

The field on a direct current motor is produced by passing current through a coil of insulated wire wound around a soft iron core. This is accomplished by any one of three methods.

The first method uses a large number of turns of relatively small wire so that the resistance will be comparatively high. This makes possible the connection of the field coils directly across the line supplying the voltage. This is called a shunt field connection, in which the field and armature circuits are in parallel. (Figure I.)

The second method uses a few turns of relatively large wire for the field coils. These are connected in series with the armature and must carry all the current supplied by the line to the motor. This method of producing the field flux is called series excitation.

The third type of field excitation is accomplished by using both a shunt and series winding on the same pole core. These two windings by their combined effects produce only one pole flux in the core. When these two coils on the pole core are both producing flux in the same direction, that is, when each one has the same polarity as the other, the core flux is cumulative and the coils are cumulatively connected. If the flux from the series coil is in the opposite direction to the flux from the shunt coil, then the coils are said to be "bucking" and the fluxes are substrative in their effects. This is called a differential connection.

ARMATURE CURRENT

The armature current of a motor passes through the armature coils and makes a magnet of the armature, thus setting up one of the magnetic fields necessary to produce torque. The current causes each tooth of the armature to become magnetized. This armature flux passes across the armature at right angles to the pole flux and is thus known as cross magnetization.

The line voltage is applied to the armature circuit. A part of this voltage causes the armature current to pass through the resistance (r) of the armature circuit. The formula for this is: $Ia = e/r$. Ia is current in the armature, r the resistance of the armature circuit, and e that part of the line voltage necessary to force Ia through r. This may also be expressed by the formula terminal voltage minus the counter-electromotive force divided by the armature resistance (r) equals the armature current (Ia). Another formula for this quantity is $Ia = \frac{TV-cemf}{r}$

This armature current functions exactly the same way in all types of direct current motors so far as the armature itself is concerned, its one function being to produce the armature flux.

The armatures for all three types of direct current motors are essentially the same. Variations in construction may occur to meet certain mechanical conditions of the various motor applications, but electrically they are identical for the shunt, series, or compound motor. Coil lead connections to the commutator will vary with the winding used.

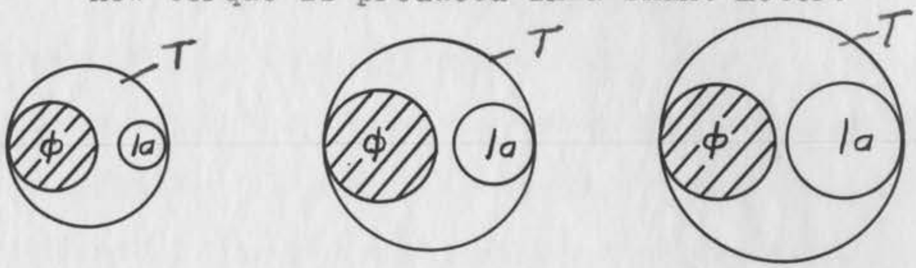
TORQUE

Torque is the turning force which makes the motor run and gives the motor necessary effort to pull the load. It is measured as the product of the turning force in pounds at the end of an arm times the length of the arm in feet. The unit of torque measurement is a pound foot. This means that torque is measured in pounds acting on a one foot radius. In some instances the unit of measurement may be an inch pound, in which case the length of the arm is measured in inches instead of feet. Torque measured by the Prony brake is not determined directly, as it is the reaction to torque that is actually measured by this method. Since action and reaction are always equal and opposite, the results are correct for torque.

The attraction and repulsion of the pole flux for the armature flux creates this turning force which we call torque. It is always necessary to have at least two magnetic fields in order to produce this turning force. If more than two magnetic fields are present, they combine in such a way that the resultants produce the torque. This is illustrated in the compound motor, where the pole flux is made up from two magnetizing forces--that is, the shunt field winding and the series field winding.

The subject of torque is more clearly and definitely understood for the three types of direct current motors from a study of the graphic illustrations for each type in Figures 1, 2, and 3.

How torque is produced in a shunt motor:



Light load Medium load Heavy load

Fig. 1 Fig. 2 Fig. 3

The outside circle represents the torque needed to care for a definite load on the motor. In the shunt motor this is produced by a constant amount of pole flux (Φ) which does not change appreciably under normal operating conditions (Figure 1). As more torque is needed for larger loads, the armature magnetism is increased by more armature current only (Figures 2 and 3). This makes the torque in a shunt motor directly proportional to armature to armature current, at least until the saturation point of the armature iron is reached.

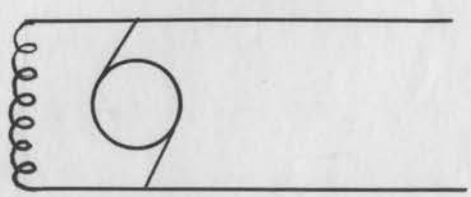


Figure 4.--Wiring diagram for direct current shunt motor

LOAD

Any work that an electric motor may be doing is called the load. Measured in units it is called horsepower (H.P.) Usually this is a productive job and involves changing the shape, surface, location, or physical qualities of materials. Naturally the amount of power used will change considerably with various conditions of the materials. Some of this variation will be caused by temperature, humidity, and physical state as well as the amounts being handled in a unit of time. Thus a motor in meeting the demands of production must vary the amount of power delivered to the machine it is driving.

The rate of production is one of the determining factors in the amount of power used by a machine. Hence speed must be considered as well as the torque when calculating or testing the power required to drive a machine. If rate of production is to be increased, either of two methods may be resorted to. The machine may be made larger and therefore will require a larger motor to operate it with no speed increase, or the machine size may remain unchanged and the speed increased. But it requires more motive power (torque) to increase the speed; so nothing whatever is gained on the power applied, although either method will increase production. This same idea is expressed by the statement that power is the product of speed and torque.

Load may be considered from two angles, namely, the power consumed by the machine or the power delivered by the motor. Obviously these are exactly the same, but for the purpose of clarifying the understanding of motor operation it may facilitate matters at times to consider the load-handling possibilities of the motor itself as the load rather than the load handled. When viewed from the angle of ability of the motor to handle load, it is easily seen how an increase of speed will increase the work performed by the motor.

SPEED

The speed of any machine is considered as the number of revolutions which occur in a definite interval of time, usually one minute or sixty seconds. This number of revolutions in one minute is referred to as the R.P.M. of the machine and is always to be found on the name-plate of rotating electrical machinery.

Speed directly affects production; therefore it should receive very careful consideration on the part of the electrician. Every factor which affects the speed of motors should be thoroughly understood and appreciated by the man in charge of electrical equipment. Load will change speed, and at the same time a change in speed will affect load (production). Any change in speed has a direct effect on the counterelectromotive force of the motor armature.

COUNTER-ELECTROMOTIVE FORCE

Counter-electromotive force is the voltage generated in a motor armature as it rotates in the magnetic field of the pole flux. It is called counter-electromotive force because it is opposite to and opposes the line voltage. For this reason it is one of the most essential factors in the control of current flow through the armature of a motor. In fact it is the one essential controlling force over the armature current in all motors under operating conditions. Counter-electromotive force may be found by driving the armature of the machine at its exact motor speed with the same amount of motor field current so that the same pole flux is cut by the armature conductors. The voltage measured on the armature terminals will be the counter-electromotive force. It is sometimes determined mathematically by subtracting the Ir drop of the armature from the line voltage. C.E.M.F. = TV - Iar.

The speed at which the armature rotates as well as the amount of pole flux (Φ) the conductors cut directly affects the counter-electromotive force. Since this counter-electromotive force is really the power governor of a motor, all the factors which cause it to change should be thoroughly understood and analyzed by the motor student.

The only thing that counter-electromotive force directly affects in motor operation is armature current, which is the variable factor in the production of torque. Armature current is **extremely** sensitive to changes in counter-electromotive force; therefore all factors which affect pole flux and speed should be thoroughly understood, as these are the ones which have a direct bearing on counter-electromotive force.

ARMATURE RESISTANCE

The resistance of the armature of a motor is determined by the winding, the size, and the number of turns per coil as well as by the number of coils. The paths through the armature also help to determine its resistance. These naturally are determined by the number of brushes making contact with the commutator.

Since all the resistance of the armature circuit is usually considered as the armature resistance, the brushes, pigtails, and contact resistance to the commutator must be included as well as the actual ohmic resistance in the armature itself. The leads through the frame also add their resistance, although this is usually rather small.

In the case of compound and inter-pole motors the resistance of both these field windings is included as part of the armature resistance. A complete picture of the resistance of an armature can be made from an investigation of the formula, $R = \frac{K\ L}{cm}$, where K is the mil foot resistance of the wire used to wind the armature, L is the total length of the winding in feet, and cm is the circular mil cross sectional area of the parallel circuits through the armature. High temperature will cause the resistance to increase. Ventilation aids in keeping the temperature down to normal, which is considered to be from 40° to 70° centigrade. Resistance in the armature circuit directly affects the current in the armature and the volt drop this current will cause in passing through.

CONDENSED INFORMATION CHART

This chart is offered as a ready reference instrument to aid in making the direct relations chart. It will be valuable not only for this purpose but should prove an excellent study device for cataloguing information on all the less important details affecting operation of motors.

BOX-HEAD INFORMATION CHART ON EIGHT BASIC MOTOR FACTORS

Basic factor	Symbol	Units of measurement	What it is	What it does	What it immediately affects
Terminal voltage	T.V.	Volt	Pressure from which the electricity comes to run the motor.	Forces the current through the motor circuits.	The current through the various motor circuits especially the shunt field.
Pole flux	Φ	Line of force	Magnetic field of the motor	Provides one of the magnetic fields necessary to run a motor.	It is one of the forces which makes the turning effort or torque.
Armature current	Ia	Ampere	Source of magnetism for the armature	Provides the second magnetic field necessary to run a motor.	It directly affects torque.
Torque	T	Pound foot	The turning effort set up by the pole flux and the armature flux.	It pulls the load and develops the speed.	The load or the speed or both may be directly affected by it.
Load	H.P.	Horse power	The work the motor does.	Causes electrical energy to be used by the motor.	The counter-electromotive force is directly affected by the armature speed.

BOX-HEAD INFORMATION CHART ON EIGHT BASIC MOTOR FACTORS (continued)

Basic factor	Symbol	Units of measurement	What it is	What it does	What it immediately affects
Speed	R.P.M.	Revolutions per minute or revolutions per second	The rate at which the armature revolves.	Causes the load to be revolved through the connecting linkage.	The counter-electromotive force is directly affected by the armature speed.
Counter-electromotive force	C.E.M.F.	Volt	The voltage generated by armature turning in the magnetic flux of the poles.	Helps control the flow of current through the motor armature.	The armature current is forced through the armature resistance by the difference between the line voltage and the counter-electromotive force.
Armature circuit resistance	r	Ohm	The ohmic resistance of the whole armature circuit.	Helps limit the current in the armature circuit when voltage changes occur.	The amount of current flowing through the armature circuit of a direct current motor.

HOW TO MAKE THE IMMEDIATE RELATIONS CHART

FOR A SHUNT MOTOR

Fig. 5

	V	Φ	Ia	T	HP	RPM	CEMF	r
V		y	y	-	-	-	-	O
Φ								
Ia								
T								
HP								
RPM								
CEMF								
r								

First rule off a rectangular set of spaces consisting of sixty-four small rectangles as shown above. From the upper left hand to the lower right hand corners draw a diagonal line across the chart. Down the left hand side and across the top, insert the symbols for the eight fundamental factors as shown. Use the identical order in both series. This arrangement provides a vertical and a horizontal column for each one of the symbols. The diagonal line blanks off the squares common to each individual symbol. This is similar to the schedule of big league baseball, in which all the playing dates of each team for the season are shown in the rectangles.

This chart provides a device on which can be shown and recorded all the relationships that exist among the eight factors. These relations carefully worked out will provide the learner with the basic knowledge required for a working knowledge of motor operation.

There are three relationships which exist among these eight basic factors: an immediate relationship, in which one factor affects one or more of the remaining ones; an indirect or relative relationship, which is an effect through one or more of the other basic factors; and no relationship at all. Examples of a direct relationship are shown by the effect of a change in voltage on the shunt field flux, of a change in load on the speed of a motor, and of a change in field flux on the counter-electromotive force. Examples of an indirect effect are shown by a change in speed of a motor when the terminal voltage changes, a change in armature current when the load is changed, and a change in speed when the field flux is increased or decreased. Illustrations of those factors which have no effect on the others are shown by the fact that speed has no effect on armature resistance, field flux has no effect on terminal voltage, and load has no effect on the resistance of the armature circuit.

An immediate relation is one in which a factor affects another without having to do it through any other member of the group. This relationship may involve other information such as Ohm's law, volt drop, circuits, etc., not mentioned directly in the eight points, but would still be considered as immediate for analytical purposes.

A fundamental knowledge of electricity, magnetism, circuits, and elementary mechanics such as is given in a high school physics course is essential before satisfactory progress can be made with this study. A clear understanding of these subjects will greatly enhance the results from this method of handling facts in gaining an understanding of direct current motor operation.

Filling in each rectangle of the chart requires a decision on three possible conditions. Is the relationship immediate, relative, or negative? Start with voltage on the left hand side and work in the horizontal column. It is desired to know what effects a change in voltage would have on each of the other factors listed across the top above this column. The first one of these is what effect voltage change has on pole flux. Referring to the diagram of the shunt motor circuits, Figure I, it will be seen that the line voltage is applied directly to the coils on the pole cores. If a change in this pressure occurs, the current flowing will change in the same way and a shift in the amount of pole flux will take place. This is a direct relation and should be so indicated by the use of the proper symbol in the rectangle. In this case it is Y. For simplicity a set of symbols to indicate these relationships has been adopted. Y indicates an immediate relation, ___ indicates relative relation, and O indicates no relationship exists. Make no attempt at this time to work out definitely the relative relations, but merely indicate whether the choice is Y, ___ , or O. These can be more easily found after this chart is completed because if there is a relative relationship it must be through a series of immediate relations which can be easily traced. This procedure is shown under the relative relations.

The second rectangle should show what effect the voltage has on the armature current Ia. From an inspection of the same diagram figure 5 , it will be seen that this is also an immediate relation and should be indicated by Y, the same symbol as is in the rectangle under field flux (Φ).

In the third rectangle it is desired to know what effect the voltage has upon the torque. An easier way to approach this relationship is to read what is written about torque and to see that it comes from the magnetic forces produced by the field flux Φ and the armature current Ia, Figures I, II, and III. It has already been decided that terminal voltage has an immediate effect on both of these factors; therefore, the relationship of voltage to torque is relative, and the rectangle under torque (T) should be filled in with the sign ___. Similarly, load and speed are both taken care of by torque, so that terminal voltage has a relative effect on both, and the rectangles under load (H.P.) and speed (R.P.M.) should be filled with relative relations signs ___.

Since counter-electromotive force is the result of the armature rotation cutting the field flux Φ and the terminal voltage (TV) has a relative effect on torque, which is responsible for speed, the applied voltage must have an indirect effect on counter-electromotive force C.E.M.F. There is also a second relative effect through field flux, because terminal voltage immediately affects this factor which has a direct effect on counter-electromotive force. A ___ should be placed in the space under C.E.M.F.

The last space to be filled in this column is the one under armature circuit resistance r. During normal operating conditions, the resistance of the armature circuit does not change to any great extent. Proper ventilation keeps the temperature nearly constant at all times so that heat is dissipated as rapidly as it is generated by the losses. Since this factor is considered as the ohmic resistance of the armature circuit, the applied voltage will have no effect on this item. Therefore an O is placed under r in this column. Under abnormal conditions, however, this conclusion may not be strictly logical because temperature rise will materially affect the resistance of any copper circuit because of the high specific resistance of this metal. If the temperature can be prevented from rising to excessive heights, a circuit will carry an unlimited amount of electrical energy without trouble.

It then becomes a matter of maintaining reasonable temperature limits to prevent serious increases in armature circuit resistance r. For more information, read temperature effects under detailed items affecting motor operation. Proceed in this manner for the remaining seven horizontal columns and complete the chart as shown in Figure 6.

RELATIVE RELATIONS CHART OF EIGHT FACTORS

FOR SHUNT MOTOR

	V	Φ	Ia	T	HP	RPM	CEMF	r
V								
Φ								
Ia								
T								
HP								
RPM								
CEMF								
r								

Fig. 6

Number the indirect relation rectangles from 1 to 24, using the same order as shown in the direct relations chart Figure 6. This arrangement of sequence will cause the indirect relations to work out in a more logical order than would otherwise be the case.

When the Relative Relations Chart is completed, both the direct and the no-relations items have been determined. This leaves only the indirect relations to be analyzed and developed. These can all be found by inspection of the chart just completed by the use of the following procedure. NOTE: The items at the left of the chart affect those at the top according to the symbols set down in the rectangular spaces, and the items at the left are affected by those at the top according to the same symbol. If this thinking procedure is not clearly understood, confusion may result when an attempt is made to use the chart.

DIRECT RELATIONS CHART OF EIGHT FACTORS FOR SHUNT MOTOR

	V	Φ	Ia	T	HP	RPM	CEMR	r
V		y	y	$\overline{1}$	$\overline{2}$	$\overline{3}$	$\overline{4}$	0
Φ	0		$\overline{7}$	y	$\overline{5}$	$\overline{6}$	y	0
Ia	0	0		y	$\overline{8}$	$\overline{9}$	$\overline{10}$	0
T	0	0	$\overline{12}$		y	y	$\overline{11}$	0
HP	0	0	$\overline{14}$	$\overline{15}$		y	$\overline{13}$	0
RPM	0	0	$\overline{16}$	$\overline{17}$	y		y	0
CEMF	0	0	y	$\overline{18}$	$\overline{19}$	$\overline{20}$		0
r	0	0	y	$\overline{21}$	$\overline{22}$	$\overline{23}$	$\overline{24}$	

Figure 7.

Number the indirect relation rectangles from 1 to 24, using the same order as shown in the direct relations chart Figure 7. This arrangement of sequence will cause the indirect relations to work out in a more logical order than would otherwise be the case.

HOW TO FIND THE INDIRECT RELATIONS OF THE EIGHT BASIC FACTORS FOR A SHUNT MOTOR.

Refer to the immediate relations chart (Fig. 6) just worked out and follow this procedure. To find how terminal voltage affects the torque of a shunt motor, set down the relationship as follows: (1) V^{-T}. Find torque T at the top of the chart and drop down this vertical column until the first direct relation which is indicated by Y is reached. At this point move horizontally to the extreme left to find what factor directly affects torque T. The first one is field flux Φ and is indicated $\Phi \rightarrow T$. Now proceed to the top of the flux column Φ and drop down to Y; then move horizontally to the left and TV is reached. The relation now becomes $TV \longrightarrow \Phi \longrightarrow T$, meaning that terminal voltage affects field flux and field flux affects torque. The second direct relationship affecting torque is armature current and is expressed in this way--$Ia \longrightarrow T$--meaning that armature current affects torque. Following down the Ia column until Y is reached and then proceeding to the left, we find $T.V \longrightarrow Ia \longrightarrow T$, which indicates that motor terminal voltage affects armature current and armature current affects torque. These two relationships can be combined into one simple diagram showing both effects thus:

$$\begin{tikzcd} & \Phi \arrow[dr] & \\ TV \arrow[ur] \arrow[dr] & & T \\ & Ia \arrow[ur] & \end{tikzcd}$$

32 Following this same procedure, all 24 relative relations for the direct current shunt motor can be very logically analyzed and developed.

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INDIRECT RELATIONS OF EIGHT FACTORS FOR SHUNT MOTOR

1. How voltage affects torque.

V^{T} .

$$\begin{tikzcd}
 & \Phi \arrow[dr] & \\
V \arrow[ur] \arrow[dr] & & T \\
 & Ia \arrow[ur] &
\end{tikzcd}$$

2. How voltage affects load.

V^{HP} .

$$\begin{tikzcd}
 & \Phi \arrow[dr] & & & \\
V \arrow[ur] \arrow[dr] & & T \arrow[rr] \arrow[dr] & & HP \\
 & Ia \arrow[ur] & & RPM \arrow[ur, leftrightarrow] &
\end{tikzcd}$$

3. How voltage affects speed.

V^{RPM} .

$$\begin{tikzcd}
 & \Phi \arrow[dr] & & & \\
V \arrow[ur] \arrow[dr] & & T \arrow[rr] \arrow[dr] & & RPM \\
 & Ia \arrow[ur] & & HP \arrow[ur, leftrightarrow] &
\end{tikzcd}$$

4. How voltage affects counter electromotive force.

V^{CEMF} .

$$\begin{tikzcd}
 & \Phi \arrow[dr] & & & \\
V \arrow[ur] \arrow[dr] & & T \arrow[r] & RPM \arrow[r] & CEMF \\
 & Ia \arrow[ur] & & &
\end{tikzcd}$$

5. How field flux affects the load.

Φ^{HP} .

$$\begin{tikzcd}
\Phi \arrow[r] & T \arrow[rr] \arrow[dr] & & HP \\
 & & RPM \arrow[ur, leftrightarrow] &
\end{tikzcd}$$

6. How field flux affects the speed

Φ^{RPM}

$$\begin{tikzcd}
\Phi \arrow[r] & T \arrow[rr] \arrow[dr] & & RPM \\
 & & HP \arrow[ur, leftrightarrow] &
\end{tikzcd}$$

7. How field flux affects armature current.

Φ^{Ia} .

$$\begin{tikzcd}
\Phi \arrow[r] & T \arrow[rr] \arrow[dr] & & RPM \arrow[r] & CEMF \arrow[r] & Ia \\
 & & HP \arrow[ur, leftrightarrow] & & &
\end{tikzcd}$$

8. How armature current affects the load.

Ia^{HP} .

$$\begin{tikzcd}
Ia \arrow[r] & T \arrow[rr] \arrow[dr] & & HP \\
 & & RPM \arrow[ur, leftrightarrow] &
\end{tikzcd}$$

9. How armature current affects the speed.

Ia^{RPM} .

$$\begin{tikzcd}
Ia \arrow[r] & T \arrow[rr] \arrow[dr] & & RPM \\
 & & HP \arrow[ur, leftrightarrow] &
\end{tikzcd}$$

10. How armature current affects the counter-electromotive force.

    Ia^{CEMF} . $Ia \rightarrow T \xrightarrow[HP]{} RPM \rightarrow CEMF$

11. How torque affects the counter-electromotive force.

    T^{CEMF} . $T \xrightarrow[HP]{} RPM \rightarrow CEMF$

12. How torque affects the armature current.

    T^{Ia} . $T \xrightarrow[HP]{} RPM \rightarrow CEMF \rightarrow Ia$

13. How load affects the counter-electromotive force.

    HP^{CEMF} . $HP \rightarrow RPM \rightarrow CEMF$

14. How load affects the armature current.

    HP^{Ia} . $HP \rightarrow RPM \rightarrow CEMF \rightarrow Ia$

15. How load affects the torque.

    HP^{T} . $HP \rightarrow RPM \rightarrow CEMF \rightarrow Ia \rightarrow T$

16. How the speed affects the armature current.

    RPM^{Ia} . $RPM \rightarrow CEMF \rightarrow Ia$

17. How the speed affects torque.

    RPM^{T} . $RPM \rightarrow CEMF \rightarrow Ia \rightarrow T$

18. How the counter-electromotive force affects the torque.

    $CEMF^{T}$. $CEMF \rightarrow Ia \rightarrow T$

19. How the counter-electromotive force affects the load a direct current shunt motor will carry.

    $CEMF^{HP}$. $CEMF \rightarrow Ia \rightarrow T \xrightarrow[RPM]{} HP$

35 20. How the counter-electromotive force affects the speed.

$CEMF^{HP}$. $\quad CEMF \rightarrow Ia \rightarrow T \xrightarrow[HP]{} RPM$

21. How the armature resistance affects the torque.

r^{-T}. $\quad r \rightarrow Ia \rightarrow T$

22. How the armature resistance affects the load.

r^{-HP}. $\quad r \rightarrow Ia \rightarrow T \rightarrow HP$

23. How the armature resistance affects the speed.

r^{-RPM-}. $\quad r \rightarrow Ia \rightarrow T \rightarrow RPM$

24. How the armature resistance affects the counter-electromotive force.

r^{-CEMF}. $\quad r \rightarrow Ia \rightarrow T \rightarrow RPM \rightarrow CEMF$.

These relative relations can be easily checked by the follwoing method. Arrange the eight factors in the form of a circle. Figure 8. Draw an arrow from the one that affects to the factor which is affected, indicating each immediate relation. All of the relative relationships can be readily determined by simply following the arrows around this circular arrangement of symbols.

This diagram method makes the procedure of determining relative relations almost 100% mechanical, and for this reason its use is not recommended except for check purposes.

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SKELETON CHART OF DIRECT RELATIONS FOR SHUNT MOTOR

The skeleton diagram Fig. 9 is an arrangement of the eight basic factors showing all the immediate relations and is at the same time a combination of all the relative relations. These can be traced for each from numbers 1 to 24 by simply following the paths indicated by the arrows, as all direct relations effects take place in the indicated direction. This diagram is the simplest and most useful for analysis and trouble-shooting purposes. It contains all the essential elements involved in an understanding of motor operation and at the same time furnishes the framework around which all the details may be grouped in a clear-cut and logical order. As soon as it has been determined which basic factor the detail affects, the influence of this item on the motor operation can be traced logically and unerringly, and correct conclusions drawn as to its effects. The next step in this development shows how changes in one of the basic factors will affect the others.

Among the more common things that happen when a motor is operated which need analysis and explanation are:

1. Increased load
2. Decreased load
3. Increased resistance in the armature circuit

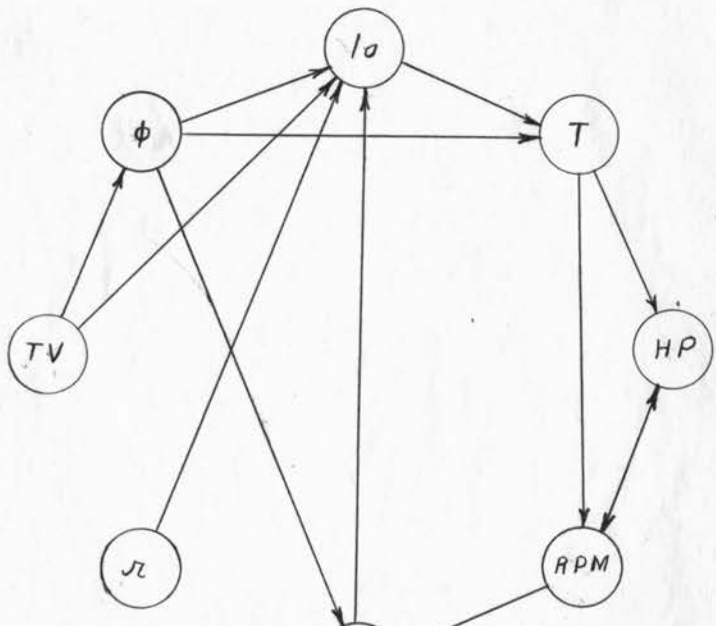

Figure .--Circular diagram of the eight basic factors for direct current motors

4. Decreased resistance in the armature circuit
5. Strengthened pole flux
6. Weakened pole flux
7. Increased terminal voltage
8. Decreased terminal voltage

The following is a brief explanation showing how the skeleton diagram may be used to gain an understanding of how load is taken care of by the direct current shunt motor. Other items such as weak field, resistance in the armature circuit, or low terminal voltage will be analyzed in a similar manner and the results charted to logical conclusions.

In Figure 10 the load symbol HP is identified by an additional circle around it showing this to be the factor in which the change originates. The arrows pointing up indicate an increase in the item, and those pointing down show a decrease. The small symbol at the end of the arrow shows the reason for the effect it marks in the change of the factor

HOW THE SHUNT MOTOR MEETS ADDED LOAD:

The motor is assumed to be running with a light load. See Fig. 2. To meet this load only a small amount of armature current is required to produce the necessary torque. In the shunt motor the pole flux does not change appreciably unless the voltage changes. Because of this fact it is necessary to have

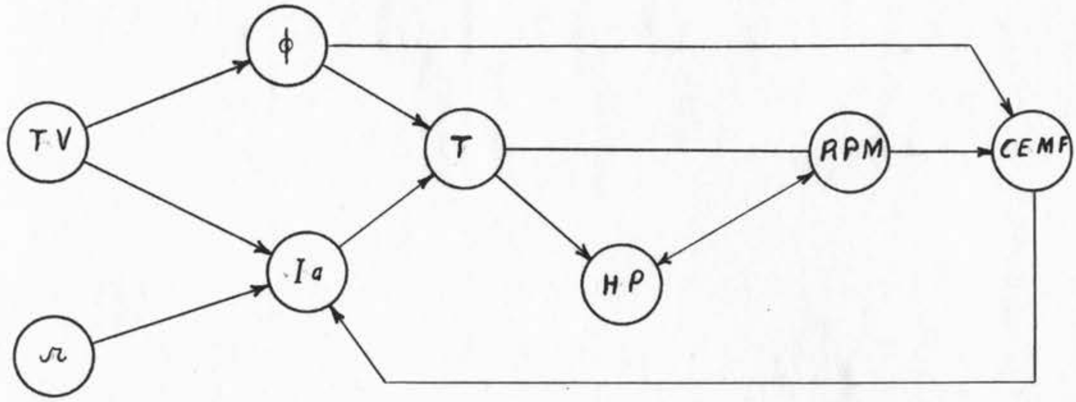

Fig. 9

Figure 9.--Skeleton diagram of eight basic factors for direct current motors

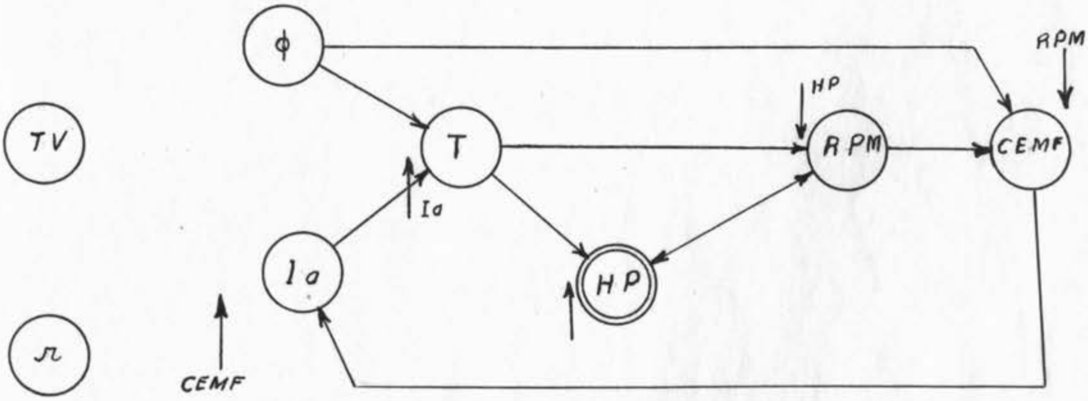

Fig. 10

Figure 10.--Skeleton diagram analysis of load increase on a direct current shunt motor

more armature current only when load is added to provide the additional torque needed. See Figs. 3 and 4.

Referring to the skeleton diagram, Fig. 10, and starting with the load (HP), place arrows at the left of each factor affected. The explanation is as follows: when the load increases, this slightly decreases the speed indicated by the downward directed arrow by (RPM) with (HP) at the upper end. Since a decrease in speed will cause a decrease in counter-electromotive force, this will permit more current to flow through the armature, as shown by the upward directed arrow at (Ia) with (CEMF) at the lower end. This increase in armature current will build up the necessary amount of torque to pull the load, as shown by the upward directed arrow at (T) with (Ia) at the lower end. Only a slight change in counter-electromotive force is necessary to permit sufficient armature current to make enough torque to pull the load. For this reason the shunt motor has a very small speed change from no load to full load.

HOW THE SHUNT MOTOR FUNCTIONS WHEN LOAD IS DECREASED:

As the load on a shunt motor is lessened for any reason, the motor is left with excess torque. See Fig. 11. Since this torque is no longer required to pull the load, the extra torque immediately increases the speed, shown by the upward arrow at (RPM) with (HP) at the lower end. The additional speed raises the counter-electromotive force indicated by the upward arrow at (CEMF) with (RPM) at the lower end, which lessens the flow of current through the armature. See downward arrow at (Ia) with CEMF at upper end. This reduction in armature current lessens the torque shown by the downward arrow at (T) with (Ia) at upper end, until the remaining load requirements are exactly taken care of. This action or characteristic accounts for the high efficiencies obtainable with electrical motors for changing electrical energy to mechanical energy. Counter-electromotive force acts as a governor or throttle and permits only enough energy to pass through the armature to provide the necessary power to meet load requirements. The fact that this factor is frictionless and also nearly instantaneous in its action makes the electric motor a very efficient machine.

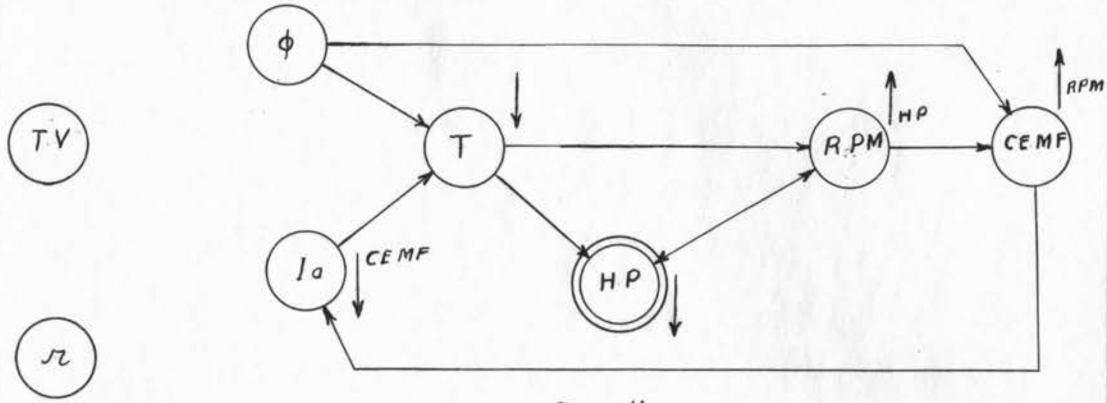

Fig 11

Figure 11.--Skeleton diagram analysis of load decrease on a direct current shunt motor

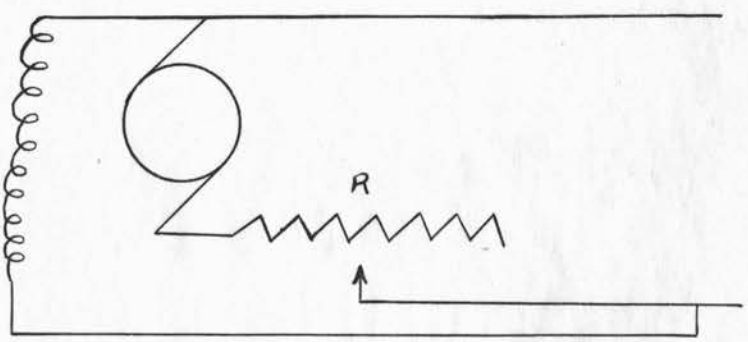

Fig 12

Figure 12.--Speed control of a direct current shunt motor using armature circuit resistance

Every change in speed makes a corresponding change in counter-electromotive force. Since a very small change in counter-electromotive force causes a considerable change in armature current, only a small variation of speed will immediately affect the armature current. For this reason the total change in speed of a shunt motor from no load to full load is relatively small. On a percentage basis this will usually range between 4% and 7%, depending upon the motor design. Armatures with low resistance have a smaller speed variation with load than those with higher resistance. Regulation is the term usually used to express the speed variation and is the change in revolutions per minute from no load to full load.

41 RESISTANCE IN THE ARMATURE CIRCUIT OF A SHUNT MOTOR

Resistance in the armature circuit of a shunt motor is frequently used with smaller motors to reduce the speed. See Fig. 12. It is convenient and a method easily used to obtain lower speeds, especially below name-plate values. In addition to the terminal voltage there are two other controls over armature current, namely, the armature circuit resistance (r) and the counter-electromotive force (c.e.m.f.), the former of which is so often used to obtain lower speeds, as mentioned before.

Resistance introduced into the armature circuit as shown by the arrow at the symbol (r) in Fig. 13 will decrease the armature current Ia, as shown by the downward arrow at Ia. Less armature current will produce a smaller torque with a resulting slower speed. This lower speed will cause the counter-electromotive force to go down and increase the armature current, which offsets the effect of the added resistance in the armature circuit. Thus the armature will turn at a reduced rate but with a resulting loss of power when any resistance is added to the armature circuit.

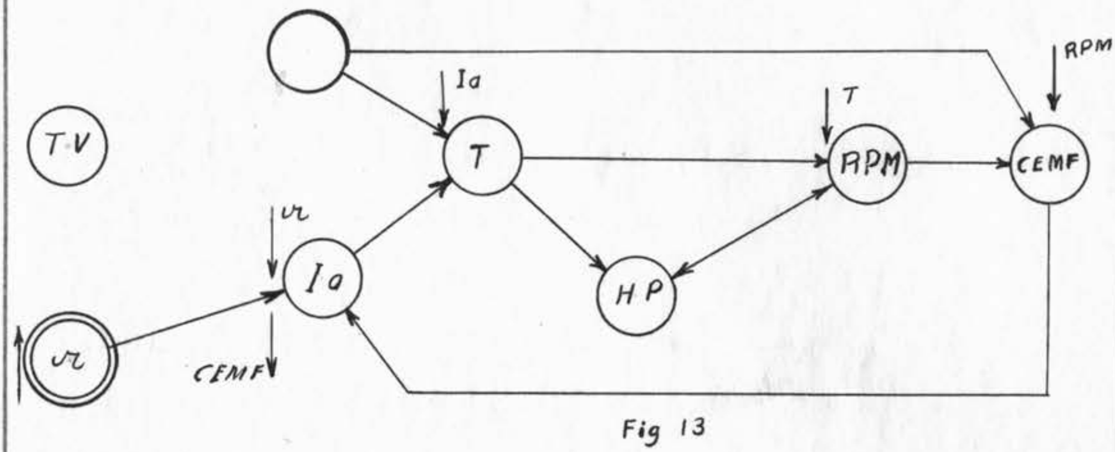

Figure 13.--Skeleton diagram analysis of increased armature circuit resistance in a direct current shunt motor

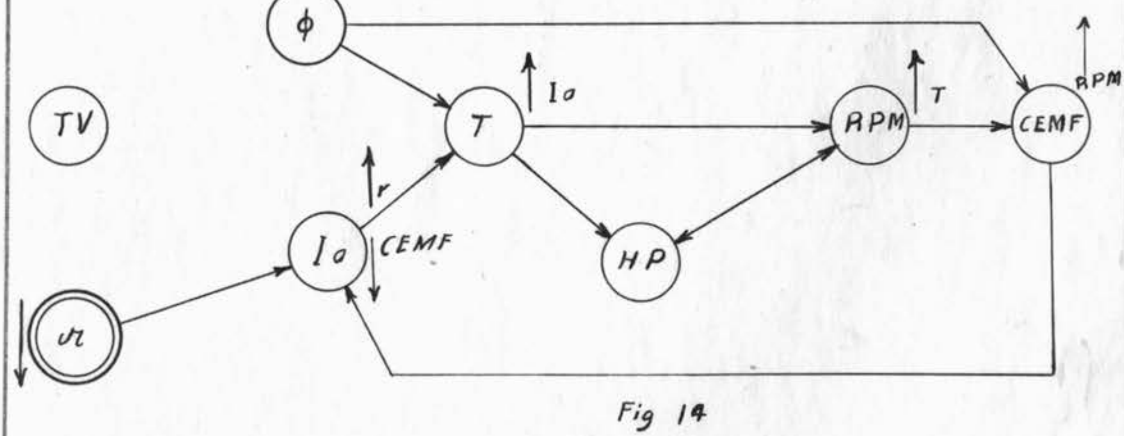

Figure 14.--Skeleton diagram analysis of decreased armature circuit resistance

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RESISTANCE IN THE ~~ARMATURE~~ ARMATURE CIRCUIT

The adjustment in the basic factors affected when resistance in the armature circuit, Fig. 12, page 120, is reduced may be seen from a study of Fig. 14. As this resistance (R) is made smaller, more current (Ia) passes through the armature increasing the torque (T) as shown by upward arrows at (Ia) and (T). The additional torque speeds up the motor armature, as shown by the arrow at (R.P.M.) which causes a corresponding increase in counter-electromotive force (C.E.M.F.). Note upward arrow at counter-electromotive force (C.E.M.F.) indicating this. Greater counter-electromotive force will immediately reduce the armature current to nearly the same value as before the resistance was changed. Therefore reduced resistance in the armature circuit manifests itself in greater speed of the motor.

HOW A WEAK FIELD AFFECTS THE OPERATION OF A DIRECT CURRENT SHUNT MOTOR.

Any weakening of the pole flux of a shunt motor is accompanied by an immediate increase in speed. To explain this action, the following analysis is offered. The weakened field shown by the downward arrow on the flux (Φ) in Fig. 15 causes a loss in this magnetic force-producing torque. This would cause a loss of speed if the armature flux produced by the armature current did not more than offset it. A weaker field causes a decrease in the counter-electromotive force, shown by the downward arrow at C.E.M.F. A small change in counter-electromotive force always results in a marked increase in armature current. This is shown by the upward arrow at Ia. The large armature flux resulting from this increased armature current creates a greater torque than existed before the field strength was diminished. This greater amount of torque immediately causes an increase in the motor speed. A shunt motor will continue to perform in this manner until the iron in the armature reaches the magnetic saturation point. After a saturated condition of the iron in the armature is reached, the armature current does not produce enough magnetism to maintain the proper torque for increasing the speed. When crowded beyond this point, the armature starts to heat. Motors

Figure 16.--When the field is weakened on a shunt, more armature current is required to maintain the same amount of torque.

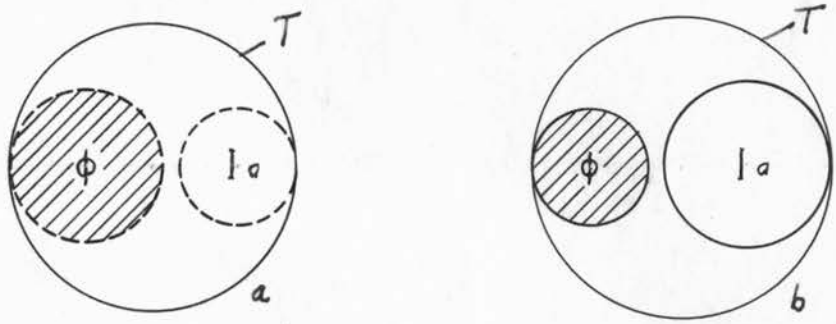

Fig 16

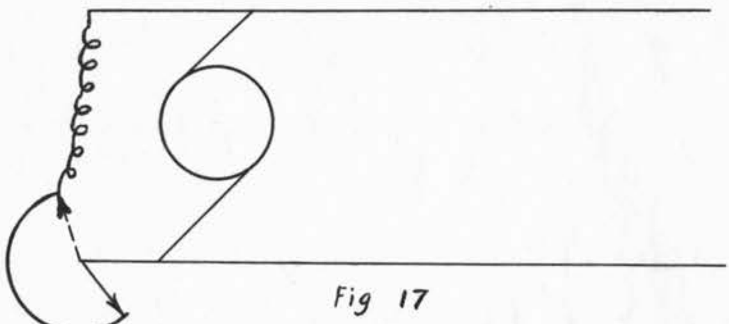

Fig 17

Figure 17.--Connection diagram for a direct current shunt motor using field resistance for speed control

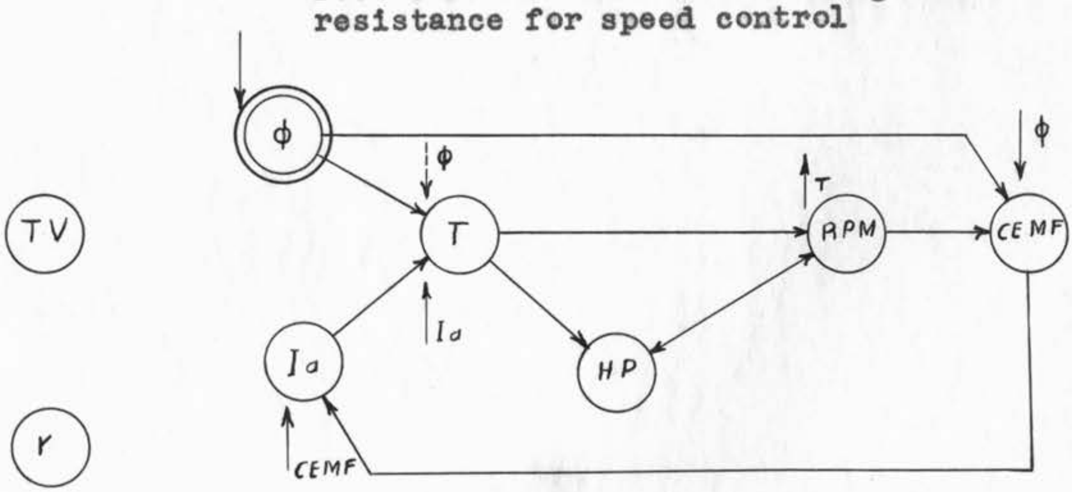

Fig 15

Figure 15.--Skeleton diagram analysis of weak field effects on a direct current shunt motor

designed to function with weakened fields are made with armatures much larger than normal. This is done to provide copper to carry the excessive armature currents and iron to take care of the additional magnetism produced in this member of the machine under operating conditions.

WEAK FIELD

Fig. 16a. Dotted circles indicate relative values of field flux (Φ) and armature flux Ia before the field is weakened. Solid circles show the same values after field is weakened. See Fig. 16b.

Fig. 16 gives an idea of the relative changes in the pole flux (Φ) and the armature flux made by the larger amount of current (Ia) in the shunt motor operating with weakened field. Note that the change in armature current is greater than the change in field flux as shown by the dotted and solid circles. The circle representing torque after the field is weakened is slightly larger than before the pole flux was weakened, because of a much greater increase in flux from the armature current.

HOW LOW TERMINAL VOLTAGE WILL AFFECT THE OPERATION OF A DIRECT CURRENT SHUNT MOTOR

If for any reason the motor is supplied with a voltage below name plate value, the resulting operating conditions can be diagnosed as follows: low terminal voltage applied to the field curcuit will result in a decreased amount of pole flux (Φ) indicated by the downward arrow at (Φ) in Fig. 18. There will also be a tendency toward less armature current indicated by the downward broken arrow at Ia. The weakened field will diminish torque in the same ratio in which it is weakened itself, indicated by the upper arrow at (T). A smaller amount of torque will result in diminished speed, which will weaken the counter-electromotive force. A weaker field will also result in less counter-electromotive force. These last two conditions are shown by downward directed arrows at C.E.M.F. Both adverse affects on the counter-electromotive force cause a very marked increase in armature current, which more than offsets the tendency of lower line voltage to weaken the armature current, and the result is a net increase in this factor. The additional armature current increases this torque factor and offsets the weaker field effect on torque. It is obvious that the motor must have sufficient torque to pull the load. To obtain this

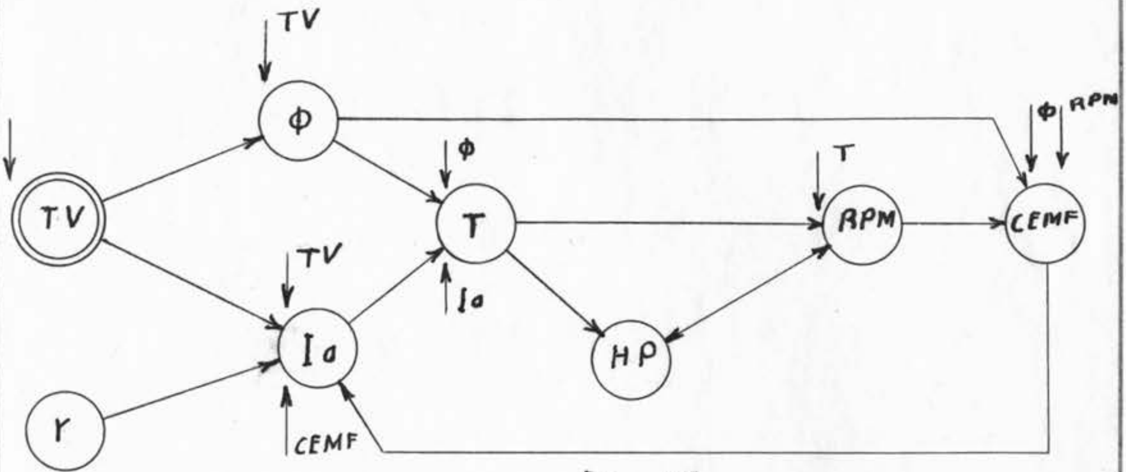

Fig 18

Figure 18.--Skeleton diagram analysis of reduced terminal voltage effects on a direct shunt motor

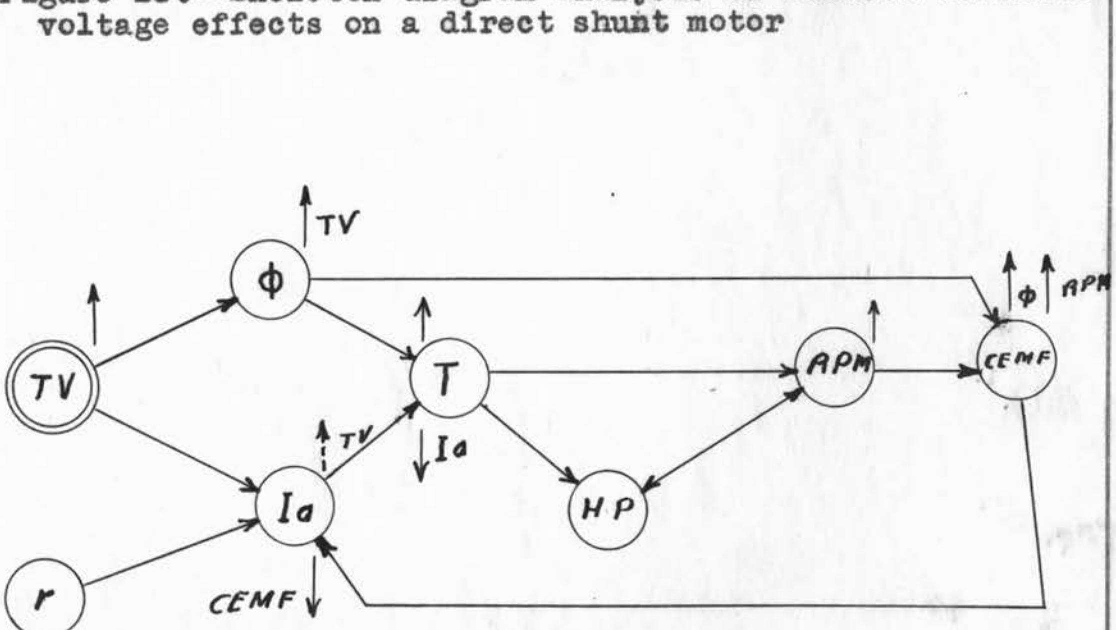

Fig 19

Figure 19.--Skeleton diagram analysis of increased terminal voltage on a direct current shunt motor

46 torque the armature current increases; therefore, if the applied voltage is below name-plate value, the speed is not up to normal and the armature current is higher than it is with the correct pressure at the motor terminals.

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HOW HIGH TERMINAL VOLTAGE WILL AFFECT THE OPERATION OF A DIRECT CURRENT SHUNT MOTOR.

When the voltage at the motor is higher than the name plate value calls for, increased current will flow through the shunt field winding, producing more flux (Φ), indicated by the arrow on the pole flux (Φ) in Fig. 19. There will also be a tendency toward increased armature current from this extra pressure on the armature circuit, indicated by the broken arrow pointing upward. The strengthening of the pole flux from the additional terminal voltage will have its effect on torque, which in turn will increase the speed at which the motor operates. Arrows at torque (T) and speed (R.P.M.) indicate these results. Additional speed builds up the counter-electromotive force, and a stronger field also increases this factor. These combined effects result in actually diminishing the armature current, although the applied voltage to the armature circuit is higher. When this situation is considered from the standpoint of the torque, it is readily to be seen that additional field strength will produce the same torque with less armature current. Voltage above name plate rating results in higher operating speed and slightly diminished armature current for the same load conditions when the terminal voltage is above name plate values.

THE DIRECT CURRENT SERIES MOTOR

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The same eight basic or fundamental factors that have been developed for the shunt motor apply also to the series motor. The only essential variation in the relationships occurs in the pole flux (Φ) column of Chart Fig. 23. In the shunt motor the pole field is produced by applying terminal voltage directly to the shunt winding, and the series motor gets its field from the armature current passing through a few turns of relatively large wire wound on the pole piece. This slight variation in the construction makes a motor with widely different behavior in its operation and performance.

The field in the series motor is dependent upon the armature current, as it is the armature current which causes the magnetization of the poles. For this reason the pole flux will be small when the armature current is small. Likewise, when the armature current is large, the poles are highly magnetized. Thus the armature current performs the double duty of magnetizing the armature and the poles, which accounts for the statement so often seen about series motors: "the torque varies as the square of the armature current". The torque and speed characteristics of the series motors are almost exactly opposite to those found in the shunt motor. See Fig. 20.

49 Terminal voltage for the series motor supplies the energy in the same way as for the shunt motor. There is this difference, however, in its application. With the series motor there is only one circuit through the motor, since the armature and field coils are connected in series, Fig. 20a, whereas the shunt motor is provided with two circuits--one for the field itself and the other for the armature.

Because the pole flux in the series motor is dependent upon the armature current for its production, the field strength varies widely in intensity. At light loads the field flux will be negligible, whereas under heavy loads the magnetism will over-saturate the iron in the poles of the motor. This great variation in field strength has a very marked effect on the torque. See Fig. 20a, b, and c.

Armature current so far as the armature itself is concerned performs the same function in identically the same manner for the series as for the shunt machine.

HOW TORQUE IS PRODUCED IN A SERIES MOTOR:

The pole flux in the series motor is a variable quantity because it is produced by the armature current. Since the armature current in this motor also produces the pole flux, a change in the current produces

Figure 20.--Torque in a series motor varies as the square of the armature current

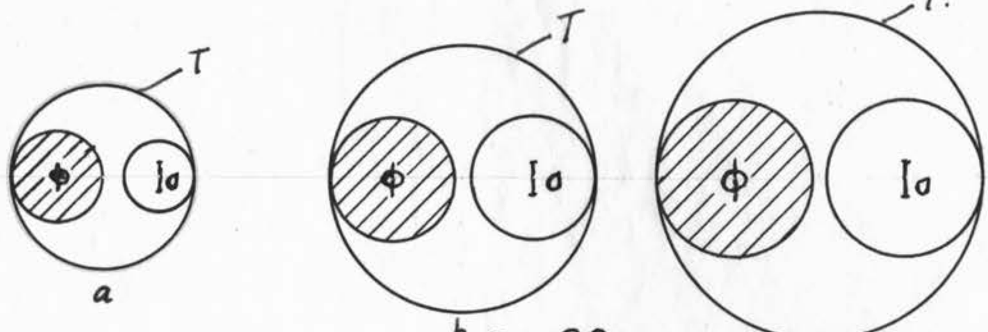

Fig 20

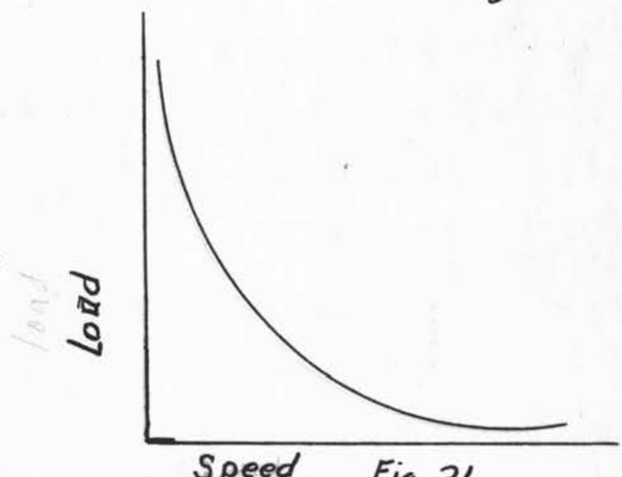

Fig 21

Figure 21.--Curve showing relationship of load and speed in a direct current series motor

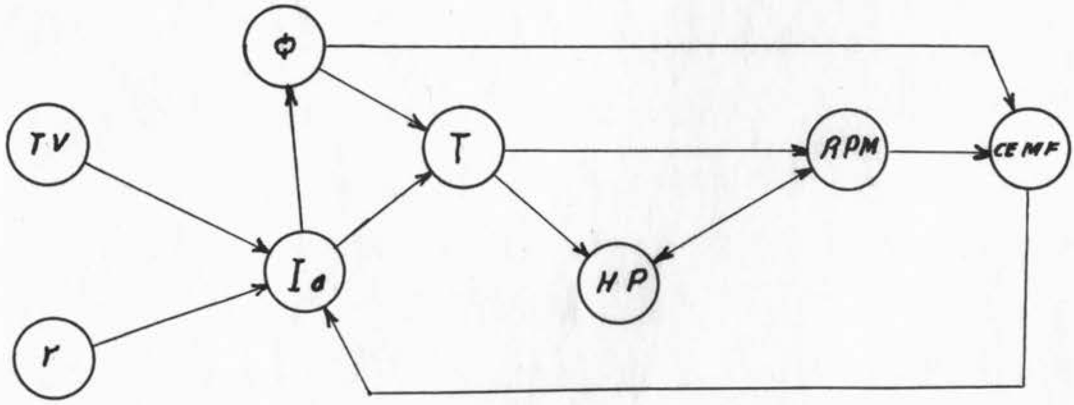

Fig 22

Figure 22.--Skeleton diagram of eight basic factors for a direct current series motor

a double effect on torque as shown by Figs. 20a, b, and c. This accounts for the statement so often made for series motors--that the torque varies as the square of the armature current. This fact is practically true up to the saturation points of the iron in the field poles and the armature iron but of course would not hold beyond these magnetic densities.

The torque characteristic for the series motor is entirely different from what was found for the shunt motor. At slow speeds the torque is extremely high and drops rapidly as the speed reaches normal values, as shown in Fig. 21. Such a combination of operating characteristics exactly matches the requirements of transportation and accounts for the almost universal application of series motors for traction purposes.

The load on a series motor has a much more marked effect on the operating characteristics than is shown by the shunt machine. Because the series motor has such exceptionally strong torque for starting and accelerating loads, it is the ideal motor for transportation purposes. The power used at high speeds is small so that the efficiency of the motor is high over its entire speed range. This fact is an important reason why the series motor is so universally used in trucks, cars, and locomotives.

51 Speed varies more in the series motor than in any other; in fact, load change on this machine is immediately accompanied by a corresponding change in speed. The fact that a series motor will run away with light or no load must be given serious consideration in all applications. For this reason it is usually geared or directly connected to the driven load. Counter-electromotive force and armature resistance have the same effects on the operation of the series motor as on that of the shunt machine.

In making the immediate relations chart, Fig. 23, for the series motor, the procedure is exactly the same as for the shunt. The relationships in all of the sixty-four rectangles are exactly the same as in the previous chart except the bottom six in the vertical field flux column under (Φ). The first of these six is the effect of armature current Ia on the pole flux (Φ). Because it is the armature current through the series winding on the poles that makes the magnetic field in the frame of a series motor, this is a direct effect. On account of this direct effect torque, load, speed, and counter-electromotive force will all have an indirect effect on the pole flux (Φ). Since the resistance (r) of the armature circuit affects the armature current directly, it will have an indirect effect on the field flux of this motor. This difference in field excitation will add five more indirect relations to those already developed for the shunt machine, all of which apply to the series motor. These can be worked out by the same method as explained before. They have been numbered from 25 to 29 inclusive, in Fig. 23, and are listed as follows:

DIRECT RELATIONS CHART OF EIGHT FACTORS FOR

SERIES MOTOR:

	V	Φ	Ia	T	HP	RPM	CEMF	r
V		Y	Y	— 1	— 2	— 3	— 4	0
Φ	0		— 7	Y	— 5	— 6	Y	0
Ia	0	Y*		~~Y~~	— 8	— 9	— 10	0
T	0	— 25*	— 12		Y	Y	— 11	0
HP	0	— 26*	— 14	— 15		Y	— 13	0
RPM	0	— 27*	— 16	— 17	Y		Y	0
CEMF	0	— 28*	Y	— 18	— 19	— 20		0
r	0	— 29*	Y	— 21	— 22	— 23	— 24	

Note: It is suggested that numbers 1 to 24 inclusive be inserted in light type, as these refer to the shunt motor and have been explained heretofore.

This chart for the series motor has only six rectangles in which the relationships are different from those developed for the shunt machine. These are all in the vertical column under field flux (Φ) and have been marked with an * in Fig. 23.

53 RELATIVE RELATIONS OF EIGHT FACTORS FOR SERIES MOTOR:

25. How the torque affects the field flux

T^{Φ} $\quad T \rightarrow RPM \rightarrow CEMF \rightarrow Ia \rightarrow \Phi$

26. How the load affects the feild flux

HP^{Φ} $\quad HP \rightarrow RPM \rightarrow CEMF \rightarrow Ia \rightarrow \Phi$

27. How the speed affects the field flux

RPM^{Φ} $\quad RPM \rightarrow CEMF \rightarrow Ia \rightarrow \Phi$

28. How the counter-electromotive force affcets the field flux

$CEMF^{\Phi}$ $\quad CEMF \rightarrow Ia \rightarrow \Phi$

29. How the armature resistance affects the field flux

r^{Φ} $\quad r \rightarrow Ia$

The last five combined with the first twenty-four form the basis for a study of the compound motor.

The skeleton diagram shown in Fig. 24 is very similar in appearance to the shunt chart, the only two differences being as follows. In this diagram the terminal voltage (V) has no direct effect on field flux (Φ) so that arrow is missing, and the armature current (Ia) in this case directly affects the pole flux (Φ), so there is an arrow between (Ia) and (Φ) to show this relationship.

This chart is used to show load effects on motor operation, the effect on the series motor of resistance in the armature circuit, the results on the machine when terminal voltage is too low or too high, and also a means for analyzing the effects of any item which may affect any of the fundamental operating factors.

When load is applied to the series motor, Fig. 24, the speed (RPM) decreases, which lowers the counter-electromotive force (C. E. M. F.) and permits more armature current (Ia) to flow, as shown by the arrows at HP, RPM, CEMF, and Ia. This current has a double effect on the torque, as it also produces the pole flux. Because a motor with stronger field would have increased counter-electromotive force (CEMF), the armature current would not increase and there would not be the necessary torque to pull the added load. Since added load requires

55 more torque, the armature current must increase to obtain it. The only way to get a reduction in counter-electromotive force, in order to have more current when field strength is increased, is through lower speed. The two downward arrows at R. P. M. indicate the slowing-down effect of the load and the depressing effect of a stronger field on the speed. For these reasons there is a marked reduction in speed when load is applied to the series motor, primarily because of this strengthening effect of the armature current on the field.

The series motor has the best torque of any motor at slow speeds because strong armature field and pole flux occur at the same time, since both fluxes are produced by the same current. See Fig. 20c.

When the load is removed from a series motor, the excess torque increases the speed shown by upward arrow at speed (RPM), Fig. 25. This speed increase builds up the counter-electromotive force (C.E.M.F.) and tends to reduce armature current as shown by arrows at (CEMF) and (Ia). But this reduced armature current weakens the field, which in turn weakens the counter-electromotive force (CEMF), and the armature current is not sufficiently affected, a condition which leaves the motor with more torque than is required for the load; so this excess torque immediately builds up the counter-

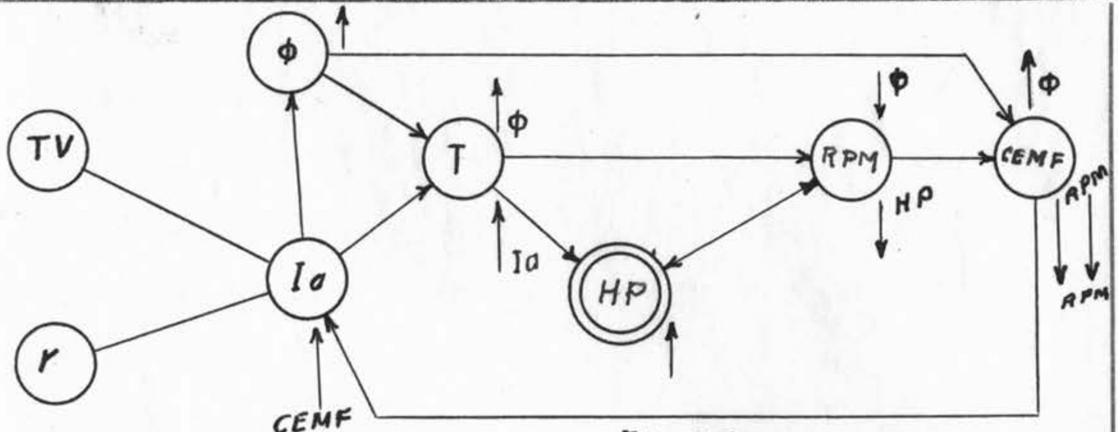

Fig 24

Figure 24.--Skeleton diagram analysis of increased load effects on a direct current series motor

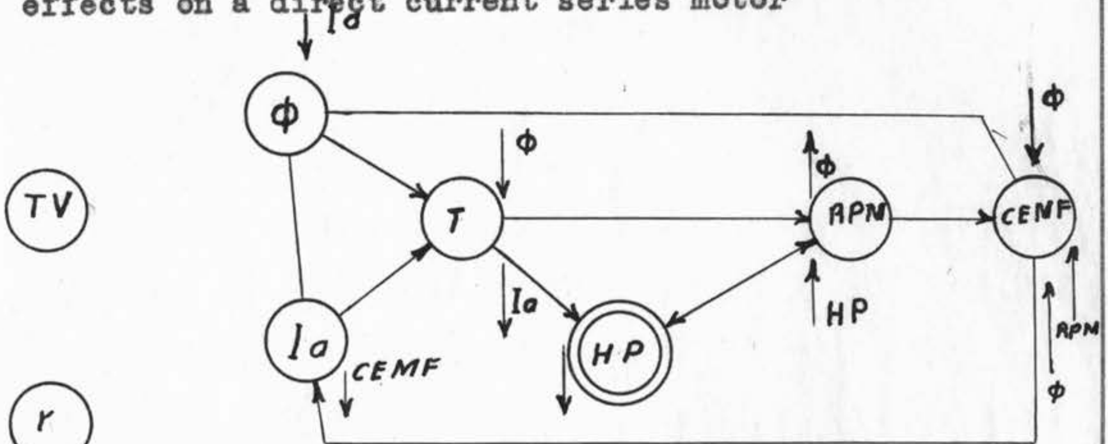

Fig 25

Figure 25.--Skeleton diagram analysis of decreased load effects on a direct current series motor

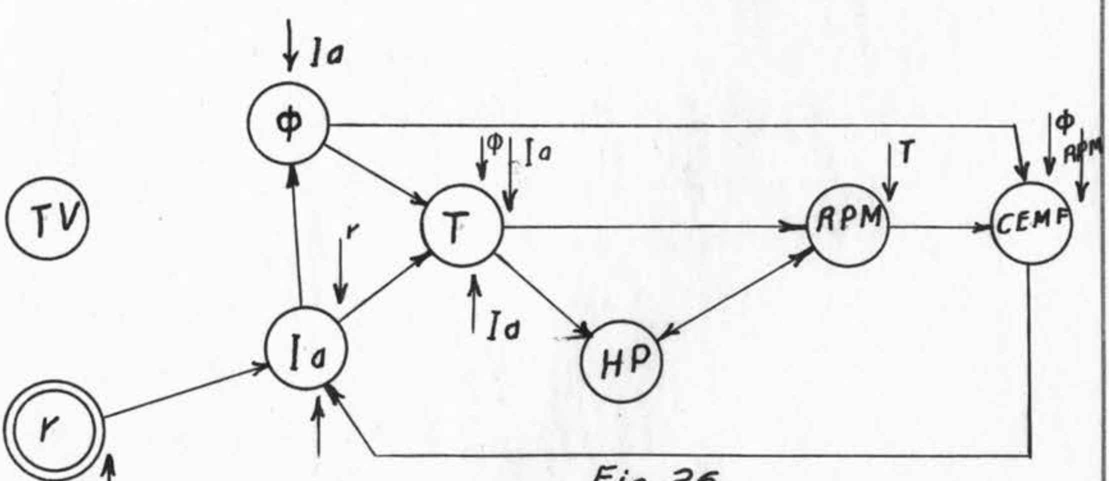

Fig 26

Figure 26.--Skeleton diagram analysis of weakened field on a direct current series motor

electromotive force (CEMF) through speed (RPM) which tends to reduce further the armature current (Ia) and still further weaken the field. These adjustments continue until there is exactly enough torque to drive what load remains on the motor.

A motor with a weak field tends to run at high speeds. Now with a series motor, the faster it goes the more the field is weakened and the faster the armature must rotate to keep up counter-electromotive force. This condition becomes exceedingly dangerous with light or no loads on series motors, as the speed will go so high that dangerous stresses are set up in the windings and commutator. The armatures will reach such a speed that they will literally fly to pieces in a very short interval of time.

A resistance added to the armature circuit of a series motor will tend to reduce the armature current (Ia). Any situation which causes change in armature current doubles its effect upon the torque withing normal operating limits of the machine. A motor must have torque, or the load will not run. This loss of torque makes itself felt in reduced speed of the motor, as shown by the downward arrow at speed (RPM) in Fig. 26. This lower speed of rotation of the armature drops the counter-electromotive force (CEMF)(as shown by the arrow) which in turn will offset the effect of increased res-

57 istance in the armature circuit. Thus the main effect of resistance in the armature circuit of a series motor is reduction of speed with of course the usual loss of power. The reasons for this can be easily seen by following the arrows in Fig. 26. Resistance in series with a motor of this type has the same effect as running the motor with lower line voltage. Any energy dissipated in the resistance cuts down the efficiency of the motor circuit. Because of this loss two or more series motors are often connected in tandem whenever practicable for use at lower speeds.

If the applied voltage at the terminals of a series motor is lower than usual, there will be a tendency toward less armature current, as shown by the downward arrow at Ia, Fig. 27. Any loss of current through the series motor immediately weakens the pole flux (Φ), and the double loss of torque is felt by the motor as shown by arrows at torque (T) and speed (RPM). The loss of speed (RPM) decreases counter-electromotive force (CEMF), which permits the armature current (Ia) to approach normal again for the load (HP) being handled. This shows that loss of applied voltage (V) is met by reduced counter-electromotive force (CEMF) obtained through lower speed (RPM). Thus the principal effect of low terminal voltage (V) on a series motor performance is indicated by speed (RPM) reduction.

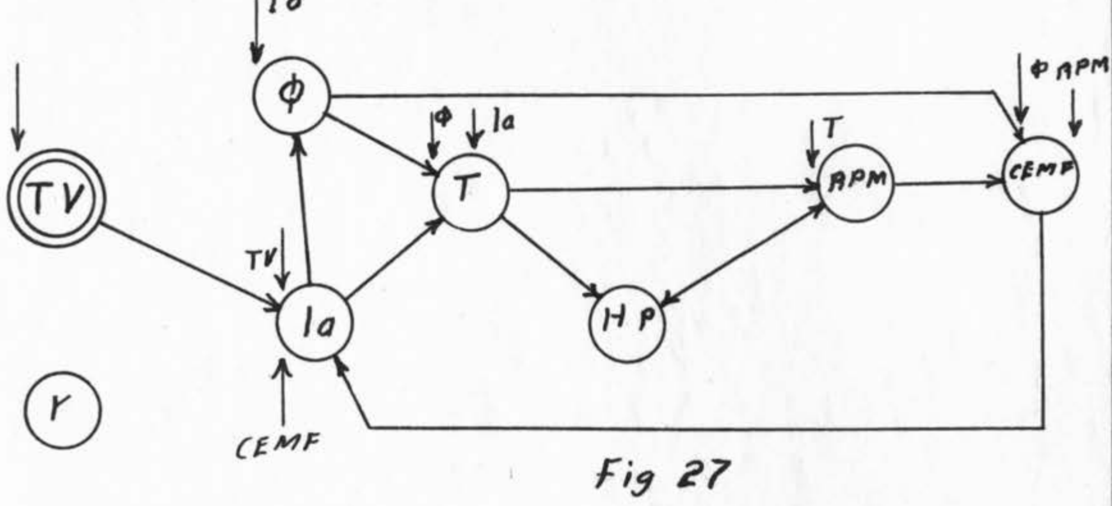

Figure 27.--Skeleton diagram analysis of low voltage effects on a direct current series motor

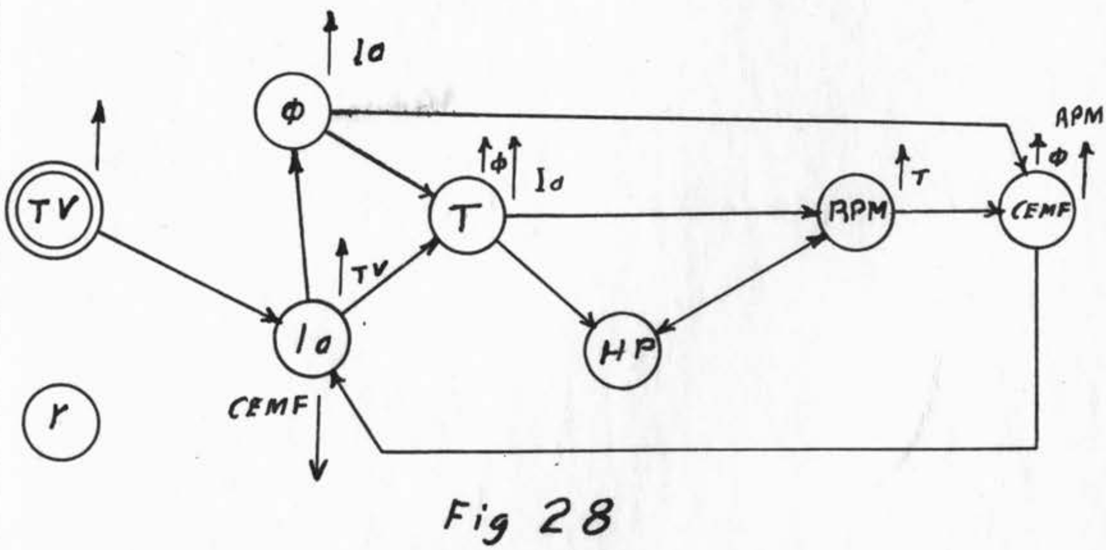

Figure 28.--Skeleton diagram analysis of high voltage effects on a direct current series motor

58 A rise in applied voltage (V) will have just the opposite effect on a series motor speed (RPM). This will be easily seen from an inspection of Fig. 28.

DIRECT CURRENT

THE CUMULATIVE COMPOUND MOTOR

The same eight basic factors used for the study of the shunt and series motor will satisfactorily explain the functioning of a compound motor connected either cumulatively or differentially. Terminal voltage, armature current, load, speed, counter-electromotive force, and resistance of the armature circuit are produced and have practically identical effects for the compound motor as heretofore explained for the shunt and series machines. There are some variations in pole flux and torque, however, which should be understood from a study of the following paragraphs on these items.

When the motor is connected cumulative compound, the shunt and the series ampere turns are both producing flux of the same polarity or direction. In this case the effects of both windings are additive and increase the pole flux if either of the magnetizing forces is increased.

In the case of a differential connection the ampere turns of the series field work against the shunt field ampere turns and weaken the pole flux when load is added to the motor. Care must be taken in connecting compound motors to have proper connections, as it is possible to connect a motor of this

60 type either cumulative or differential. Thus we have a motor which has some of the characteristics of both the shunt and series motor. More information of these combined characteristics will be found under the discussion of torque for the compound motors.

The development of torque in a cumulative-connected compound motor differs from a shunt motor in the following way. The armature current in a shunt motor has no direct effect on the amount of pole flux produced. At very light loads this armature current is small and has little if any appreciable effect on the pole flux, Fig. 29a. Note the increase in the pole flux, as shown in the above Figs. 29b and 29c, when the armature current is increased. This increase in pole flux as the load is applied causes the motor to develop more torque for the same armature current than is the case with the shunt motor.

In order to obtain the largest amount of flux with the least expenditure of electrical energy, the best grades of iron are used in the magnetic circuit, consisting of the pole core, yoke, and armature laminations. The correct flux density is also used, and the air gap is made as small mechanical conditions conveniently permit.

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	V	Φ	Ia	T	HP	RPM	CEMF	r
V		Y	Y	—— 1	—— 2	—— 3	—— 4	O
Φ	O		—— 7	Y	—— 5	—— 6	Y	O
Ia	O	Osh Ys		Y	—— 8	—— 9	—— 10	O
T	O	Osh —— 25s	—— 12		Y	Y	—— 11	
HP	O	Osh —— 26s	—— 14	—— 15		Y	—— 13	O
RPM	O	Osh —— 27s	—— 16	—— 17	Y		Y	O
CEMF	O	Osh —— 28s	Y	—— 18	—— 19	—— 20		O
r	O	Osh —— 29s	Y	—— 21	—— 22	—— 23	24	

Fig. 32

Immediate Relations Chart of Eight Factors For Direct Current Compound Motors.

The Immediate relations chart for the direct current compound motor, Fig. 32 is very similar to those developed for the shunt and series machines. It is really a combination of the two former developments and is alike in all columns except the one for pole flux. This must show both the shunt and series coil effects on pole flux, as both coils are active in producing the magnetic field in the compound motor. This chart should be developed from an analysis of the material on the eight fundamental factors discussed in previous pages.

The indirect relations for the compound motor are identical with those developed for the

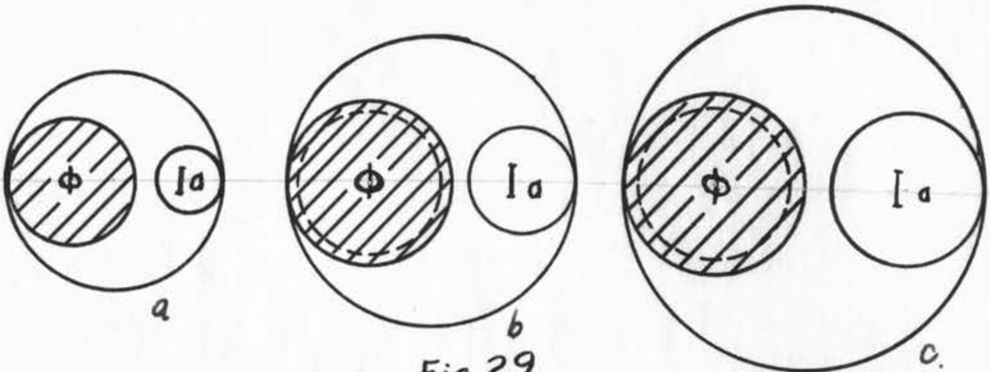


Fig 29

Figure 29.--How armature current and field flux make torque in a direct current cumulative compound motor

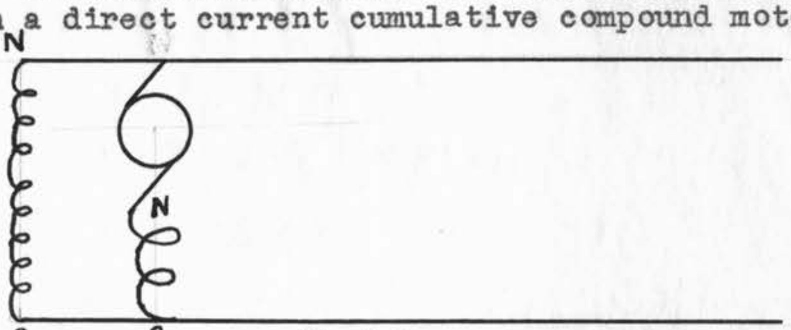


Fig 30

Figure 30.--Wiring connections for a cumulative connected

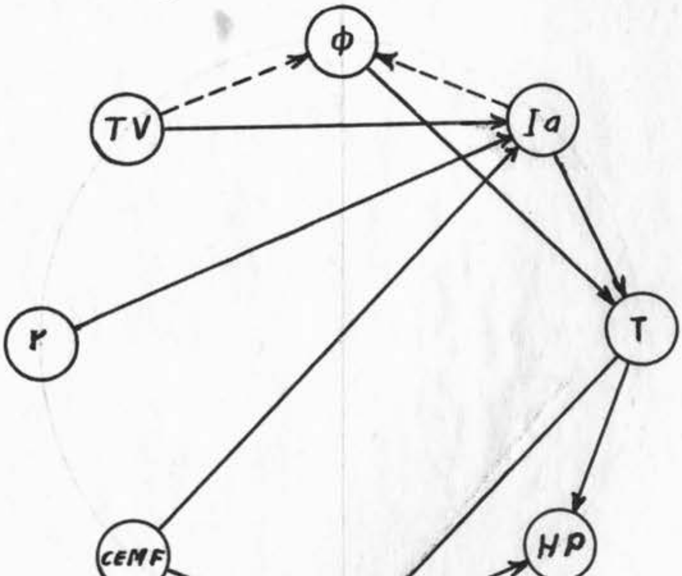


Fig 31

Figure 31.--Circular arrangement of basic factors for direct current cumulative compound motor

shunt and series motor, pages **111-13, 138. The first** twenty-four are the same as for the shunt machine, and those from twenty-four to twenty-nine are those caused by the series coil winding, Fig. 30.

Figs. 30 and 31 provide a mechanical means of arriving at or checking all of the twenty-nine indirect relations for the compound motor.

It will help the learner a great deal if he will always have a symbol of the particular motor being studied where it can easily be seen. The circuit arrangement and construction details should be known and never lost sight of if confusion of ideas is to be avoided.

The skeleton diagram for this type of motor, Fig. 33, shows all the relationships existing among the eight factors. Note that this diagram is a combination of the skeleton diagrams for the shunt and series motors discussed on pages **117** and **134.** This arrangement lends itself most clearly to analyzing the various changes which occur when these motors are operated and hence will be used for explanations of compound motor operating conditions.

The compound motor is different from the shunt and series in construction only in the matter of field windings. The compound, as the name indicates, has both a shunt and a series winding on the pole

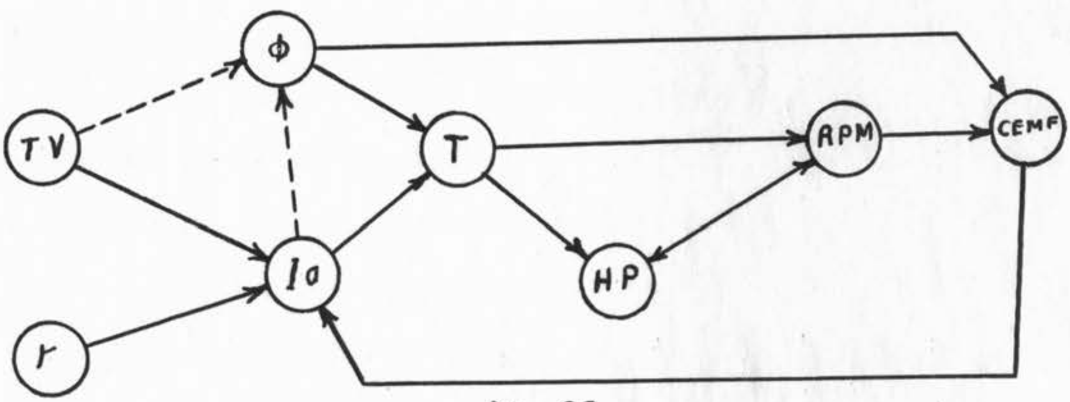


Fig 33

Figure 33.--Skeleton diagram arrangement for.cumulative connected compound motor

pieces. When these windings are connected so that both produce flux in the same direction, the motor is said to be connected comulative compound. With both shunt and series coils producing flux of the same polarity on the pole pieces, the motor has some of the characteristics of both the shunt and series motors. Fig. 51a shows the torque condition for light load on the motor. When the armature current is low in value, it has only a very slight effect on the pole flux. This condition exists when the load is light. An inspection of Fig. 29b and 29c will show how the armature current increases the pole flux as the load increases, thus producing a somewhat larger torque than the same armature current made in a shunt motor. Compare Figs. 29a, b and c, and 2, 3, and 4.

Load (HP) added to the compound motor reduces the speed (RPM) which effects counter-electromotive force (CEMF) in like manner, as shown by arrows in Fig. 34. This permits more current (Ia) to pass through the armature circuit, which will have its direct effect on torque (T). At the same time it slightly strengthens the pole flux (Φ) which also increases torque (T), as indicated by the arrows. But increased pole flux (Φ) holds up the counter-electromotive force (CEMF) and would not permit sufficient armature current (Ia) to pass. Now added load (HP)

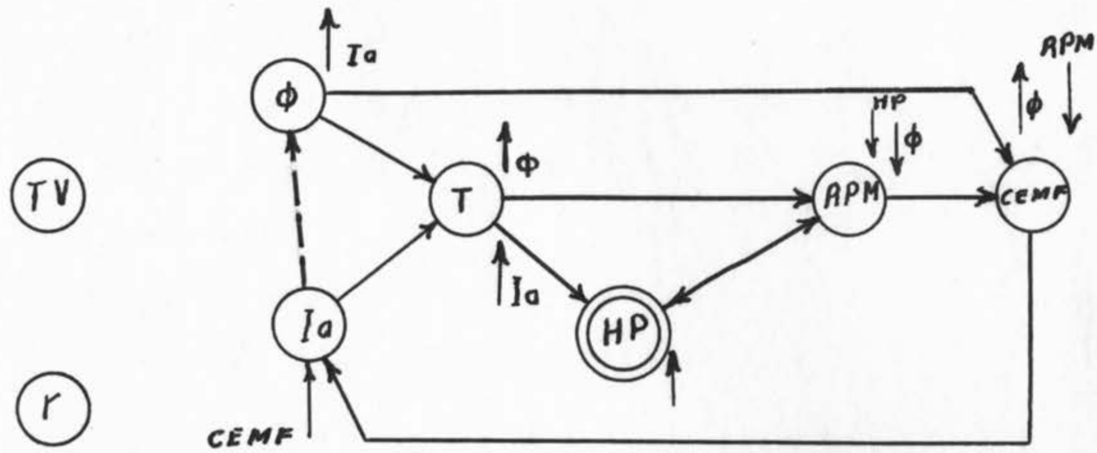


Fig 34

Figure 34.--Skeleton diagram analysis of increased load effects on the cumulative compound motor

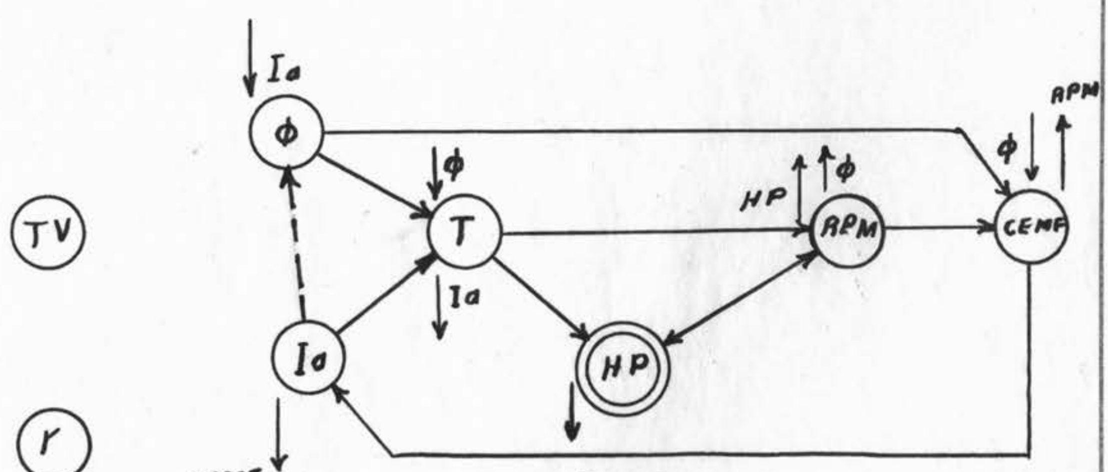


Fig 35

Figure 35.--Skeleton diagram analysis of reduced load effects on the cumulative compound motor

requires more torque (T) if the motor is to meet increased load; hence a further reduction of speed (RPM) is necessary to lower the counter-electromotive force (CEMF) if the increased armature current is to flow in the armature circuit. The additional downward directed arrow at (RPM) with the symbol (Φ) at the end shows the additional change in speed because of the strengthening of the field when load (HP) is added.

This means a greater speed change in a compound motor than occurred in a shunt motor for the same load. This greater change in speed must take place on account of the series field effect in the compound motor when load is added. A wider range in speed regulation for the cumulative compound motor is to be expected from the combined characteristics of the shunt and series motors, since the series motor has a very poor speed characteristic.

Because the pole strength is increased when the armature current is high, the cumulative compound motor gives better torque than is found in the shunt motor. This provides a field of application in industry, where it is necessary to start rather heavy loads and also where more rapid acceleration of load is required. Good speed regulation must be sacrificed to some extent to gain starting torque. There are

65 many types of machines to be driven to which the cummulative coupound motor is admirably adapted; many of these may be found listed in motor manufacturers' bulletins.

As load is reduced on the cumulative compound motor, the excess torque (T) increases the speed(RPM), which raises the counter-electromotive force (CEMF), thus reducing the armature current (Ia), which reduces torque (T). All of this is shown by the arrows at each one of the symbols for these factors in Fig. 35. But this reduced armature current (Ia) weakens the pole flux (Φ) through the series field effect, which reduces counter-electromotive force (CEMF). As this condition would still permit too much armature current to flow in meeting the torque needs of the load, this excess torque immediately increases the speed to offset the weakened field, as indicated by arrows, Fig. 35. This causes a greater increase in speed for the same load change on a cumulative compound motor than on a shunt motor under the same conditions.

HOW A VARIATION IN TERMINAL VOLTAGE AFFECTS THE OPERATION OF A CUMULATIVE COMPOUND DIRECT CURRENT MOTOR

Any increase in terminal voltage on a cumulative compound motor will result in more field pole flux with a tendency toward greater current in the armature circuit, as shown by the arrows at field flux (Φ) and armature current (Ia) in Fig. 36. This increase in field flux (Φ) and the momentary increase in armature current both increase the torque, as shown by the arrows at (T). This immediately increases speed (RPM) and results in higher counter-electromotive force (CEMF). The greater field flux (Φ) also increases this factor, both of which are shown by the upward directed arrows at (CEMF), in the diagram. This increase in the control factor over armature current may actually result in a decreased amount of armature current when a rise in terminal voltage occurs.

Terminal voltage below normal value will result in a weak field and momentarily in a tendency toward less current in the armature, as shown by the arrows at field flux (Φ) and armature current (Ia) in Fig. 25. Loss of either field flux or armature current will result in less torque, as shown by the arrow at (T), and a decrease in speed (RPM) results in a loss in counter-electromotive force (CEMF)

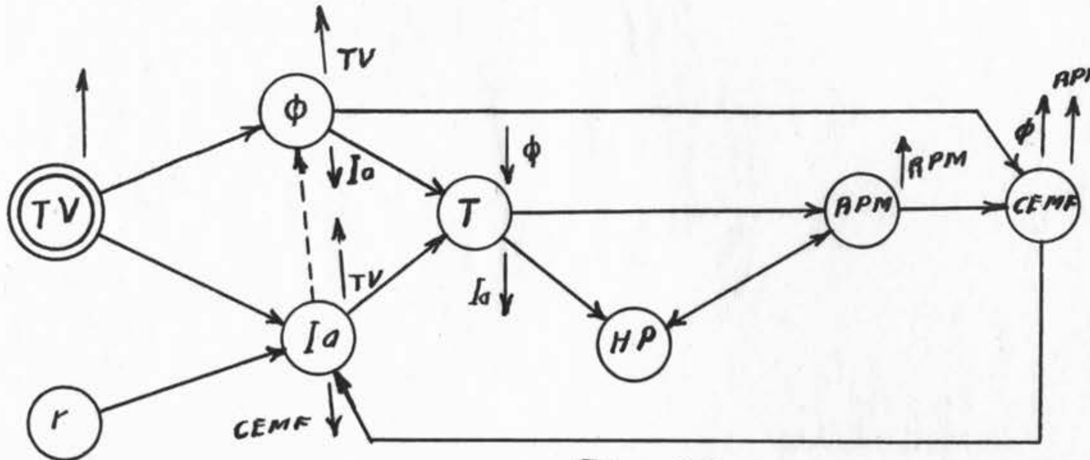


Fig 36

Figure 36.--Skeleton diagram analysis of high voltage effects on the cumulative compound direct current motor

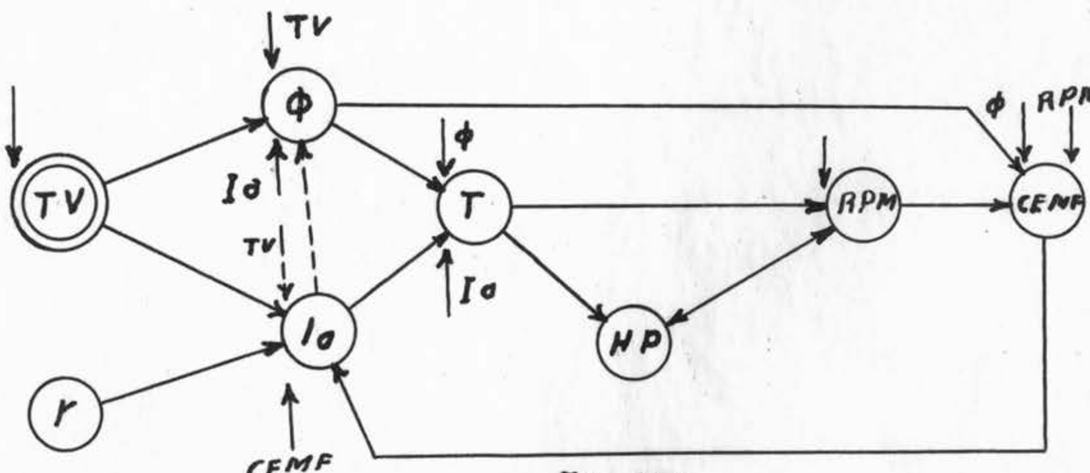


Fig 37

Figure 37.--Skeleton diagram analysis of low voltage effects on the cumulative compound direct current motor

67 This together with the weaker field shown by the downward arrows at (CEMF).permits a greater amount of current to pass through the armature circuit as shown by the upward arrow at 'Ia). This extra armature current is needed to offset a weaker field if the motor is to have torque to pull the load. At the same time the speed will be below normal when voltage is low.

68 Fig. 38 How Torque is Produced in a Differentially Connected Compound Motor.

When the series field is connected so that the flux produced is opposite to that of the shunt field, the effect is called differential. Since both field windings are around the one pole core, the resultant flux must be the difference between what is made by the shunt winding and the series winding. At light load the armature current, being small, causes little if any effect on the pole flux, Fig. 38a. As the armature current is increased the differential effects on the pole flux are shown by Figs. 38b and 38c. Under normal operating conditions, the shunt field has a larger number of ampere turns and controls the polarity of the poles. However, under some conditions the series field ampere turns may become greater than the shunt field ampere turns. This might happen when a differentially connected motor is starting a load or when a heavy over-load is applied.

Since the armature current passing through the series field weakens the pole flux, any increase in torque must be made at a very much greater increase of armature current than is the case with either the shunt or series motor. This fact is very clearly shown in Figs. 38b and 38c. Note how much smaller the actual pole flux becomes, and how large the armature flux, to produce an increase in torque as load is increased on

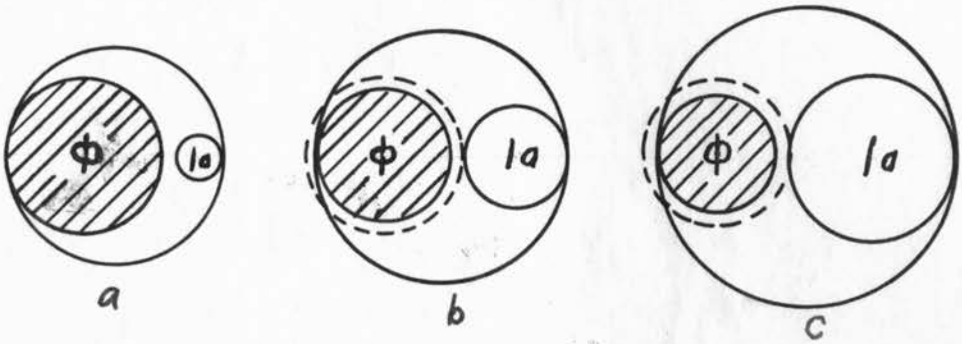


Fig 38

Figure 38.--How field flux and armature current produce torque in the differentially connected compound motor

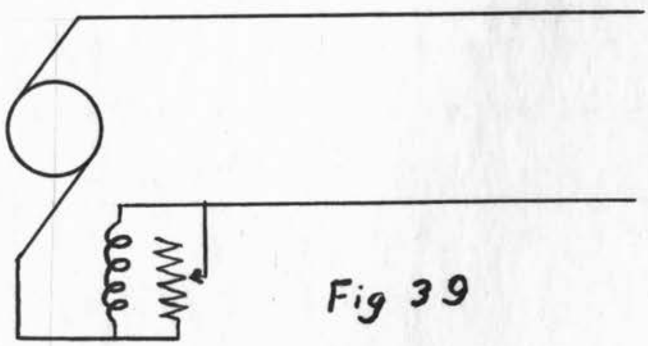


Fig 39

Figure 39.--Wiring diagram for the differentially connected compound motor

69 the motor, Fig. 38c.

The amount of influence the series field has on the pole flux can be adjusted by a shunt placed across the series field shown. Fig. 39. This method of changing the compounding is universally used on both cumulative and differentially connected compound motors.

The only difference between the cumulative and the differentially connected motor is in the direction of the armature current through the series field. However, these two connections give the motor widely different operating characteristics.

In Fig. 40 an increase in the load (HP) on the motor tends to reduce the speed (RPM). This slight reduction in speed reduces the counter-electromotive force and causes an increase in armature current (Ia). Any increased armature current increases the torque (T) which pulls the load (HP). But this increase in current (Ia) also weakens the pole flux (Φ) and tends to weaken the torque (T) slightly. At the same time it decreases the counter-electromotive force (CEMF), which will permit a larger quantity of current to pass through the armature. This additional armature current (Ia) produces more torque (T) than is required to take care of the extra load (HP); so this excess torque (T) immediately tends to raise the speed (RPM).

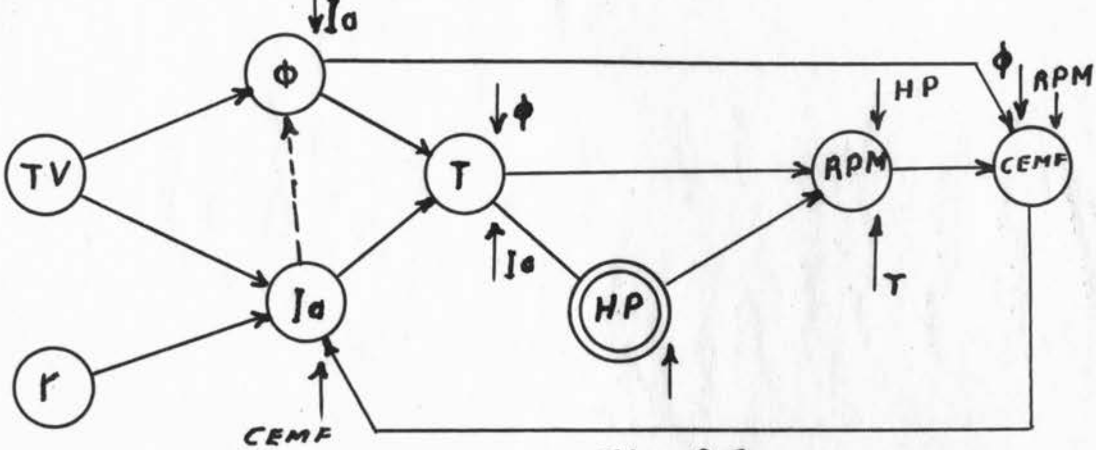


Fig 40

Figure 40.--Skeleton diagram analysis of increased load effects on the differentially connected compound motor

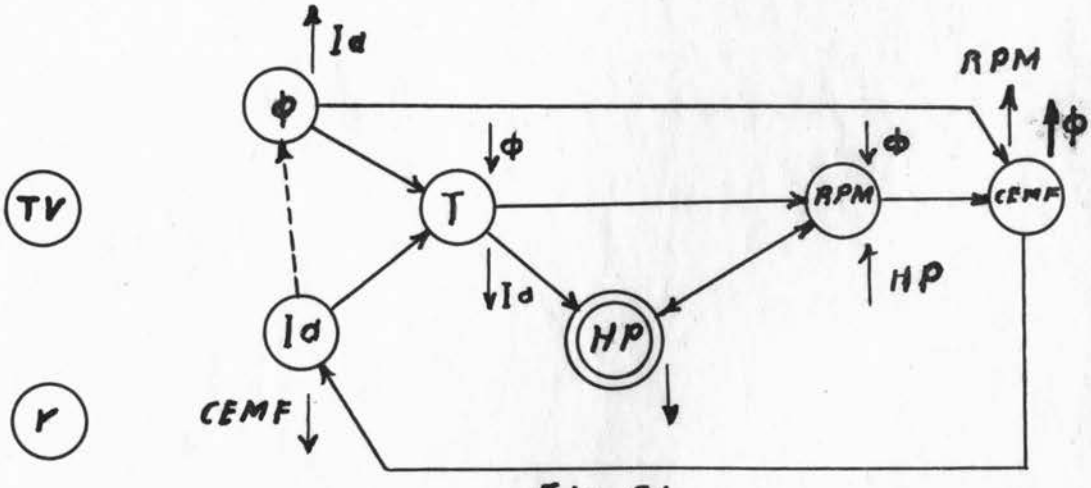


Fig 41

Figure 41.--Skeleton diagram analysis of decreased load effects on the differentially connected compound motor

The differential affect of the series field winding on the pole flux affects the counter-electromotive force so as to allow excessive armature current. As the armature current is one of the torque-producing forces, the conditions may be such as to produce an actual increase in speed as load is applied.

This method of obtaining speed control is not economical from a power standpoint but is used in some industrial applications in which the motor requirements are under two horsepower and very close speed regulation is essential.

In Figs. 38c and 29c note the larger amount of armature current necessary in the differential compound motor as compared to the pole flux available for producing torque. The same amount of torque is required to move any given load provided the speeds are the same. If one torque component is weakened, the other must be strengthened, as illustrated in these figures. This excessive armature current causes increased power bills. Motors built specifically for speed regulation through the differential actions of the field windings are constructed with larger armatures to handle the extra armature current and resulting armature flux required.

71 HOW THE DIFFERENTIALLY CONNECTED COMPOUND MOTOR MEETS DECREASED LOAD.

When load (H.P.) is decreased on a differentially connected compound motor, Fig. 41, the excess torque (T) immediately tends to increase the speed (R.P.M.), thus increasing the counter-electromotive force (C.E.M.F.), which in turn lowers the armature current (Ia), thus reducing the torque. Arrows with markings show the trends at each symbol, verifying the previous statement. But a reduction of armature current (Ia) strengthens the field and tends to increase counter-electromotive force (C.E.M.F.). This double effect on counter-electromotive force would allow too little armature current to produce the necessary torque; therefore the speed would tend to drop because of the strengthening of the field flux. Hence we have the field flux tending to decrease speed, as shown by arrows. Under these conditions the speed tends to remain constant or change very little. With just the right compound effect on the pole flux the speed can be made to hold almost without change as load is varied on the motor. A group of motors operating as a unit will all be subjected to the same voltage variation and will respond with identical speed changes. To certain manufacturing processes this is an absolute necessity, and the

72 differentially connected compound motor meets the requirements in an excellent way.

73 How a Veriation in Terminal Voltage Affects the Operation of Differentially Connected Compound Motors.

When the terminal voltage on a differentially connected compound motor is increased, the shunt field current will increase, producing greater pole flux from the shunt field winding. At the same time there is a tendency for greater armature current to pass through the armature circuit. These effects are shown by arrows at (Φ) and (Ia) in Fig. 42. This additional armature current passing through the series field coil tends to cut down the pole flux in the motor field. Just what will be the result in any individual motor is difficult to predict, as it will depend almost entirely in the design characteristics of the machine.

If the relationships of the shunt field flux and the series field flux are such that little change in field flux results, then only the armature current will increase and tend to increase speed. If these are such that an actual decrease in pole flux results, than there may be little if any change in torque and no resulting change in speed when voltage increases. What happens to the counter-electromotive force will be largely determined by the resulting pole flux. Should the pole flux increase, an increase will take place in counter-electromotive force, which will

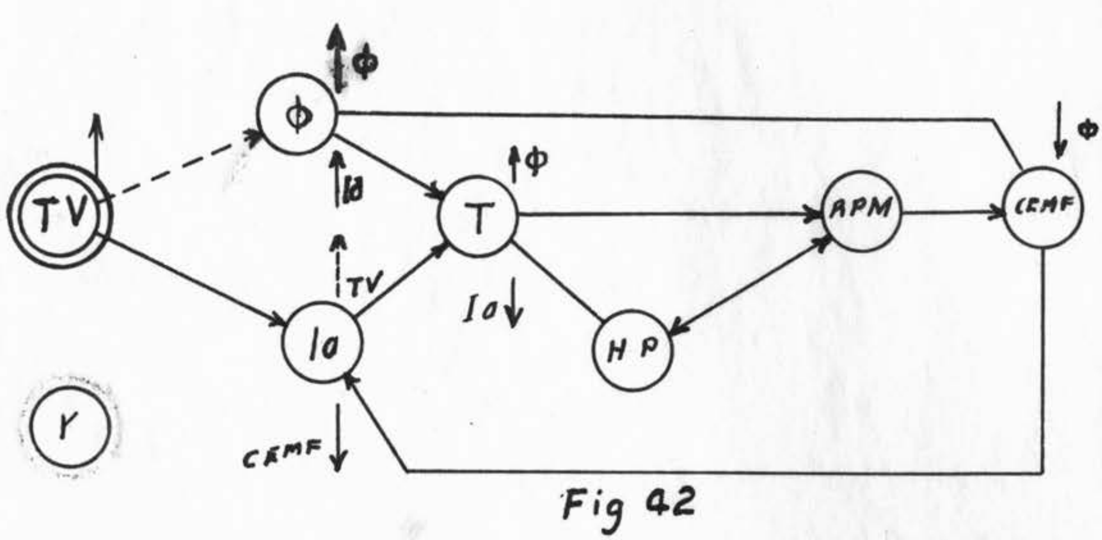


Figure 42.--Skeleton diagram analysis of increased terminal voltage effects on the differentially connected compound motor

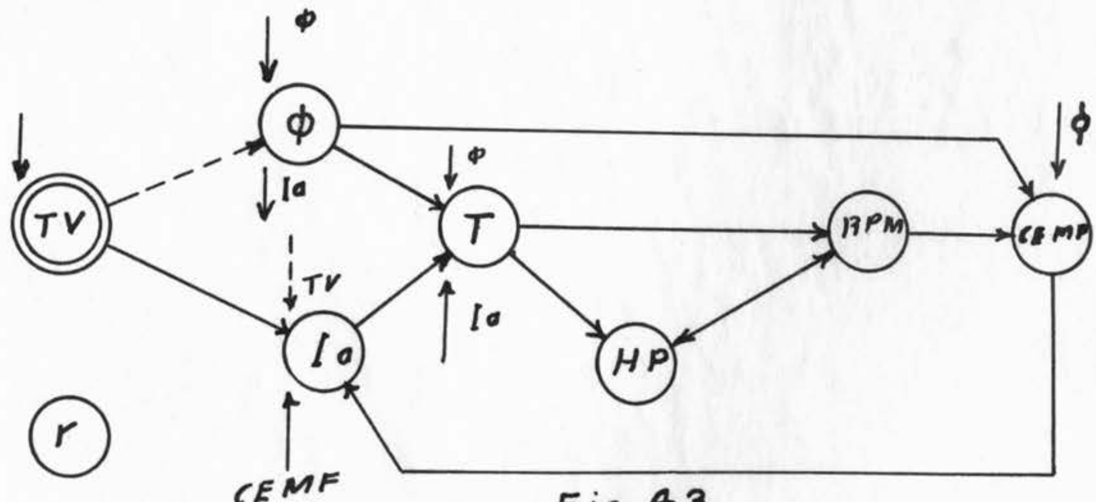


Figure 43.--Skeleton diagram analysis of reduced terminal voltage effects on the differentially connected compound motor

cut down the armature current. If, however, the pole flux decreases, an increase will take place in the current required to drive the machine. The tendency then is for the differentially connected machine to maintain fairly constant torque, which will keep the speed practically constant with a rise in voltage on the line.

If for any reason the terminal voltage of a differentially connected compound motor is decreased below normal, the shunt field flux will be less and the armature current will tend to drop. See Fig. 43. This smaller amount of field flux will adversely affect the counter-electromotive force and permit more armature current to pass through the armature circuit. When this passes through the series field, it will decrease the field effect on torque, whereas, while the armature flux tends to increase torque. These two opposing tendencies of field flux and armature current affecting torque tend to maintain a uniform torque and hence practically constant speed. This condition would last until the voltage change became over ten percent below normal, beyond which no machine will maintain these conditions unless it is specially designed for weak field operation.

Appendix B

PERSONNEL WHO VALIDATED

TEST ITEMS AND

TEST QUESTIONS

C O P Y

STATE OF FLORIDA

DEPARTMENT OF PUBLIC INSTRUCTION

TALLAHASSEE, FLA.

May 11, 1939

Mr. L. R. Drinkall, Department Head
Electrical Department
Wm. Hood Dunwoody Industrial Institute
818 Wayzata Boulevard
Minneapolis, Minnesota

Dear Mr. Drinkall:

I have read with interest the copy of the objective test on the subject of D.C. Machinery sent to me for comment and criticism. I find little to criticise and much upon which to comment very favorably.

I believe you have done an excellent job of reducing a very subjective course content to an objective basis of grading. I am well aware of the difficulties involved in doing this and I believe you have disproved the claim I have heard so often repeated that "It can't be done in this subject except on a True - False basis".

Your unique presentation on the basis of a statement of a situation, with a multiple choice of results, and another series of reasons to complete each test item is thought-provoking and a real test of reasoning power.

The test items are such as to involve the application of technical knowledge and the exercising of judgment in the evaluation of the contributing factors pertaining to typical electrical situations and problems confronting a worker in this field.

As to the validity of the test, I am able to state this is unquestioned. By long experience in the electrical department at Dunwoody I am familiar enough with the subject matter covered in the unit course on D.C. Machinery to know the items used in the test have been amply covered by classroom discussion, in which the conference method is freely used, and by laboratory tests made by the students themselves. The items embrace the full range of the subject matter in an excellent manner.

My compliments to you, Mr. Drinkall, for this fine piece of work.

Yours very sincerely,

H. F. Hinton, Teacher Trainer
Trade and Industrial Education

HFH:bb

C O P Y

State of Minnesota

The State Board of Electricity

St. Paul, Minn.

July 5, 1939

Mr. L. R. Drinkall
505 South Cedar Lake Road
Minneapolis, Minnesota

Dear Sir:

I have read with great interest the Objective Test covering Direct Current Motors and Control Apparatus, which you left with me.

As I proceeded with a study of the test, I was more and more impressed with the thoroughness with which you have covered the subject in respect to care, maintenance, installation, operation and repairs to this equipment.

The manner in which you have covered this subject is somewhat new to me. It has occurred to me that this method has great possibilities in the type of examination given by our Board, as it requires clear, concise and logical thinking on the part of the examinee.

Allow me to compliment you most highly on your treatise on this subject.

Very truly yours,

George R. Jones
Industrial Electric Company

Geo.R.Jones:ef

C O P Y

THE WILLIAM HOOD DUNWOODY INDUSTRIAL INSTITUTE

MINNEAPOLIS, MINNESOTA

July 17, 1941

Mr. L. R. Drinkall
505 South Cedar Lake Road
Minneapolis, Minnesota

Dear Mr. Drinkall:

I have made a careful study of your Electrical T. K. Test No. 2 on D. C. Machinery. I was very favorably impressed with this test.

In my opinion, the manner in which you have arranged the multiple choice test questions is unusual, and might advantageously serve as a pattern for tests on other subject matter.

From the standpoint of content, your treatment embraces the features and characteristics of direct current equipment and control devices, as well as the problems and conditions of installation and repair in a very thorough manner.

The questions are all clearly stated, and require exact reasoning on the part of the learner being tested. His ability, or inability, to deal with the problems outlined can leave little doubt concerning his understanding of direct current equipment.

It has not previously been my privilege to exam a test involving so much functioning material on a difficult technical subject and yet so consistently and closely adhering to good testing principles.

Very truly yours,

John A. Butler, Department Head
Air Conditioning Department

C O P Y

July 23, 1941

Mr. L. R. Drinkall, Department Head
Electrical Department
Wm. Hood Dunwoody Industrial Institute
Minneapolis, Minnesota.

Dear Mr. Drinkall:

I have checked very closely the Objective Tests covering Direct Current Motors and Controls, which you left with me.

As an electrical instructor for the past eleven years I have tried and devised a great number of tests. I have never used a test that to my estimation was as thought provoking or to the point as the tests which you have compiled.

I wish to compliment you on a fine piece of work and if possible would appreciate receiving a copy of this test.

Very truly yours,

Al. J. Diebold

C O P Y

INTERNATIONAL BROTHERHOOD OF ELECTRICAL WORKERS

LOCAL UNION NO. 110

ST. PAUL, MINN.

July 21st. 1939.

Mr. L. R. Drinkall,
Ft. Collins, Colo.

Dear Sir:

Hoping the enclosed meets the requirements that you have requested. If you think my letter head in any way might be a detriment just use your own judgement.

Hoping for your success, I remain

Yours respectfully

Harry Talbot, Bus. Mngr.
Local Union #110.I.B.E.W.

C O P Y

INTERNATIONAL BROTHERHOOD OF ELECTRICAL WORKERS

LOCAL UNION NO. 110

ST. PAUL, MINN.

July 21st. 1939.

To whom it may concern:

The attached names are men who are working in some field of the Electrical Industry all having either Masters license or Journeyman license, and we believe that this test covers the subject of direct current motors their care, installation, operation, maintenance and repair.

Yours very truly,

Harry Talbot, Bus. Mngr.
Local Union #110 I.B.E.W.
St. Paul, Minnesota.

NAME	ADDRESS
	St. Paul, Minnesota.
1. Harry Talbot, Bus. Mgr., Elec. Union #110	418 N. Franklin St.
2. Raymond Roith, Lic. Electrician	849 Thomas St.
3. Henry G. Doeren, Lic. Electrician	615 N. Lexington
4. James F. Roach, Lic. Electrician	956 Tuscarora.
5. T. A. Jackson, Lic. Electrician	702 Dayton Ave.
6. R. J. Abblett, Lic. Electrician	394 Fry St.
7. Paul Albrecht, Lic. Electrician	114 E. Acker
8. Ole Anderson, Lic. Electrician	674 Hawthorn
9. W. Barkland, Lic. Electrician	204 N. Western
10. Chass. Brett, Lic. Electrician	Como Station #3
11. Joseph W. Dunn, Lic. Lineman	42 College Ave.
12. Aug. Zastrow	1287 Juliet St.
13. Bjorn Holm	116 W. 9th St.
14. Ed Stewart	454 Aurora Ave.
15. Robt. Moore	1009 Hudson Ave.
16. Henry Hucke	314 W. 4th St.
17. Walter Meikel	249-6th Ave., S., South St. Paul

NAME	ADDRESS
	St. Paul, Minnesota
18. Ed O'Grosky	R.F.D. #3, White Bear Lake
19. Arthur Johnson	1118 Blair St.
20. Ed Gill	218 Sidney St.
21. John Kotas	979 Otto Ave.
22. Henry Holdun	394 E. Lawson St.
23. Otto Lehman	1162 E. Lawson St.
24. Lawrence Horner	760 Mt. Curve Blvd.
25. Wm. Eitel	481 Como Ave.
26. Percy F. Bennett, Lic. Govt. Radio Operator	1015 Edmund St.
27. Ed Larson	670 E. Rose St.
28. Frank Jungwirth	489 Blair St.
29. Ralph Woodward	811 S. Lexington
30. Henry Dillgard	1675 Edmund St.
31. Einar Wardrum	1088 Edgerton St.
32. Frank Eppinger	319 N. Chatsworth
33. H. V. Nelson	1054 De Sota St.
34. Carl Smith	649 N. Dale St.
35. Russell Nelson	2171 Jefferson Ave.
36. Jos. A. Yares	1001 Otto Ave.
37. Geo. Schultz	1926 Sargent Ave.
38. L. Von Linden	787 Jenks St.
39. Ray Swanson	1212 Margaret St.
40. Henry Simons	1292 Hartford Ave.
41. Thos. Griffith	902 Grand Ave.

NAME	ADDRESS
	St. Paul, Minnesota
42. Harald Roberts	Como Station, R. #3
43. Harry Staples	948 Palace St.
44. R. E. Guilbert, City Inspector	2050 Lincoln Ave.
45. Joe Misera	526 W. 7th St.
46. John Mullen	1636 Selby Ave.
47. Jos. Nemetz	1703 Taylor Ave.
48. Neil Neilson	266 Sidney St.
49. Henry Hodurn	394 E. Lawson St.
50. Austin Eddy	418 N. Franklin

Appendix C

LIST OF TEST ITEMS FROM

WHICH TEST QUESTIONS

WERE DRAWN

Test Items

for

A COURSE IN INSTALLATION, CARE, MAINTENANCE, OPERATION, AND REPAIR OF DIRECT CURRENT MOTORS AND CONTROL APPARATUS

accelerating contactors
additive
air-gap
ambient temperature
armature circuit resistance
armature construction
armature conductors
armature current
armature reaction
automatic starters
base
barriers
bearings, types of
   ball
   pedestal
   roller
   self-aligning
   sleeve
bearing wear
blowout coils
bucking
brush construction
brush fitting
brush maintenance
brush selection
commutator
   color
   construction
   maintenance
   repair
controller
constant torque
control circuit
cooling fan
cross-magnetization
corrosive fumes
counter electromotive force
cumulative
cutout
differential
dirt effects on
   commutator
   windings
drip-proof
drives, types of
   chain
   direct
   gear
   V-belt
dual ventilation
dust-proof
dust-tight
dynamic brake
end-bell
   bonnet
   housing
   end-shield
element
explosive dust
explosive vapors
field current
field flux
field resistance
fire-proof
flame-proof
grid resistance
grounding-motor frames
grounded armature coils
grummet
guide rails
guarded
heat effects on motors
interlock
insulation on lead wires
line drop
load
load effects
low voltage effects
low voltage protection
magnetic brake

Test Items (continued)

moisture, effects of
motor applications
motor selection
motor lead wire
motor lubrication
motor ratings
  closed
  continuous
  intermittent
  open
  temperature 40°-50°
mounting requirements
name plate data, uses for
no-field protection
oiling systems
  drip
  grease-pack
  force-feed
  ring
  wick
open armature coil
open field coil
overload protection
permeability
pipe-ventilation
plugging
power circuit
predetermined time control
Prony brake
pole flux distortion
power circuit
regenerative braking
regulating duty
relays
resistance, effects of in
  armature
running protection field
reversing controls
reversing motors, methods of
schematic diagrams
semi-automatic starters
series
shields
short circuited
  armature coils
  field coils
shunt
sparking at brushes
  causes
  symptoms
  remedy
solenoid brake
speed effects
speed regulation
splash proof
starting box manual
starting contactor
starting currents for motors
starting resistance
slot insulation
temperature rating
terminals, code requirements
torque
  constant
  variable
torque effects
total flux
variable speed
variable torque
ventilated winding
ventilation ducts
water-proof
weak field effects
wire insulation
  class A
  class B
winding insulation
  lacquer
  varnish compounds
wiring diagram

Appendix D

TEST QUESTIONS

THE WILLIAM HOOD DUNWOODY INDUSTRIAL INSTITUTE

DAY SCHOOL
Electrical T.K. Test #2

ELECTRICAL DEPARTMENT
D-c. Machinery 2nd Mo.
D-c. Motors and Control App.

1. The three-point starting box provides a shunt motor with:
   1. no voltage release
   2. overload protection
   3. under load protection
   4. no field protection
   5. low voltage protection

   because:
   (a) the holding coil is across the line.
   (b) the holding coil is protected by starting resistance.
   (c) the shunt field is in series with the holding coil.
   (d) a holding coil resistor protects the holding coil.
   (e) the voltage across the coil will be low.

2. The four-point starting box provides a compound motor with:
   1. no voltage release
   2. overload protection
   3. under load protection
   4. no field protection
   5. low voltage protection

   because:
   (a) the holding coil is across the line.
   (b) the holding coil is protected by starting resistance.
   (c) the shunt field is in series with the holding coil.
   (d) a holding coil resistor protects the holding coil.
   (e) the voltage across the coil will be low.

3. A speed regulating box differs from a box used for starting duty only in:
   1. the resistance of the elements
   2. the change in resistance between contacts
   3. the current carrying capacity of the elements
   4. the cooling qualities of the elements
   5. the temperature coefficient of the elements

   because:
   (a) the regulating duty element is in service longer.
   (b) the element operates at a higher temperature.
   (c) the air does not circulate freely in a starting box.
   (d) the voltage drop is greater in the regulating box.
   (e) the regulating duty box protects the motor.

4. Regulating duty boxes for lowering the speed of a shunt motor are made with:
   1. resistance for the field circuit
   2. resistance for the armature circuit
   3. resistance for both the field and the armature circuit
   4. a shunt for the series field
   5. a resistor for the series field

   because:
   (a) resistance in the armature circuit increases speed.
   (b) resistance in the field reduces speed.
   (c) resistance in the field increases speed.
   (d) resistance in the armature circuit decreases speed variation.
   (e) resistances used with both gives wider range of speed.

5. Regulating duty boxes for increasing speeds of compound motors above name plate valves only are made with:
   1. a shunt for the series field
   2. a resistor for the series field
   3. resistance for the shunt field circuit
   4. resistance for the armature circuit
   5. a combination of resistances for field and armature

   because:
   (a) resistance in the armature circuit increases speed.
   (b) resistance in the field circuit increases speed.
   (c) resistance in the armature reduces speed.
   (d) resistance in the field circuit reduces speed.
   (e) the speed range is widened by using both resistances in the field and armature circuits.

6. Controllers are used for speed control of series motors in preference to speed regulating boxes because
   1. they usually give better speed control
   2. they are more rugged and more adoptable for reversing purposes
   3. they give better protection to the motor
   4. they are more easily installed
   5. they are provided with a grounded case

   and
   (a) holding coils are usually not necessary.
   (b) only one resistance is required with series motors.
   (c) they give better protection to the motors.
   (d) they prevent the motor from racing.
   (e) they save material when installed.

7. The use of semi-automatic motor starting devices in preference to manual starters gives
   1. quicker starting of the motors
   2. better motor protection
   3. more uniform starting of motors
   4. easier starting of load
   5. better motor supervision

   and provides for
   (a) more uniform starting intervals.
   (b) less trouble and maintenance on equipment.
   (c) more reliable motor performance.
   (d) easier stopping of equipment.
   (e) greater safety for the operator.

8. Three and four point starting boxes provide d-c. motors with:
   1. mechanical time control
   2. remote control starting
   3. reversing control
   4. speed regulation
   5. manual control on starting
   6. automatic start and stop control

   because
   (a) the starting time can be varied.
   (b) the motor connections may be reversed.
   (c) the speed can be regulated.
   (d) they require manual operation.
   (e) the motor will start and stop automatically.
   (f) the starting box may be installed in any convenient location.

9. The National Electric Code requires name plate data on motors. so that the maintenance man may: ___
   1. properly install the correct size wires
   2. make the motor run at the right speed
   3. maintain and provide preventive maintenance
   4. order repair parts when necessary
   5. provide correct motor surroundings.

   because this will help:
   (a) eliminate the fire hazard.
   (b) eliminate delay when making repairs.
   (c) avoid too high speeds.
   (d) to provide proper lubricants.
   (e) install the motor in a dry cool place.

10. The National Electric Code provides for
   1. 150% of normal current for running protection
   2. 115% of normal current for running protection
   3. 110% of normal current for running protection
   4. 125% of normal current for running protection
   5. 100% of normal current for running protection

   as
   (a) this will take care of overloads.
   (b) provide for all motor emergencies.
   (c) protect the line to the motor.
   (d) provide reasonable motor protection.
   (e) prevent the motor from running away.

11. A regulating rheostat used with direct current motors controls;
   1. output
   2. torque
   3. speed
   4. input
   5. motor efficiency
   6. armature current

   because:
   (a) resistance and counter electromotive force control armature current.
   (b) when speed is varied output changes.
   (c) a motor is more efficient at higher speeds.
   (d) when armature is varied torque is controlled.
   (e) input varies with armature current.

12. Controllers provide direct current motors with:
   1. automatic control
   2. remote control
   3. automatic starting
   4. mechanical time control
   5. reversing control

   because:
   (a) the controller can be located within sight of the motor and up to 25 feet away from the motor.
   (b) an automatic controller starts and stops the motor mechanically.
   (c) a reversing controller makes the motor operate in either direction.
   (d) mechanical time control fixes the interval of starting a motor.

13. Controllers and motor starting devices are frequently protected from arcs by ________________ (pick the false answer).
   1. barriers
   2. shields
   3. carbon contacts
   4. multiple breaks at contact points
   5. blowout coils
   6. solenoid coils

   because:
   (a) shields prevent grounds from arcs.
   (b) barriers prevent arcs between contacts.
   (c) the solenoid provides a magnetic release brake.
   (d) multiple breaks tend to quench the arcs.
   (e) carbon contacts act as resistance in a circuit at break.
   (f) blowout coils set up magnetic fields which repel electric arcs.

14. Push button starters provide direct current
   1. remote control starting
   2. speed regulation
   3. manual starting
   4. mechanical time control
   5. automatic time control

   which means that the motor can be
   (a) regulated as to speed changes.
   (b) started by hand operation.
   (c) automatically timed between starting periods.
   (d) started from any convenient location.
   (e) mechanically timed for the starting interval.

15. The best automatic time control for motor starting devices under all weather conditions is:
   1. clock mechanism
   2. air dash pot
   3. oil dash pot
   4. counter electromotive force type
   5. circuit breaker type

   because:
   (a) the circuit breaker type can be operated as desired.
   (b) the air dash pot will operate at the same speed at all times if the leather on the plunger does not stick.
   (c) the oil dash pot may be slower when real cold.
   (d) the counter electromotive force type is electrically controlled.
   (e) the clock mechanism may be a trifle slower if the coil on the bearings is stiff.

16. The motor frame which provides the best ventilation for the motor is:
   1. dual ventilation type
   2. totally enclosed
   3. drip proof
   4. explosion proof
   5. open end shield
   6. semi enclosed

(cont.)

16. (cont.)
because:
(a) dual ventilation circulatex air inside and outside the frame when the motor runs.
(b) the drip proof is arranged so that flying particles cannot enter.
(c) the explosion proof frame is strong enough to withstand all pressures from the inside.
(d) the totally enclosed frame keeps out all dirt and fumes.
(e) partially enclosed and open types permit free circulation of air currents.

17. The most economical method of braking motor driven equipment from the power consumed is:
1. dynamic
2. solenoid release gravity type
3. magnetic
4. regenerative
5. friction discs in oil
because:
(a) the solenoid release requires only the line current to release the brake.
(b) the magnetic brake takes a small amount of electrical energy to magnetize the brake coil.
(c) the energy from the rotating machine is converted into heat in a resistor when dynamic braking is used.
(d) the friction discs in oil operate similar to an automobile clutch.
(e) regenerative braking sends power back into the power system.

18. Brushes should be fitted to the commutator by using
1. sand paper
2. emery paper
3. emery cloth
4. a grinding stone
5. a half round file
6. the wear from the commutator
because:
(a) sandpaper will cut the brush rapidly and is not apt to injure the commutator.
(b) emery paper will cut faster wear longer and is very abrasive.
(c) emery cloth will last longer than paper.
(d) a grinding stone will be permanent and can be used for other purposes.
(e) a half round file can be used to file a curve in the brush.
(f) if it wears in it will fit the commutator.

19. High operating temperatures of direct current motors are most likely to cause damage first to
1. brushes
2. commutator
3. field coils
4. armature coils
5. coil leads to risers
because the heat:
(a) will cause sparking and burn the brush contact.
(b) damage the mica between the commutator segments.
(c) injure the insulation in the field coils.
(d) ground the armature coils.

20. The proper lubrication for motors with sleeve bearings having oil rings is:
    1. lard oil
    2. hard oil
    3. cutting oil
    4. light medium engine oil
    5. graphite and oil

    because:
    (a) lard oil is a good cooling agent.
    (b) hard oil will flow when hot.
    (c) cutting oil will penetrate to all parts of the bearing.
    (d) light medium engine oil has body and will float the shaft in the bearing.
    (e) graphite and oil is a good lubricating combination.

21. The load on a direct current shunt motor causes a large change in:
    1. field flux
    2. terminal voltage
    3. armature circuit resistance
    4. speed
    5. armature current

    because:
    (a) the generator voltage drops.
    (b) more field flux is needed.
    (c) the resistance in the armature circuit is greater.
    (d) the motor needs more torque.
    (e) the load makes an immediate change in speed.

22. The speed of a direct current shunt motor is increased by
    1. reducing the armature current
    2. reducing the terminal voltage
    3. increasing the load
    4. increasing the armature resistance
    5. increasing the torque

    because:
    (a) increased armature resistance reduces armature current.
    (b) line drop decreases terminal voltage.
    (c) increased load reduces speed.
    (d) torque is increased by more armature current.
    (e) a motor must have higher speed to produce more power.

23. The field flux of a direct current shunt motor primarily affects
    1. speed and load
    2. torque and counter electromotive force
    3. armature current and torque
    4. torque and load
    5. counter electromotive force and speed

    because:
    (a) terminal voltage affects field flux and speed.
    (b) field flux affects torque and counter electromotive force.
    (c) armature current and field flux affect torque.
    (d) torque affects speed and load.
    (e) speed and field flux affect counter electromotive force.

(cont.)

24. The torque of a direct current shunt motor is used in producing:
    1. greater counter electromotive force
    2. greater armature current
    3. more field flux
    4. more speed and load handling ability
    5. more speed and armature current

because:
    (a) counter electromotive force controls armature current.
    (b) speed and pole flux control counter electromotive force.
    (c) torque is required for load and speed.
    (d) field flux and armature current combine to produce torque.
    (e) terminal voltage affects field flux and armature current.

25. The counter electromotive force of a direct current shunt motor affects:
    1. the resistance in the armature circuit.
    2. the field flux
    3. the terminal voltage
    4. the speed
    5. the armature current

because:
    (a) torque produces speed and load.
    (b) field flux and armature current produce torque.
    (c) speed and field flux produce counter electbomotive force.
    (d) load affects speed which changes counter electbomotive force.
    (e) terminal voltage and armatnre resistance affect armature current.
    (f) armature resistance and counter electromotive force control armature current.

26. The one variabkle item which directly affects torque in a direct current shunt motor is
    1. field flux
    2. terminal voltage
    3. counter electromotive force
    4. armature resistance
    5. speed
    6. armature current.

because:
    (a) counter electromotive force directly affects armature current.
    (b) terminal voltage affects both field flux and armature current.
    (c) armature resistance affects armature current.
    (d) field flux affects torque.
    (e) armature current affects torque.
    (f) speed affects counter electromotive force.

27. Resistance in the armature circuit of a direct current shunt motor will cause the motor to have less:
    1. torque
    2. speed
    3. field flux
    4. counter electromotive force
    5. armature current

because:

27. (cont.)
(a) motor must have the same torque to pull the load.
(b) counter electromotive force must be greater.
(c) field flux is not affected.
(d) armature current must pass through more resistance.
(e) terminal voltage will be the same as without resistance.

28. The terminal voltage of a direct current shunt motor will be affected by:
1. armature current
2. field flux
3. armature resistance
4. generated electromotive force
5. counter electro force

because:
(a) counter electromotive force depends upon speed and field.
(b) armature curr nt depends upon counter electromotive force.
(c) generated electromotive force and line drop fix terminal voltage.
(d) armature resistance affects speed.
(e) field flux and speed fix counter electromotive force.

29 Terminal voltage on a direct current series motor is directly responsible for
1. speed
2. armature current
3. field strength
4. armature resistance
5. torque
6. counter electromotive force

because:
(a) counter electromotive force depends upon speed and field.
(b) armature resistance controls armature and field current.
(c) generated electromotive forc e and line drop fix terminal voltage.
(d) field strength depends upon armature current.
(e) armature current and field current depend upon voltage.

30. Resistance is used p rimarily with a direct current series motor to control
1. load
2. counter electromotive force
3. torque
4. field flux
5. armature current
6. terminal voltage

as this prevents
(a) excessive speeds.
(b) weak fields.
(c) low voltage.
(d) excessive torque.
(e) overloads.
(f) low counter electromotive force.

(cont.)

31. Armature current in a direct current series motor may be increased by:
 1. adding resistance to the field circuit
 2. adding resistance to the armature circuit
 3. increasing speed
 4. increasing torque
 5. reducing terminal voltage
 6. reducing resistance in the armature circuit

 for this will
 (a) cut down current flow to the field.
 (b) maintain the field current.
 (c) control the current in the armature circuit.
 (d) reduce the counter electromotive force.
 (e) maintain the motor torque.

32. Field flux in a direct current series motor is variable due to:
 1. changing terminal voltage
 2. changing armature current
 3. changing armature resistance
 4. changing load
 5. changing torque

 because:
 (a) a change in armature current changes field excitation.
 (b) a change in resistance changes speed.
 (c) a change in torque changes speed.
 (d) a change in counter electromotive force changes armature current.
 (e) a change in load changes speed.
 (f) a change in speed and field changes counter electromotive force.

33. The counter electromotive force in a series motor is dependent upon:
 1. Speed and torque
 2. field flux and torque
 3. armature resistance and terminal voltage
 4. speed and field flux
 5. field flux and armature current

 because:
 (a) the armature conductors cutting pole flux sets up counter electromotive force.
 (b) the torque produced the speed and pulls the load.
 (c) armature resistance and terminal voltage affect armature current.
 (d) field flux and armature current produce torque.
 (e) counter electromotive force controls armature current and field flux.

34. Torque for the direct current series motor is said to vary:
 1. directly with the terminal voltage
 2. inversely as the armature circuit resistance
 3. directly as the armature current
 4. directly as the square of the field strength
 5. directly as the square of the armature current

 because:
 (a) the field strength depends upon the armature current.
 (b) the terminal voltage increases the armature current.
 (c) the watts equal the volts x the amperes.
 (d) the armature current is variable in a series motor.
 (e) the resistance in the armature circuit controls the current

35. The speed of a direct current series motor changes greatly with
    1. terminal voltage
    2. counter electromotive force
    3. resistance in the armature circuit
    4. torque
    5. load

    because:
    (a) armature current produces both sources of torque.
    (b) load changes speed which affects armature current.
    (c) the speed and field flux work against each other in producing counter electromotive force.
    (d) terminal voltage is the source from which the armature current comes.
    (e) resistance controls current flow in the armature circuit.

36. The load on a direct current series motor causes a large change in:
    1. armature circuit resistance
    2. terminal voltage
    3. field flux and armature current
    4. generated electromotive force
    5. shunt field current

    because:
    (a) the armature circuit resistance is low.
    (b) the generator load is increased.
    (c) the torque is obtained from armature current only.
    (d) terminal voltage must be maintained.
    (e) the current in the shunt field is constant.

37. The differential connected compound motor has
    1. only a series field
    2. only a shunt field
    3. both a shunt and series coil but the series coil is open
    4. a shunt coil across the line and a series coil with the same polarity as the shunt coil
    5. a shunt coil across the line and a series coil with opposite polarity to the shunt coil

    because this connection:
    (a) makes more pole flux.
    (b) is cumulative
    (c) causes the same flux direction for both coils.
    (d) makes the flux direction opposite for the coils.
    (e) reverses the armature current.

38. A change in terminal voltage will affect the speed of a ________ less under constant load.
    1. shunt
    2. series
    3. cumulative compound
    4. differential compound

    because
    (a) the series motor speed is very sensitive to load changes.
    (b) the shunt motor speed changes only slightly with load.
    (c) increased armature current makes a stronger field with the cumulative connection.
    (d) increased armature current with the differential connection weakens the pole flux.
    (e) torque depends upon field strength and armature current.

(cont.)

39. The load on a cumulative compound direct current motor will cause greater ________ ________ than occurs in a shunt motor of the same size and type.
   1. torque change
   2. counter electromotive force change
   3. speed increase
   4. speed decrease
   5. armature current change

because:
   (a) the field flux increases.
   (b) the counter electromotive force is increased.
   (c) series motor characteristics are added.
   (d) more torque will be produced.
   (e) the same load will be handled.

40. The speed of a direct current cumulative compound motor will be ________________ motor for the same load.
   1. higher than a shunt
   2. lower than a series
   3. higher than a differentially connected compound
   4. equal to a differentially connected compound
   5. equal to a series
   6. between the shunt and the series

because:
   (a) the series field effect tends to lower the speed of the compound motor when load is added.
   (b) the compound motor has the highest speed at no load.
   (c) the series motor speed is very low at full load.
   (d) the combined affect of series and shunt winding tends to produce intermediate characteristics.
   (e) the differentially connected compound motor has weak field under load.

41. The torque produced in a direct current cumulative compound motor for a given armature current is
   1. greater than in a series motor
   2. less than in a shunt motor
   3. equal to a differentially connected compound motor
   4. equal to a shunt motor
   5. greater than in a shunt motor

because:
   (a) the fields are "bucking".
   (b) the pole flux is less.
   (c) the armature current is greater.
   (d) the pole flux is stronger.
   (e) the armature flux is increased.

42. The field excitation on a direct current cumulative compound motor is obtained from:
   1. the shunt field winding
   2. the series field winding
   3. the armature current
   4. the terminal voltage
   5. the shunt field coil and the series field coil

because
   (a) the series coil has no magnetizing affect at no load.
   (b) the motor has two field coil windings.
   (c) the voltage is applied to both field and armature.
   (d) the fields are stronger under load.
   (e) the pole pieces contain more iton.

43. High terminal voltage on a direct current shunt motor will cause
 1. increased field flux and increased armature current
 2. weaker field flux and increased armature current
 3. greater torque and decreased power
 4. increased speed and increased armature resistance
 5. about the same torque with smaller load

because:
 (a) more field flux will increase counter electromotive force which will be offset by reduced r.p.m.
 (b) more torque will produce greater speed.
 (c) less torque will produce less speed.
 (d) higher voltage causes greater field flux and more armature current.
 (e) less torque will pull smaller loads.

44. A stronger field flux on a direct current shunt motor results in
 1. more counter electromotive force and less speed
 2. increased torque and greater speed
 3. higher terminal voltage and greater armature current
 4. higher speed and less counter electromotive force
 5. decreased armature resistance and more load

which will produce
 (a) the same torque and greater speed.
 (b) less armature current and the same torque.
 (c) more power and greater production.
 (d) less counter electromotive force and higher speed.
 (e) the same torque and less output.

45. A weak field on a direct current shunt motor results finally in a change in ________ which affects production
 1. counter electromotive force
 2. armature current
 3. motor load
 4. motor speed
 5. terminal voltage

because:
 (a) motor speed increases with a weak field.
 (b) motor load will be affected to a large extent.
 (c) more armature current is necessary.
 (d) the torque is less than before.
 (e) load causes an increase in terminal voltage.

46. Resistance added to the armature circuit of a direct current shunt motor will cause the ________ to decrease greatly
 1. armature current
 2. torque
 3. counter electromotive force
 4. field flux
 5. speed

because:
 (a) resistance decreases current flow.
 (b) more counter electromotive force is needed.
 (c) greater line voltage will be necessary.
 (d) speed must decrease so the counter electromotive force will be decreased.
 (e) the field flux remains unchanged.

(cont.)

47. The greatest starting torque obtainable from direct current motors is provided by the:
  1. shunt connection
  2. series connection
  3. cumulative connection
  4. differential connection
  5. cumulative short shunt connection
  6. cumulative long shunt connection

because:
  (a) the shunt connection gives constant field flux and variable armature flux.
  (b) the series connection gives maximum field when armature currdnt is greatest.
  (c) the cumulative connection increases pole flux somewhat with armature current increase.
  (d) the differential connection decreases pole flux somewhat with armature current increase.
  (e) the cumulative short shunt has slightly less shunt field flux than the long shunt connection gives.

48. The greatest running torque obtainable from direct current motors is provided by the
  1. shunt connection
  2. series connection
  3. cumulative connection
  4. differential connection
  5. cumulative short shunt connection
  6. cumulative long shunt connection

because:
  (a) the shunt connection gives constant field flux and variable armature flux.
  (b) the series connection gives maximum field when armature current is greatest.
  (c) the cumulative connection increases pole flux somewhat with greater armature currents.
  (d) the differential connection decreases pole flux xomewhat with armature current increase.
  (e) the long shunt cumulative connection provides a trifle more pole flux than the short shunt connection.

49. Speed regulation is measured in:
  1. change from no load to full load
  2. feet per minute
  3. revolutions per minute
  4. revolutions per second
  5. feet per second

and per cent regulation is based on
  (a) no load speed
  (b) change in speed from no load to full load
  (c) full load speed
  (d) half load speed
  (e) overload speed

(over)

50. The best speed regulation obtainable from direct current motors for moderate load is provided by the:
   1. shunt motor
   2. series motor
   3. short shunt cumulative compound motor
   4. differential compound motor
   5. long shunt cumulative compound motor

   as this connection:
   (a) provides practically no speed variation with load change.
   (b) is classed as a constant speed motor.
   (c) has some decrease in speed as load is added.
   (d) provides higher voltage on the shunt field under load.
   (e) varies the speed greatly with load change.

51. Armature reaction is the same as the:
   1. cross magnetization of the armature
   2. magnetism in the air gap
   3. flux from the interpoles
   4. compensating winding
   5. distortion of the main pole flux

   and is caused by the:
   (a) action of the interpole flux on the main flux.
   (b) compensating winding correcting the armature action.
   (c) armature action on the pole flux.
   (d) effect of the air gap.
   (e) voltage generated by the short circuited coils.

52. Worn bearings on a direct current machine will cause (pick the wrong statement.)
   1. Loss of capacity
   2. heating
   3. circulating currents in the armature
   4. unbalanced magnetic circuits
   5. increase in speed

   because:
   (a) unbalanced magnetic circuits will weaken the field and cause the motor to run faster.
   (b) the circultaing currents use up the capacity of the conductors to carry useful current.
   (c) the extra currents cause an increase in the heating.
   (d) unbalanced magnetic circuit sets up unequal voltages on the coils between brushes.
   (e) heating will increase the armature resistance.

53. When the prony brake is used to find motor output the quantity measured is:
   1. speed
   2. horsepower
   3. input
   4. output
   5. torque

   because
   (a) the speed is found with a tachometer.
   (b) the input is found from the meter readings.
   (c) the onput is calculated from the torque and speed.
   (d) the torque is the product of the arm and the scale reading.
   (e) 33000 ft. lbs. per minute equals one horsepower.

54. The brushes on a direct current motor should: (pick wrong statement)
   1. be equally spaced around the commutator
   2. all have the same pressure against the commutator
   3. always be all set at the same angle with the commutator
   4. always be set at a trailing angle to the commutator rotation.
   5. always have good contact area with commutator

   for:
   (a) equal pressures cut down circulating currents.
   (b) the same angle helps keep brushes equally spaced.
   (c) good contact with commutator insures high conductivity.
   (d) equal spacing helps insure equal voltages between brushes.
   (e) the trailing angle provides best brush operation in the holder.

Appendix E

SHOP JOBS USED FOR DIRECT

CURRENT MOTOR

INSTRUCTION

THE WILLIAM HOOD DUNWOODY INDUSTRIAL INSTITUTE

DAY SCHOOL
DES 4-10.1

ELECTRIC DEPARTMENT
D.C. Machinery
D.C. Motors &
Control Apparatus

JOB: Test and diagram 3-point and 4-point starting boxes

Materials, tools, equipment:
3-point starting box, 4-point starting box, load bank, hand tools, ammeter, voltmeter, lead wire

General instructions:
Read this job sheet carefully. You are doing this job to become familiar with the construction and internal connections of various types of starting rheostats. Put your name, section, job sheet number, and date finished on your report.

Operating steps:
1. Select 3-point and 4-point boxes from the rack.
2. Inspect the drawings of the starting box diagrams on window curtains in the shop.
3. Make a front view drawing of the box, showing and marking the terminals and external connections.
4. Using a load bank in series with one side of the line, check the external points which have connections inside.
5. Indicate them on your drawing.
6. Follow the diagram as shown in Figure I, and measure the resistances between each of the points connected.
7. Place these values on your diagram.
8. If the boxes have any special features explain their uses.
9. Note the holding coil connection in these boxes.
10. Is there special provision made to protect the holding coils?
11. Inspect the insulation and construction details of these boxes.
12. Compare these boxes.

Sketches:

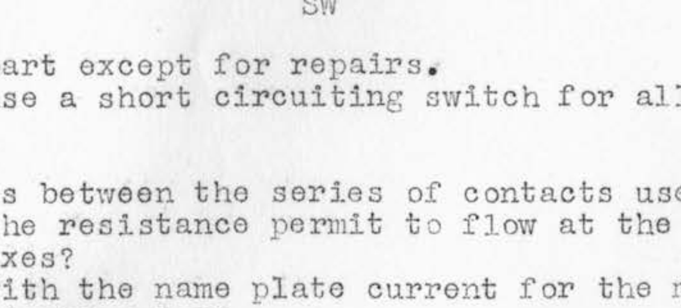


Fig. I

Precautions:
Do not take these boxes apart except for repairs.
Avoid short circuits and use a short circuiting switch for all ammeters.

Questions:
1. What are the resistances between the series of contacts used for?
2. How much current will the resistance permit to flow at the rated voltage on the boxes?
3. How does this compare with the name plate current for the motor corresponding to this starting box?
4. How much above normal current does the starting box permit to start D.C. motors? See Code.
5. If the holding coils of these boxes were connected directly across the line by mistake calculate the current which would pass through them.
6. Would the coils carry this amount of current?
7. Under proper conditions how much current do the holding coils have through them?

Questions (con't)

8. Is this true of all boxes, both 3-point and 4-point?
9. If the name plate became lost from a starting box how could you determine the size of motor this box would start successfully
10. How much time normally is used in starting a motor?
11. Why are these boxes for starting duty only?
12. In what ways do these boxes protect motors?
13. Does the code specify other protection for motors in addition to the starting box?
14. What would you use to lubricate cutting contacts on a starting box?
15. Do these boxes introduce resistance into the shunt field circuit of the motor when starting?
16. What percent increase is made by this added resistance?

Written report questions:

1. Turn in complete diagrams of these starting boxes connected to shunt motors.
2. What is the function of a starting box?
3. Give the code specifications for installing starting boxes.

References:

Electric Motors and Control - Fox
Electrical Machinery - Annett
Elements of Electricity - Timbie
Croft's Handbook
Principles and Practice of Electrical Engineering - Gray

THE WILLIAM HOOD DUNWOODY INDUSTRIAL INSTITUTE

DAY SCHOOL
DES 4-10.2

ELECTRIC DEPARTMENT
D.C. Machinery
D.C. Motors & Control Apparatus

JOB: Test and diagram speed regulating rheostats

Materials, tools, equipment:
Speed regulating rheostats, Cutler hammer and Westinghouse, load bank, hand tools, ammeter, voltmeter, lead wires

General instructions:
Read this job sheet carefully. It may be for any regulating duty rheostat.
You are doing this job to become familiar with the construction and internal connections of various types of starting rheostats.
Put your name, section, job sheet number, and date finished on your report.

Operating steps:

1. Make a front view sketch of the boxes showing and marking the terminals and external connections.
2. Test and connect the internal circuits.
3. Note the heavy duty character of the armature starting resistance. (Westinghouse starter)
4. Note how the high resistance is connected. Speed regulation may be accomplished in either of the two following ways - high resistance may be added to the field circuit to increase speed or low resistance may be connected in series with the armature to reduce the speed.
5. Note any distinctive mechanical or electrical features of these rheostats.
6. Record the name plate data.
7. Note the resistance material and its installation in the box.
8. Measure the amounts of the resistances in these boxes.

Sketches: To be made by student.

Precautions:
Be very careful not to break leads or grids on these starting and regulating rheostats.
Handle motors carefully.
Cast resistance grids are very brittle and easily broken.

Questions:

1. Name the parts of these boxes.
2. What is the function or use of each one?
3. In this box used to increase motor speed above rated value by increasing resistance in the field circuit or is it used to reduce motor speed below rated value by the use of resistance in the armature circuit? Can both high and low speeds be obtained with one rheostat?
4. Does each have both resistances?
5. Why is the armature resistance more rugged and open in this type of box than in one used for starting duty only?
6. How is the arm held in the various running positions?
7. Does it make use of a holding coil?
8. Is a starting and regulating rheostat suitable for shunt, compound, and series motors? Why?
9. Has this box any protective features to protect the motor? Explain their function if there is one.
10. Why does the resistance used with the field circuit have to be so much greater than the armature circuit resistance?
11. Name the two factors which cause volt drop.
12. What is the cost of a box of this type?

Questions (con't)

13. What are the code requirements for mounting starting and regulating rheostats?
14. What insulation is used for internal connections for boxes of this type? (See Westinghouse Starter)
15. What are the code specifications on this wire?

Written report questions:

1. Turn in neat drawings of the wiring connections for these starters.
2. Write the specifications for ordering these rheostats.

References: Electric Motors and Control - Fox
Electrical Machinery - Annett
Croft's Handbook
Principles and Practice of Elec. Eng. - Gray
Catalogs and bulletins

6/14/35

THE WILLIAM HOOD DUNWOODY INDUSTRIAL INSTITUTE

DAY SCHOOL
DES 4-10.3

ELECTRIC DEPARTMENT
D.C. Machinery
D.C. Motors & Control Apparatus

JOB: Inspect, test and diagram a G.E. Type B. 109-A drum controller #360887

Materials, tools, equipment:
Bell-test set, hand tools, controller, resistance and lead wire.

General instructions:
This equipment is expensive and should be handled carefully. These pieces of equipment with slight changes in contacts and loads may be used with several circuits and various industrial applications.

Operating steps:

1. Inspect the controller for identifying numbers.
2. Inspect the grid resistance and note the contacts and method of insulating the various sections.
3. Test the resistance with the bell test set in order to find the circuits through it.
4. Remove the cover from the controller by loosening the nuts on the sides and swiging them out.
   NOTE: Loosening the thumb nut at the top of the controller allows the plate covering the contactors to swing back out of the way.
5. Inspect and test the circuits through the controller. Note that the rotating element is cylindrical in shape and that this is laid out flat on the drawing.
6. Secure an extra copy of this drawing and mark the polarity of the line and follow the path of the current through the diagram using arrows with numbers as follows: 1. ⟶ for the first contact, 2. ⟶ for second contact, etc. CAUTION: DO NOT MARK THE JOB SHEET. Use two colors on arrows, one for lower and the other for hoist. Note the dotted lines from top to bottom. They indicate the various handle positions which the rotating element takes.
7. Put the controller handle into a reverse position and indicate the current paths as in 6, but use dotted arrows or colored pencil for identification.
8. Carefully remove two or three of the contact fingers and examine their construction and assembly.
9. Note the mechanical construction of this controller.
10. Inspect the condition of the electric contacts and also the pressure on each.
11. Note the provisions made to prevent arc damage.
12. After noting the questions leave the apparatus completely reassembled as it should be. If in doubt about this consult the instructor.
13. Record the name plate data.

Sketches: See following page.

Precautions:
Handle this apparatus with judgement and report anything which does not appear right.
Do not connect to the line in this job.

Questions:

1. What type of motor is this controller used with?
2. Why are all contacts heavy duty?
3. What would you use to lubricate any contacts or parts which were cutting?
4. How is the rotating element stopped and held on the contacts?
5. What would probably result if this mechanism was out of order?
6. How does the construction of parts and the provisions made for carrying current compare with the three and four-point starting boxes?
7. What is the difference between starting and regulating duty and controller duty?
8. What does a controller do that a rheostat does not do?
9. What is the purpose of the plates with the shields mounted on them?
10. What takes place in the motor circuit when the controller is in reverse?
11. Could this controller be used on a shunt or compound motor?
12. Why is the cast grid so heavy and so freely ventilated?
13. Is there any protection for the motor in this controller?
14. What does the code require for protection of motors used with controllers?

Sketches: See separate sheet.

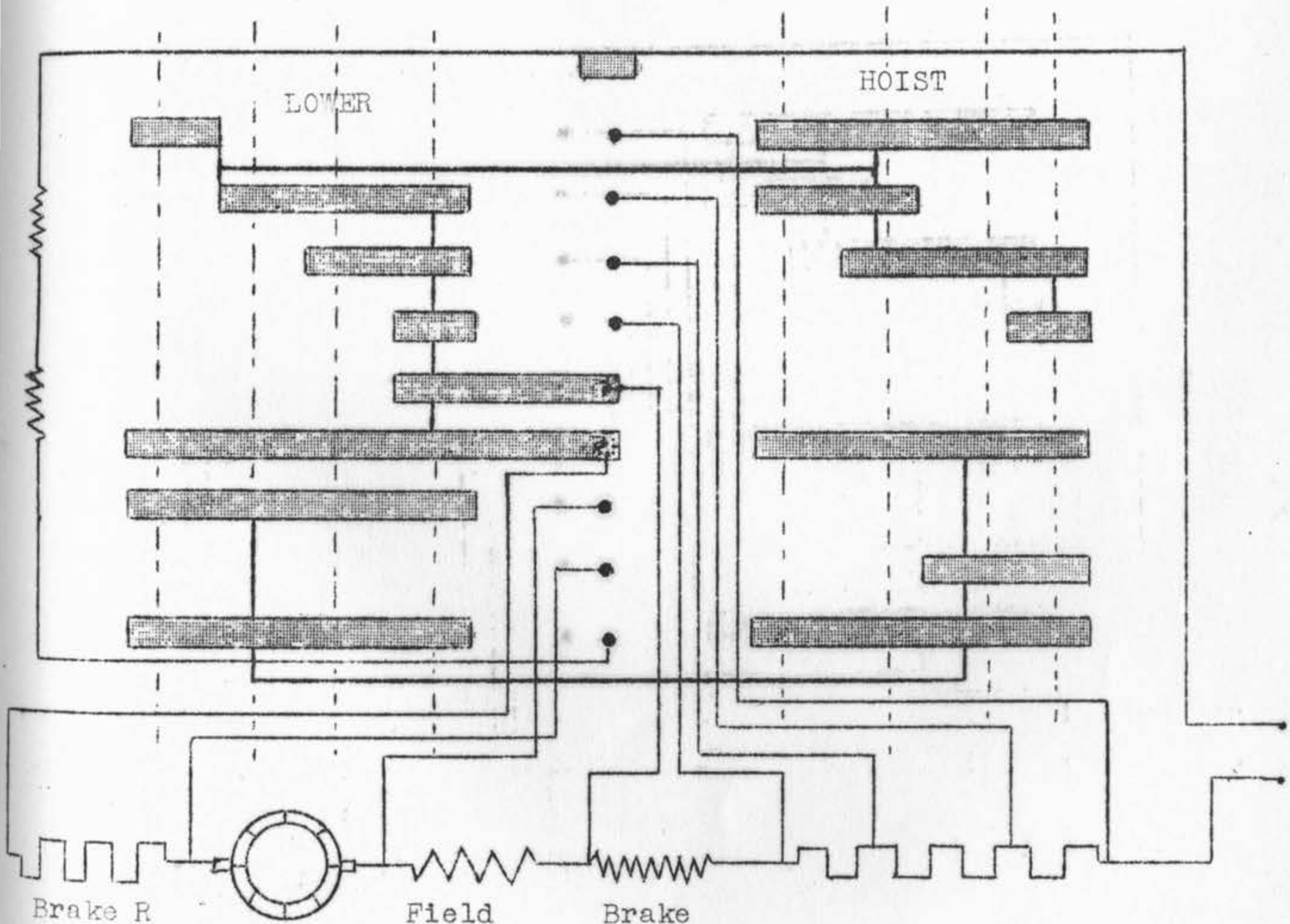
Written report questions:

1. Turn in a drawing with current directions completely indicated by arrows.
2. Write an order to the company for purchase of this controller.

References:

1. Electric Motors and Control - Fox
2. Electrical Circuits and Machinery - Morecroft - Hehre
3. Electrical Machinery - Croft
4. Bulletins and catalogs.

Sketches;



G.E. Type B-10.9A

THE WILLIAM HOOD DUNWOODY INDUSTRIAL INSTITUTE

DAY SCHOOL
DES 4-10.4

ELECTRIC DEPARTMENT
D.C. Machinery
D.C. Motors & Control Apparatus

JOB: Inspect, test and diagram a $1\frac{1}{2}$ H.P. G.E. Type R-301 Dynamic brake controller #359138

Materials, tools, equipment:
Bell-test set, handtools, controller, lead wire

General instructions:
This equipment is expensive and should be handled carefully. There are various methods for obtaining dynamic braking. Controller engineering practice utilize the equipment for as many methods as is possible. This is done to cut down engineering and factory costs.

Operating steps:

1. Inspect the controller for identifying numbers.
2. Inspect the controller for location of resistance - Do not take apart.
3. Remove the cover by loosening the nuts at the sides and swinging the holding bolts outward.
4. Inspect the moving contacts.
5. Test the various circuits through the contacts and fingers.
6. Consult the drawing on the shop curtain. Note that the moving element is cylindrical in shape but is laid out flat on the drawing.
7. Secure an extra copy of the diagram and mark the polarity of the incoming lines (+) and (-) and follow the path of the current through the drawing 8 and 9. For armature circuit only.
8. Indicate these directions using arrows and numbers as follows: 1. ⟶ first contact path, 2. ⟶ second contact path, etc. DO NOT MARK THE JOB SHEET.
9. Put the controller handle in reverse position and indicate the current paths as in 8, but use dotted arrows or a colored pencil.
10. Inspect the construction of the contact fingers and examine the adjustments and condition of the contact surfaces.
11. Note the provisions made to prevent arc damage.
12. After noting the questions on this sheet carefully reassemble the apparatus as it should be. If there is any doubt on this part of the job, consult the instructor.
13. Record the name plate data.
14. Save your noates. You may need them on a data job.

Sketches: See next page.

Precautions:
Handle this apparatus with judgement and report anything which does not appear to be right. Do not attempt to connect to the line on this job.

Questions:

1. What types of motors can this controller be used with?
2. Why are all contacts heavy duty on this controller?
3. What would you use to lubricate cutting contacts?
4. How is the rotating element stopped and held in the proper position for making contacts?

Questions (con't)

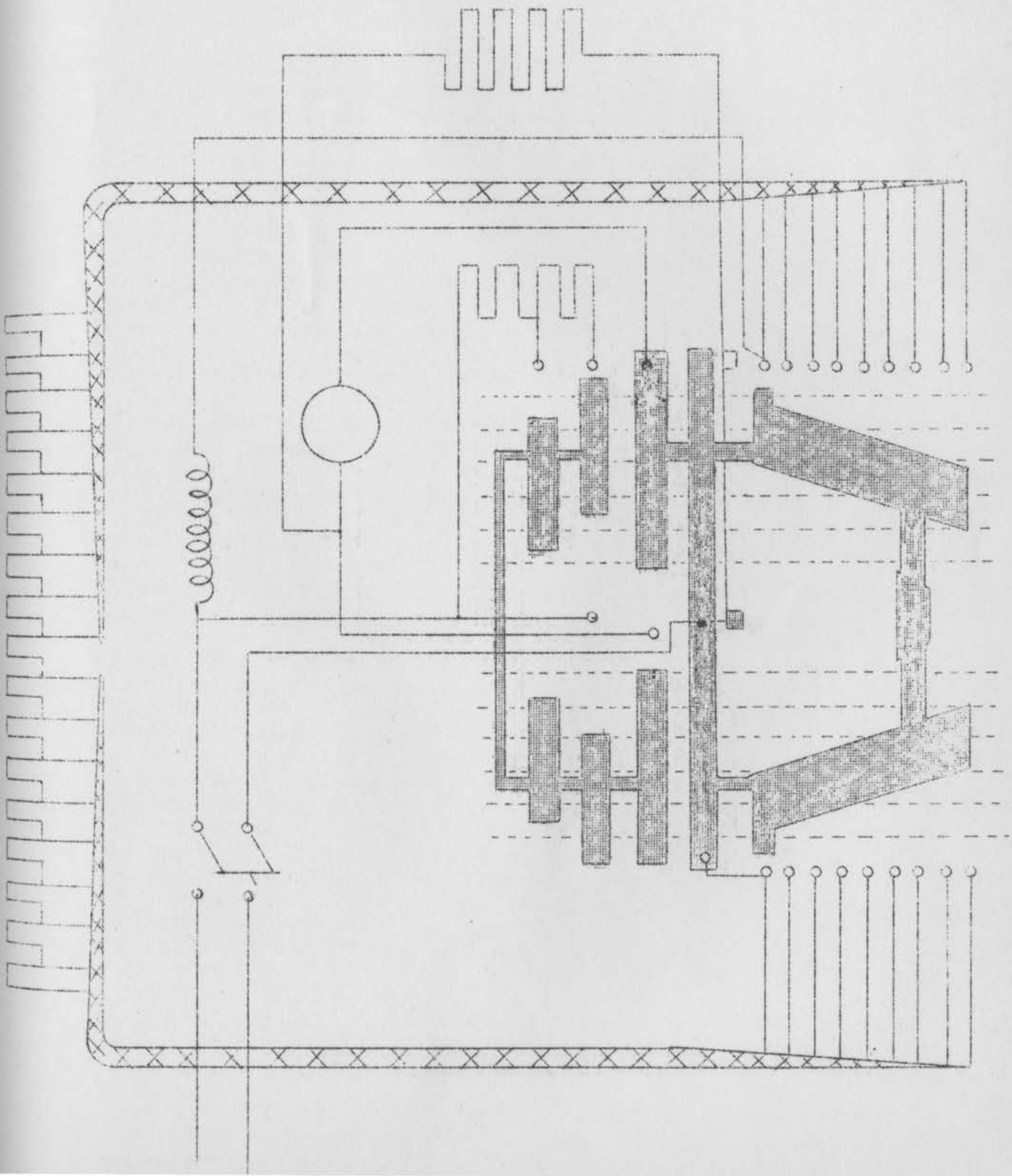
5. What would result if this mechanism did not function?
6. What provisions are made to reduce arcing and guard against arc damage?
7. Does this controller offer any motor protection other than for starting the load?
8. How is the motor reversed with this controller?
9. What is dynamic braking?
10. How is this obtained with this controller?
11. How is the speed varied from 150 R.P.M. to 1500 R.P.M. with this controller?
12. When is the field resistance introduced with this controller?

Written report questions:

1. Turn in a drawing with current directions indicated as called for in this job sheet.
2. Draw diagrams showing motor connections which will produce dynamic braking.
3. Explain how dynamic braking is accomplished.

References: Electric Motors and Control - Fox
Electrical Circuits and Machinery - Morecroft & Hine
Electrical Machinery - Croft
Principles and Practice of Elect. Eng. - Gray
Croft's Handbook
Trade Catalogs and bulletins

SKETCHES:



THE WILLIAM HOOD DUNWOODY INDUSTRIAL INSTITUTE

DAY SCHOOL
DES 4-11.1

ELECTRIC DEPARTMENT
D.C. Machinery
D.C. Motors and Control Apparatus

JOB: Connect and operate a 2 H.P. shunt motor using three-point and four-point starting boxes.

Materials, tools, equipment:
Motor, starting boxes, hand tools, prony brake, ringer test set, load wire, platform scale, water pan, ammeter, speed indicator

General instructions:
Follow this job sheet carefully. In this job you should learn to connect a motor with a 3-point and 4-point starting boxes. Work intelligently - do not guess.
Read your references. See that the motor has oil.

Operating steps:

1. Use the starting rheostats on the frame with a 2 H.P. motor.
2. Make a sketch from the information you have on starting boxes, showing the connections to the motor.
3. Test and mark all loads.
4. From your diagram and the information found from testing, connect the three-point starting box to the motor.
5. Use the circuit breaker on the frame above the motor as a line switch.
6. Put the prony brake on the pulley and set up the scale. Have brake arm horizontal. DO NOT TIGHTEN THE BRAKE.
7. Complete the connections to the line and check the motor rotation with reference to the brake arm requirements.
   CAUTION: If the motor does not start on the third contact or before, hold the starting box arm stationary and open the line circuit breaker. THIS IS IMPORTANT.
8. Place the ammeter in the line to the motor and avoid placing the motor where water may get on it. Use the motor tables.
9. Note the action of the ammeter as the rheostat arm is moved slowly from contact to contact.
10. Check and record the speed at no load.
11. Take the voltage at the motor when load is full value. Adjust this to the name plate value when readings are being taken.
    NOTE: If the motor speed increases when load is added the brushes probably need setting. Consult instructor.
12. Tighten the drum on the brake arm until the ammeter reads full load value of current. Put water inside pulley drum for cooling.
13. Balance and record the platform scale reading for full load current. Stop the motor by opening the breaker.
14. With brake arm set as in 13, start up the motor and note ammeter deflections when starting a load.
15. Take a good field rheostat from the rack and place it in the field circuit. With about 75 ohms added to the field circuit rerun steps 12, 13, and 14.
16. Tighten drum until scale reading was the same as full load under normal conditions, i.e. before resistance is added to field circuit.

Precautions:
Make sure the field circuit is complete.
If the motor fails to start after the rheostat arm has passed two or three contact studs, do not move the handle farther, but OPEN THE MAIN SWITCH OR CIRCUIT BREAKER, and bring the handle back to the starting point. NEVER STOP THE MOTOR BY PULLING BACK THE STARTING HANDLE. Always open the main-line switch.

Precautions: (con't)

The handle of the starting box must never be moved too rapidly. To do so defeats the purpose of the starting-box. The motor must not be allowed to run for any length of time with the starting resistance wholly or partly in the circuit. To do so is apt to overheat the resistance coils.

Questions:

1. Why does a motor have to have a field and an armature circuit?
2. Why is it so essential to have field leads mechanically and electrically good?
3. How is the holding coil connected in this circuit?
4. Does this in any way affect the field strength of the motor at name plate voltage?
5. How is the torque developed in a motor?
6. If the field was weakened how would the same amount or more torque be developed?
7. Compare the values of armature current when various resistances are in the field circuit for same brake arm reading.
8. Explain the findings from the previous question.
9. Define torque.
10. How is torque produced electrically?
11. How did weakening the field affect the speed?
12. Explain the reason for this.
13. Why did the ammeter go so high on the first contacts and then gradually drop back?
14. What two factors limit the current in starting a motor?
15. Which one increases and which decreases as the motor is started? Explain.
16. If the motor field became too weak what would happen?
17. If the motor has load on it would this increase in speed always take place? Explain.
18. Would the overload protection provided protect the loaded motor against a weak field?
19. Why do all manufacturers of three-point starting boxes desire to have complete information regarding the motor you propose to operate with the box?
20. What will the holding coil resistance do to the operation of the motor?
21. Repeat the above procedure using the four-point box. Use the same line voltage in both cases.

Written report questions:

1. Make a diagram of your hook-ups for this job.
2. Fill in the following table for both tests.

	NO LOAD RPM	NO LOAD I	VOLTS	FU LOAD I	FU LOAD RPM	SCALE READ	Fu LOAD I WITH WEAK FIELD
3 pt.							
4 pt.							

3. What conclusions have you as to 3 and 4 point starting box operation?

References: Electric Motors and Control - Fox
Electric Circuits and Machinery - Morecroft and Hehre
Electrical Machinery - Croft
Croft's Handbook
Catalog and Bulletins
Electrical Machinery - Annett

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THE WILLIAM HOOD DUNWOODY INDUSTRIAL INSTITUTE

DAY SCHOOL
DES 4-11.2

ELECTRIC DEPARTMENT
D.C. MACHINERY
D.C. Motors & Control Apparatus

JOB: Connect and operate a 2 K.W. 115 V. G.E. Company generator as a shunt motor: (1) using Cutler-hammer multiple switch starter (a) using Westinghouse Type I regulating rheostat

Materials, tools, equipment:
Hand tools, ammeter, voltmeter, speed indicator, rheostats, motor, lead wire, prony brake, scale, test set.

General instructions:
This job should increase the students knowledge of motor starting and regulating apparatus. We learn when we think -- doing without thinking is wasted time and effort. Make these jobs mean something to you.

Operating steps: Part I.

1. Test and diagram the multiple switch starter.
2. Note its construction details and method of operation.
3. Make a diagram showing connections to the motor.
4. Connect the starter to the motor, putting the ammeter in the line to the motor.
   NOTE: With this type of starter a main-line switch or circuit breaker is not necessary. Fuses only need be provided.
5. Check the direction of rotation of the motor.
6. Put on the brake and level the arm on the platform scale.
7. With the brake drum loose start up the motor and note the ammeter deflections.
8. Tighten the drum until the machine is taking one-half of full load current.
9. Adjust voltage to name plate value at the motor.
10. Balance the scale and read the beam.
11. Shut the machine down without loosening the brake drum.
12. Start the machine under load and compare the starting current at each step with those for no load.
13. Check the time intervals in both cases that is the time between closing the one contact and the next.
    NOTE: Hold one arm down as long as the current is decreasing - then close the next; check the time interval.

PART II

14. Repeat steps k,2,3 and 4 using the Westinghouse Type I starter. In step 4 put an additional ammeter (3A) in the field circuit use a short circuiting switch with this motor.
15. Check rotation of the motor. It should be right for your Pronybrake setting.
16. Start the motor noting the deflection of the ammeter between steps. Check time.
17. Record the deflections and the time the speed is increasing between contacts. At the same time note the field current on each step and record your findings.
18. Move the handles so that the field resistance is introduced into the circuits. Tabulate your results, field amps, armature amps and speed. BE SURE YOU HAVE PROPER VOLTAGE AT THE TERMINALS OF THE MOTOR.

19. Tighten the drum until you have one half of the name plate amperes with starting box handle on normal running position. Record scale beam weights.
20. Shut down the machine and start it up again under these load conditions. Note results when 17 and 18 are repeated under load conditions. Keep the scale beam balanced.
21. Make a complete record of all your findings.

Sketches: To be made by student.

Precautions:

DANGER!!! Avoid all possibilities of open field circuits!!
Handle all apparatus intelligently.
Use 30A fuses for protection on this job. Check diagrams and circuit connections carefully.

Questions: PART I

1. How many steps are used in starting this motor with the multiple switch starter?
2. Why is it not necessary to provide a main line switch with this starter?
3. Why does the motor take more starting current when the brake arm is tightened?
4. Why is the time interval greater with than without load?
5. If the holding coil did not trip when it should, how could you regulate this?
6. Does the holding coil on this starter have to be designed for any special amount of current? Why?
7. Suppose you desired to change motors with this starter what things must be considered?
8. What are some of the advantages you can think of for this equipment?
9. What are some of the factors against it?
10. Why is a main line switch not necessary with the multiple switch starter?

PART II

11. How does this starting rheostat differ from the previous one in its control of the motor?
12. How is the arm on the controller held in the various running positions?
13. Why is it necessary to keep the same scale reading when making these tests?
14. Plot a curve showing the variations of the field and armature currents with armature amps as the base.
15. Plot a curve of armature current and speed on the same sheet.
16. What do these graphs show?
17. Does speed regulation cost extra money? Why?

Written report questions:

1. Make a diagram of each of these rheostats.
2. Tabulate the data of both tests and turn in the curves called for in 14 and 15.

References:

1. Electric Motors and Control - Fox
2. Electric Circuits and Machinery - Morecroft and Hehre
3. Electrical Machinery - Croft
4. Croft's Handbook
5. Catalogs and Bulletins
6. Electrical Machinery - Annett

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DAY SCHOOL
DES 4-11.3

ELECTRIC DEPARTMENT
D.C. Machinery
D.C. Motors & Control Apparatus

JOB: Connect and operate a 2 H.P. Peerless motor using a Cutler-hammer speed regulating rheostat

Materials, tools, equipment:
Motor, hand tools, two ammeters, speed indicator, rheostat, Prony brake, platform scale, voltmeter, test set, lead wire

General instructions:
Information on the effect of speed regulation devices on the operation of motors is the chief objective in this job as well as to increase the students knowledge of starting boxes.

Operating steps:
1. Test and diagram this starting box
2. Note the construction details as well as the method of operating it.
3. Draw a diagram showing this box connected to the motor.
4. Connect the starter to the motor. Use the circuit breaker as a main line switch and use 30A fuses in the cabinet.
5. Put on the brake loosely and check the direction of rotation, on the motor armature.
6. Level the brake arm on the platform scale.
7. With the brake drum loose start up the motor and note the ammeter deflection, both armature and field.
   NOTE: Handle this starting box properly as it will arc badly if used as a switch.
8. Take the speed reading when voltage at the motor is at name plate value.
9. Move the arm so that the speed is increased. Make records of the speed, armature current, and field current at each point on the starting box above normal speed.
10. Tighten the drum until the motor is taking nearly full load current, balance and read scale, and then shut it down.
11. Start up the motor with this load and note ammeter deflections.
12. Repeat Step 9 under load conditions and record results of armature current, field current and speed. Keep scale and balanced when making this test.
13. Recude the voltage to 105 volts and repeat 12.
14. Raise the voltage to 125 volts and repeat 12.

Sketches: To be made by student.

Precautions:
Do not take chances on poor connections.
Protect your meters and testing apparatus as it is easily damaged and is expensive.

Questions:
1. Can this box be used for lowering the speed below normal? Why?
2. What actually makes the speed of the motor increase?
3. With less field current why is there not less torque?
4. If the motor speed could not increase with weakened field what would happen?

Questions (con't)

5. Will over-load protection save a motor under these conditions?
6. How does low line voltage affect the current a motor requires?
7. How does this affect the speed of the motor?
8. If this motor was driving a production machine in a factory, by what percentage would production be reduced by this change of 10 volts below normal?
9. How much was the armature current changed?
10. How does over voltage affect the speed and the armature current?
11. If the voltage was high what part of the motor would likely to be overheated?
12. What part of the machine would burn out first due to low voltage? Why?
13. How is the holding coil on this box protected against too weak field current when the motor is run above normal speed?

Written report questions:

1. Make a diagram of this set-up.
2. Plot a set of curves of armature current and field current at normal voltage, armature amps as base.
3. On this same sheet show speed and armature current.
4. Show how speed and field current vary.

References:

1. Electric motors and control - Fox
2. Electric circuits and machinery - Morecroft and Hehre
3. Electrical Machinery - Croft
4. Croft's Handbook
5. Catalogs and Bulletins
6. Electrical Machinery - Annett

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DAY SCHOOL
DES 4-11.4

GENERAL SHOPS DEPT.
D.C. MACHINERY
D.C. MOTORS & CONTROL
Apparatus

JOB: Connect and operate a 3 H.P. G.E. Company motor using a G.E. manually operated speed regulating starter.

Materials, tools, equipment:
Hand tools, ammeter, speed indicator, rheostat, Prony brake, platform scale, voltmeter test set, lead wire, load bank, field rheostats

General instructions:
Additional information on the effect of speed regulating devices on the operation of motors is the chief objective of this job as well as to increase the students knowledge of starting boxes.

Operating steps:

1. Test and diagram this starting box.
2. Note the construction details as well as the method of operating it.
3. Draw a diagram showing this box connected to the motor.
4. Connect the starter to the motor. Use the circuit breaker as a main line switch and use 30A fuses in the cabinet.
5. Put on the brake loosely and check the direction of rotation of the motor armature.
6. Level the brake arm on the platform scale.
7. With the brake drum loose start up the motor and note the ammeter deflection both armature and field.
8. Take the speed reading when voltage at the motor is at name plate value.
9. Move the arm to the first notch and take the speed of the motor and volts across the armature and regulating resistance separately.
10. Repeat (9) for each contact tabulating the data.
11. Tighten the drum until the motor is taking about two thirds full load current. Adjust the voltage until you have name plate value at the motor.
12. Shut down the motor and repeat (9).
13. Repeat the test at 1/2 and full load.
14. Repeat 12 at 10% over voltage.
15. Repeat 12 at 10% under voltage.
16. Tighten drum securely to pulley so it will not rotate and take scale arm readings as the armature current is varied in 2 ampere steps from 0 to 20 amperes. Tabulate your results.
17. Place a 16A current through the armature and vary the field current in 12 steps by the use of field rheostats, from 0 to full value.

Sketches: To be made by the student.

Precautions:
Do not take chances on poor connections.
Protect your meters and testing apparatus as it is easily damaged and is expensive.

Questions:

1. Can this box be used for raising the speed above normal? Why?
2. What does the starting box actually do to decrease the speed of the motor?
3. With less armature current is there less torque?
4. At normal line voltage and this box could you overheat this armature with too much load?
5. Is overload protection needed for a motor with this type of speed regulating device?

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6. What does over voltage do to the speed?
7. Would a varying source of voltage change the speed of motors connected to such a source?
8. How is the holding coil connected on this box?
9. What means is used to hold the rheostat arm on the various positions for running?
10. Does this box provide for no voltage release? Explain.
11. Does the volt drop across the armature added to the volt drop across the rheostat equal the line voltage?
12. With armature readings as horizontal values plot curve showing how torque changes (Scale readings vertical) Shunt field constant.
13. With field readings as horizontal values plot another curve showing how torque changes. (Scale readings vertical) Armature current constant.
14. Under normal operating conditions with a shunt motor how is variable torque produced to meet a changing load condition?

Written report questions:

1. Make a diagram of this job.
2. What is the relation of speed to volts across the armature?
3. Explain why there is no change in field current with this type of speed regulation.
4. Turn in the graphs showing how torque varies with armature current when voltage is normal and also above and below normal.

References:

Electric motors and Control - Fox.
Elo ctric Circuits and Machinery - Morecroft and Hehre
Electrical Machinery - Croft
Croft's Handbook
Catalogs and Bulletins
Electrical Machinery - Annett

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THE WILLIAM HOOD DUNWOODY INDUSTRIAL INSTITUTE

DAY SCHOOL
DES 4-12.1

ELECTRIC DEPARTMENT
D.C. Machinery
D.C. Motors & Control Apparatus

JOB: Connect and operate a 2 H.P. 115V Roth series motor using Union Electric Controller

Materials, tools, equipment:
Motor, controller, test set, Prony brake, scale, ammeter, voltmeter, loads, speed indicator.

General instructions:
Series motors unless geared or direct connected to their loads are extremely dangerous. Motors of this type over two horsepower will wreck themselves through excessive speed.

Operating steps:
1. Test and mark motor leads.
2. Test and mark controller and resistance leads.
3. Follow the drawing and connect the motor for operation with ammeter in the circuit. Use the circuit breaker for a line switch.
4. Check for correct direction of rotation. Clockwise rotation of armature from the commutator end should be forward.
5. Attach the prony brake arm (drum loose) and set up your scale so the brake arm is horizontal.
6. With brake drum loose check speed and current on each step. Check voltage at the motor.
7. Apply the load, tighten brake drum, in ten steps about $1\frac{1}{2}$ amps, per step and take the current and speed at each step. Tabulate your results.
8. Change the Prony brake and repeat step 7, running the motor in the reverse direction. Make sure your line voltage does not change more than a volt or two.
9. Secure an extra copy of the stencilled diagram for this job.
10. Mark with (+) and (-) signs the incoming line wires to the hook-up and indicate with arrows the direction of the current through the circuits. 1. ⟶ first step, 2. ⟶ second step, etc.
11. Use dotted arrows or colored arrows for the reverse direction. DO NOT MARK THE JOB SHEET.
12. Record all name plate data on this controller and motor.
13. Tighten the brake arm securely to the pulley.
14. Take a set of readings of the current and brake arm pressures for each step on the controller. Balance the scale at each current reading.

Sketches: See attahced sheet.

Precautions:
Do not throw the motor from forward into reverse with the ammeter in the circuit. Do not allow the motor to run at high speed longer than necessary.

Questions:

1. What type of circuit is made in this job?
2. Will this controller work with a shunt or compound motor?
3. Explain what is necessary if it is used with other than a series motor.
4. How is the reversal of the motor accomplished?
5. Is this resistance and controller made for constant or starting duty?
6. What types of jobs are best performed by the series motors?
7. Are any provisions made to prevent or take care of arcing in this controller?
8. How does the current vary with the load on a series motor?
9. How does the speed vary with the load?
10. Does the motor work equally well in both directions of rotation?
11. Why does the series motor speed race with light loads?
12. How are series motors connected to loads in industrial applications?
13. Plot a curve of load and speed using the load (amperes) as the horizontal variable.
14. Plot the torque and amperes on the same sheet.
15. How does the torque vary with the armature current in series motor?

Written report questions:

1. Turn in your copy of the hook-up in this job with current directions indicated.
2. Turn in the data and curves called for.
3. Explain how torque is developed in a series motor.

References: Electric Motors and control - Fox
Electric Circuits and Machinery - Morecroft & Hehre
Electrical Machinery - Croft
Croft't Handbook
Trade Catalogs and Bulletins

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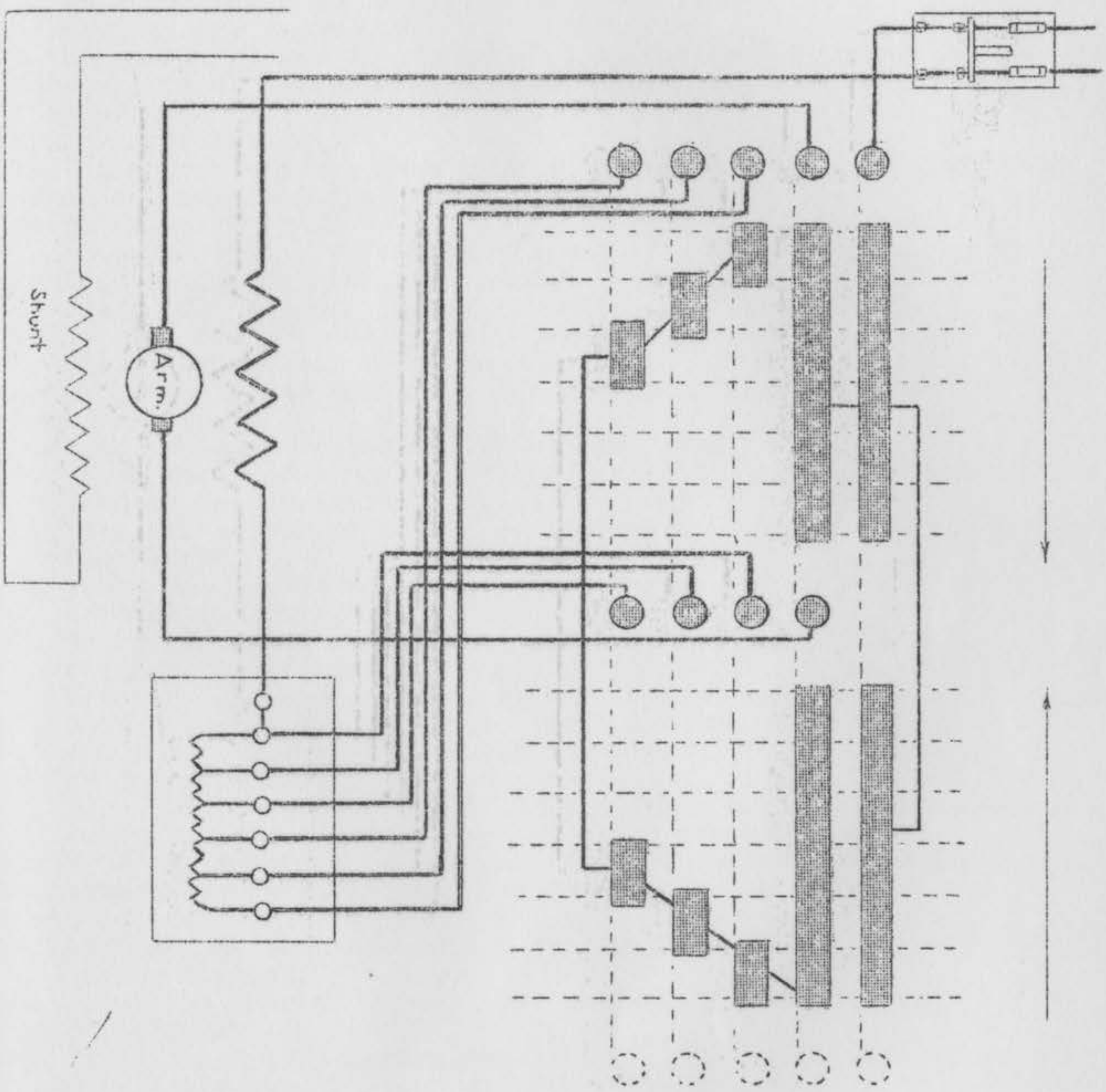
Shunt
Arm.

THE WILLIAM HOOD DUNWOODY INDUSTRIAL INSTITUTE

DAY SCHOOL
DES 4-12.2

ELECTRIC DEPARTMENT
D.C. Machinery
D.C. Motors & Control Apparatus

JOB: Connect and operate a 3 H.P. G.E. series crane motor with solenoid brake and reversing controller.

Materials, tools, equipment:
Motor, solenoid brake, controller, resistance grid, hand tools, ammeter, leads, Prony brake, speed indicator, remote controlled line switch.

General instructions:
The doing of this job should teach you how to connect electrical crane and hoist equipment.

Operating steps:

1. Refer to Job 10.4 for diagram and circuits in the controller.
2. Follow this diagram and connect the apparatus listed.
3. Connet the ammeter in the line circuit to the motor.
4. Use the single pole circuit breaker in one side of your line.
5. Close the breaker and turn the controller handle to the first notch in the hoist position. If the motor starts proceed to the next point, etc.
6. Note the ammeter deflection at each step.
7. Check the lowest and highest speed of the armature on hoisting. Also at intermediate points.
8. Note the action of the solenoid brake. Just when does the brake function?
9. Check the reverse direction or lowering and note the current through the armature.
10. Check the speed on lowering all points. NOTE: The motor may not start to rotate until the second notch on the controller is reached. This gives some little control when lowering the load.
11. What does the brake do when the speed gets rather high? Note the armature current at this time. Check this on both hoist and lowering.
12. Note the heavy duty shaft and the taper ends, also the means of fastening the brake pulley and the drive gear.
13. Note the construction of the motor frame and the housing.
14. Attach the brake arm and put load on the motor-hoisting.
15. Hold the brake arm down and try in a lowering position.
16. Connect the line starter switch in the circuit and overload the motor-hoisting.
17. Allow the thermal element two or three minutes to cool before resetting.
18. Explain how this across-the-line starter switch operates.
19. Make a diagram of it.
20. Trace the hoisting circuit.
21. Trace the lowering circuit.
22. Does this controller provide dynamic braking?
23. Mark the circuit on 103 diagram with blue pencil.

Sketches: Use the same stencil as in DES 4-10.3

Precautions:
Do not throw the controller handle from one direction to the other without stopping at the "off" position until the motor stops.

Questions:

1. Is this motor reversible in the frame?
2. Can this motor be used out of doors?
3. Why is the armature and commutator so much larger than for other motors of the same rating?
4. Why does the motor run better hoisting than lowering?

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Quostion (con't)

5. How doos tho brako function?
6. Why doos it limit tho spood of tho armaturo? Why?
7. Would it hold tho load if tho powor failod? How?
8. What other typos of brakos aro usod for hoists?
9. Would this apparatus bo satisfactory for an olovator? Why?
10. What doos olovator work requiro that this apparatus cannot do?
11. Look up tho Ward Loonard Control systom for olovator work.
12. What is moant by tho torm "micro-adjustmont" drivo?

Writton roport quostions:

1. Turn in a diagram of your hook-up for this job using tho "cross-tho-lino" startor switch.
2. Explain tho oporation of a thormal rolay.
3. Explain tho action of tho so-callod solonoid brako.

Roforoncos: Eloctric Motors and Control - Fox
Eloctric Circuits and Machinory - Morocroft and Hohro
Eloctrical Machinory - Croft
Trado Catalogs and Bullotins

6/15/35

THE WILLIAM HOOD DUNWOODY INDUSTRIAL INSTITUTE

DAY SCHOOL
DES 4-12.3

ELECTRIC DEPARTMENT
D.C. Machinery
D.C. Motors &
Control Equipment

JOB: Connect and operate $1\frac{1}{2}$ H.P. shunt motor with dynamic brake control

Materials, tools, equipment:
Motor, controller, hand tools, lead wire, ammeter 0-center scale if possible.

General instructions:
Refer to Job 10.4 for diagram of this starter. Read the references and analyze what you are doing.

Operating steps:
1. Test and mark the motor leads.
2. Follow the diagram and connect the controller to the motor without braking.
3. Check the speed of the motor at each notch on the controller. At the same time make a record of the armature current for each contact.
4. Bring the motor up to full speed and quickly swing the handle to the "off" position. Note the time the armature and flywheel coast.
5. Repeat #4 in the reverse direction.
6. Connect the dynamic braking feature and repeat (4) and (5).
7. Connect the ammeter in an armature lead and note the current through armature on running and braking.
8. Check the stopping time from full speed down.
9. With the armature stopped and the control handle in the "off" position test for magnetism in the field.
NOTE: Do this by carefully bringing the point of your screwdriver near the pole face. If the field is on the screwdriver will be drawn to the pole.
10. Start the motor. Bring it to full speed. Trip the breaker and quickly bring the controller handle to the off position and note what happens.

Sketches: Same stencil as DES 4-10.5 for this job.

Precautions:
Do not swing the controller handle past the "off" position when motor is running.
Do not advnace controller arm too fast as the flywheel has a very high momentum. Watch flywheel for any signs of looseness or unbalancing.

Questions:
1. List all the purposes this controller will accomplish in operating a motor.
2. What is dynamic braking?
3. How is it accomplished in this job?
4. Why is the armature so large on this motor, its rating is only one and one half horsepower?

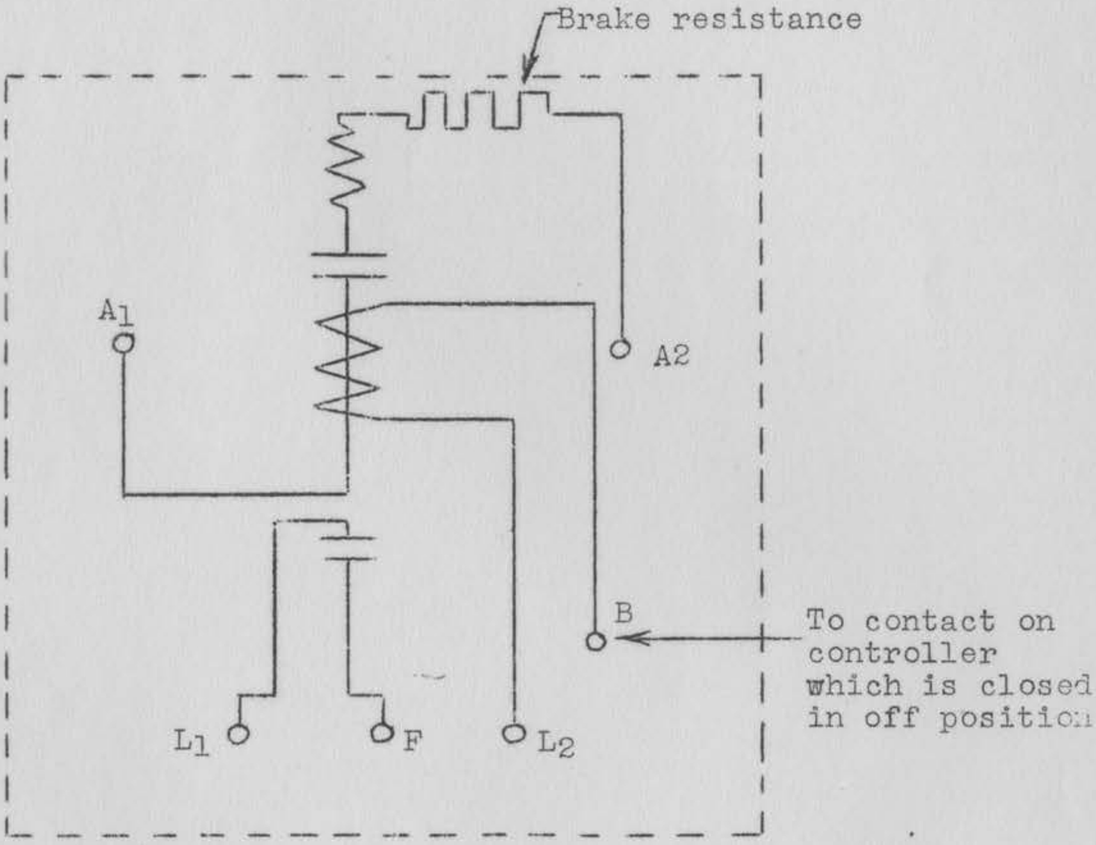
Questions (con't)

5. If the power would fail could this machine be made to control the load? How?
6. Would a motor used with dynamic breaking ever be to small to hold any load it would start or hoist? Why?
7. What are some advantages of dynamic braking in industry?
8. What is regenerative braking?
9. How is it accomplished?
10. Where is it used most advantageously in industry?
11. What is the difference between dynamic and regenarative braking?
12. What advantage does regenerative braking have over dynamic braking?
13. What is the advantage of dynamic braking over mechanical braking?
14. What is the purpose of the flywheel on this motor shaft?
15. What is the maximum safe peripheral speed for cast iron flywheels?
16. How does this compare with safe armature peripheral speeds?
17. What safety protection does this controller give to the motor if any?

Written report questions:

1. Draw a graph showing the relation of the armature current and speed, armature current as base.
2. List the advantages and disadvantages of dynamic braking.

References: Electric Motors and control-Fox
Electrical Circuits and Machinery - Morecroft & Hehre
Electrical Machinery - Croft
Croft's Handbook
Trade Bulletins and Catalogs



Dynamic Braking Control Device

for Job 12.3

THE WILLIAM HOOD DUNWOODY INDUSTRIAL INSTITUTE

DAY SCHOOL
DES 4-13.1

ELECTRIC DEPARTMENT
D.C. MACHINERY
D.C. Motors & Control Apparatus

JOB: Connect and operate a $1\frac{1}{2}$ H.P. - G.E. motor with a 115 volt Cutler hammer push button starter

Materials, tools, equipment:
Motor, starter, hand tools, ammeter, voltmeter, lead wire

General instructions:
Automatic starting and control equipment is intricate and expensive. For these reasons it should be handled with care and judgement. Be sure to read the manufacurer's bulletins on this equipment if there is one.

Operating steps:

1. Study the wiring of this apparatus.
2. Read the description of the operation of this equipment several times.
3. Open or remove the front cover so you can see the construction of the starter.
4. Inspect the apparatus and test the circuits with a test set.
5. Locate and identify corresponding points on the diagram and in the starter.
6. While testing with the test set push the various contactors in with the fingers and determine what they do in the circuit when they close. Be careful of the adjustment while you are doing this!
7. Test and mark the motor loads.
8. Connect the motor and the starter to the line. NOTE: Use the single pole circuit breaker as a main line switch.
9. Push the start button and note the action of the starter.
10. Push the stop button and see how the apparatus functions.
11. Check the time between closing of the starting contactors. NOTE: Operate motors at rated voltage for best results.
12. Push the start button before the armature has completely stopped and note the time between closing of the contactors.
13. Check the ammeter deflections as the starter starts the motor.
14. Trace (on your copy of this diagram) the power circuit in heavy black lines and the control circuit in light red lines. DO NOT MARK THE JOB SHEET.
15. Record the name plate data of all equipment for this job.
16. How can the time of starting be adjusted to various loads the motor might have to operate?

Sketches: See separate sheet.

Precautions:
Do not attempt to alter or change this equipment in any way. If you do not understand it consult the instructor.

Questions:

1. How many steps in the starting resistance with this starter?
2. How and when is the shunt field circuit for the motor made?
3. How is the starter button shunted when the motor starts?
4. Is there a control circuit and a power circuit in this starter? Trace them.
5. What determines or limits the time of starting the motor with this starter?
6. Can the time of starting be controlled with this starter? How?
7. Is there provision made in this starter to protect the motor against over-loads?

8. Explain how it works. Does it open the control circuit or the power circuit directly? Is it thermally or magnetically operated?
9. What provisions are made to prevent or take care of arcing?
10. What does a starter of this type cost?
11. What advantages does automatic starting have over manual starting of motors?
12. Would the size of the motor have any bearing on the selection of the starting equipment - i.e., manual or automatic?
13. Will this starter reverse the direction of rotation of the motor without changing the connections?
14. Mark the incoming lines to this starter with (+) and (-) signs, on diagram.
15. Indicate with arrows the direction of current in the various circuits: 1. ⟶ 2. ⟶ first contact, second contact, respectively.
16. Trace and indicate the control circuit for starting on diagram.
17. Trace and indicate the power circuit on the starting position.
18. Trace and indicate the control circuit on each succeeding position.
19. Trace and indicate the power circuit on each succeeding position.
20. Letter your diagram with your own lettering and write a description of the operation of this starter.

Written report work:

1. Turn in a marked drawing of the circuits in this starter.
2. Write complete description for ordering this starter.

References: Electric Motors - Fox
Croft's Handbook
Principles and Practice of Elec. Eng. - Gray
Electric Circuits and Machinery - Morecroft & Hehre
Trade bulletins

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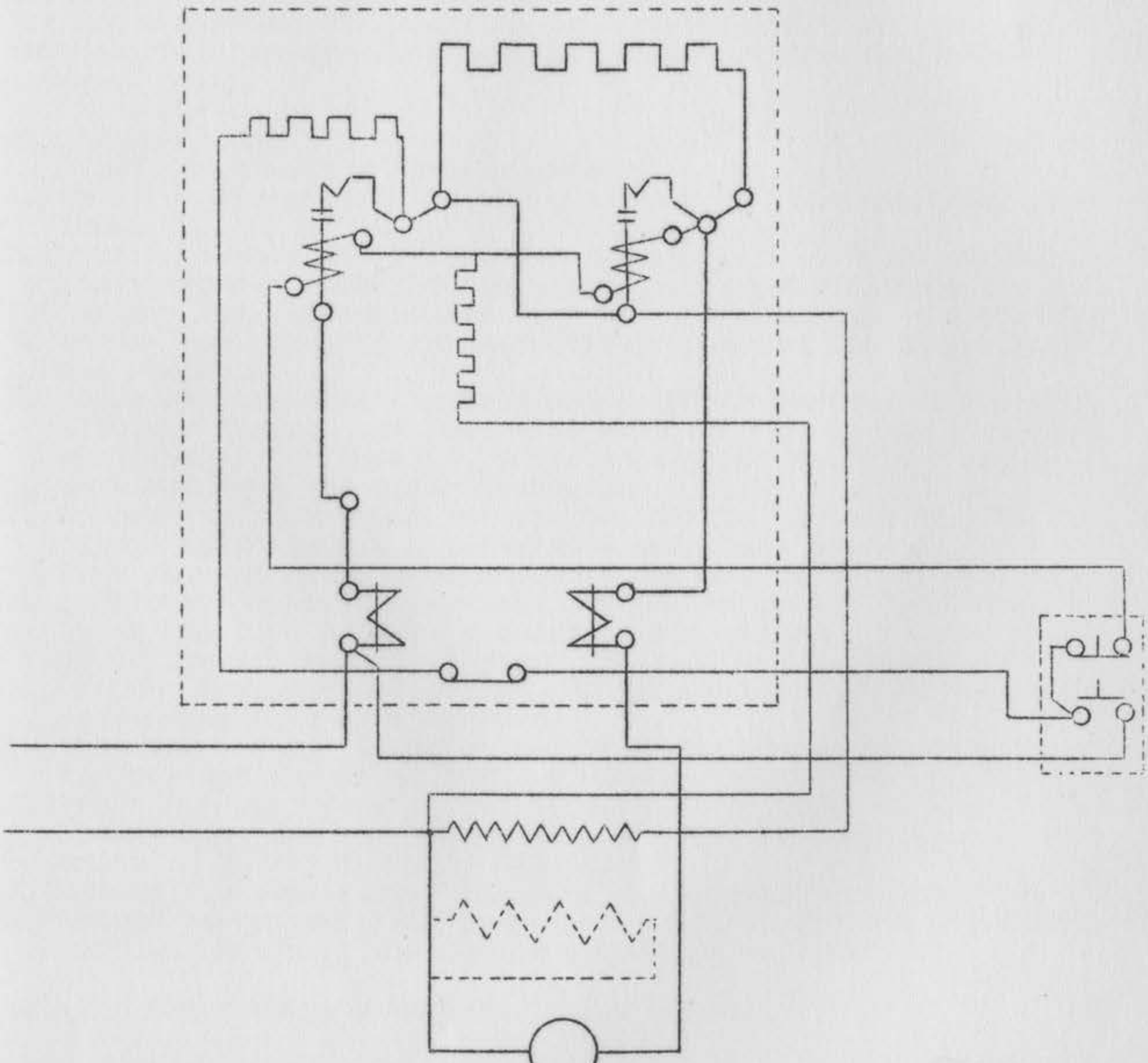
C-H STARTER 1 H.P. NO-6102 H5B



THE WILLIAM HOOD DUNWOODY INDUSTRIAL INSTITUTE

DAY SCHOOL
DES 4-13.2

ELECTRIC DEPARTMENT
D.C. MACHINERY
D.C. Motors & Control Apparatus

JOB: Connect and operate a 2 H.P. - G.E. C.R. 4012-C1 C.E.M.F. starter with relay coils to a 2 H.P. motor

Materials, tools, equipment:
Motor, starter, handtools, ammeter, voltmeter, wire, Prony brake, water pan.

General instructions:
Automatic starting and control equipment is intricate and expensive. For these reasons it should be handled with care and judgement. Be sure to read the manufacturers bulletins on this equipment if there is one.

Operating steps:

1. Study the wiring of this apparatus.
2. Read the description of the operation of this equipment several times.
3. Open or remove the front cover so you can see the construction of the starter. NOTE: Do not remove the apparatus from the case.
4. Inspect the apparatus and test the circuits with a test set.
5. Locate and identify corresponding points on the diagram and in the starter.
6. While testing with the test set push the various contactors in with the fingers and determine what they do in the circuit when they close. Be careful of the adjustment while you are doing this
7. Test and mark the motor leads.
8. Connect the motor and the starter to the line. NOTE: Use the single pole circuit breaker as a main line switch.
9. Push the starter button and note the action of the starter.
10. Push the stop button and see how the apparatus functions.
11. Check the time between closing of the starting contactors. NOTE: Operate motors at rated voltage for best results.
12. Put the brake on the pulley and adjust friction so that armature is drawing full load current.
13. Stop the motor. Start it and note the change in deflection of ammeter and also time between closing of the second contact.
14. Trace (on your copy of this diagram) the power circuit in heavy black lines and the control circuit in light red lines. Use arrows. DO NOT MARK THE JOB SHEET.
15. Record the name plate data of all equipment for this job.
16. Change the weight setting on the pendulum arm and repeat 13. CAUTION: Use care and do not operate with cover off.

Sketches: See tracing attached.

Precautions:
Do not attempt to alter or change this equipment in any way. If you do not understant it consult the instructor.

Questions:

1. How many steps in the starting resistance with this starter?
2. How and when is the shunt field circuit for the motor made?
3. How is the start button shunted when the motor starts?
4. Is there a control circuit and a power circuit in this starter? Trace them.
5. What determines or limits the time of starting the motor with this starter?
6. Can the time of starting be controlled with this starter? How?
7. Is there provision made in this starter to protect the motor against over loads?
8. Explain how it works. Does it open the control circuit or the power circuit directly? Is it thermally or magnetically operated?
9. What provisions are made to prevent or take care of arcing?
10. What does a starter of this type cost?
11. What advantages does automatic starting have over manual starting of motors?
12. Would the size of the motor have any bearing on the selection of the starting equipment - i.e., manual or automatic.
13. Will this starter reverse the direction of rotation of the motor without changing the connections?
14. Mark the incoming lines to this starter with (+) and (-) signs.
15. Indicate with arrows the directions of current in the various circuits: 1. ⟶ first contact, 2. ⟶ second contact, etc.
16. Letter your diagram with your own lettering and write a description of the operation of this starter.

Written report work:

1. Turn in a marked drawing of the circuits in this starter.
2. Write complete description for ordering this starter.

References: Electric Motors - Fox
Croft's Handbook
Principles and Practice of Elec. Eng. - Gray
Electric Circuits and Machinery - Morecroft & Hehre
Trade bulletins.

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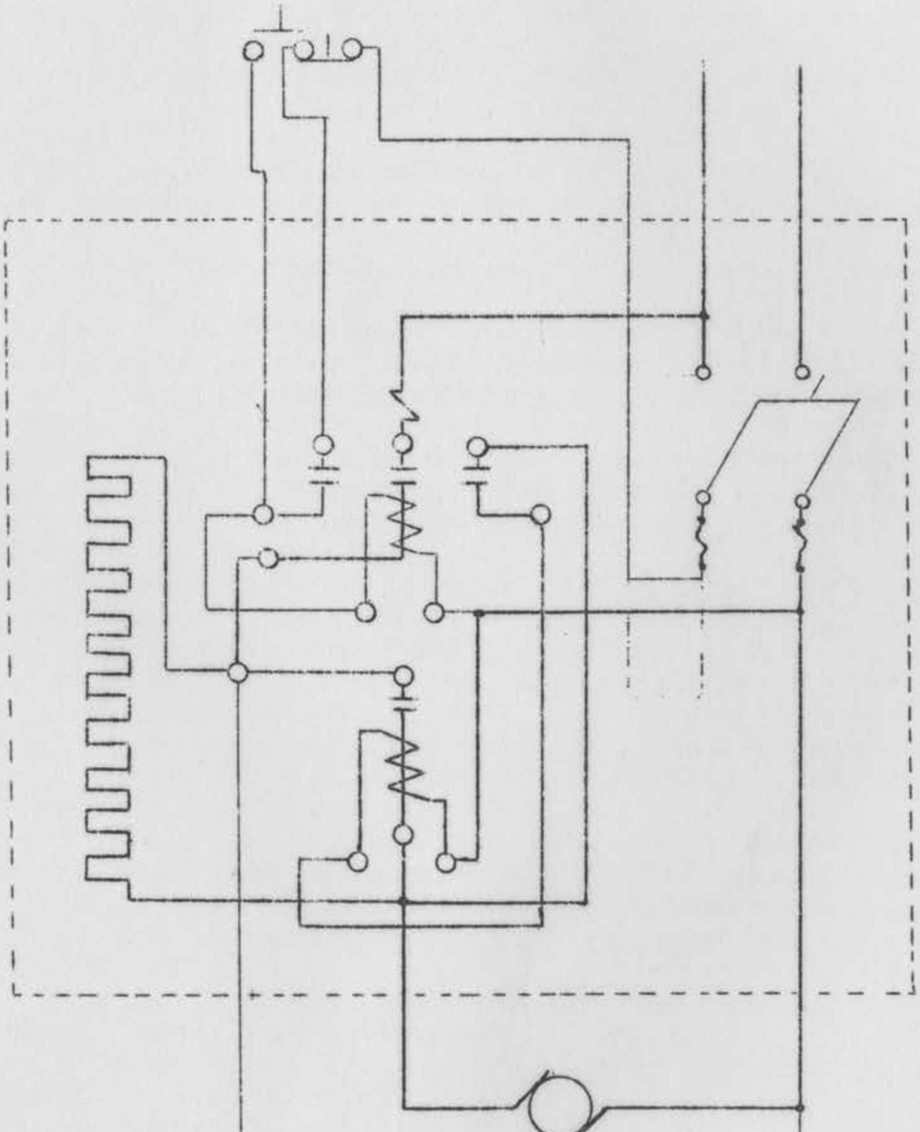
GENERAL ELECTRIC CR402C1 AUTO STARTER



THE WILLIAM HOOD DUNWOODY INDUSTRIAL INSTITUTE

DAY SCHOOL
DES 4-13.3

ELECTRIC DEPARTMENT
D.C. Machinery
D.C. Motors & Control Apparatus

JOB: Connect and operate a 2 H.P. - G.E. motor with a $1\frac{1}{2}$ H.P. C.N. 4-65 - A-8 push button controller

Materials, tools, equipment:
Motor, controller, hand tools, Prony brake, wire, ammeter, voltmeter water pan.

General instructions:
Automatic starting and control equipment is intricate and expensive. For these reasons it should be handled with care and judgement. Be sure to read the manufacturers bulletins on this equipment if there is one.

Operating steps:

1. Study the wiring of this apparatus.
2. Read the description of the operation of this equipment several times.
3. Open or remove the front cover so you can see the construction of the starter.
   NOTE: Do not remove the apparatus from the case.
4. Inspect the apparatus and test the circuits with a test set.
5. Locate and identify corresponding points on the diagram and in the starter.
6. While testing with the test set push the various contactors in with the fingers and determine what they do in the circuit when they close. Be careful of the adjustment while you are doing this
7. Test and mark the motor leads.
8. Connect the motor and the starter to the line. NOTE: Use the single pole circuit breaker as a main line switch.
9. Push the start button and note the action of the starter.
10. Push the stop button and see how the apparatus functions.
11. Check the time between closing of the starting contactors.
    NOTE: Operate motors at rated voltage for best results.
12. Put the brake on the pulley and adjust friction so that armature is drawing full load current.
13. Stop the motor. Start it and note the change in deflection of ammeter and also time between closing of the second contact.
14. Trace (on your copy of this diagram) the power circuit in heavy black lines and the control circuit in light red lines. DO NOT MARK THE JOB SHEET.
15. Tighten drum until motor is drawing 20 amperes and check the time before thermal element opens the circuit?
    NOTE: Wait three minutes before resetting the thermal device. This allows it time to cool.

Sketches: See attached sheet.

Precautions:
Do not attempt to alter or change this equipment in any way. If you do not understand it consult the instructor.

Questions:

1. How many steps in the starting resistance with this starter?
2. How and when is the shunt field circuit for the motor made?
3. How is the start button shunted when the motor starts?
4. Is there a control circuit and a power circuit in this starter? Trace them.
5. What determines or limits the time of starting the motor with this starter?

6. Can the time of starting be controlled with this starter? Why?
7. Is there provision made in this starter to protect the motor against over loads?
8. Explain how it works. Does it open the control circuit or the power circuit directly? Is it thermally or magnetically operated?
9. What provisions are made to prevent or take care of arcing?
10. What does a starter of this type cost?
11. What advantages does automatic starting have over manual starting of motors?
12. Would the size of the motor have any bearing on the selection of the starting equipment - i.e. manual or automatic?
13. Will this starter reverse the direction of rotation of the motor without changing the connections?
14. Mark the incoming lines to this starter with (+) and (-) signs.
15. Indicate with arrows the direction of current in the various circuits 1. —— first contact, 2. —— second contact, etc.
16. Letter your diagram with your own lettering and write a description of the operation of this starter.

Written report work:

1. Turn in a marked drawing of the circuits in this starter.
2. Write complete description for ordering this starter.

References: Electric Motors - Fox
Croft's Handbook
Principles and Practice of Elec. Eng. - Gray
Electric Circuits and Machinery - Morecroft and Hehre
Trade Bulletins.

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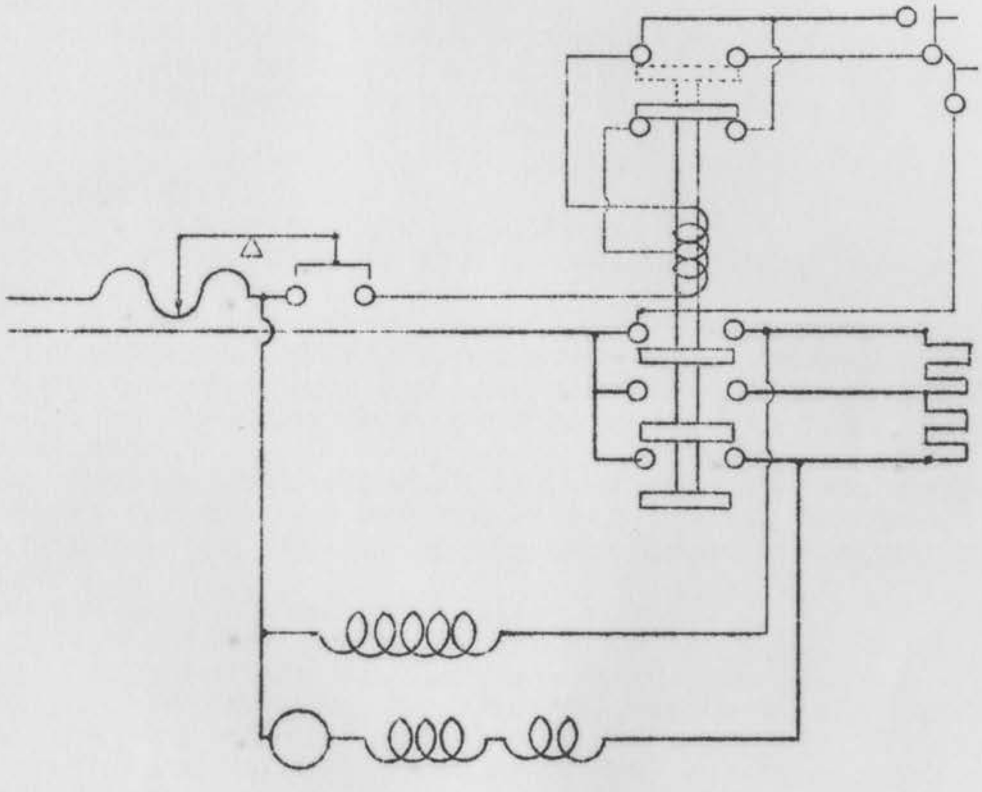
DES 4-I3.3

ELECTRIC DEPARTMENT
D.C. Machinery
D.C. Motors and Control



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THE WILLIAM HOOD DUNWOODY INDUSTRIAL INSTITUTE

DAY SCHOOL — ELECTRIC DEPARTMENT

DES 4-13.4 — D.C. Machinery

JOB: Connect and operate a 3 H.P. - G.E. motor with C.E.M.F. starter equipped with thermal protection and push-button starting.

Materials, tools, equipment:
Motor, starter, ammeter, voltmeter, test set, wire, Prony brake, hand tools, water pan.

General instructions:
Automatic starting and control equipment is intricate and expensive. For these reasons it should be handled with care and judgement. Be sure to read the manufacturers bulletins on this equipment if there is one.

Operating steps:

1. Study the wiring of this apparatus.
2. Read the description of the operation of this equipment several times.
3. Open or remove the front cover so you can see the construction of the starter. NOTE: Do not remove the apparatus from the case.
4. Inspect the apparatus and test the circuits with a test set.
5. Locate and identify corresponding points on the diagram and in the starter.
6. While testing with the test set push the various contactors in with the fingers and determine what they do in the circuit when they close. Be careful of the adjustment while you are doing this.
7. Test and mark the motor loads.
8. Connect the motor and the starter to the line. NOTE: Use the single pole circuit breaker as a main line switch.
9. Push the start button and note the action of the starter.
10. Push the stop button and see how the apparatus functions.
11. Check the time between closing of the starting contactors. NOTE: Operate motors at rated voltage for best results.
12. Put the brake on the pulley and adjust friction so that armature is drawing full load current.
13. Stop the motor. Start it and note the change in deflection of ammeter and also time between closing of the second contact.
14. Trace (on your copy of this diagram) the power circuit in heavy black lines and the control circuit in light red lines.
    DO NOT MARK THEJOB SHEET.
15. Record the name plate data of all equipment for this job.

Sketches: See attached sheet.

Precautions:
Do not attempt to alter or change this equipment in any way. If you do not understand it consult the instructor.

Questions:

1. How many steps in the starting resistance with this starter?
2. How and when is the shunt field circuit for the motor made?

Question (con't)

3. How is the start button shunted when the motor starts?
4. Is there a control circuit and a power circuit in this starter? Trace them.
5. What determines or limits the time of starting the motor with this starter?
6. Can the time of starting be controlled with this starter? How?
7. Is there provision made in this starter to protect the motor against over-loads?
8. Explain how it works. Does it open the control circuit or the power circuit directly? Is it thermally or magnetically operated?
9. What provisions are made to prevent or take care of arcing?
10. What does a starter of this type cost?
11. What advantages does automatic starting have over manual starting of motors?
12. Would the size of the motor have any bearing of the selection of the starting equipment, i.e., manual or automatic?
13. Will this starter reverse the direction of rotation of the motor without changing the connections?
14. Mark the incoming lines to this starter with (+) and (-) signs.
15. Indicate with arrows the direction of current in the various circuits (1) ⟶ first contact, (2) ⟶ second contact.
16. Letter your diagram with your own lettering and write a description of the operation of this starter.

Written report questions:

1. Turn in a marked drawing of the circuits in this starter.
2. Write a complete description for ordering this starter.

References: Electric Motors - Fox
Croft's Handbook
Principles and Practice of Elec. Eng. - Gray
Electric Circuits and Machinery - Morecroft and Hehre
Trade Bulletins

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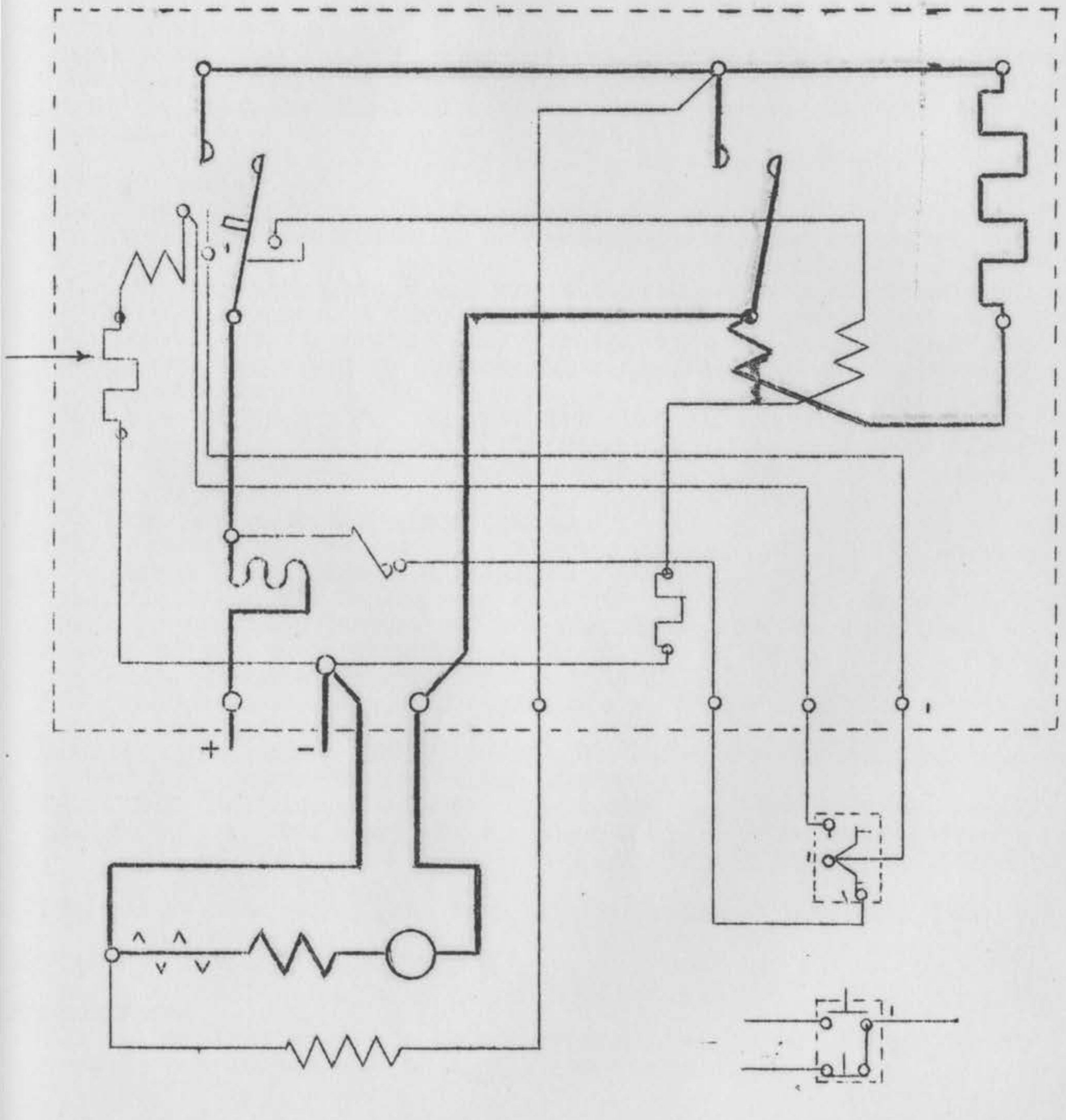


THE WILLIAM HOOD DUNWOODY INDUSTRIAL INSTITUTE

DAY SCHOOL — ELECTRIC DEPARTMENT
DES 4-13.5 — D.C. Machinery

JOB: Connect and operate a 3 H.P. motor to a Sundh push-button starter.

Materials, tools, equipment:
Motor, starter, ammeter, voltmeter, test set, wire, Prony brake, hand tools, water pan

General instructions:
Automatic starting and control equipment is intricate and expensive. For these reasons it should be handled with care and judgement. Be sure to read the manufacturers bulletins on this equipment iff there is one.

Operating steps:
1. Study the wiring of this apparatus.
2. Read the description of the operation of this equipment several times.
3. Open or remove the front cover so you can see the construction of the starter. NOTE: Do not remove the apparatus from the case.
4. Inspect the apparatus and test the circuits with a test set.
5. Locate and identify corresponding points on the diagram and in the starter.
6. While testing with the test set push the various contactors in with the fingers and determine what they do in the circuit when they close. Be careful of the adjustment while you are doing this!
7. Test and mark the motor loads.
8. Connect the motor and the starter to the line. NOTE: Use the single pole circuit breaker as a main line switch.
9. Push the start button and note the action of the starter.
10. Push the stop button and see how the apparatus functions.
11. Check the time between closing of the starting contactors. NOTE: Operate motors at rated voltage for best results.
12. Put the brake arm on the pulley and adjust until the motor is drawing about 20 amperes.
13. Stop the motor. Start it up and note change in the deflection of the ammeter as the motor starts.
14. Check the time of starting both with load and without load.
15. Trace (on your copy of this diagram) the power circuit in heavy black and the control circuit in light red lines. DO NOT MARK THE JOB SHEET.
16. Record the name plate data of all equipment for this job.

Sketches: See tracing attached.

Precautions:
Do not attempt to alter or change this equipment in any way. If you do not understand it consult the instructor.

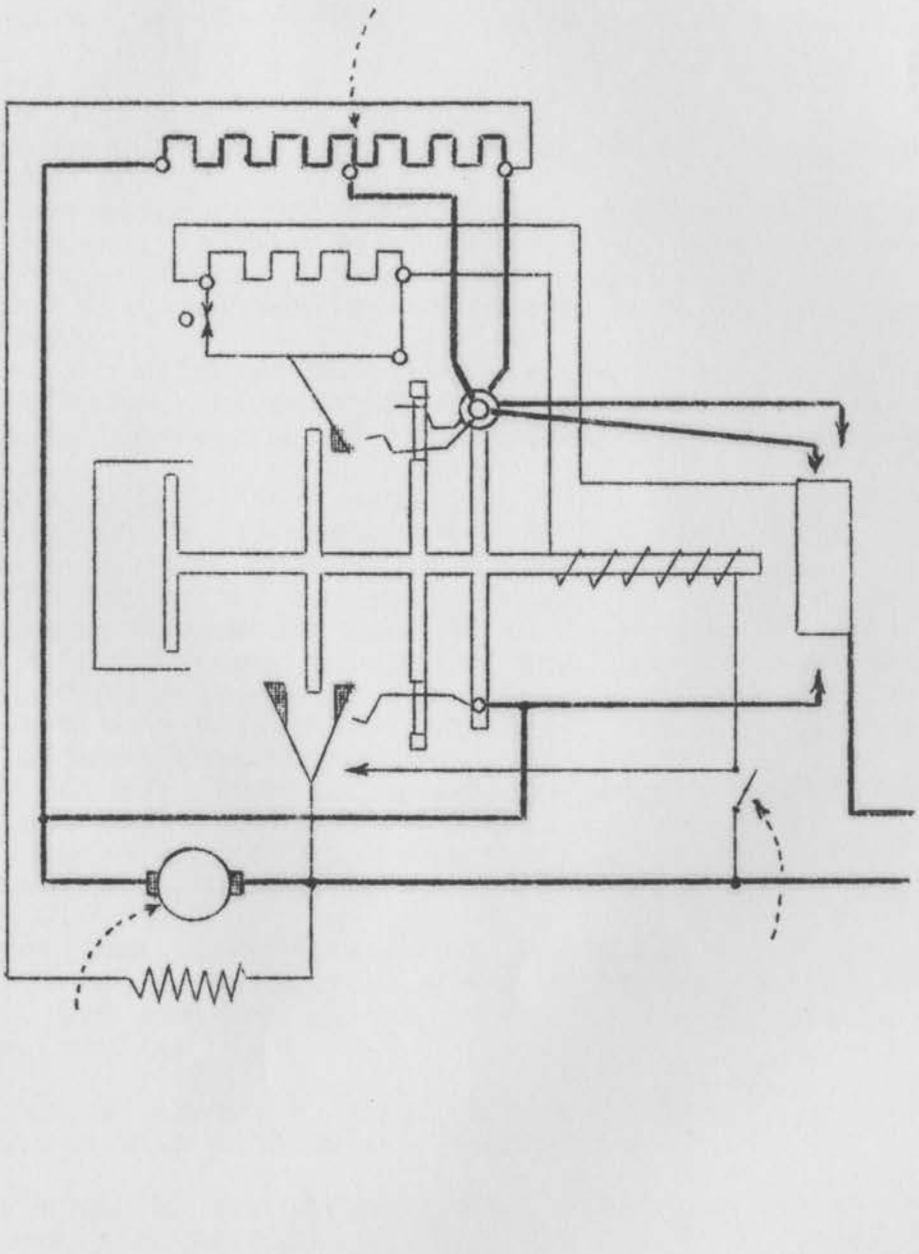
Questions:

1. How many steps in the starting resistance with this starter?
2. How and when is the shunt field circuit for the motor made?
3. How is the start button shunted when the motor starts?
4. Is there a control circuit and a power circuit in this starter? Trace them.
5. What determines or limits the time of starting the motor with this starter?
6. Can the time of starting be controlled with this starter? How?
7. Is there provision made in this starter to protect the motor against over loads?
8. Explain how it works. Does it open the control circuit or the power circuit directly? Is it thermally or magnetically operated?
9. What provisions are made to prevent or take care of arcing?
10. What does a starter of this type cost?
11. What advantages does automatic starting have over manual starting of motors?
12. Would the size of the motor have any bearing on the selection of the starting equipment - i.e., manual or automatic?
13. Will this starter reverse the direction of rotation of the motor without changing the connections?
14. Mark the incoming lines to this starter with (+) and (-) signs.
15. Indicate with arrows the direction of current in the various circuits: 1. ⟶ first contact, 2. ⟶ second contact, etc.
16. Letter your diagram with your own lettering and write a description of the operation of this starter.

Written report questions:

1. Turn in a diagram marked as indicated in question #15.
2. Write the specifications for ordering this equipment.

References: Electric Motors - Fox
Croft's Handbook
Principles and Practice of Elec. Eng. - Gray
Electric Circuits and Machinery - Morecroft & Hehre
Trade bulletins.



THE WILLIAM HOOD DUNWOODY INDUSTRIAL INSTITUTE

DAY SCHOOL
DES 4-13.6

ELECTRIC DEPARTMENT
D.C. Machinery

JOB: Connect and operate a 3 H.P. motor with a Westinghouse time-limit push-button starter.

Materials, tools, equipment:
Motor, starter, ammeter, voltmeter, test set, wire, Prony brake hand tools, water pan.

General instructions:
Automatic starting and control equipment is intricate and expensive. For these reasons it should be handled with care and judgement. Be sure to read the manufacturers bulletins on this equipment if there is one.

Operating steps:

1. Study the wiring of this apparatus.
2. Read the description of the operation of this equipment several times.
3. Open or remove the front cover so you can see the construction of the starter. NOTE: Do not remove the apparatus from the case.
4. Inspect the apparatus and test the circuits with a test set.
5. Locate and identify corresponding points on the diagram and in the starter.
6. While testing with the test set push the varous contactors in with the fingers and determine what they do in the circuit when they close. Be careful of the adjustment while you are doing this.
7. Test and mark the motor leads.
8. Connect the motor and the starter to the line. NOTE: Use the single pole circuit breaker as a main line switch.
9. Push the start button and note the action of the starter.
10. Push the stop button and see how the apparatus functions.
11. Check the time between closing of the starting contactors. NOTE: Operate motors at rated voltage for best results.
12. Put the brake on the pulley and adjust the friction until the motor armature draws 20 amperes.
13. Stop the motor. Start it up and note change in deflection of the ammeter and also time between closing of contacts.
14. Trace (on your copy of this diagram) the power circuit in heavy black lines and the control circuit in light red lines. DO NOT MARK THE JOB SHEET.
15. Record the name plate data of all equipment for this job.
16. Change the weight setting on the pendulum arm and repeat 13. CAUTION: Use care and do not operate with the cover off.

Sketches: See tracing.

Precautions:
Do not attempt to alter or change this equipment in any way. If you do not understand it consult the instructor.

Questions:

1. How many steps in the starting resistance with this starter?
2. How and when is the shunt field circuit for the motor made?
3. How is the start button shunted when the motor starts?
4. Is there a control circuit and a power circuit in this starter? Trace them.
5. What determines or limits the time of starting the motor with this starter?

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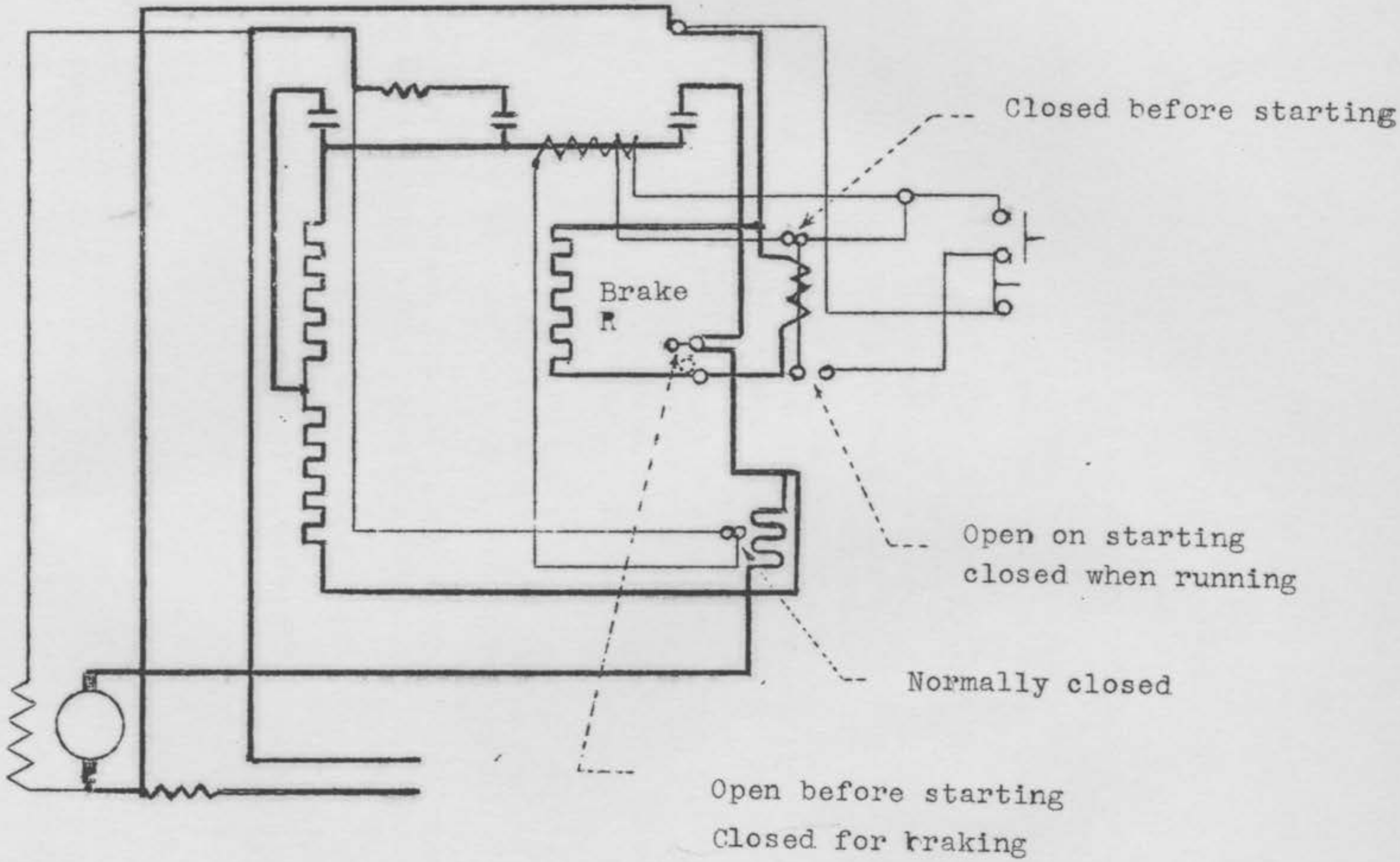
6. Can the time of starting be controlled with this starter? How?
7. Is there provision made in this starter to protect the motor against over loads?
8. Explain how it works. Does it open the control circuit or the power circuit directly? Is it thermally or magnetically operated?
9. What provisions are made to prevent or take care of arcing?
10. What does a starter of this type cost?
11. What advantages does automatic starting have over manual starting of motors?
12. Would the size of the motor have any bearing on the selection of the starting equipment - i.e., manual or automatic?
13. Will this starter reverse the direction of rotation of the motor without changing the connections?
14. Mark the incoming lines to this starter with (+) and (-) signs.
15. Indicate with arrows the direction of current in the various circuits: 1. ⟶ first contact, 2. ⟶ second contact, etc.
16. Letter your diagram with your own lettering and write a description of the operation of this starter.

Written report questions:

1. Turn in a diagram as called for in question #15.
2. Order this piece of equipment.

References: Electric Motors - Fox
Croft's Handbook
Principles and practice of Elec. Eng. - Gray
Electric Circuits and Machinery - Morecroft & Hehre
Trade bulletins

6/17/35


Closed before starting
Brake
R
Open on starting
closed when running
Normally closed
Open before starting
Closed for braking

THE WILLIAM HOOD DUNWOODY INDUSTRIAL INSTITUTE

DAY SCHOOL — ELECTRIC DEPARTMENT
DES 4-13.7 — D.C. Machinery

JOB: Connect and operate a 2 H.P. 115 V. motor with a Cutler-Hammer C.E.M.F. speed regulating, push-button starter.

Materials, tools, equipment:
Starter, motor, wire, brake arm, ammeter, voltmeter speed indicator, hand tools, water pan.

General instructions:
Automatic starting and control equipment is intricate and expensive. For these reasons it should be handled with care and judgement. Be sure to read the manufacturers bulletins on this equipment if there is one.

Operating steps:
1. Study the wiring of this apparatus.
2. Read the description of the operation of this equipment several times.
3. Open or remove the front cover so you can see the construction of the starter.
4. Inspect the apparatus and test the circuits with a test set.
5. Locate the identify corresponding points on the diagram and in the starter.
6. While testing with the test set push the various contactors in with the fingers and determine what they do in the circuit when they close. Be careful of the adjustment while you are doing this!
7. Test and mark the motor loads.
8. Connect the motor and the starter to the line. NOTE: Use the single pole circuit breaker as a main line switch.
9. Push the start button and note the action of the starter.
10. Push the stop button and see how the apparatus functions.
11. Check the time between closing of the starting contactors. NOTE: Operate the motors at rated voltage for best results.
12. Put the brake on the pulley and adjust the load on the armature to 15 amperes.
13. Stop the motor. Start it up and note the (1) current through the armature (2) time of closing of the contacts (3) speed of motor (4) voltage across the armature.
14. Set the controller arm so that the motor is running below normal speed and repeat 13.
15. Change position of the arm and repeat.
16. Set the arm so that the motor is above normal speed and repeat 14 making a record of the results.
17. Repeat 17 on two different settings of the arm. Record results each time.

Sketches: see tracing.

Precautions:
Do not attempt to alter or change this equipment in any way. If you do not understand it consult the instructor.

Questions:

1. How many steps in the starting resistance with this startor?
2. How and when is the shunt field circuit for the motor made?
3. How is the starter button shunted when the motor starts?
4. Is there a control circuit and a power circuit in this starter? Trace them.
5. What determines or limits the time of starting the motor with this starter?
6. Can the time of starting be controlled with this starter? How?
7. Is there provision made in this starter to protect the motor against over loads?
8. Explain how it works. Does it open the control circuit or the power circuit directly? Is it thermally or magnetically operated?
9. What provisions are made to prevent or take care of arcing?
10. What does a starter of this type cost?
11. What advantages does automatic starting have over manual starting of motors?
12. Would the size of the motor have any bearing on the selection of the starting equipment - i.e., manual or automatic?
13. Will this starter reverse the direction of rotation of the motor without changing the connections?
14. Mark the incoming lines to this starter with (+) and (-) signs.
15. Indicate with arrows the direction of current in the various circuits: 1. ⟶ first contact, 2. ⟶ second contact, etc.
16. Letter your diagram with your own lettering and write a description of the operation of this starter.
17. How does this starter start a motor when the speed is above normal? Explain the advantages of this method of starting a motor.

Written report questions:

1. Turn in a diagram as called for in question 15.
2. Order this piece of equipment.

References: Electric Motors - Fox
Croft's Handbook
Principles and Practice of Elec. Eng. - Gray
Electric Circuits and Machinery - Morecroft & Hehre
Trade bulletins.

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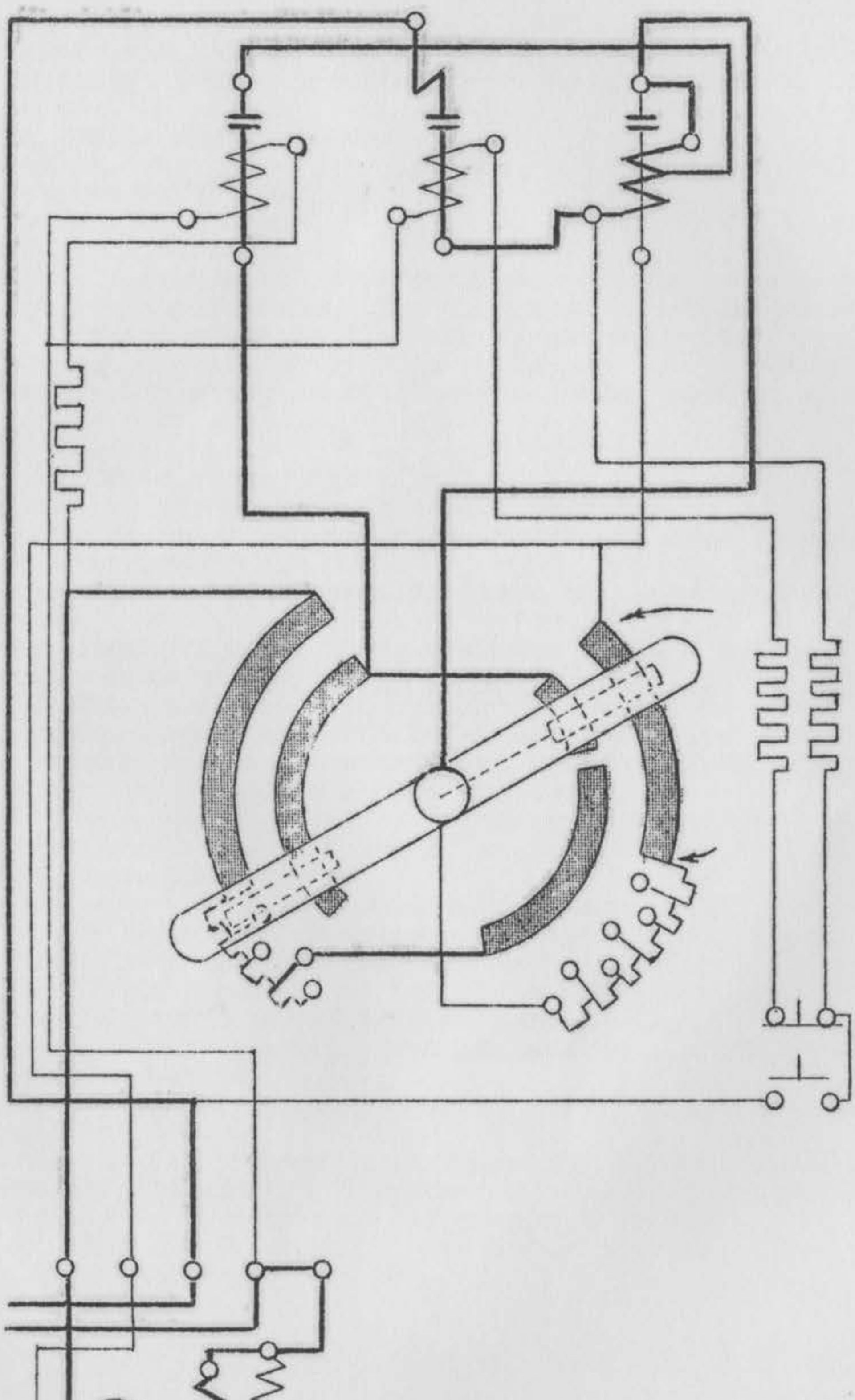

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THE WILLIAM HOOD DUNWOODY INDUSTRIAL INSTITUTE

DAY SCHOOL
DES 4-14.1

ELECTRICAL DEPARTMENT
D-c. Machinery
D-c. Motora and Control Apparatus

JOB: Connect and Operate a 2 HP 115 V. Westinghouse Starting and Reversing Controller with a 2 HP Compound Motor.

Materials, Tools and Equipment:
Hand tools, wire test set, starter, motor ammeter, voltmeter, Prony brake field rheostat.

General Instructions:
Automotic starting and reversing controllers are common in some machine tool operations. The diagrams with this job are copied without change from the diagrams furnished by the manufacturer of this equipment. Study them until you have a definite idea of the parts that apply particularly to this piece of equipment.

Operating Steps:

1. Check the diagram carefully.
2. Remove the cover from the controller box.
3. Locate the various connection points on both the diagram and the apparatus.
4. Trace the wiring connections from the apparatus to the terminal board.
5. With chalk or paper slips work the various connections on the terminal board. Leave no permanent marks on the terminal strip.
6. Make the necessary connections from motor to terminal strip.
7. Test the operation. CAUTION: (1) Make sure you can instantly disconnect motor in case of weak field. (2) Do not push reverse button until motor has come to rest.
8. Put Prony brake on pulley, ammeter in armature circuit and fasten brake arm to frame so that it will not strike anyone when motor is reversed.
9. Tighten arm until motor is taking about half load and test starter both forward and reverse operation. Check voltage across field and armature for both directions of rotation.
10. Put a field rheostat in the field circuit so that the motor speed may be increased above normal.
11. Repeat step 9 and note what happens to the field relay. Also armature current!
12. Make an assembled drawing similar to those issued to you for previous jobs.
13. Indicate with arrows and numbers the current directions in all parts of the circuit diagram for each step of operation.
14. Return all apparatus to its proper location.
15. Make list of all symbols with their meanings which are used in this diagram.

Sketches:
One supplied on additional sheets. One to be made by student.

Precautions:
Do not attempt to adjust these relays. Do not push the contactors in by hand when power is on. Inspect but do not handle the wiring on the panel.

(over)

Questions:

1. What is the cost of a control panel and cabinet similar to this one?
2. Why are these so expensive?
3. Which is reversed when the rotation of the armature is changed the field or the armature current?
4. What operation does a two button station give? a three button? a four button?
5. What is the inch button used for?
6. Is this a c.e.m.f. starter?
7. What is an elementary diagram?
8. What does the field relay do when starting or running a motor with too much overlood?
9. Howdoes this thermal overload relay operate?
10. Does this starter have dynamic braking?
11. Trace the circuit with a third color pencil.
12. What is a jumper?
13. How many symbols used are standard?
14. How many are special with Westinghouse Co.?
15. Could this starter be used with a shunt motor?
16. What would have to be increased in number on this controller if it were used with a twenty-five horsepower motor?
17. What machines driven by electrical motors would this starter handle satisfactorily?
18. Is there any means provided on this starter for compensating the thermal element for extremes in temperature, i.e., very hot locations and extremely cold locations?
19. How could this be done?

References:

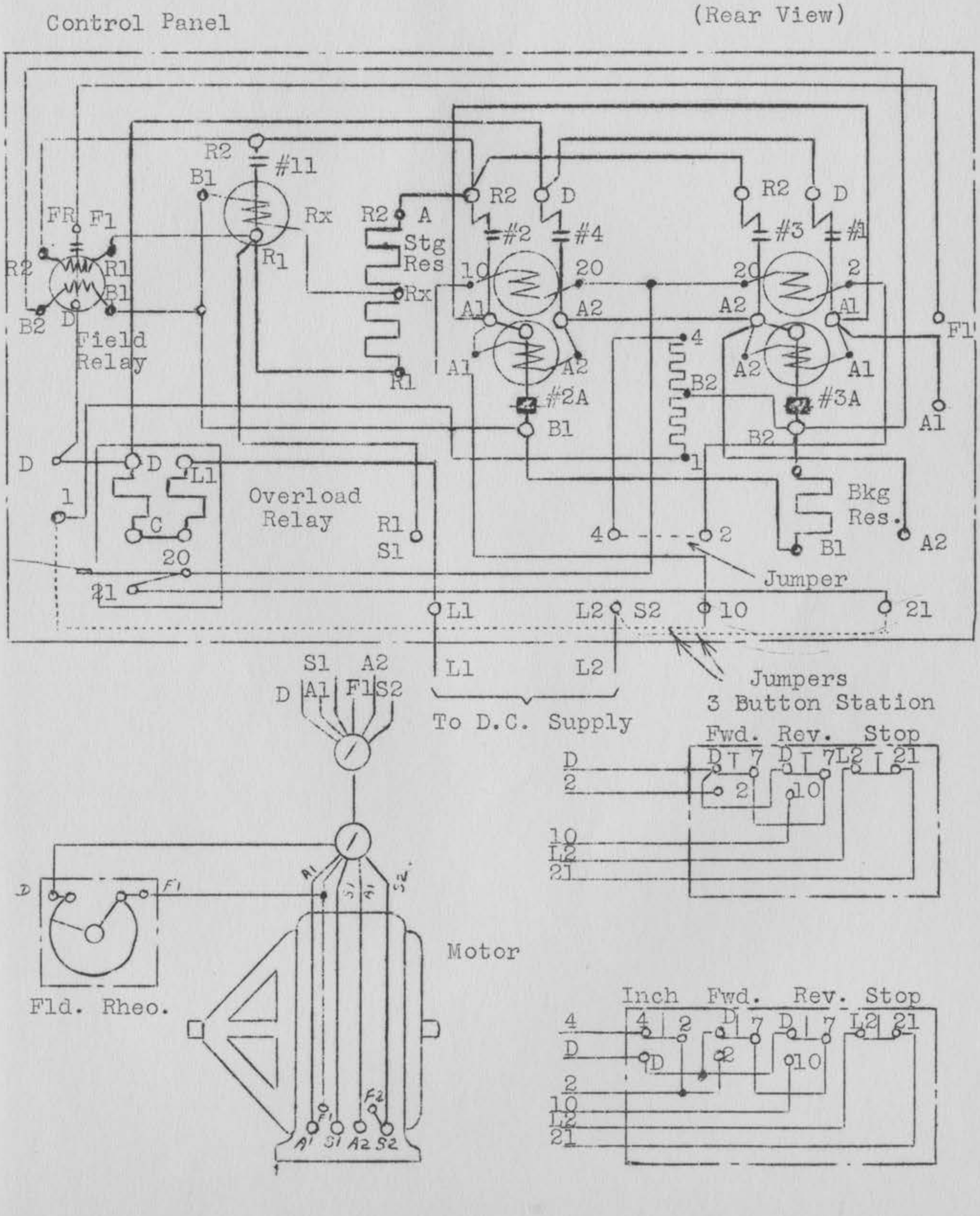
Croft's Handbook
Motor Controls by Fox
Trade Catalogues and Bulletins

WESTINGHOUSE ELECTRIC AND MANUFACTURING CO., E. Pittsburgh, Pa. USA

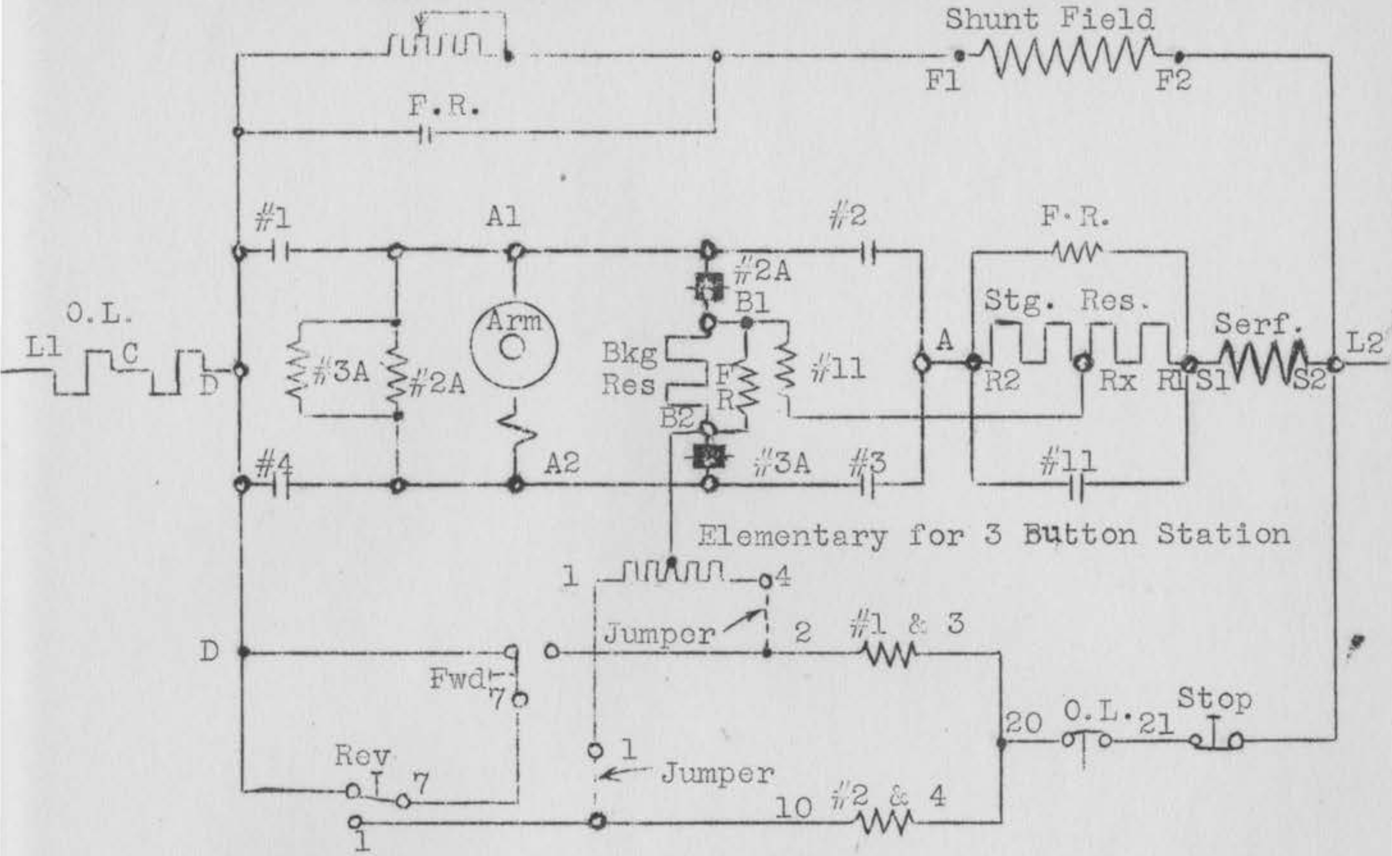
Controller Wiring Diagram
Type "C" D.C. Controller

DWG. No. 467026

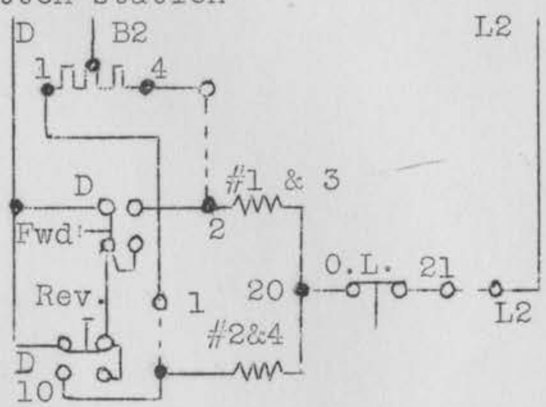
Sub. No. X2



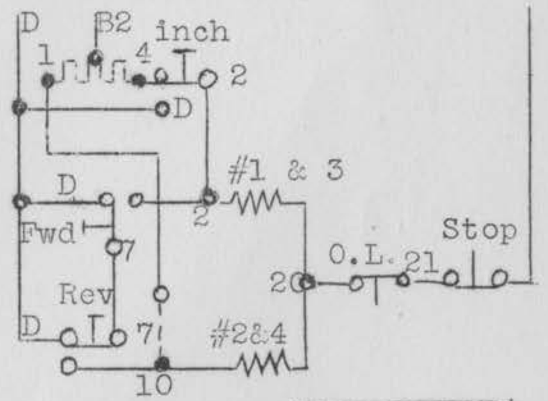
Elementary Controller Diagram



Elementary for 2 button station



Elementary for 4 button station



Note #1: Connect jumper on front of control panel

Note #2: Connect marked leads on desired P.B. to similarly marked terminals on control panel.

Note #3: When 4 button station is used omit jumper "4" - "2"

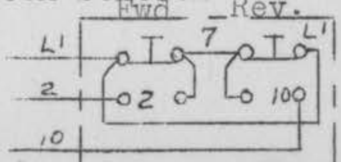
Note #4: When 2 buttons station is used omit jumpers "4" - "2" and "1" - "10"

Note #5: When 3 or 4 button station is used omit jumper "21" - "12"

Control Sequence table

Cont	Fwd		OFF	Rev	
				1	2
1	O	O			
2				O	O
3	O	O			
4				O	O
2A	O	O	O		
3A			O	O	O
11	O				O

2 Button Station



Appendix F

RAW DATA FROM WHICH THE

MATERIAL FOR THIS

EXPERIMENT WAS DRAWN

Table 1.--RAW DATA: EXPERIMENTAL GROUP

Name	Age in months	Months in D.I.I.	Previous school years	T. K. Test scores 52 Qs begin	T. K. Test scores 52 Qs complete	Shop Grade
C.A.	298	12	12	7	30	86.0
H.B.	237	14	12	13	35	83.8
J.C.	281	7	12	8	30	75.9
J.D.	227	11½	12	8	37	76.0
G.F.	241	11½	12	4	35	77.2
H.F.	231	11	12	4	30	72.0
J.H.	291	11½	13	5	34	75.3
H.M.	227	9	12	2	29	78.2
G.M.	232	12	12	5	25	73.8
F.P.	233	11	12	7	39	88.6
H.W.	301	11	12	8	35	84.7
H.A.	259	13½	12	13	31	83.2
H.A.	275	11	12	11	33	72.8
G.B.	269	13½	12	14	35	83.8
L.C.	272	11½	12	6	33	70.6
J.	233	9½	12	11	23	70.5
F.L.	256	7	12	15	30	71.6
H.L.	246	14	12	9	30	81.7
F.R.	258	11	12	9	27	73.3
J.S.	274	12	13	9	31	72.0
F.T.	246	9½	12	11	36	77.8
R.C.	241	10	12	7	22	78.5
G.C.	288	10	12	4	31	83.6
J.D.	245	13	12	7	40	83.1
G.G.	243	11	12	8	39	83.7
H.G.	261	9½	12	10	34	81.3
G.G.	272	10½	12	15	38	77.2
V.L.	241	11½	12	4	35	80.9
H.M.	231	11½	12	2	27	73.7
E.O.	258	11½	12	5	35	69.9
H.O.	227	12	1yr"U"	7	27	78.7
J.P.	233	12	12	0	37	88.1
G.R.	266	11	12	11	39	89.4
J.R.	263	11½	12	7	27	75.4
S.	300	12	9	3	29	78.7
R.E.	235	11½	11	5	34	83.8
L.G.	245	10	12	5	33	72.5
A.G.	256	13	12	8	34	83.8
H.I.	240	13½	12	7	35	81.7
I.J.	264	11	12	6	34	73.6
H.K.	244	11½	12	7	33	84.5
E.O.	332	11	11	3	30	70.5

Table 1.--RAW DATA: EXPERIMENTAL GROUP
(continued)

Name	Age in months	Months in D.I.I.	Previous school years	T. K. Test scores 52 Qs begin	T. K. Test scores 52 Qs complete	Shop Grade
H.S.	244	10½	12	3	26	74.5
J.S.	238	8	12	3	29	71.2
G.B.	247	13	12	9	23	81.2
G.B.	255	13½	12	6	23	72.2
J.D.	263	8	12	7	24	75.9
H.D.	260	13½	12	8	28	75.3
H.G.	234	13	12	13	32	74.5
F.K.	247	9	12	14	30	83.4
H.L.	234	12	12	8	37	83.8
G.M.	245	14	12	13	31	69.1
H.N.	249	9	12	8	29	75.6
J.N.	260	13	12	12	40	69.9
M.P.	276	11	12	13	23	79.0
R.R.	207	9	9	2	26	77.1
G.S.	284	14	12	8	35	84.0
F.V.	232	12½	12	9	35	77.0

Table 2.--RAW DATA: CONTROL GROUP

Name	Age in months	Months in D.I.I.	Previous school years	T. K. Test scores 52 Qs begin	T. K. Test scores 52 Qs complete	Shop Grade
G.B.	275	10	14	14	33	79.5
F.C.	270	10	12	11	26	74.5
H.H.	232	11	12	7	30	77.2
G.S.	289	8	12	7	30	77.0
T.T.	223	9½	12	8	32	78.0
F.T.	269	8	10	12	32	78.2
J.W.	231	11½	12	8	36	80.8
H.	222	7½	12	12	27	80.9
H.H.	249	8	12	11	20	75.8
J.J.	299	10½	12	13	31	79.5
G.M.	242	10	12	9	31	70.8
G.O.	240	8	13	10	30	84.6
F.O.	282	8½	12	15	34	72.0
H.P.	266	11½	12	8	19	77.5
F.R.	230	8½	12	9	26	82.0
H.S.	247	13½	12	15	30	80.8
G.T.	235	13½	12	10	24	76.3
C.B.	250	9	12	10	27	73.4
G.D.	298	11½	12	15	32	76.3
G.D.	268	13	12	14	37	78.4
F.F.	280	12	12	12	29	73.7
G.G.	248	12	12	8	30	88.1
G.G.	243	11½	12	7	34	70.9
H.H.	240	11	12	5	30	71.8
G.K.	257	9	1yr.WM	6	17	75.7
F.L.	248	8	12	14	33	78.3
G.M.	221	9	12	11	26	75.5
F.P.	253	11½	12	4	21	77.2
G.S.	274	9	12	5	25	73.4
F.B.	243	9	12	8	23	74.4
G.B.	253	10½	12	3	37	86.2
H.B.	243	10½	12	7	31	78.5
J.C.	254	11	12	12	32	76.3
J.E.	256	11	12	5	35	71.3
A.F.	271	9½	12	3	29	89.4
J.H.	249	10	10	4	28	86.0
F.H.	248	11	1yr"U"	2	24	72.6
H.H.	231	7½	12	8	28	79.4
F.K.	217	12	12	15	33	76.1
H.K.	226	11	12	15	41	76.3
H.L.	225	11½	12	10	28	80.9
J.O.	248	10	1yr"U"	4	31	77.5

Table 2.--RAW DATA: CONTROL GROUP
(continued)

Name	Age in months	Months in D.I.I.	Previous school years	T.K. Test scores 52 Qs begin	T.K. Test scores 52 Qs complete	Shop Grade
R.	221	11½	12	1	17	76.3
T.	242	7½	12	10	33	89.4
H.B.	255	10½	10	7	27	74.5
G.B.	235	14	12	9	22	72.2
H.B.	244	11½	12	15	22	73.6
H.B.	252	12	12	7	31	76.4
G.C.	248	12½	12	8	35	92.6
F.D.	240	16½	12	3	30	73.2
F.E.	236	14	12	13	35	75.3
M.E.	238	11½	12	5	30	73.6
G.G.	288	10	12	8	32	75.7
F.J.	320	12	12	12	35	82.7
H.R.	256	13½	12	9	30	85.5
C.S.	287	13	12	14	34	73.0
G.S.	250	11	12	5	18	69.5
B.V.	235	14½	12	13	32	84.6

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