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MECHANICAL DISPLACEMENT METER PROVERS

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MECHANICAL DISPLACEMENT METER PROVERS

1. INTRODUCTION

The conventional pipe provers were first introduced into crude oil measurement for custody transfer purposes in the Middle East in the early 1960's. Since then they have become the recognised calibration standard for all fiscal metering systems throughout the world. Recent improvements in the detection of displacers and pulse interpolation techniques have made it possible to design "compact" provers with greatly reduced swept volumes.

The main factors which influence the design and repeatability of both the conventional and compact are considered in this paper.

2. CONVENTIONAL PROVERS

a. Principle of Operation

The conventional pipe prover uses an oversized rubber or plastic sphere, which is filled with water, in commercial grade industrial pipe. The internal surface of the pipe is usually coated with a baked-on phenolic resin to protect it from any corrosive elements in the crude oil or products. The advantage of the rubber sphere is that it automatically changes its shape to follow the varying contours of the pipe as it moves between the detector switches. The over-sizing of the sphere (2 to 4 per cent larger than the internal pipe diameter) ensures that it acts like a squeegee and prevents by-pass leakage. (See figure 1).

b. Repeatability

The repeatability of the pipe prover is mainly a function of the repeatability of the detectors in establishing the horizontal location of the sphere or displacer. (See figure 5).

Most of the provers used for fiscal metering purposes have mechanically operated micro-switches for detecting sphere location. A distance between detectors of 20 metres is usually chosen in order to achieve a repeatability (expressed as the range) of 0.05% for 10 consecutive runs when proving a turbine meter on crude oil.

Recent experience with piston provers using two proximity type detector switches at 10 metres apart have indicated that on a Round Trip (Forward plus Backward runs) a range of 0.05% can be achieved for 5 consecutive proving runs. (See Figure 2).

The sphere hardness can marginally influence the repeatability of the prover but not sufficiently so that the swept volume can be significantly reduced.

The use of pairs of detectors in place of one detector at either end of the prover has many advantages:

- The repeatability of the detectors can be monitored.

- The mean of the two swept volumes, individually calibrated, can be used to improve the uncertainty. (Fig.6).

c. Reduction in Length

One feature of the conventional prover was the long distance between the launching chamber and the first detector. This was to ensure that when the sphere was launched, it did not arrive at the first detector before the main flow valve was sealed.

This run up distance was virtually eliminated by the use of a launching system which used a ram for holding back the sphere until the main flow valve was fully sealed. (See figure 7).

d. 4-Way Valve

A major item of cost has always been the 4-way valve which represents as much as a third of the total cost of the pipe prover.

The main reason for this cost is that the valve has to be designed so that the integrity of the seals can be monitored during a proving run. Also special consideration has been given to ensure that the seals are not damaged during the cycling of the valve. Most valves are designed so that the seals are withdrawn before rotating. Two well known valves raise the plug containing the ports vertically before rotating. (See figure 8).

Any leak across the seals can be observed by monitoring the pressure in the valve casing when it is in the fully seated condition.

3. COMPACT PROVERS

a. Principle of Operation

The swept volume of a pipe prover can be reduced by using a piston and a rod with special detectors. The pistons slide in precision machined cylinders with lip seals around the periphery of the piston. The piston rod slides through a seal in the end chamber and the detector switches are situated on the rod outside the prover barrel. These detectors have such a high resolution that the distance between them can be reduced from the usual 20m ns with conventional provers to less than 1m with a corresponding decrease in the swept or calibrated volume.

b. Non-Linearity of the Meter

As the swept volume is decreased the inter-rotational non-linearity (IRL) of the meter being proved becomes significant.

The linearity of the turbine meter is dependent on the evenness of the spacing between adjacent magnetic points in the rotor rim (or shroud) or tips of rotor blades. The IRL is sometimes defined as half the difference between the maximum and minimum time periods between adjacent blades during one revolution. (See figure 9).

In France a piston prover with two rods is used for proving small nutating disc type displacement meters on LPG. As these meters are non-linear in their throughput the prover calibration volume - and hence the distance between the external detectors - is so sized that the volume corresponding to the non-linearity represents less than 0.02 per cent of the proving volume (See figure 3).

There are two alternative methods for overcoming the non-linearity problem of turbine and displacement meters with small volume provers. These are as follows:

(i) Multiple Chronometry and Pulse Interpolation

Pulses generated by the meter are fed to a signal processor which times precisely each individual pulse during one complete cycle or revolution of the meter. Also the processor identifies each pulse with a particular rotor blade.

By timing the prover in and out gating signals in relation to the meter pulses it is possible to remove the error due to any non-linearity in the meter under test. (See figure 9).

(ii) Prover Pulse Generator

By using a device which converts the linear travel of the piston rod into pulses - sometimes called a linear motion translator - the pulses generated by the meter can be synchronized with the pulses emitted by the prover. A micro-computer can then correct for any non-linearity in the meter pulse output, viz counting the prover pulses between whole revolutions of the meter. (Fig.10).

Also this system would measure accurately the average flow rate during the proving operation.

c. Leakage past the Piston

In the conventional prover the sphere is 2-4% oversize and is highly flexible so that it acts as an energised seal. However, with a piston it is not possible to make an energised seal without introducing the problem of deformation which could contribute to a significant error in the short swept volume. In order to obtain an adequate seal therefore, it is necessary to have a very small interference fit in the precision made prover barrel. This seal could be damaged by fine particles and it is considered necessary by certain authorities to monitor the integrity of the seals during the prover run.

One method is to observe the pressure drop across two parallel seals by means of a suitable transient analyser.

d. Valves

External valves or an internal poppet valve (see figure 4) are used with compact provers for directing the flow but all of these devices should be monitored for leakage during the proving runs.

e. Means for By-Passing Flow

It is essential to ensure that the prover has some means of by-passing flow at the beginning and end of the proving run. Some designs rely on the rapid closing of external valves for directing flow. This can create unacceptable pressure surges due to the need for extremely rapid cycling in order to reduce the run up distance before the calibration section.

One method used by a number of manufacturers of compact provers is to have large end chambers and a means of controlling (externally) the movement of the piston. The 4-way valve or individual valves can then by cycled and the seating monitored before releasing the piston for the proving run.

The large end chambers also ensure that most of the non-organic particles such as pipe rust etc., do not enter the main prover barrel. (See figure 10).

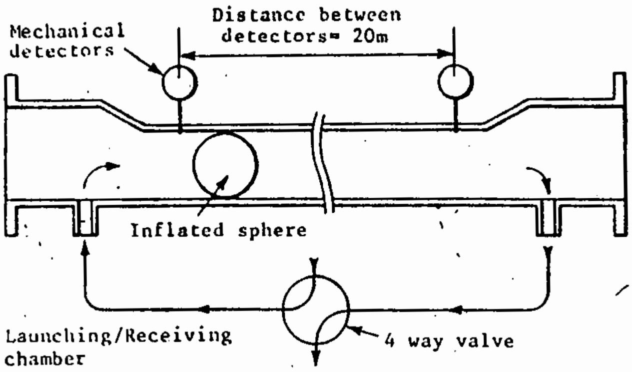


FIG I_CONVENTIONAL PROVER (BI-DIRECTIONAL)

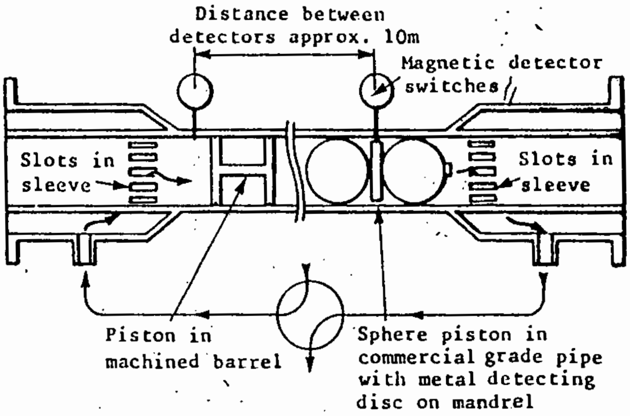


FIG 2_ SHORT PISTON PROVERS (INTERNAL DETECTORS)

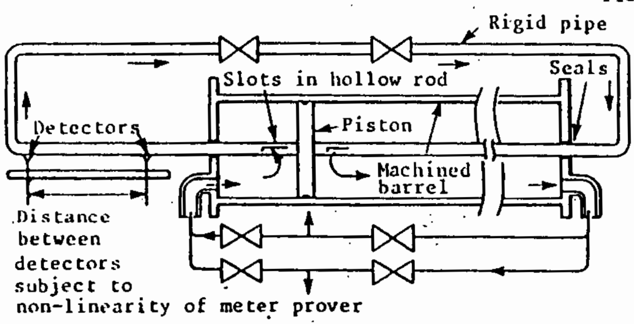


FIG3_SHORT PISTON PROVER
(EXTERNAL DETECTORS AND VALVING)

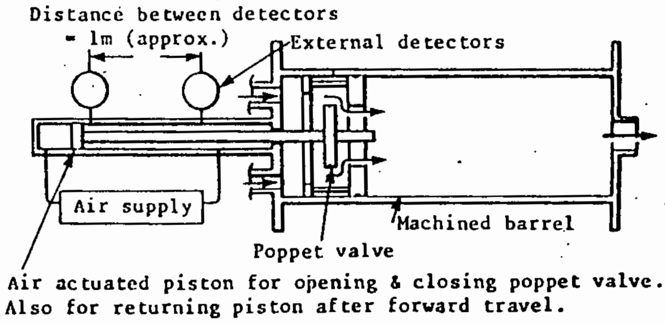


FIG4_ SHORT PISTON PROVER
(EXTERNAL DETECTORS AND INTERNAL VALVE)

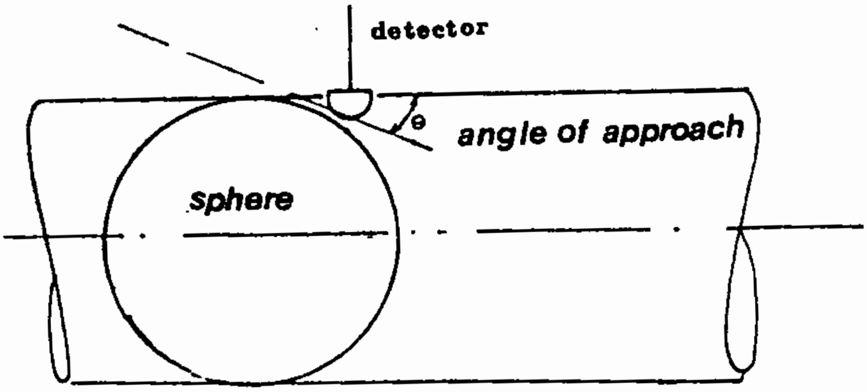
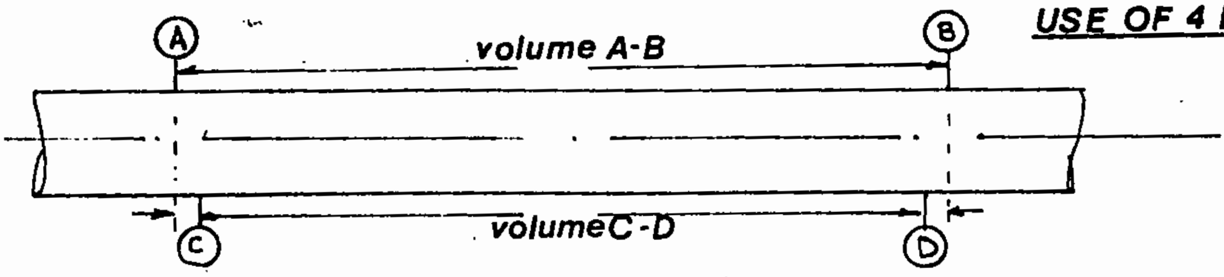


FIG 5

SWITCH REPEATABILITY

FIG 6

USE OF 4 DETECTORS



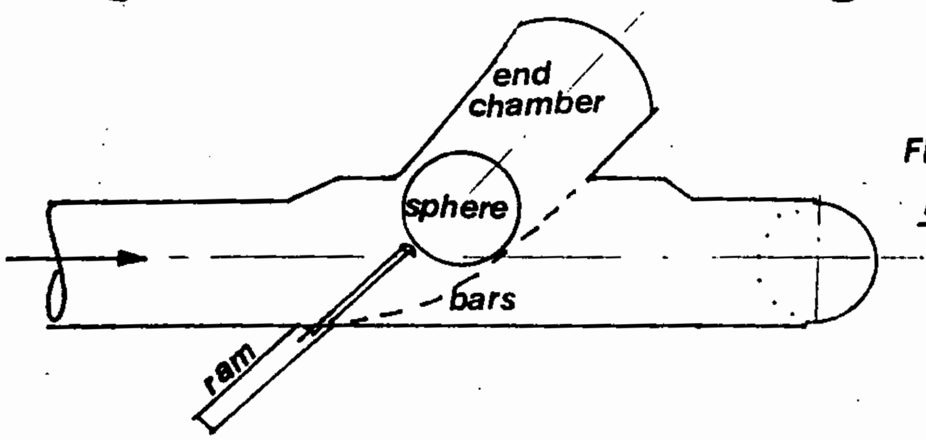
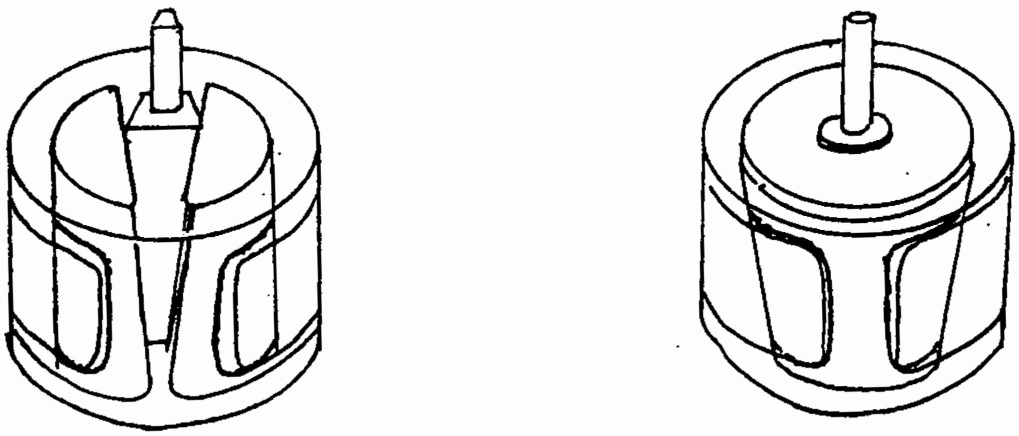


FIG 7

LAUNCH RAM



Split Seal

RISING PLUG

FIG 8 4 WAY VALVE DESIGN

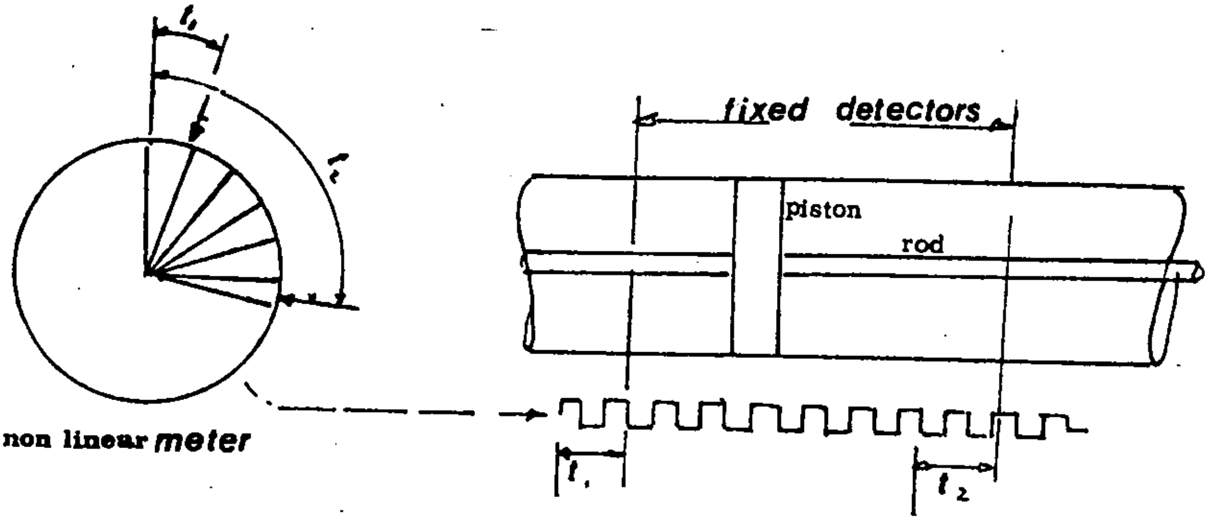
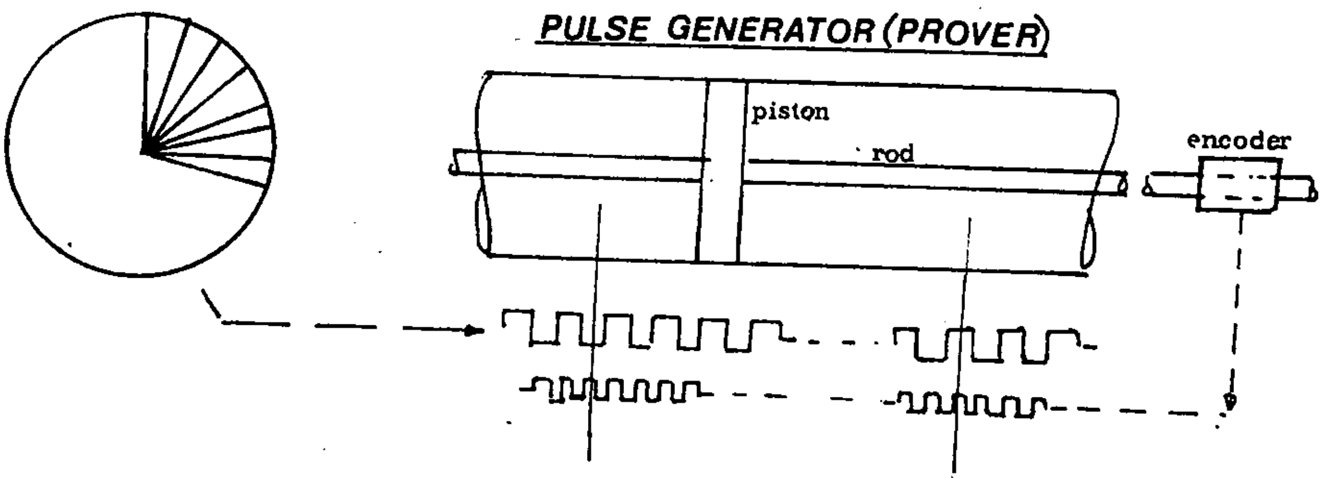


FIG 9 MULTIPLE TIMING METHOD



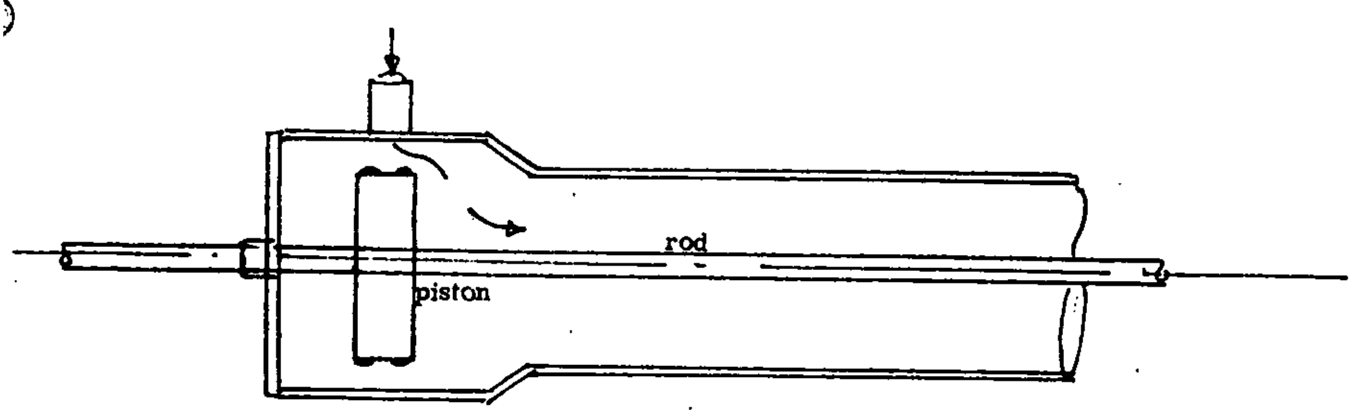


FIG 10 _ END CHAMBER

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.