REVIEW OF COMPACT PROVERS

by

W C PURSLEY

NATIONAL ENGINEERING LABORATORY

PAPER 5.1

NORTH SEA FLOW METERING WORKSHOP 1984

16-18 October 1984

National Engineering Laboratory
East Kilbride, Glasgow

REVIEW OF COMPACT PROVERS

Dr W C Pursley

1 INTRODUCTION

The compact prover, or small volume prover as it is more properly known, is probably the most significant development in hydrocarbon flow measurement since the introduction of the ball prover more than thirty years ago. These conventional devices, while providing the necessary accuracy of proving, did this at the expense of vast size and weight; the cost of metering stations incorporating such proving devices can moreover represent a significant proportion of a production system whether it be on a platform or at a refinery unloading terminal.

The demand for savings in platform space and equipment weight, together with a growing need for some proving device which could be used as a transfer standard, has led in recent years to the development of several different techniques of pipe proving all of which may be classed under the general title of 'small volume provers'. Table 1 shows a comparison of two typical proving devices, a compact prover and a conventional ball-type prover. It can be seen that more than twice the flowrate can be achieved for only a fraction of the ground area or space occupied.

However bulky and expensive are the ball-type provers in terms of weight and space there can be no doubt about their repeatability, wide range, overall measurement accuracy and general reliability. In order to meet the performance criteria demanded by the various standards and codes, fiscal authorities etc, the small volume devices must therefore be shown to be at least the equal of the conventional provers they are expected to replace. That this is so has not yet been proved conclusively for most of the devices considered in this review.

Nevertheless much test work is in progress, both on site and in laboratories such as NEL where controlled conditions can be obtained and sophisticated measurement techniques can be employed.

The first, and so far the only one, of the small volume provers to be used in North Sea applications is the Brooks Compact Prover, manufactured in the USA, and two papers describing field experience with this device will be given later in the session. Other small volume provers however, both from the USA and the UK, are likely to be used in North Sea area in the near future, and it is the purpose of this paper to review the techniques employed by five of these devices, including the Brooks Prover.

The paper will describe briefly the physical principles of each of the designs of prover and compare and contrast their various features. A closer look will then be taken at one of the essential components in the measurement of volume using small volume provers - pulse interpolation. The paper will end with a discussion on some possible future developments in proving techniques.

2 PROVER DESIGNS

The range of small volume prover designs is growing rapidly. It has been estimated for example that up to a dozen varieties are either available or are under development in the United States. For the purposes of this review, however, five designs of immediate interest to North Sea operators will be considered. These consist of three provers from the USA, the Brooks compact prover, which is the first device to be marketed and used in the North Sea environment, the Waugh Microprover which is well established in the USA but is still to be used off-shore, and the Smith Systems small volume prover which until recently was an in-house reference device but is now being marketed in the USA and in Europe. In addition to these American based provers, the review also considers two British devices, the Skeltonhall prover and the General Descaling prover which are beginning to come on to the UK market.

All five provers have the same basic components - a piston in a precision bore tube of relatively small pre-calibrated volume, together with some method of detecting the movement of the piston within this volume and a means of returning the piston to its starting point at the beginning of the proving cycle. Beyond this, however, there are many variations as can be seen when each design is considered in turn.

2.1 Brooks Compact Prover

This prover was originally developed and manufactured by Flow Technology Inc, Arizona, and sold under the trade name 'Ballistic Prover'. It is shown schematically in Fig. 1. The prover consists basically of a carbon steel nickel-plated measuring cylinder inside which a piston moves under the action of the flow. The piston is fitted with a co-axially mounted poppet valve which eliminates the need for a bypass valve circuit. The actuating rod for the poppet valve is brought out from the rear of the measuring tube to a hydraulic/pneumatic cylinder. The poppet valve is closed by applying pressurised gas (normally nitrogen) to one side of the actuating rod, thus enabling the piston to move down the cylinder under the action of the flow. During its passage down the cylinder the gas pressure on the upstream face of the actuator piston is sufficient to overcome piston inertia and seal bearing friction which might otherwise affect the flowrate through the meter being proved. At the end of the pass the poppet valve is opened and the piston returns, by means of hydraulic pressure applied to the actuating rod, to its starting point where the poppet valve is held open ready for the next pass.

No provision is available for dynamic checking of the critical piston seals, although these can be checked statically at the end of each operation if required.

Three detector switches, of the optical (infra-red) type are used, and are actuated by a flag mounted on the detector shaft which is rigidly connected to the piston. Two of these switches mark the beginning and end of the calibrated section of the prover while the third senses the position of the piston at the upstream end of the cylinder.

2.2 General Descaling Compact Prover

This prover is being manufactured by GD Engineering under licence from Moore, Barrett & Redwood Ltd, and is shown schematically in Fig. 2. The design is based on a free-travelling piston operating in the bi-directional mode in a double shell barrel. The double shell arrangement eliminates the need for any pressure correction and assists in the stabilisation of temperature. The direction of flow in the flow tube is changed by means of a spool-type 4-way valve mounted externally, and launch actuators at each end push the piston into the flow tube. The inner flow tube is fitted with integral detectors and is completely removable via quick acting end closures, enabling the tube to be calibrated off-site. Two pairs of detector switches of the magnetic inductive type are used to ensure continuity in the event of failure. These switches are actuated by a magnet mounted on the free travelling piston, not shown in Fig. 2.

The piston embodies a seal-checking system which enables the seals to be checked dynamically during proving, while the integrity of the 4-way valve seals can also be monitored continuously. A static check of the piston seal can also be made whenever this is required.

2.3 The Skeltonhall Compact Prover

The device was developed by Maurer Instruments Ltd and is being manufactured, in the larger sizes, by Skeltonhall Ltd. The prover, shown schematically in Fig. 3, consists of a piston which is free to move along a calibrated measuring cylinder under the action of the flowing fluid. The measuring cylinder is contained within an outer cylinder, the space between being filled with flowing liquid. Thus pressure corrections are zero and the temperature stability is enhanced. Flow is directed into the prover chamber by the operation of a bypass valve, and at the end of a pass the piston enters a recessed portion of the tube, allowing the flow to bypass it. The bypass valve is then opened and a 'nudge' cylinder used to move the piston back into the main part of the cylinder. Thereafter circuit design ensures that the differential pressure across the piston is sufficient to move the piston back to its starting position ready for another pass. The 'nudge' cylinder also acts as a hydraulic damper, and helps to decelerate the piston at the end of the pass.

The piston seals can be monitored and the pressure in the pressurised space between them compared while the piston is in motion, with line pressure by a differential pressure transducer within the piston head. Static testing of the seal can be carried out using a bleed system in the chamber end closure.

The fundamental difference between this device and the others considered in this review is the method of measurement. Here the measuring system consists of a linear transducer mounted on the piston rod which detects pulses from a linear encoder mounted on a rigid 'INVAR' block. No detector switches are fitted although it can be used in a fixed volume mode by utilizing a fixed portion of the linear encoder.

2.4 Smith Systems Small Volume Prover

This consists of a barrel containing the measurement chamber and the piston which moves along it under the action of the flow. A bypass circuit round the barrel enables flow to be directed either through the bypass or through the barrel according to the position of a hydraulically operated bypass valve.

The operational sequence is shown in Fig. 4. The piston is first returned by the hydraulic system to its upstream configuration, with the bypass valve open. When the piston reaches the stop at the end of the barrel, the bypass is closed by the actuator and the piston begins its proving run. At the end of the proving pass the bypass valve opens and the proving cycle is ready to be repeated.

The detectors are of the optical (infra-red) type and are mounted on an INVAR bar in a special bracket which allows replacement without recalibration. A third switch is fitted on the INVAR rod to act as a positional sensor, while a further pressure switch monitors the pressure between the two piston seals so that dynamic leak testing of the piston can be effected during a proving run. Dynamic leak testing of the bypass valve can also be carried out.

A unique feature of the Smith Systems prover is that either vertical or horizontal operation can be selected, using a hydraulic positioner to alter the mode of operation.

2.5 Waugh Controls Microprover

In this device the measuring cylinder is contained within an outer housing containing the fluid which therefore eliminates the need for pressure correction. The presence of the fluid surrounding the measuring cylinder also provides good thermal stability. Apart from this feature however, the layout is similar to the Smith Systems device described in Section 2.4.

The prover is shown schematically in Fig. 5. The fluid passes through the bypass valve or into the measuring cylinder (through a series of slotted parts), according to the position of the bypass valve. The piston moves down the cylinder under the action of the flow and is returned by means of a hydraulically operated return actuator. Two marks on the piston rod operate a single optical sensor at the beginning and end of each pass.

Dynamic checking can be carried out on the three critical seals in the system - the piston seal, the annular seal in the space between the inner and outer cylinders, and the bypass valve seal, which is of the block-and-bleed type.

3 A COMPARATIVE REVIEW

Table 2 shows a comparison of the five prover designs. A mid-range model, suitable for 8 inches (208 mm) main line operation, is chosen as the basis for the comparison.

It can be seen from the Table that the term 'compact' or 'small volume' has no precise definition. On the basis of floor area occupied the provers vary by a factor of more than 3 to 1, while on the basis of space occupied the factor by which the provers vary is more than 8 to 1.

Thus the 'bulkiest' prover (ie in terms of volume) is the General Descaling device while the most compact is the Skeltonhall prover. In terms of floor area the biggest is again the General Descaling prover and the smallest is the Skeltonhall device. It should be noted that comparison of the provers in simple terms of ground area or space occupied is not strictly fair to some of the models. For example the dimensions of the Waugh prover include the height to the top of the hydraulic actuator for the bypass valve. Presumably if height were critical the layout could be re-arranged. On the other hand the overall dimensions of the General Descaling prover conceal the fact that an extra 2.5 m at one end for tube replacement and 1.5 m at each end for normal maintenance are required.

The weight of the provers also show a large variation, by a factor of about 3 to 1, with the Skeltonhall prover being the lightest and the Brooks being the heaviest.

Table 3 gives a comparison of various features of the five provers.

All but the Brooks version employ some form of bypass valve. In the Brooks device the piston poppet valve serves the same purpose, that of providing a means of returning the piston to the other end of the cylinder. In most of the other devices this bypass valve is a simple two-way device, but in the General Descaling version, since this is designed for bi-directional flow, a four-way valve (spool type) has to be used. Thus this device sacrifices the increased weight and cost of this valve for the ability to operate in the bi-directional mode.

The advantages of the double shell design, offered by the General Descaling, Skeltonhall and Waugh provers, are the elimination of any pressure correction factor and the increase in thermal stability which such an arrangement affords. The disadvantages are the increased construction cost and the increase in the overall weight. However when this feature is combined with the facility of replacing the flow tube in the event of damage or for pre-calibration off-site, as with the General Descaling prover, then the advantage of such a design would appear to outweigh any disadvantage of cost and weight. The replacement due to damage of a complete prover on an offshore platform, for example, must prove to be a very expensive operation in comparison with on-site replacement by a pre-calibrated tube carried as a spare.

The number of detectors varies from none in the Skeltonhall prover (since it utilizes a linear encoder) to four in the General Descaling prover. The General Descaling prover uses two pairs of switches as a guard against faulty operation, while the Brooks prover used three detectors - one to sense the presence of the retracted piston and two to measure the piston travel. The Waugh prover uses only one detector, of the optical type, which senses the passage past it of gate marks on the piston rod. Both the Waugh and Smith switches can be replaced without the need for recalibration of the prover barrel.

The assistance of subsidiary systems such as hydraulic and pneumatic circuits ranges from none in the case of the Skeltonhall and General Descaling devices, to both hydraulic and gas systems in the Brooks prover. No external assistance is required in the case of the Skeltonhall prover, which utilizes differential hydrodynamic forces to draw the piston back along the tube or in the General Descaling device which operates in the bi-directional mode. The Waugh and Smith provers utilize a hydraulic system to retract the piston while a combined pneumatic/hydraulic system in the Brooks prover serves two purposes: first to return the piston to the other end of the cylinder, and second to close the poppet valve and to assist the movement of the piston against the resistance offered by the inertia of the piston and the piston seals. The gas pressure behind the piston can be adjusted to minimise the differential pressure across it, thus minimising the effect of any leak at the piston or poppet valve seals.

The dynamic piston seal checking facility is available in all versions except the Brooks; however because of Brooks' unique facility for balancing the differential pressure across the piston the lack of dynamic seal checking is less important.

4 PULSE INTERPOLATION

Because of the small volumes utilized in compact provers, the number of meter pulses generated by the meter during a proving pass is almost always small enough to make errors of discrimination significant in relation to the required overall uncertainty of proving. A pulse count of 10 000 for example, is necessary to provide a discrimination error of ± 0.01 per cent. An 8-inch (204 mm) turbine meter, however, may only generate about 100 pulses between the detectors of a typical small volume prover. This would produce a discrimination error of ± 1 per cent and is clearly unacceptable; enhancement of the pulse count by pulse interpolation must be carried out. Thus pulse interpolation is as much a part of a small volume prover as for example the piston or the detectors, and for this reason it is worth considering separately in this review.

At present there are three basic methods of pulse interpolation available to compact prover designers - the double timing or double chronometry method, the quadruple timing method, and the phase lock loop method. The ISO document (ISO 7278/3) on pulse interpolation which will form part of the ISO Standard on pipe provers describes these three basic techniques, although at present it does not consider refinements and variations incorporated for particular applications.

The choice of pulse interpolation method for use with a small volume prover must take into account the meter being proved and the proving conditions which will be experienced in the field. The most important factor which has to be considered is the reaction of the pulse interpolation system to changes in the frequency of the pulses emitted by the meter being proved. These frequency changes can arise either from external sources ie flowrate changes which are generally of lower frequency, or from sources within the meter such as bearing wear or intra-rotational non-linearity in turbine meters or inherent periodicity arising from hydrodynamic sources in devices such as vortex meters. These are of much higher frequency, and because of the relatively short transit times in small volume provers it is the behaviour of the pulse interpolation system with short pulse timescale variations which are the greatest potential source of error and which therefore are of most interest.

A systematic study of the behaviour of the various pulse interpolation techniques in the wide variety of flow conditions which might be experienced in the field has not yet been carried out. A programme of work at NEL, however, is under way and will be undertaken in conjunction with the present evaluation work on small volume provers.

At present, however, certain conclusions can be drawn on the existing methods. For example the original quadruple timing method of pulse interpolation, shown in Fig. 6, is very susceptible to errors arising from differences in the widths of adjacent pulses. The phase lock loop system, shown in Fig. 7, must be designed to ensure that its response to sudden changes in pulse frequency is sufficient to cope with such changes which might arise from, for example, the poor intra-rotational linearity of a turbine meter.

The pulse interpolation techniques employed in the five small volume provers considered in this review are shown in Fig. 8. Four designs use double timing, while the fifth uses quadruple timing. Brooks, Smith and Skeltonhall (in the fixed volume mode) use double timing, in which the time between the leading edge of the first pulse after the first detector signal and that of the first pulse after the second detector signal is measured, together with the time between the detector signals themselves.

The Skeltonhall prover provides a refinement of the double chronometry method in which successive pulse widths are measured and stored throughout the prover pass. If any pulse width falls outside certain prescribed limits, then an alarm signal is given.

The Waugh technique is similar, except that the first time is taken as that between the leading edge of the first pulse <u>before</u> the first detector signal and that before the second detector signal.

The quadruple timing method employed by General Descaling is a distinct improvement over the original technique shown in Fig. 6. Here the interpolation is carried out on the actual pulses which are being generated while the detectors are being actuated. This means that the effects of intra-rotational non-linearity can be removed, although at the expense of the extra circuitry required to measure four periods instead of two.

Finally on the subject of pulse interpolation it should be stressed that the limitations to the various techniques have not yet been studied and reported in any detail. These limitations must also be considered in relation to the acceptable uncertainty and the tolerable variation in pulse frequency. Thus if a low level of interpolation was required, ie if a meter with a fairly high pulse density was being proved, then for a given uncertainty level a fairly wide variation of pulse frequency may be allowed. However if a meter with a very low pulse density was being proved, requiring a high degree of pulse interpolation, then very strict limits would have to be put on pulse frequency variations, otherwise a deterioration in the uncertainty level would be incurred. Quantification of these inter-related effects, however, awaits the outcome of further study.

5 FUTURE DEVELOPMENTS

This review of small volume provers has presented a survey of the characteristics of five provers from different manufacturers which are either established in the US or European market or are about to become available within the next year. It is believed that other designs both in the US and the UK are being considered for the North Sea market; however these designs are not sufficiently novel or different from those covered in this review, to be worth considering separately; nor are they likely to be in use in the next twelve months.

It is expected that the next few years will see the consolidation and acceptance of small volume provers in areas previously dominated by large conventional sphere type provers. It is extremely unlikely however that conventional provers will be completely superseded, certainly not before the end of the century. The shift of oil industry interest however, to deep sea wells, with the greatly increased production costs which this entails will mean that platform or vessel space will be even more critically allocated; it is unlikely in these high cost production systems therefore that off-shore proving would be carried out by conventional means. If off-shore metering was considered necessary this would almost certainly be done by a small volume prover.

The small size and low weight of these devices and their consequent transportability make them extremely attractive as transfer standards for locations where it is neither physically practicable nor economically desirable to install a dedicated proving system. Thus it may be that in future off-shore metering stations proving will be carried out by portable compact provers belonging perhaps to one of the calibration service companies who would be responsible for on-shore water draw calibrations against measures which are traceable to national standards. This arrangement would obviously involve the fiscal authorities and require considerable evidence of credibility.

With respect to the devices themselves all appear to show the promise of effectiveness in crude oil service. Apart from convincing the fiscal authorities of this fundamental design changes to the hardware is not envisaged. On the instrumentation ar1 software side it is expected that as in other areas of technology, substantial development will take place. Such developments are likely to include self checking facilities, more refined control chart analysis, and pulse interpolation systems which can be used with confidence under a wider range of conditions and with a wider range of meter types as these become more acceptable to the industry.

The lack of an in-line prover for natural gas is limiting the uncertainty levels achievable in gas flow measurement. There is in theory no reason why the small volume prover principle should not be applied to natural gas, and even with a slight reduction in the uncertainty level this would still be an attractive prospect.

It is to be hoped that future North Sea Flow Metering Workshops can report such developments and provide a forum for a critical discussion of their merits.

LIST OF TABLES

LIST OF FIGURES

T A B L E 1

COMPARISON OF A COMPACT AND CONVENTIONAL PROVER

	Compact	Conventional
Length (m)	3.0	14
Width (m)	1.2	1.5
Height (m)	0.76	2.4
Weight (kg)	1450	3000
Ground area occupied (m^2)	3.6	21.0
Space occupied (m^3)	2.74	50.4
Max. rated flowrate (m^3/h)	400	190

← dry weights

T A B L E 2

COMPARISON OF FLOWRATE RANGE, PHYSICAL DIMENSIONS AND WEIGHT

	Brooks	General Descaling	Skeltonhall	Smith	Waugh
Inlet/outlet dia., in	8	8	8	8	8
Max. flowrate, m^3/h	795	600	720	795	681
O/A dimensions: length, m	4	4.2	2.9	4.6	3.7
O/A dimensions: width, m	1.2	2.15	0.6	1.5	1.3
O/A dimensions: height, m	1.2	1.8	0.6	1.2	1.8
Weight, kg	2722	2500	900	2270	1451
Volume between switches, l	120	156	98*	159	87
Ground area occupied, m^2	4.8	9.03	1.74	5.9	4.81
Space occupied, m^3	5.76	16.25	1.04	7.08	8.66

*Prover swept volume

TABLE 3

COMPARISON OF FEATURES

Features	Brooks	General Descaling	Skeltonhall	Smith	Waugh
Mode of operation	UNI	BI	UNI	UNI	UNI
Bypass valve type	-	4-way spool	2-way ball	2-way plunger	2-way ball
Double barrel	No	Yes	Yes	No	Yes
Replaceable flow tube	No	Yes	No	No	No
Detector type	optical	inductive	-	optical	optical
Replaceable detector (without recalibration)	No	No	-	Yes	Yes
Pulse interpolation method	2-timing	4-timing	2-timing	2-timing	2-timing
Hydraulic system required	Yes	No	No	Yes	Yes
Gas supply required	Yes	No	No	No	No
Dynamic piston seal check	No	Yes	Yes	Yes	Yes
Turn-down	1000:1	1000:1	2000:1	1000:1	1000:1
Number of detectors	3	2 x 2	-	3	1

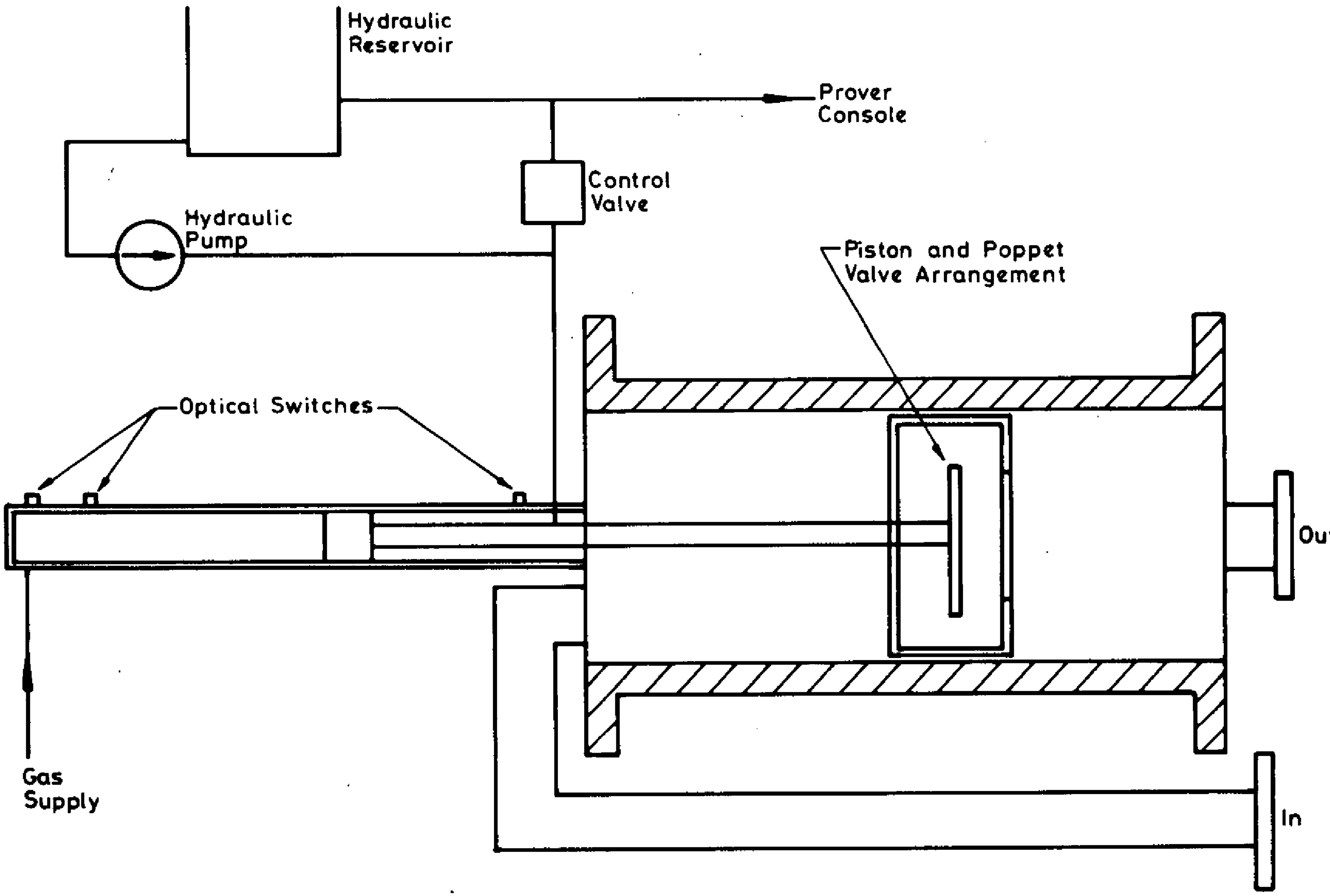


Fig 1   Schematic Diagram of Brooks Compact Prover

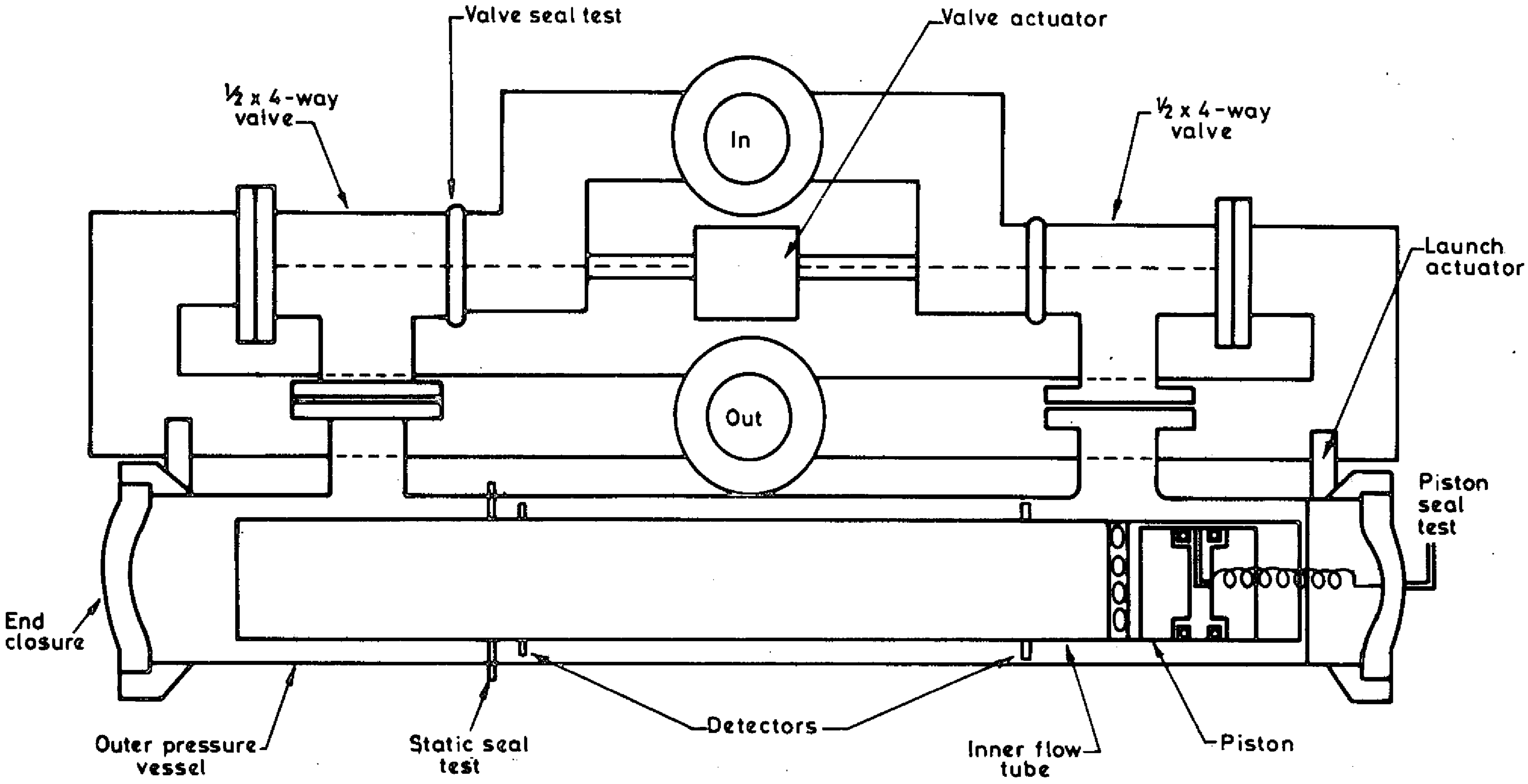


Fig 2 Schematic Diagram of General Descaling Prover

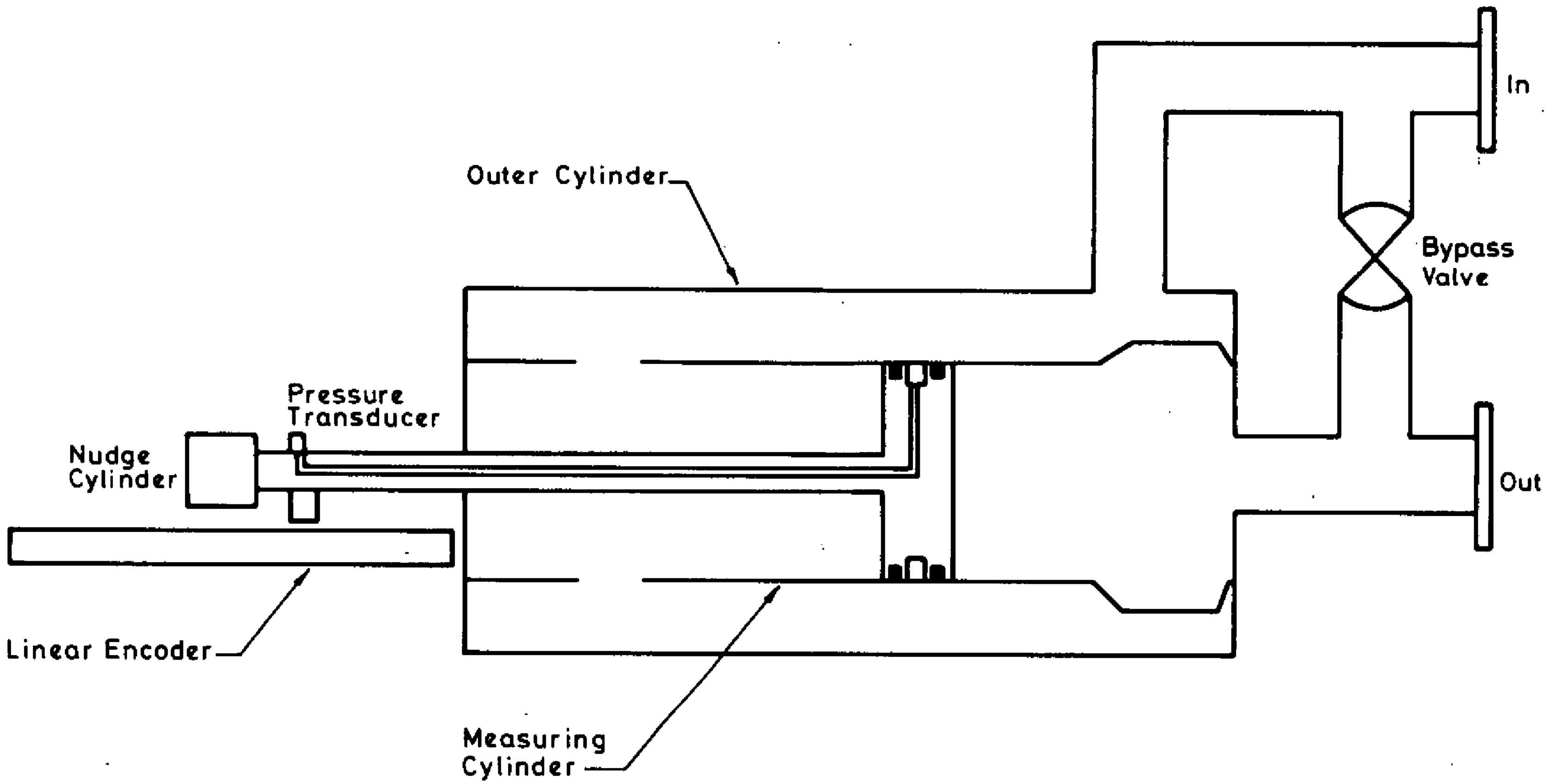


Fig 3 Schematic Diagram of Skeltonhall Prover

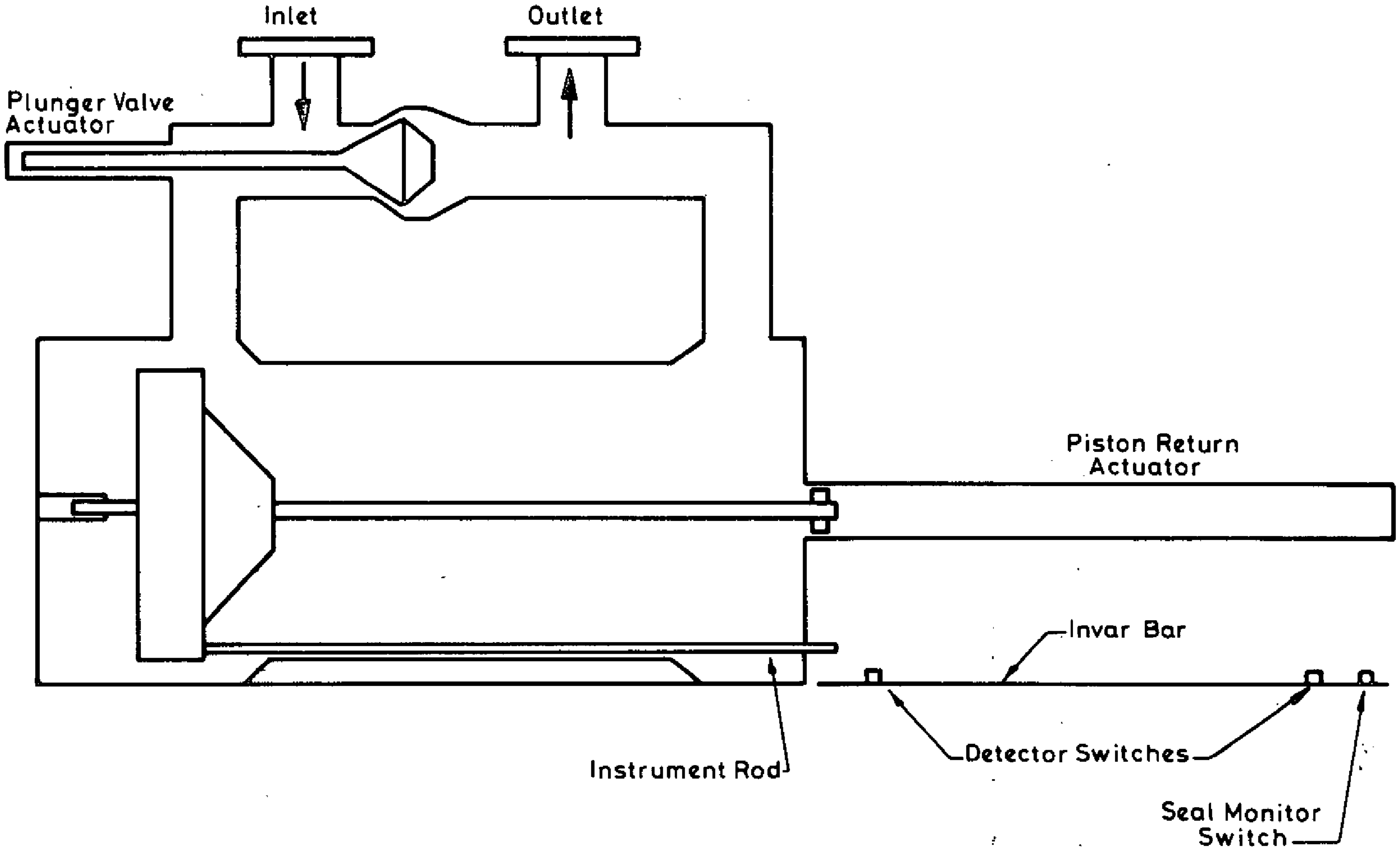


Fig 4 Schematic Diagram of Smith Systems Prover

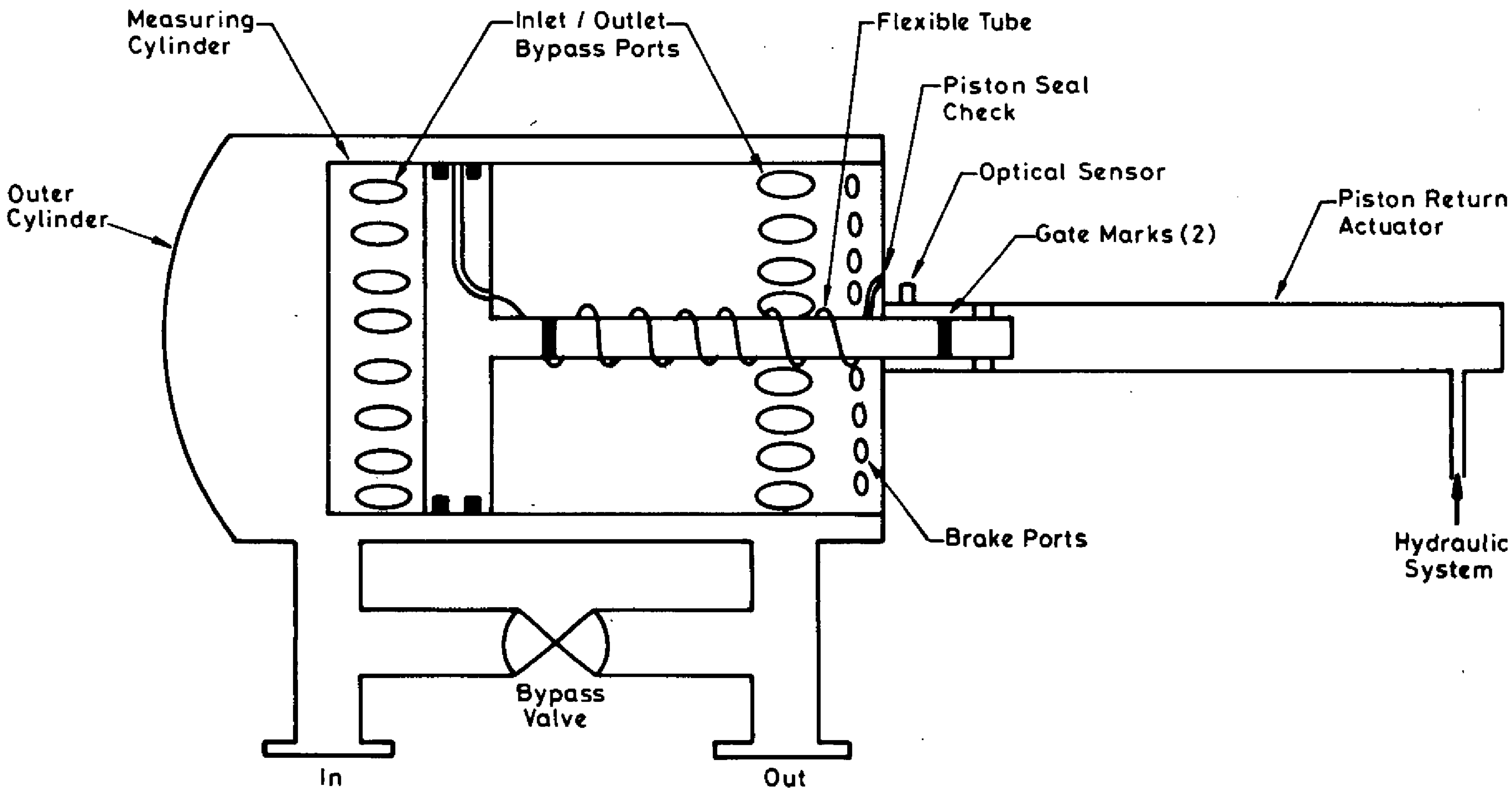
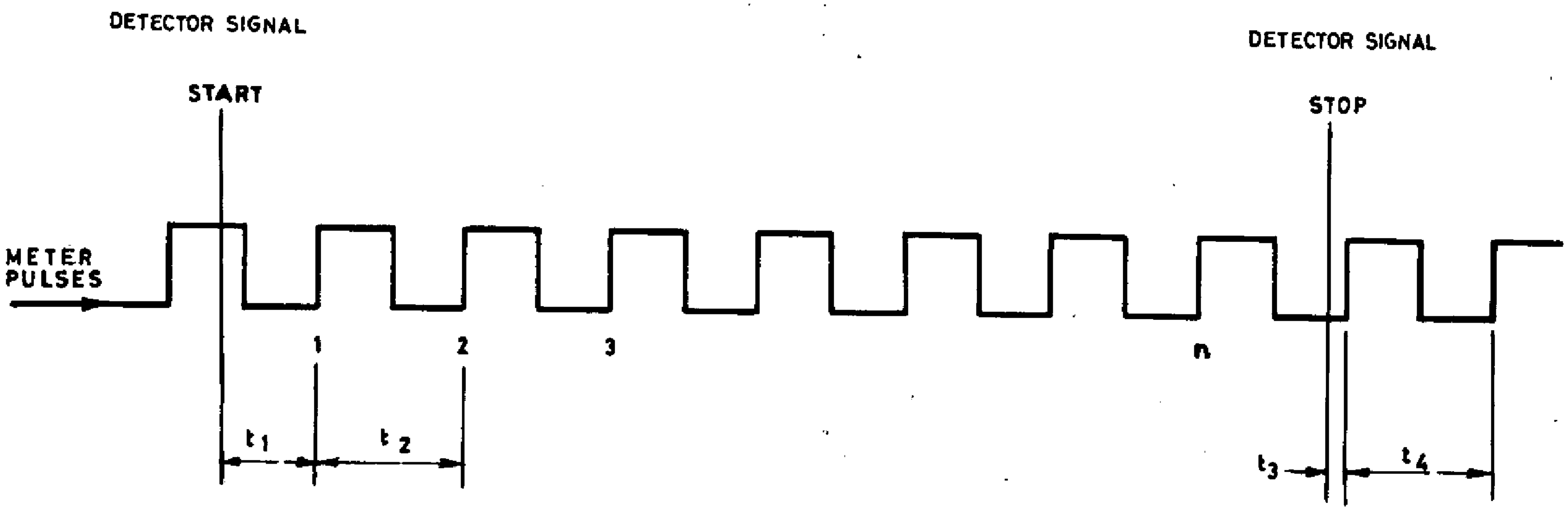
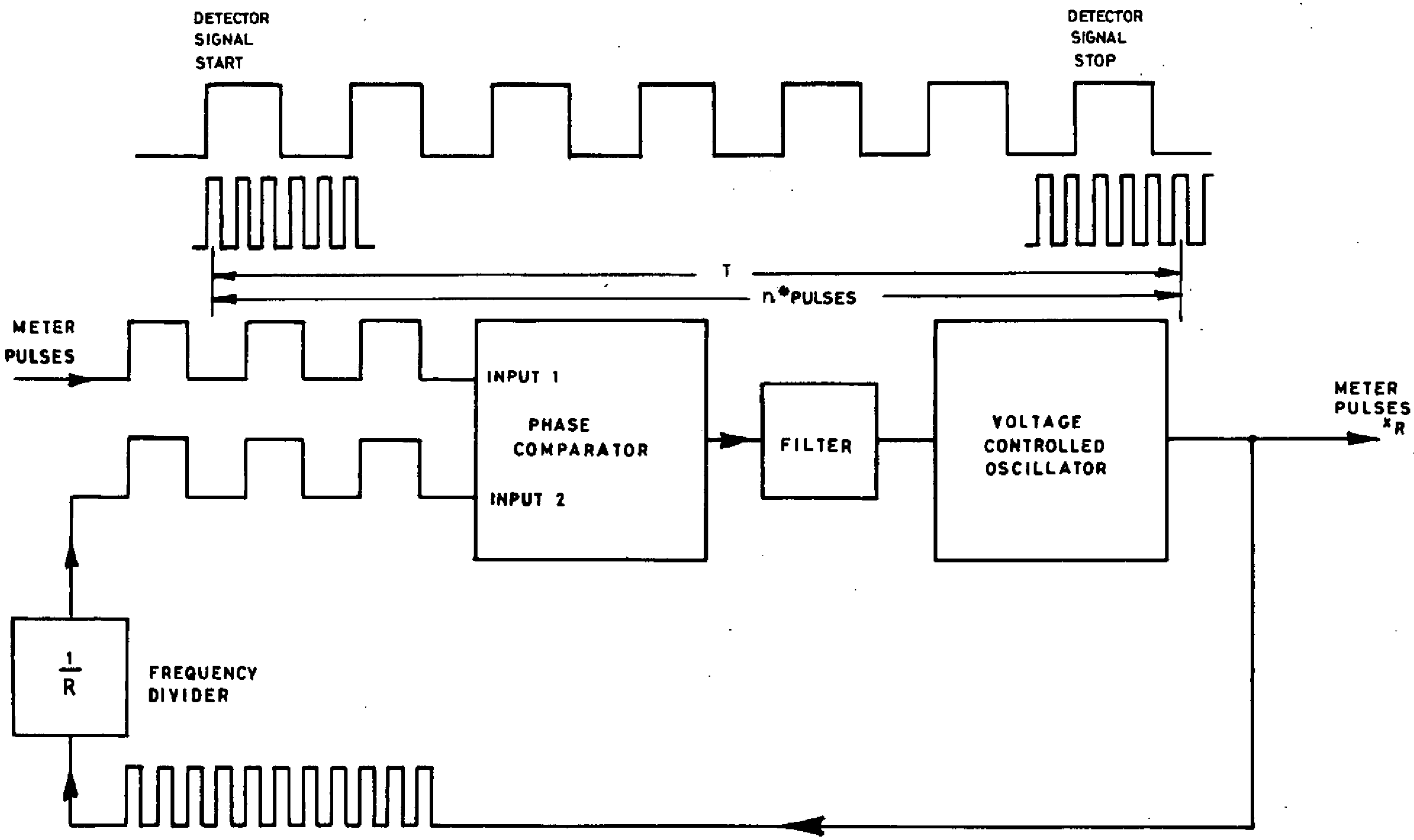


Fig 5 Schematic Diagram of Waugh Microprover



INTERPOLATED NUMBER OF PULSES $n' = n + \frac{t_1}{t_2} - \frac{t_3}{t_4}$

Fig 6 Original Quadruple Timing Method



INTERPOLATED NUMBER OF PULSES, $n' = \frac{n^*}{R}$

FIG. 7 PHASE-LOCKED-LOOP METHOD.

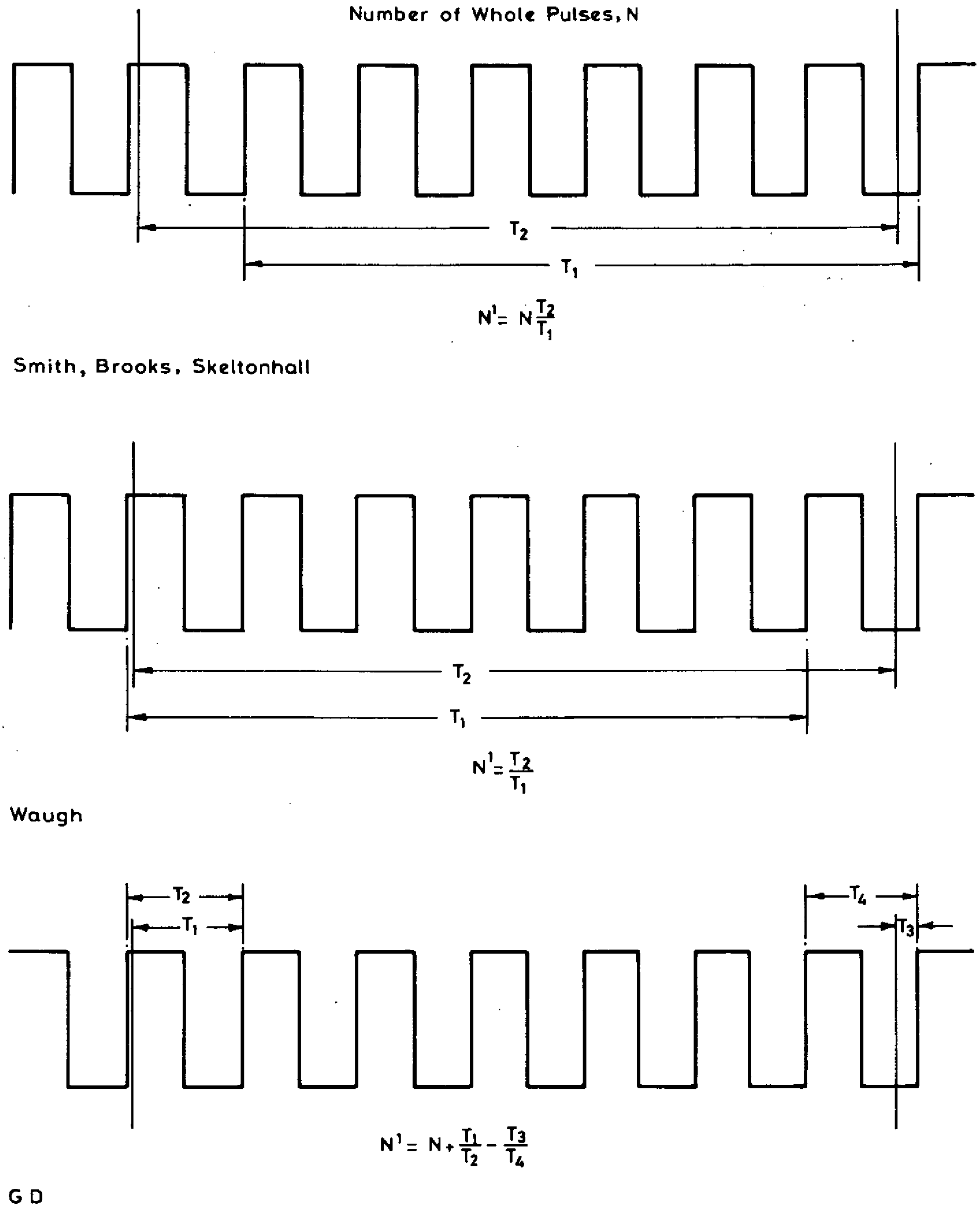


Fig 8 Comparison of Pulse Interpolation Methods

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.