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TURBINE METERS

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TURBINE METERS

1. INTRODUCTION

This paper reviews the design, performance and application of turbine meters for custody transfer measuring systems.

The details of the mechanical displacement provers are reviewed separately in another paper.

2. DESIGN

2.1 Theoretical Design Considerations

A simplified equation showing the relationship between the torque due to bearing friction and pick-up drag is given below:

$$T_{B+P} = n\int_{r_1}^{r_2} \tfrac{1}{2}\rho V_R^{\,2}(C_L \mathrm{SIN}\beta - C_D \mathrm{COS}\beta)\ell r.dr$$

Where:

n	is number of blades of rotor
r_1	is radius of root of blade
r_2	is radius at tip of blade
ℓ	is length of blade
ρ	is density of fluid
C_L	is coefficient of lift
β	is relative velocity angle
C_D	is coefficient of drag
r	is radius
T_{B+P}	is torque from bearing and pick-up drag

An ideal turbine meter requires a constant meter factor, so that the velocity of the blades must be directly proportional to the velocity of the flowing fluid. It is evident from figure 1 that this will only occur if the angle β is the same at all flowrates. If this were to be the situation then the above equation can be reduced to the form given below where A and B denote composite constants

$$\begin{array}{ccccc} \text{LIFT} & & \text{DRAG} & & \text{TORQUE} \\ AC_L & = & BC_D & + & T_{B+P}/V_R^{\,2} \end{array}$$

This equation is only valid if each separate term within it remains the same at all flowrates. The first term satisfies this condition, as the coefficient of lift does not vary. However, this is not fulfilled with the second term because C_D - the coefficient of drag varies with Reynolds number. Also the third term, T_{B+P}, the torque due to the combined effects of bearing friction and pick-up drag does not increase in proportion to the square of the relative velocity.

It is evident, therefore, that a meter cannot be designed to produce a constant K factor.

The art of the manufacturer is to produce a meter with a near constant K factor over a wide working range of flowrate.

The above equation assumes a flat velocity profile i.e. the velocity is the same at all points in the cross-section of the pipe whereas in practice the velocity profile in the turbulent range (Re>3000) will be a parabola. This is another reason why it is not possible to exactly predict the behaviour and performance of a turbine meter.

.2 Performance

a. Characteristic Curves

All turbine meters have a characteristic curve (K factor versus flowrate) of a general form (see figure 2).

The best meters may achieve a variation in K factor of ± 0.25% over a flow range of 10 to 100%. However, there will always be a sharp fall in K factor at the low flowrates because the coeffient of drag increases at low Reynolds numbers and because of the increased significance of bearing friction at low rotation speeds.

b. Linear Meters

In order to improve the linearity some manufacturers have recently designed turbine meters so that the torque due to the bearing friction and pick-up drag have been reduced.

One meter utilizes two rotating elements instead of one; and up-stream indicating turbine rotor which induces the signal and a down-stream slave turbine rotor. The shaft with the slave rotor attached rides on one set of bearings and the indicating rotor rides upon a separate set of bearings attached to the rotating shaft. The separate shaft arrangement ensures that the relative motion between the indicating rotor and its bearing remains at a near zero level irrespective of the velocity of the fluid passing through the meter. The pick-up drag normally due to inductance or variable reluctance when generating pulses is eliminated by using a sensing system based on high frequency radio-wave signals.

Another meter employs a rotor which rotates on a tungsten carbide shaft which in turn rotates in two tungsten carbide journals. This arrangement ensures that relative motion between the rotor and the journals is reduced.

One important advantage of these new types of meter is that they can withstand very high flowrates (sonic velocity) associated with vapour boil off conditions often encountered in LPG systems without bearing failure.

c. Viscosity, Density and Size of Meter (See figures 3 & 4)

The effects of viscosity becomes progressively greater as the size of meter becomes smaller. Also the linearity deteriorates as the meter becomes smaller. The effect of increasing viscosity is not only to change the K factor but it also reduces the rangeability of the meter. (This is due to the increased bearing friction with the more viscous oils). As the density of the fluid is reduced the linearity of the meter deteriorates. This is mainly due to reduction in the fluid momentum available for overcoming the rotor torque.

APPLICATION

In order to achieve a satisfactory performance from a turbine meter a number of conditions must be fulfilled when designing the installation.

Swirl

Liquid swirl in a flowing liquid is mainly caused by pipe bends and fittings and can effect the K factor and repeatability. (Swirl is not constant).

In practice it is necessary to install a flow straightener (5 diameters) upstream of the meter and to ensure that there are no pipe fittings directly downstream of the meter.

Cavitation

In order to prevent cavitation in the meter it is essential to maintain a back pressure above the minimum specified by the manufacturer.

Air

In order to remove entrained air - particularly in viscous oils - it is necessary to ensure that the level of liquid in the tank supplying the meter is 2-3 metres above the suction or alternatively to keep the floating roof floating at all times.

REPEATABILITY

The turbine meter can be likened to a flywheel as its function is to dampen down the random or individual variations in velocity of the flowing fluid.

With meters such as the Ultrasonic or Vortex with no moving parts it is necessary to have sufficient volume throughput in order to obtain a good repeatability. Whereas turbine meter repeatability can be achieved with a relatively small throughput volume.

INTEGRATION OF THROUGHPUT

a. Variations in Flowrate

Experience has shown that there are often considerable variations in the flow conditions in offshore production metering and onshore ship loading terminals. While there are often dedicated pipe provers on hand to prove the individual meters, there are usually problems in carrying out this task.

For instance, the meter must be calibrated immediately after the flow conditions alter significantly or errors may be incurred in the integration of the throughput due to the incorrect meter calibration factor being applied.

5. Linearising K Factors

One method of overcoming the problem of meters sensitive to changes in flow conditions is to use a micro-computer programmed to read the flowrate, temperature and pressure signals in the line and to apply a varying K factor to the meter integration of throughput.

7. Calibration Procedure (See Fig.5)

A method of combining central proving with on-site proving is described below:

a. Laboratory Proving

The performance of the meter is usually established by initially proving at a central laboratory where the curves of K factor versus flowrate are obtained with a pipe prover using several oils of differing viscosities. At least three flowrates are required at each viscosity in order to determine a curve.

b. Meter Performance

The data obtained from the initial proving are plotted on a performance chart. A suitable equation, usually a polynomial derived by a least square method, is fitted to the proving data or alternatively a matrix for use with linear interpolation technique is derived. This information is programmed into a micro-computer which will read the flowrate (frequency), temperature and pressure as transmitted from a number of transducers installed directly in the metering runs. As there is a linear relationship between temperature and log viscosity for each type of crude oil it may be sufficiently accurate to measure temperature rather than viscosity directly in the line.

c. On-Site Measurement

The meters are then installed on-site and reproved. The micro-computer then automatically applies the appropriate K factor to the meter scaler for the flow conditions experienced during the throughput measurement integration.

d. Re-Proving

It is necessary to re-prove the meters at regular intervals so as to establish the long term scatter (see Fig.6) and to up-date the original performance curve. The mean K factor curve can then be established over a period of months and set into the micro-computer. This would shift the emphasis from changing K factor to monitoring K factor. (See Fig.7)

The long term drift of K factor with time due to bearing wear or rotor damage can also be monitored by analysing the moving average of 10 consecutive (period) K factors.

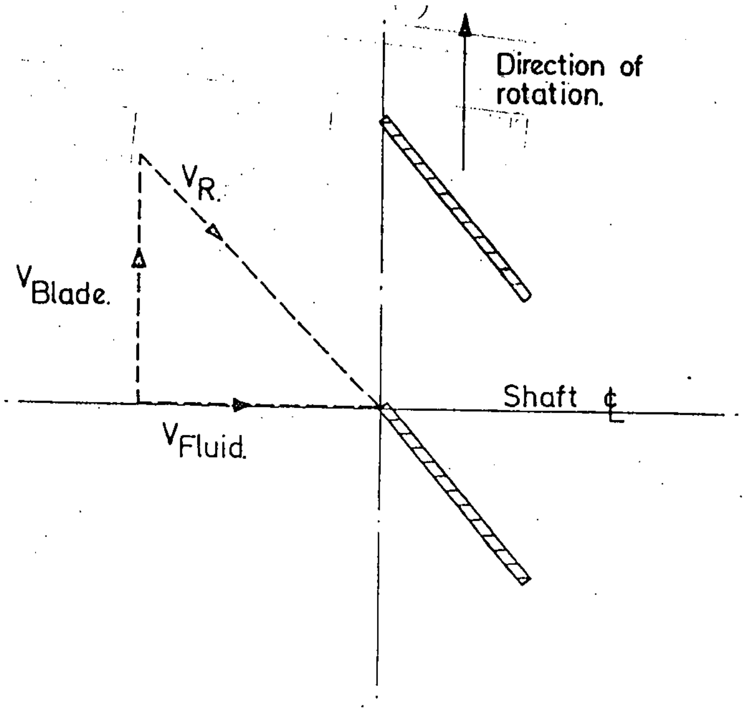


FIG. 1 INLET VELOCITY DIAGRAM.

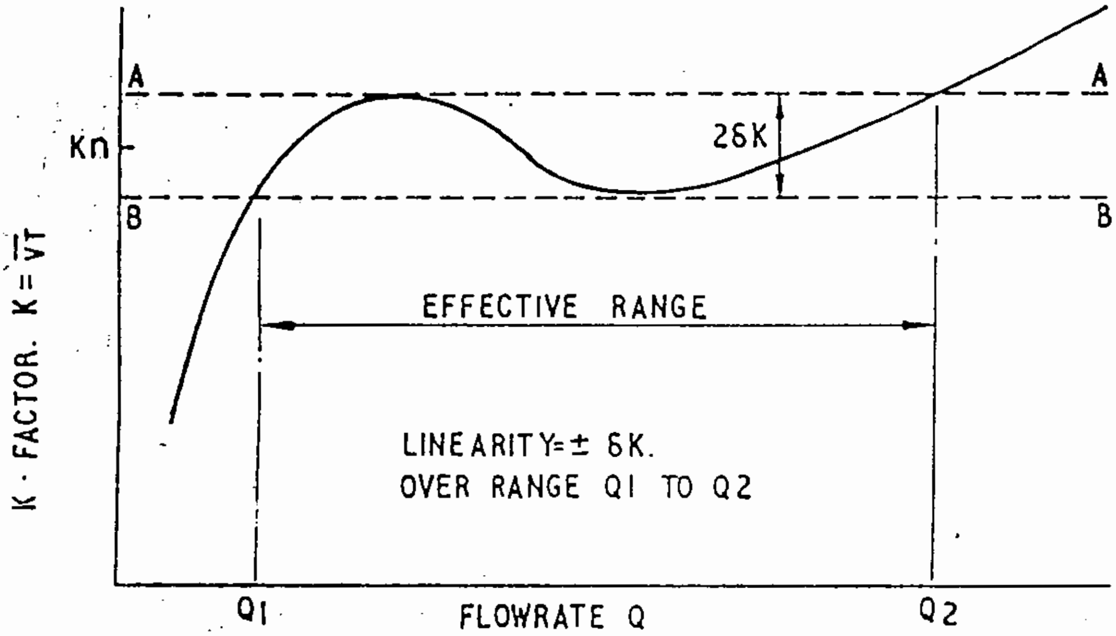
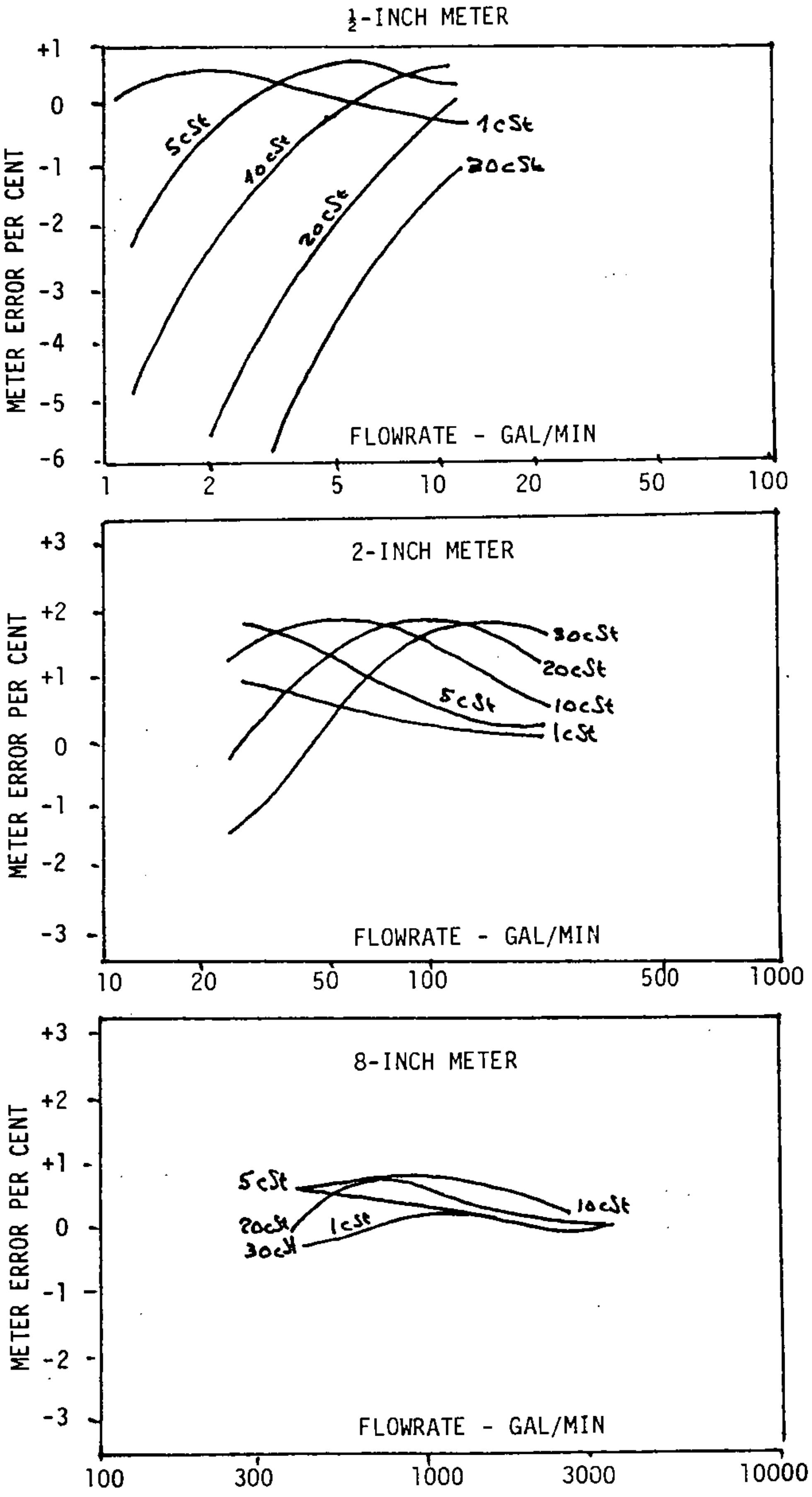


FIG. 2 TURBINE METER CHARACTERISTIC CURVE.

GURE 3



EFFECT OF VISCOSITY ON METER FACTOR

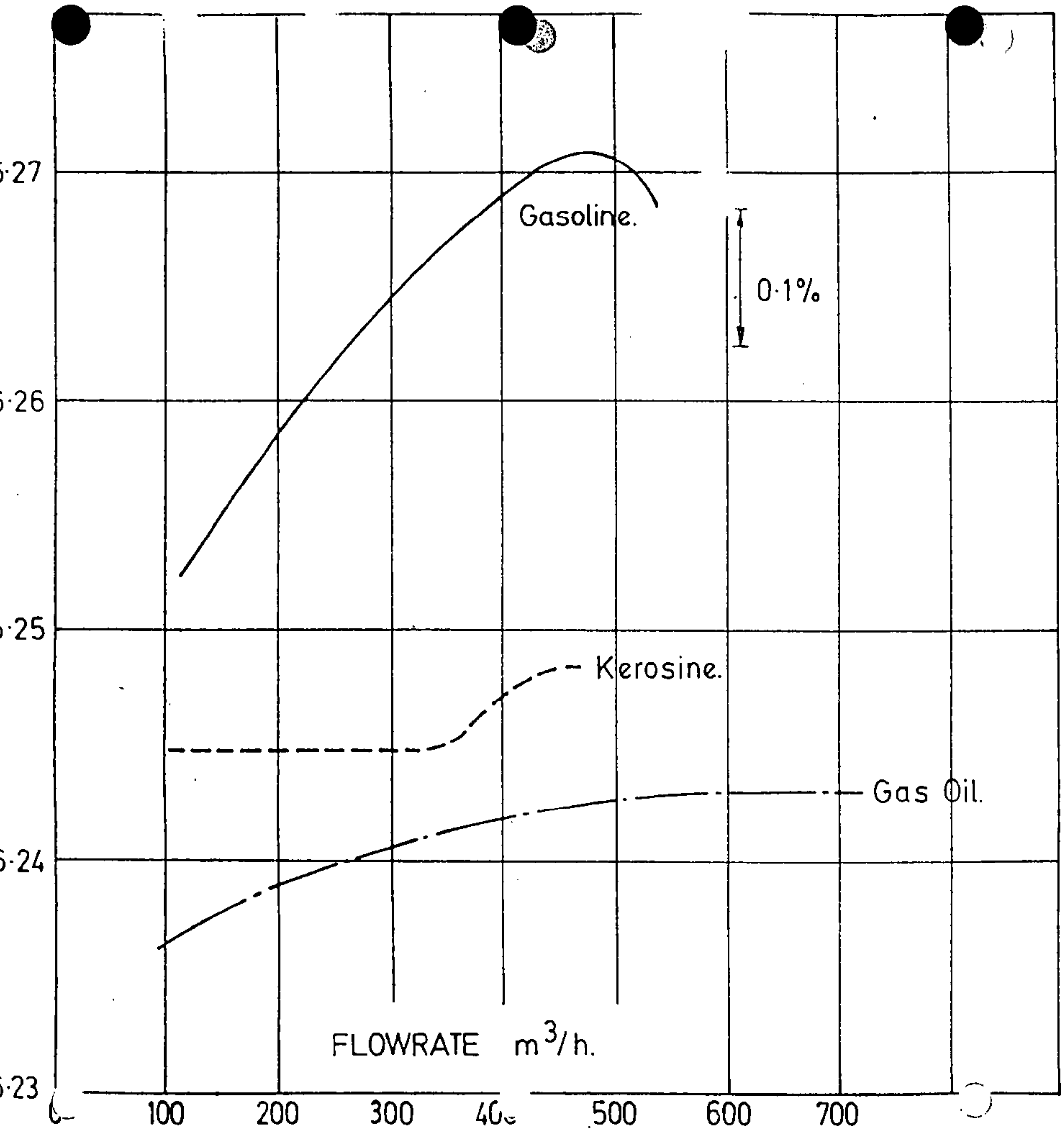
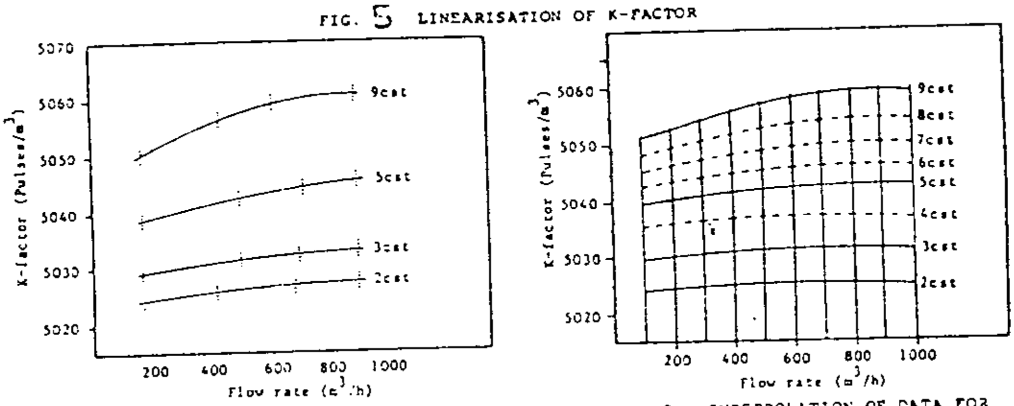


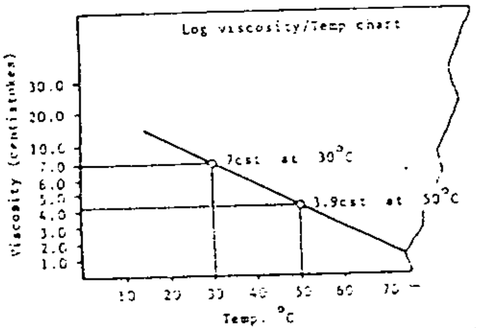
FIG. 4.
SOME TEST RESULTS OBTAINED IN THE FIELD WITH A 6-INCH TURBINE METER & A PIPE PROVER.

FIG. 5 LINEARISATION OF K-FACTOR



STEP 1 - PERFORMANCE CURVES
(Obtained from flow laboratory on various viscosity oils)

STEP 2. INPERPOLATION OF DATA FOR MATRIX (or best fit curve)

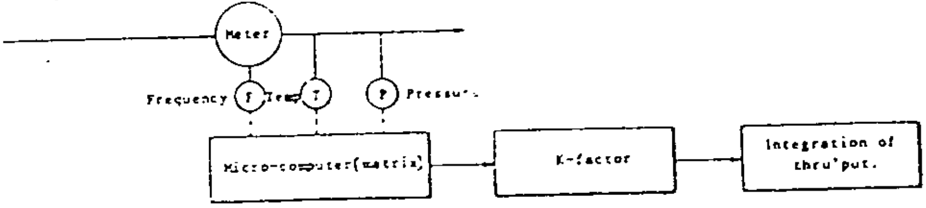


STEP 3 - CRUDE OIL VISCOSITY/TEMP. RELATIONSHIP
(Based on laboratory tests)

Matrix

Flow rate (m^3/h)	K-factor (Pulses/m^3)			
	2cst	3cst	4cst	5
	82°C	60°C	49°C	
100	5025.1	5029.6	5035.1	
200	5025.5	5030.1	5	
300	5026.1	5031.0		
400	5026.6			
500	5			

STEP 4 - CONSTRUCT MATRIX FOR MICRO-COMPUTER



STEP 5 - METER INSTALLED ON SITE

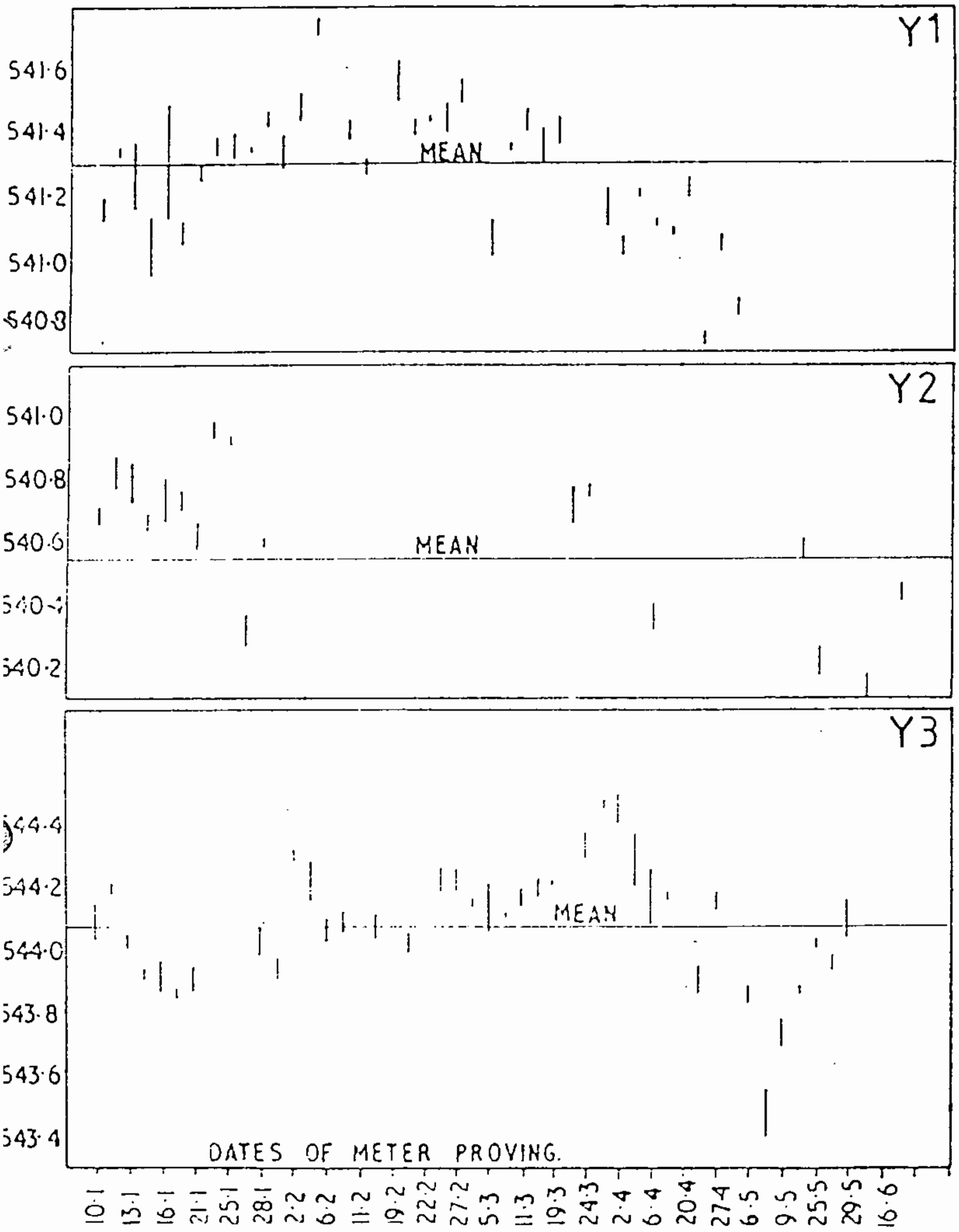
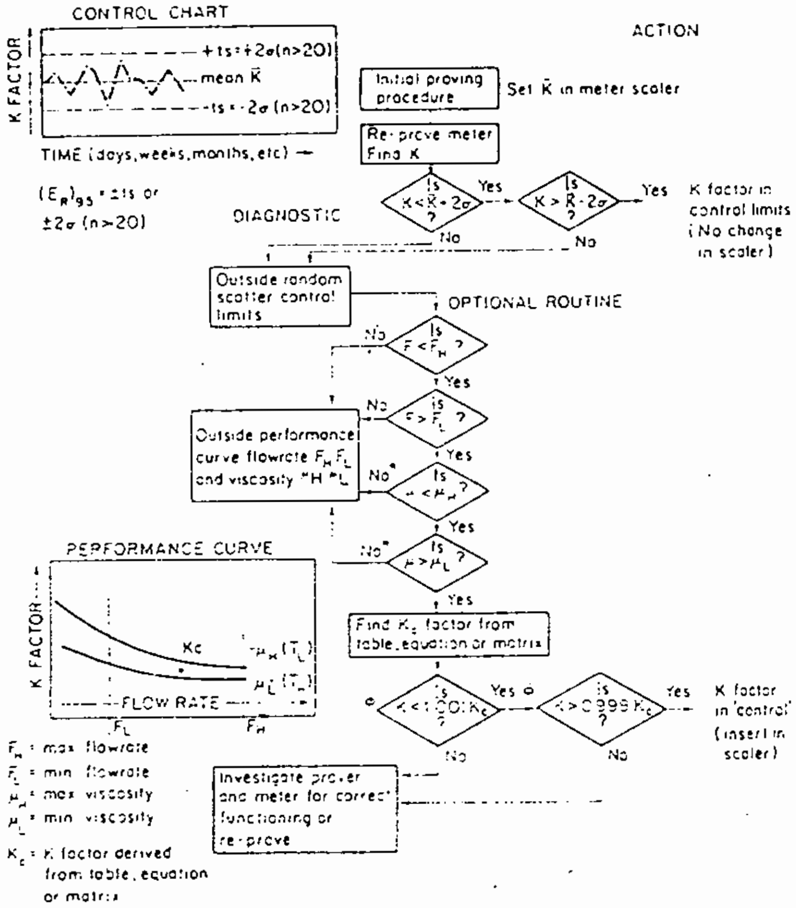


FIG. 6. CONTROL CHARTS FOR METERS Y1, Y2 AND Y3 SHOWING



N.B. *For one grade, temperature can be used instead of viscosity

⊕ This limit of ±0.10% can be varied

FIG. 7 Statistical control—Meter proving using control charts.

References

[1] Paper presented at the North Sea Flow Measurement Workshop, a workshop arranged by NFOGM & TUV-NEL

Note that this reference was not part of the original paper, but has been added subsequently to make the paper searchable in Google Scholar.