EVALUATION OF THE PERFORMANCE OF TURBINE-TYPE FLOWMETERS - A SUMMARY REPORT

by

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INTRODUCTION

During the period from October 1957 to March 1960 a series of tests were conducted on turbine-type flowmeters to evaluate the important performance characteristics. Flowmeters from three companies, Potter Aeronautical, Fischer and Porter and Waugh were tested. Basically the tests were made to determine the effects of piping geometry, and flow and fluid properties on the rotor speed of the meter. Each series of tests were reported separately as listed in the Reference Section of this report. The purpose of this Summary is to combine the results of all the tests conducted on turbine flowmeters in one report.

LINEARITY AND RANGE

Turbine flowmeters are designed on the theory of axial-flow turbo-machinery. The speed of the rotor is a function of certain geometric, fluid, and flow properties and can be expressed functionally as

$$f = \phi_1(Q, \nu, \rho, D, \Delta p, E, \text{etc.}), \tag{1}$$

where

f = Speed of the rotor in revolutions per second

Q = Volumetric discharge

ν = Kinematic viscosity

ρ = Mass density

D = Meter diameter

Δp = Pressure loss through the meter

E = Fluid elasticity.

If

$$\frac{df}{dQ} = \text{Constant}, \tag{2}$$

the meter is said to be linear, that is, frequency is linear with discharge. Because of the effects of various hydraulic and mechanical losses, $\frac{df}{dQ}$ is not a constant for all f, but varies considerably for both small and large values of f. The range of discharge where $\frac{df}{dQ}$ is approximately constant is termed the range of the meter. It is necessary to recognize that the actual rotor speed may vary from a theoretical relationship even within the range of the meter.

The results of tests on Potter meters from 3/16 to 6-1/2 inches in size, and Fischer and Porter Meters and Waugh meters to 2 inches in size showed linear characteristics within specific ranges of the meters using water and hydraulic oil as the meter fluids. At high velocities, that is, at large Reynolds Numbers of flow, cavitation and separation developed and the meters did not behave linearly. In nearly all cases the ranges of the meters were about 8 to 10 times the minimum discharge, using the vendor's recommendation for the maximum discharge.

Normally, a flowmeter coefficient is expressed as a constant,

$$\bar{k} = \frac{\Sigma f}{\Sigma Q} \tag{3}$$

This method is satisfactory if the linear relationship includes $f = 0$, $Q = 0$ as significant to the function. As determined from this study however, the origin of coordinates is not a significant point of the linear frequency-discharge relationship. Better meter coefficients can be expressed with a functional relationship of the type

$$f = MQ + F_o \tag{4}$$

Both M and F_o can be calculated by linear regression of calibration data. M is the slope of the frequency discharge curve and F_o is a correction to be applied to the frequency output of the meter.

ACCURACY AND REPEATABILITY

The accuracy of turbine flowmeters are generally within $\pm$ 1.0 per cent in a specified flow range. In a few instances, an accuracy of $\pm$ 0.5 per cent may exist. Accuracy is interrelated with the definition of linearity and flow range. If linearity is expressed by $\bar{k}$, defined by Eq. 3, and only the large discharges, or the upper portions of the ranges of the meters are used, the accuracy can be well within $\pm$ 1.0 per cent. If the functional relationship of Eq. 4 is used, accuracies may be less than $\pm$ 1.0 per cent, but at the same time the meter range will be considerably increased. It was found in the study that generally, repeatability of the meters with respect to any particular frequency was within $\pm$ 0.5 per cent. Thus the accuracy of a meter can also be within meter repeatability of $\pm$ 0.5 per cent if a meter is calibrated with the same fluid that is to be metered, and if individual calibration points are used in calculating discharge, rather than using a single calibration coefficient for the meter.

BEARING LIFE

Studies of bearing wear were made on several flowmeters. Each flowmeter was run continuously for a period of 100 hours at three-fourths of the maximum rated discharge. The results showed no difference in the calibration curve before, during, or after the test run. It should be noted however, that there are flowmeters that were calibrated originally at Colorado State University and used by the Martin Company, which show differences between the original calibration and the recalibration curves. The actual amount of use of these meters were not known. Some of the calibrations for these meters are shown in Report CER60SSK14. It is recommended therefore that flowmeters should be recalibrated periodically to be assured of correct metered results.

EFFECT OF PIPING GEOMETRY

The studies concerned with pipe geometry were qualitative and in most cases conducted with only a few flowmeters.

Approach Tubing Size

Within the limitations of this study, it was found that a reduction in size of the approach tubing did not affect the rotor speed of the flowmeter. It should be noted however, that the expansion from the approach tubing to the meter will have considerable effect on meter performance if separation cavities are developed at the transition.

Elbows

Elbows will affect the rotor speed of the flowmeter if located in close proximity to the flowmeter. Where possible, the meter should be provided with about 8 to 10 diameters of straight approach pipe length. It should be noted that in normal hydraulic practice, at least 20 diameters of straight approach piping should be provided. For the turbine meters this requirement is reduced because straightening vanes are provided with the meters.

Fluid Rotation

Turbine meters are designed to rotate counterclockwise, looking downstream into the flow meter. Tests were made to determine the effects of fluid rotation in the direction of the rotor and also in counter-rotation to the meter rotor. The results showed that fluid rotation in the direction of the rotor augments the normal rotor speed, thus, giving erroneously large discharge readings. Conversely fluid rotation countering the meter rotor reduces the rotor speed, giving erroneously small discharge readings. In either event, it should be noted that in this study the magnitude of the influence of fluid rotation was within $\pm$ 2.0 per cent of the normal condition. To avoid these problems a straight approach section should be provided for the meters.

EFFECT OF FLUID PROPERTIES

Viscosity

The effect of increase of fluid viscosity on turbine-type flowmeters is to reduce the speed of the rotor to give erroneously small discharge readings. The results of tests conducted on 3/4-inch flowmeters showed that there are apparently two regions of flowmeter performance with changing viscosity. In the region for fluids with viscosities less than about 3 centistokes only a small correction factor need be applied to the frequency output of the meter. The trend, or slope of the linear frequency-discharge relationship remained the same. For fluids with viscosities greater than 4 centistokes however, both the slope of the line and the frequency correction factor changed significantly with increasing fluid viscosity. The approximate relationships for the 3/4-inch meters tested are given in Report CER60SSK19.

Fluid Mass Density

Tests were made with a Potter Aeronautical Flowmeter Model 6-424 to evaluate the effects of changes in fluid mass density. Water was used as the metered fluid and air was introduced into the flow upstream from the flowmeter. The study qualitatively determined that a change in mass density of a fluid will produce large errors in meter calibration. At large discharges the effect is not too great, but for small discharges rotor frequency was very unstable.

EFFECT OF FLOW PROPERTIES

Fluid Turbulence

A Potter Aernoautical Flowmeter Model 6-424 was tested to determine the effects of turbulence in the flow. A turbulence grid was established in the line and the meter was tested for the full range of discharges. There was no effect of turbulence on the speed of the rotor and this was attributed largely to the existence of the straightening vanes in the meter.

Line Pressure

Changes in line pressure could affect rotor speed only if the pressure is reduced sufficiently to cause cavitation at some point within the meter. Increase in line pressure could not functionally affect the turbine-meter performance.

Cavitation

Report CER59SSK45 reports the study of cavitation effects on the "floating rotor" design of the Potter Aeronautical Company. Qualitative tests showed that the original design was conducive to cavitation which was corrected in the revised design. Specifically, cavitation pockets developed at the upstream flow contraction cone which was eliminated in the revised design by constructing the turbine rotor diameter to be the same size as the contraction cone. Cavitation pockets within the meter causes the frequency-discharge relationship to become non-linear.

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