BRIEF NOTE ON MECHANICAL MEANS OF GENERATING A CONFUSED SEA

by

R. E. Glover

Prepared for David Taylor Model Basin
under
Contract Nonr 1610(02)

Technical Report No. 3

Colorado A and M College
Department of Civil Engineering
Fort Collins, Colorado

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ABSTRACT

Two simple mechanical systems by means of which one can give any prescribed oscillatory motion to a plunger type wave generator are described. A procedure, including an example, is given showing how one can determine the proper wave program to put into the generator in order to obtain a specified wave train at the center of the test area of a circular wave basin.

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Recent studies of wave forms met at sea under storm conditions, and analyses made for purposes of correlation, indicate that such seas are produced by the superposition of elemental waves of varying amplitude and wave length. It may be desirable to reproduce such waves in model tanks in order to permit a more faithful reproduction of the conditions the prototype ship will encounter at sea and these researches provide a clue as to how this may be accomplished.

If the wave generator is of the plunger type, it must be given a motion represented by a sum of the components contributing to the actual wave profile. Since the wave generator will generally be at some distance from the test area, it will be necessary to account for the differences in wave travel time for waves of different wave lengths and the different diffraction characteristics associated with the different wave lengths.

CONTROL OF THE MOTION OF THE WAVE GENERATOR

A mechanism for generating such wave trains would have essentially two parts.

1. A means of generating the sum of the selected wave components.
2. A means of imposing the sum on the plunger of the wave generator.

If the sum of a finite number of components can be used satisfactorily, their sum can be produced by a device of the following sort. If a taut cord is fastened at one end and passes over a series of pulleys of which alternate ones have fixed axles and the remainder are attached to cranks, the free end of the cord will generate the sum of the motions contributed by the cranks. A schematic drawing of this arrangement is shown in Fig. 1. The throw of the cranks can be made adjustable to permit the contribution of each component to be varied. An alternative device is provided by a cam cut to the shape required by the wave profile. The device,(Fig. 2).

however, permits no adjustment and can be altered only by the cutting of a new cam.

By making the cams of aluminum sheet and using the outer race of a small ball bearing as a roller, the production of cams can be simplified. The wave profile can be plotted directly on the sheet, corrections made for the roller diameter, and the desired profile roughed out with a scroll saw. Final finishing can be done with rasps and files used for wood working. Since the outer race of the ball bearing is smooth and true and will roll freely without abrasion, such a cam should last a long time. An identification of the wave profile it produces can be permanently attached to it.

The merit of the device of Fig. 1 is the ease with which a new profile can be set up if the Fourier coefficients of the desired wave profile are known. The cams, however, are much more compact, can be laid out directly from the desired wave profile without development into a Fourier series, and should be easily produced.

Having produced the motion to be followed, it remains to impose this motion on the plunger. This will require some form of servo-motor. For the sake of economy of time and funds this device should make use of existing equipment whenever possible. Since most shops and laboratories have a compressed air supply, it is proposed to use a device commonly interposed between the fly-ball governor head and the relay valve of hydraulic governor mechanisms. This device is shown schematically in Fig. 3. The motion to be followed is communicated to a spool valve with a movable sleeve. The sleeve is connected to the piston rod of the servo-motor cylinder in such a way that the induced movement of the piston rod tends to close the valve. In this way the piston rod follows faithfully the motion of the spool valve.

It is suggested to arrange the wave making plunger and the servo-motor drive as a unit mounted on a frame, to bring the compressed air supply to it through a flexible hose and to convey the cam motion to the spool valve by means of a Selsyn motor. In this way the wave generator can be made movable and the cams can be located in any convenient housing. The wave motions produced by these devices will be reproducible.

WAVE COMPUTATIONS

If a device such as is shown in Fig. 1 is used, the amplitudes and periods of the wave components will be known but if a cam is to be used to generate an arbitrary wave profile, it will be necessary to develop this sequence as a Fourier series based upon the period of revolution of the cam. The series so obtained will represent the wave motion in the test area. In order to produce these phase and amplitude relationships in the test area, it will be necessary to shape the cam to compensate for differences in the wave velocities of the components and to adjust the plunger amplitude for each component for the diffraction pattern produced by each ratio of plunger length to wave length. In the following paragraphs it will be assumed that the wave generating plunger is narrow in the direction of wave propagation so that it produces displacements essentially along a line.

The length of the wave generator used may depend somewhat upon the shape of the model basin. If the basin is circular a wave generator having a length equal to the wave length of the longest period wave to be propagated may be a good choice. In a rectangular tank the wave generator may extend along the entire length of an end or a side. The following formulas are adapted from "Wave Motion Produced by Linear Wave Generators", by R. E. Glover, Technical Report No. 1, Contract Nonr 1610(02), December, 1956.

Let:

A represents an amplitude constant,

C the speed of propagation of a wave,

g the acceleration of gravity,

h depth of a basin,

L length of a wave generator,

Q_m the maximum volume displacement produced by a linear wave generator,

r radius

R the distance from the center of a wave generator to the point at which a wave amplitude is to be computed,

t time,

T the period of a wave,

W unit weight of water,

x, y, z coordinates,

α the angle between the length of a wave generator and a line drawn outward from the center of the wave generator.

ζ the height of the surface of a wave above the undisturbed level,

λ the wave length,

$$\sigma = \frac{2\pi}{T} .$$

$$n = \frac{2\pi}{\lambda} .$$

$\cong$ approximately equal to , $>>$ large compared to.

The wave amplitude ζ is given approximately by an expression of the form:

$$\zeta \simeq \frac{n^2 Q_m}{4} \frac{\sin\left(\frac{\pi L}{\lambda} \cos\alpha\right)}{\left(\frac{\pi L}{\lambda} \cos\alpha\right)} \sqrt{\frac{2}{\pi (nR)}} \left[\cos\left(nR - \frac{\pi}{4}\right) \cos \sigma t + \sin\left(nR - \frac{\pi}{4}\right) \sin \sigma t \right] . \qquad (1)$$

Valid if $R \gg \frac{L}{2}$ and $(nR) \gg 1$.

The maximum amplitude, without regard to phase position is:

$$\zeta_m = \frac{n^2 Q_m}{4} \frac{\sin\left(\frac{\pi L}{\lambda} \cos\alpha\right)}{\left(\frac{\pi L}{\lambda} \cos\alpha\right)} \sqrt{\frac{2}{\pi (nR)}} . \qquad (2)$$

Valid if $R \gg \frac{L}{2}$ and $(nR) \gg 1$.

Example:

Suppose the record has been analyzed and that the longest wave length in the model scale is 10 ft and that it is desired to provide a wave of amplitude 0.25 ft and wave length 5.0 ft as one component. It will be assumed that the wave generator is 10 ft long and the wave is to be produced at the center of a circular tank of 40 ft radius and a water depth of 4 ft.

From Eq 2, with

$\zeta_m = 0.25$ ft ,

$L = 10.0$ ft ,

$\lambda = 5.0$ ft ,

$\alpha = 90°$,

$R = 40$ ft ,

one has $n = \frac{2\pi}{\lambda} = \frac{6.2832}{5} = 1.257$, $n^2 = 1.576$, $nR = 503$, and $nR = 158$

From the chart of Fig. 3 (Technical Report No. 1, Contract Nonr 1610(02), with

$$\frac{\pi L}{\lambda}\cos\alpha = 0 \text{ , one has } \frac{\sin\frac{\pi L}{\lambda}\cos\alpha}{\frac{\pi L}{\lambda}\cos\alpha} = 1.000 \text{ .}$$

Then, in this case,

$$\zeta_m = \frac{n^2 Q_m}{4}\sqrt{\frac{2}{\pi(nR)}} = \frac{1.576}{4} Q_m \sqrt{\frac{2}{158.}} = Q_m .0444$$

and

$$Q_m = \frac{0.25}{0.0444} = 5.64 \text{ cubic feet .}$$

With a generator plunger 1 ft wide and 10 ft long it would require 0.564 feet of vertical movement to produce this displacement. However, if the wave generator is located near the wall of the tank, wave energy can be propagated only toward the center of the tank and this figure can be cut in half (In the report referred to, it is explained how the effect of the wall can be accounted for by the use of images) Then the amplitude of the plunger motion needed to maintain this wave component is $\frac{0.564}{2} = 0.282$ ft. It remains to adjust the phase. This is best done by compensating for the difference in wave travel times. The wave velocity is:

$$C = \sqrt{\frac{g\lambda}{2\pi}\tanh\frac{2\pi h}{\lambda}} \tag{3}$$

valid if $nr \gg 1$.

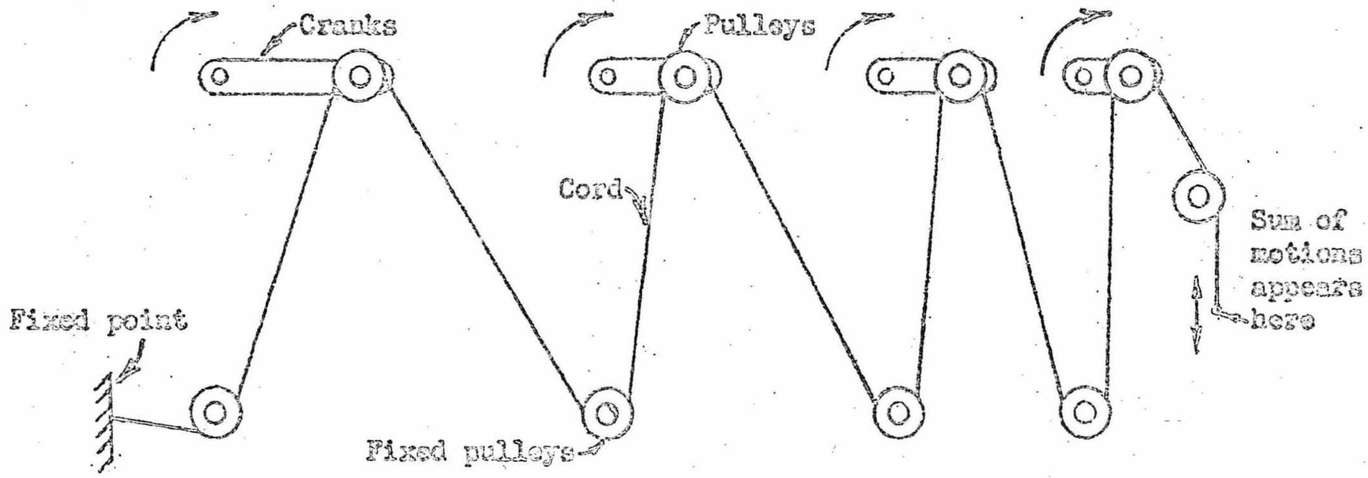
The wave velocities for the two waves described above may be computed as follows:

Wave Length λ (feet)	Depth h (feet)	Acceleration of Gravity g (ft/sec²)	$\frac{g\lambda}{2\pi}$ (ft²/sec²)	$\frac{2\pi h}{\lambda}$ ——	$\tanh\frac{2\pi h}{\lambda}$ ——	C (ft/sec)
10	4	32.2	51.3	2.52	0.9871	7.12
5	4	32.2	25.6	5.03	1.0000	5.06

The travel distance is 40 ft and the travel times and the time shifts to put the shorter wave in its proper position at the center of the wave basin may then be computed as follows:

Wave Length (feet)	Travel Time (Seconds)	Time Shift (Seconds)
10	5.62	0
5	7.91	2.29

Then the 5-ft wave-length component must be set ahead 2.29 seconds on the cam to give it enough lead on the 10-ft wave-length component to have it arrive in its proper phase relationship at the center of the tank.



Note: Distance between fixed and movable pulleys to be made large compared to crank throws.

Fig. 1 Device for adding sinusoidal motions.

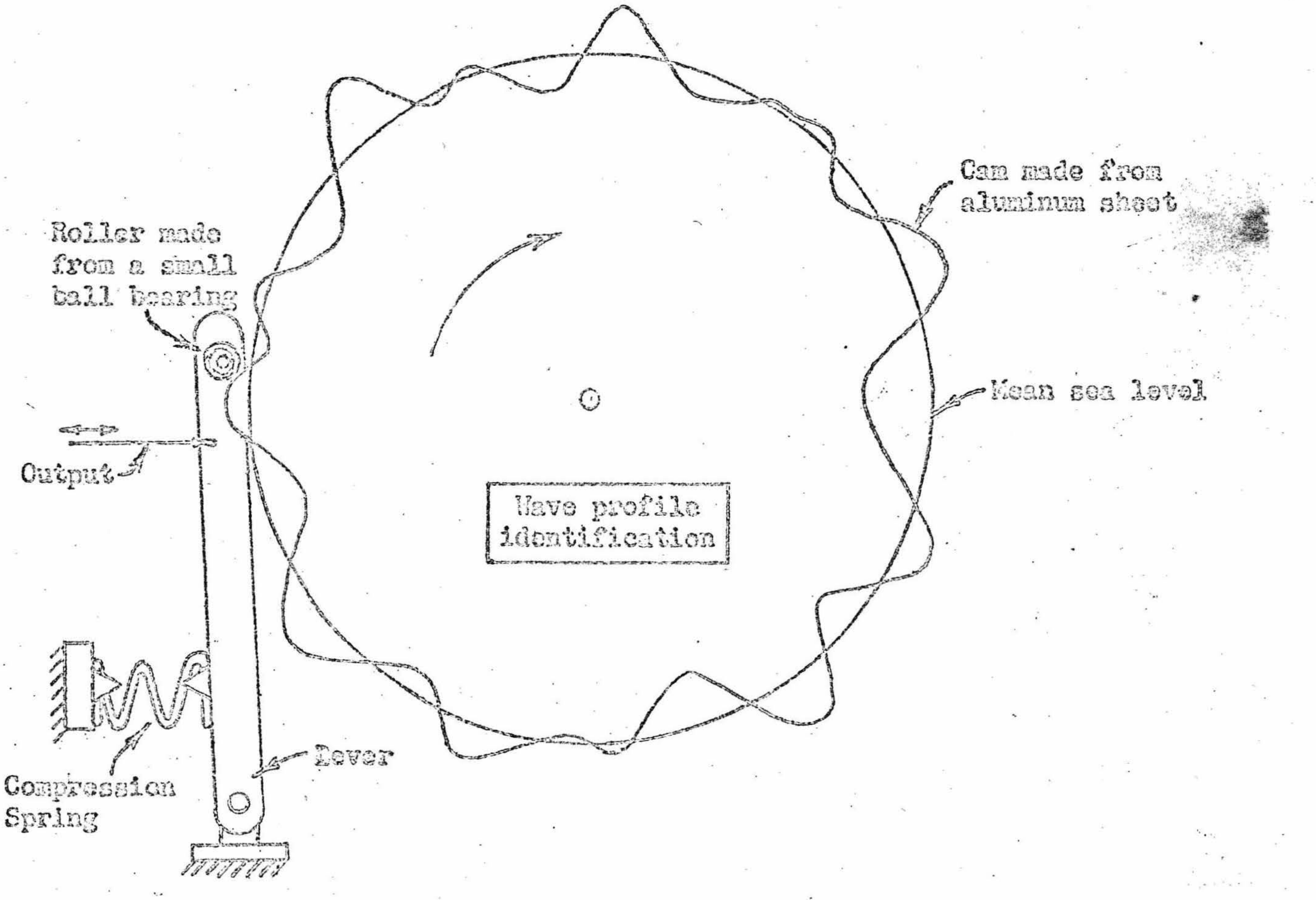


Fig. 2 Cam

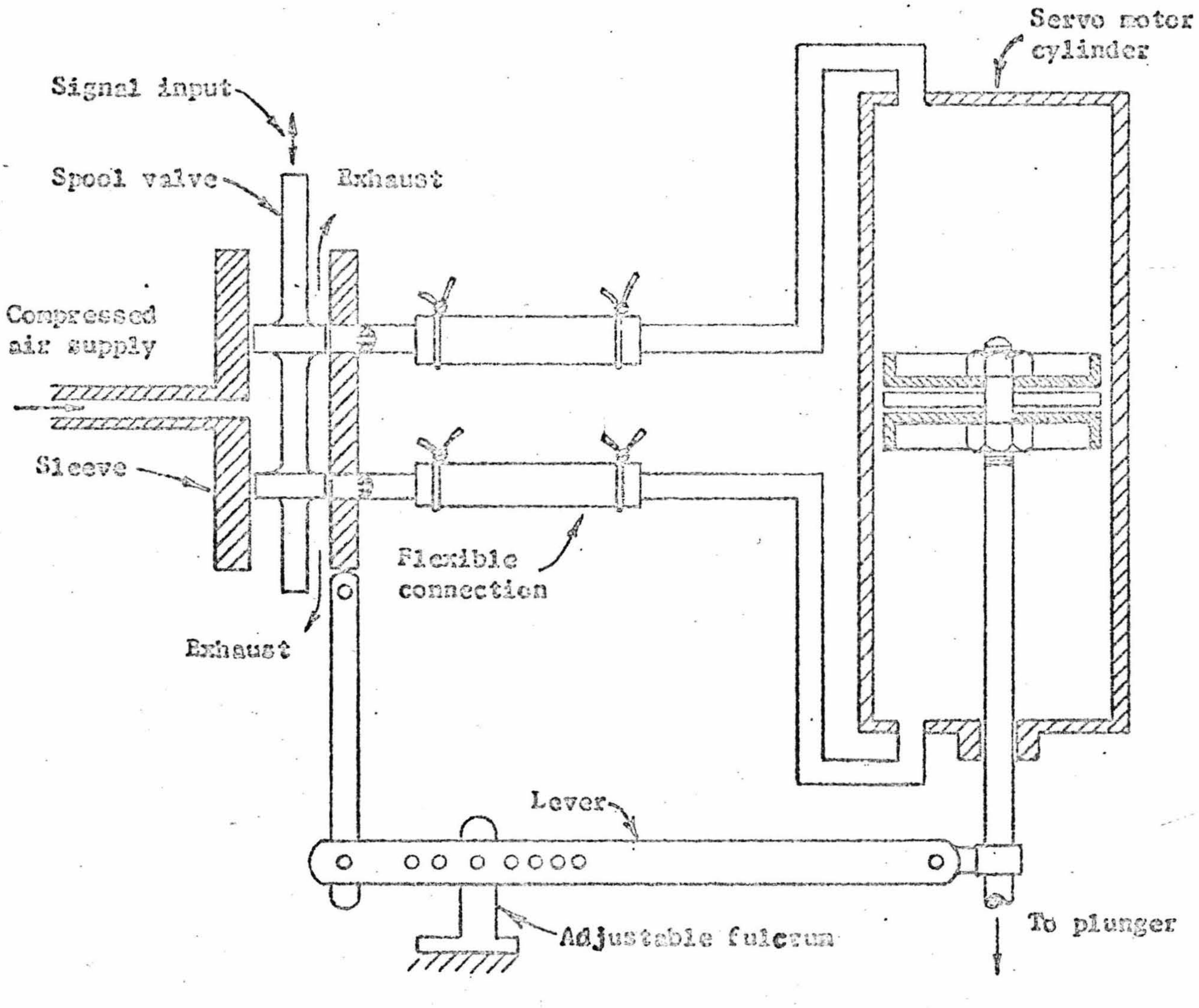


Fig. 3 Wave generator drive.

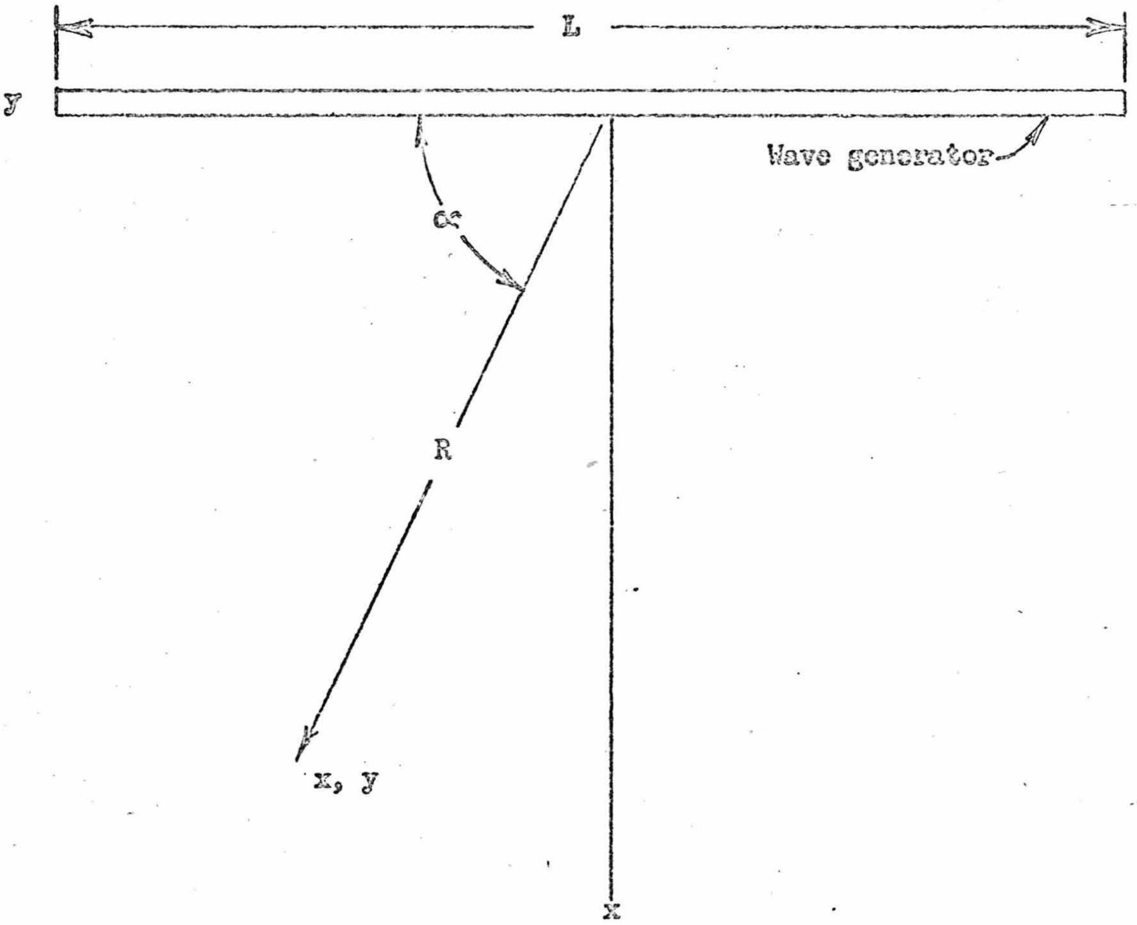


Fig. 4 Wave generator notation.