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Theory and Application of Pulse Interpolation to Prover Systems

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This paper discusses a fractional pulse counting technique, which in its application to flow measurement (proving), has made small volume provers a practical reality.

History

In May 1978, the API Manual of Petroleum Measurement Standards was revised to allow bidirectional provers to be sized on the basis of a minimum number of pulses (10,000) per half trip of the displacer from the meter being proved.

Prior to 1978 the API Standard for bidirectional provers recommended a calibrated prover volume of 0.5% of the maximum hourly flow rate. A 2,500 BPH prover was required to have a volume of 12.5 barrels or 525 gallons.

For certain sized meter/prover combinations, the calibrated volume could be made smaller; thus, a smaller prover could be used with the associated lower cost. Due to the change in the requirements, various techniques have been developed to obtain additional pulses per unit of volume for meters used for petroleum custody transfer measurement, primarily positive displacement and turbine meters.

How are Meter Pulses Produced?

In order to fully understand the pulse interpolation discussion which follows, we need to know something about the source of meter pulses used for proving. The pulses obviously are produced by various devices within or attached to the meters themselves.

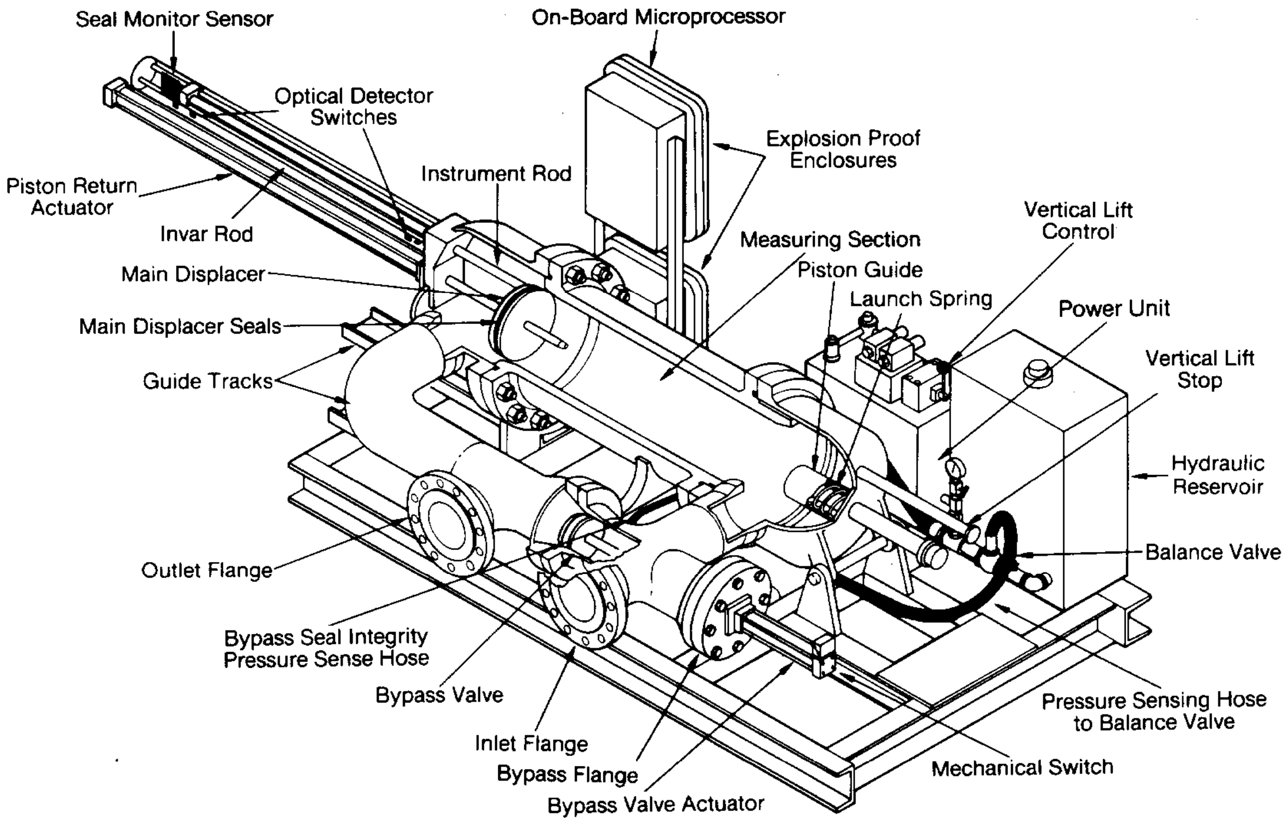


Figure 1 - Typical Small Volume Prover

Turbine meter pulses are usually produced by the action of a hi-mu button set into a rotor rim or by magnetic rotor blades themselves. This button, rotating past a reluctance type pickup coil, produces a sine wave output which can be made into a square wave or other configuration using electronic circuits. Up to four pulses per button or blade can be produced. In using these multiple pulses for proving, it is important that they represent true rotor motion, which is proportional to volume through the meter. Usually the rotor buttons must be approximately equal in size to the space between them, in order for multiple pulses per button to represent equal increments of rotor motion.

On positive displacement meters, optical transmitters, in combination with gears, are normally used to give pulse outputs even at zero velocity. Using various combinations of gears and optical discs, a variety of pulses

(1) Power Off State
Power is OFF; solenoids and hydraulic system will not operate. Fluid flow is illustrated with bypass valve fully open, the piston downstream and the selected meter run on-line with uninterrupted flow.

(2) Idle State
The piston is fully downstream after completing the prove cycle. The bypass valve remains closed until another proving cycle is commanded. The unit automatically remains "powered-up" for ten minutes unless manual shutdown or multiple proving cycles are selected.

(3) Return State
The bypass valve is opened momentarily, the piston is commanded to return to its upstream position. Fluid flow in the piston chamber briefly changes direction in response to piston movement.

(4) Pre-Prove State
When proximity sensing finds the piston fully extended, and the bypass valve fully closed, all flow is directed through the measurement chamber.

(5) Proving State
When bypass valve seal integrity is achieved, the piston is launched into the measurement chamber. As the piston assembly and instrument rod retract downstream, optical detection is triggered when the instrument rod flag passes each detector. Simultaneously, meter pulses and proving data are transmitted. Dynamic seal integrity is monitored while the piston passes through the measurement chamber and transmitted to the analog device at the end of piston travel.

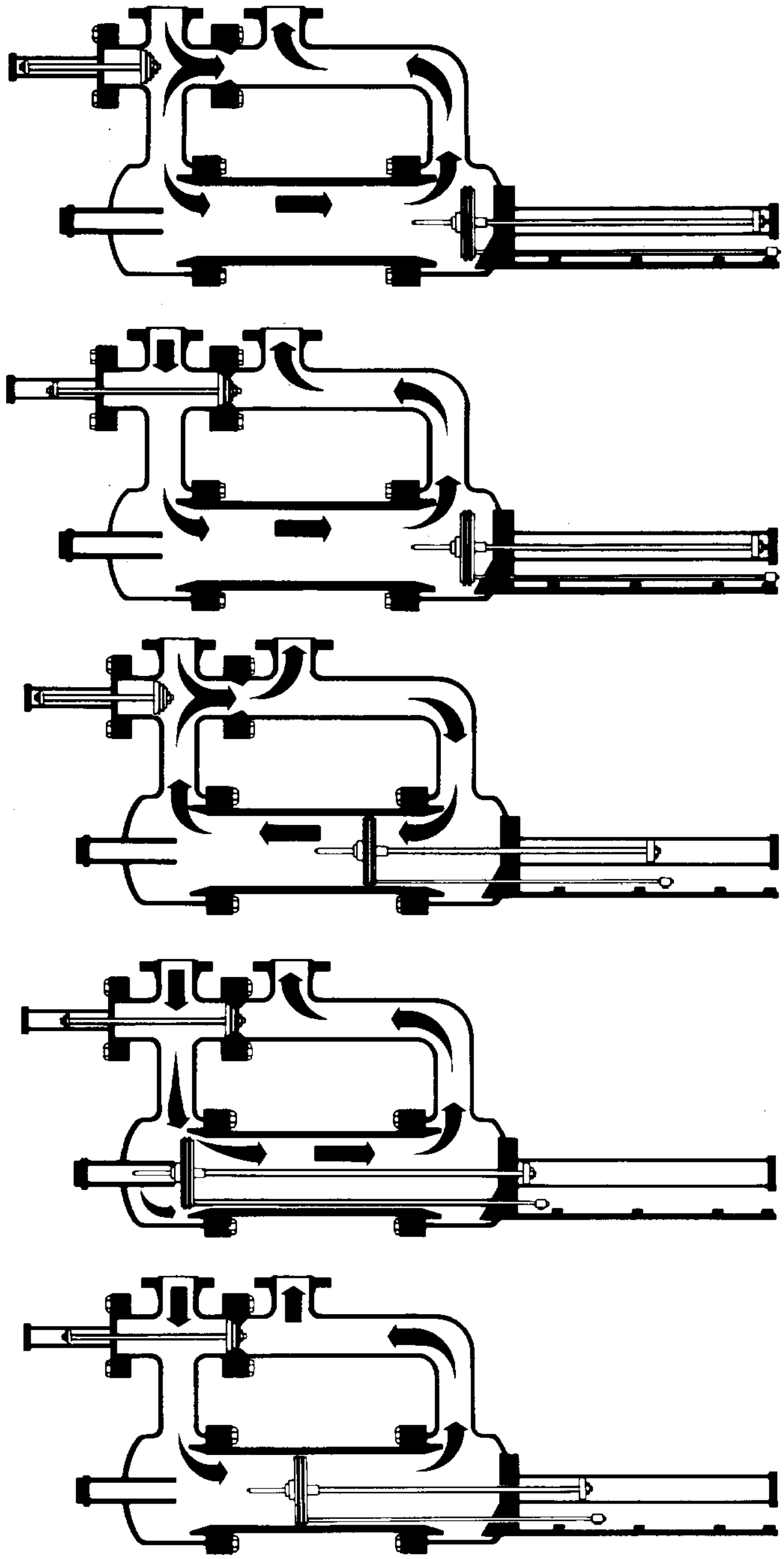


Figure 2 — Typical Small Volume Prover - Sequence of Operation

per unit volume are usually available; however, there are a number of practical limitations on the maximum pulses available per unit volume. These pulses represent equal volume increments, only if the associated gear trains and optical disks are made with great precision.

In order to gain even more enhanced resolution from either type of meter pulse, interpolation techniques are used.

What is Pulse Interpolation?

Most of the techniques used to achieve additional pulses are dependent on resolving or "interpolating" the fractional difference between a) the start of the calibrated proving volume and the first meter pulse, and b) the last pulse before the end of the calibrated proving volume and the end of the proving volume. This then allows counting of the full pulses, plus the two fractional amounts, and adding of the two fractional amounts to the whole pulses, alternatively, the fractional pulse between the end of the proving volume, and the pulse after the proving volume can be subtracted from the full pulses counted. The sum of the two fractional amounts can vary from slightly more than zero to just less than two complete pulses. The precise resolving of these fractional pulses is termed pulse interpolation. The ability to accurately and economically perform this interpolation, paved the way for provers with relatively small volumes.

Why Resolve Fractional Pulses?

Resolving fractional pulses into a large number of parts allows the use of considerably smaller volumes between detectors. The use of smaller volumes presents the following advantages:

a. Proving time is considerably shorter using a small volume prover. A proving which previously required 35 seconds, now only requires one second.
b. A smaller amount of fluid is required to pass through the prover to accomplish the proving. This is significant when proving, for example, a load rack meter, where the fluid used must pass into a relatively small tank truck compartment. A 525 gallon prover can be reduced to 15 gallons.
c. Due to short proving time and compact size, one small volume prover can serve a large number of meters, either through permanent piping or through a portable arrangement for meters equipped with quick connection devices.
d. For equivalent maximum flow rates, a small volume prover is less costly than a bidirectional or unidirectional prover.
e. Applications with restricted space requirements, such as offshore platforms, favor use of small volume provers.
f. Small volume provers offer rangeability of the order of 1,000 to 1; thus, one prover can serve a larger variety of meter sizes.

Figure 1 shows a typical small volume prover and Figure 2 shows the sequence of operations.

What Techniques are Used to Resolve the Pulses?

Various techniques can be used to perform pulse interpolation. They involve multiple timers and/or high speed electronic devices. Fortunately modern microprocessors are able to be programmed to perform the high speed computations required.

Four Timer Technique

One technique is the low frequency pulse technique or the four timer technique, said to be developed by the Japanese (see Figure 3). Note that TA, TB, TC, and TD are each timers with start and stop representing displacement detectors. TB and TD represent time for complete pulses immediately adjacent to those to be resolved. TA represents a time proportional to the fraction of the pulse after the start to be added to N, the whole number of pulses, and TC represents a fraction of a whole pulse beyond the stop which must be subtracted from N. Thus, the exact number of pulses between start and stop is:

$$N' = N + \frac{TA}{TB} - \frac{TC}{TD}$$

Note that this method has the advantage that TB and TD are measured adjacent to the fractional pulses and are proportional to the flow rate at the beginning and the end of the proving run; thus, it can compensate for flow rate variations during proving.

Phase Locked Loop Technique

The second method, which is attributed to the British, is the phase locked loop technique (see Figure 4). A voltage controlled oscillator is used to produce a high frequency pulse stream at a factor, X, higher than the input pulse stream. This pulse stream is continuously divided by X and compared with the incoming stream by a phase comparator. The phase comparator output is routed via a filter to the control input of the voltage control output. The effect of the comparator/filter combination is to precisely adjust the VCO output to keep X an integral number through the use of a precise divide circuit, 1/X. This electronic "flywheel" compensates for changes of flow rate pulse by pulse. The output is N times X. The phase locked loop method can reliably interpolate only symmetrical meter pulses.

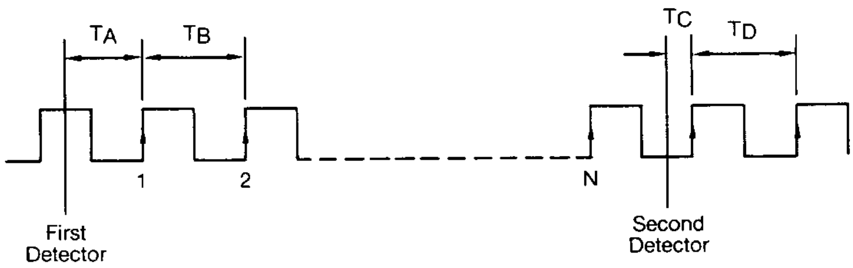
Dual Pulse Chronometry

The third technique, developed by the French, is termed dual pulse chronometry and is illustrated in Figure 5. High resolution crystal controlled clock pulses (approximately 150,000 Hz) are gated into counter T1, by integral meter pulses beginning with the first meter pulse after the first detector switch and ending with the first meter pulse after the second detector switch. These clock pulses are termed T1. N is the number of whole meter pulses which occurred in the time interval represented by T1. T1/N is equal to the number of clock pulses equivalent to a whole meter pulse.

A second precision counter, T2, is capable of accumulating the same high resolution clock pulses from the same source as Counter T1. Counter T2 starts accumulating clock pulses when the first detector switch is activated and stops after the second detector is activated. T2 then represents the number of clock pulses equivalent to the precisely calibrated prover volume.

By dividing T2 by the pulses per whole meter pulse T1/N, we can then determine the magnitude of the fractional meter pulses which occur between the first detector and the first meter pulse and the last detector and the next to the last meter pulse. This formula reduces to N (T2/T1) and is equal to N' the exact number of whole and fractional meter pulses between detectors.

All of the above methods have been used for pulse interpolation with acceptable results.



$$\text{Interpolated Pulses } N^1 = N + \frac{T_A}{T_B} - \frac{T_C}{T_D}$$

Example:

$N = 6{,}100$
$T_A = 40$
$T_B = 45$
$T_C = 10$
$T_D = 50$

$$N^1 = 6{,}100 + \frac{40}{45} - \frac{10}{50} = 6{,}100 + 0.888 - .02 = 6{,}100.688$$

Figure 3 — Four Timer or Low Frequency Pulse Technique

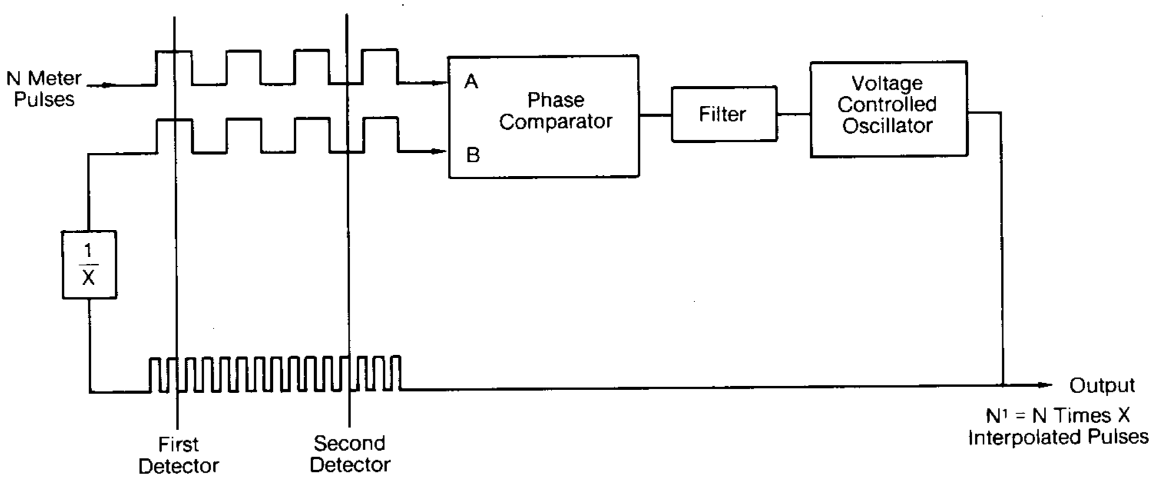


Figure 4 — Phase Locked Loop Method

Application to Small Volume Provers

Independent of the method of pulse interpolation, small volume provers must be constructed with detector switches that are repeatable to better than 0.02% or 2 parts in 10,000. A typical small volume prover optical detector is, in fact, repeatable to 0.001 inch in 27.4 inches or 1 part in 27,400. Detectors which determine the precise volume must be mounted on a material which does not change the length between switches due to temperature changes. This is usually an invar type of material.

In addition to the pulse interpolation electronics, small volume provers are typically equipped with electronics to provide control and data collection functions.

What Other Components are Necessary for Use of the Technique with Small Volume Provers?

A small volume prover performs the proving function by displacing a volume of fluid through a cylinder with a piston. The piston is propelled through the cylinder by the flow of the fluid itself. When the prover is idle, the piston is removed from the flow stream. Normally, a proving constitutes the displacing of fluid during motion of the piston in one direction. The prover is cocked or prepared for a proving stroke by moving the piston upstream using an external pneumatic, hydraulic, or mechanical means. When the piston is being moved upstream, the flow is diverted through a bypass path in order to not shut off the flowing stream. The bypass is then closed and all flow is through the calibrated measuring section. The piston is mechanically, hydraulically, or pneumatically pushed or launched into the flow stream and carried to the opposite end of the measuring section by the flow stream itself. The displacement of the piston is communicated out of the cylinder by a device attached to the piston. This device carries a flag to activate the displacement sensing equipment. Positive sealing of both the main piston and the bypass arrangement is essential to proper small volume prover operation.

Piston seals are normally of the dual cup type and are designed to positively seal from one side of the piston to the other. In order to prove the integrity of the seal, monitoring of the cavity between the seals is essential. This can be done using various pressure or differential pressure sensors.

In order to properly seal, and not cause excessive seal wear and provide accuracy through the displacer stroke, smooth surface finish, roundness, and concentricity of the measuring section cylinder bore is essential. Cylinder bores are normally honed and plated and have a thick wall for dimensional stability. Seal life and cylinder bore life can be greatly increased when using dirty products if the measuring section is mounted vertically, so particulate matter cannot collect in the bore. It is also desirable to have the seals leave the bore on each stroke so they may be flushed by the fluid stream.

During the upstream stroke of the main piston, equipment must be provided to divert flow. This is usually done with some sort of bypass valve. It is desirable to construct the bypass arrangement so that seal integrity can be monitored. This can be done using double seals with pressure monitors in between. Normally, the bypass is an integral part of the prover.

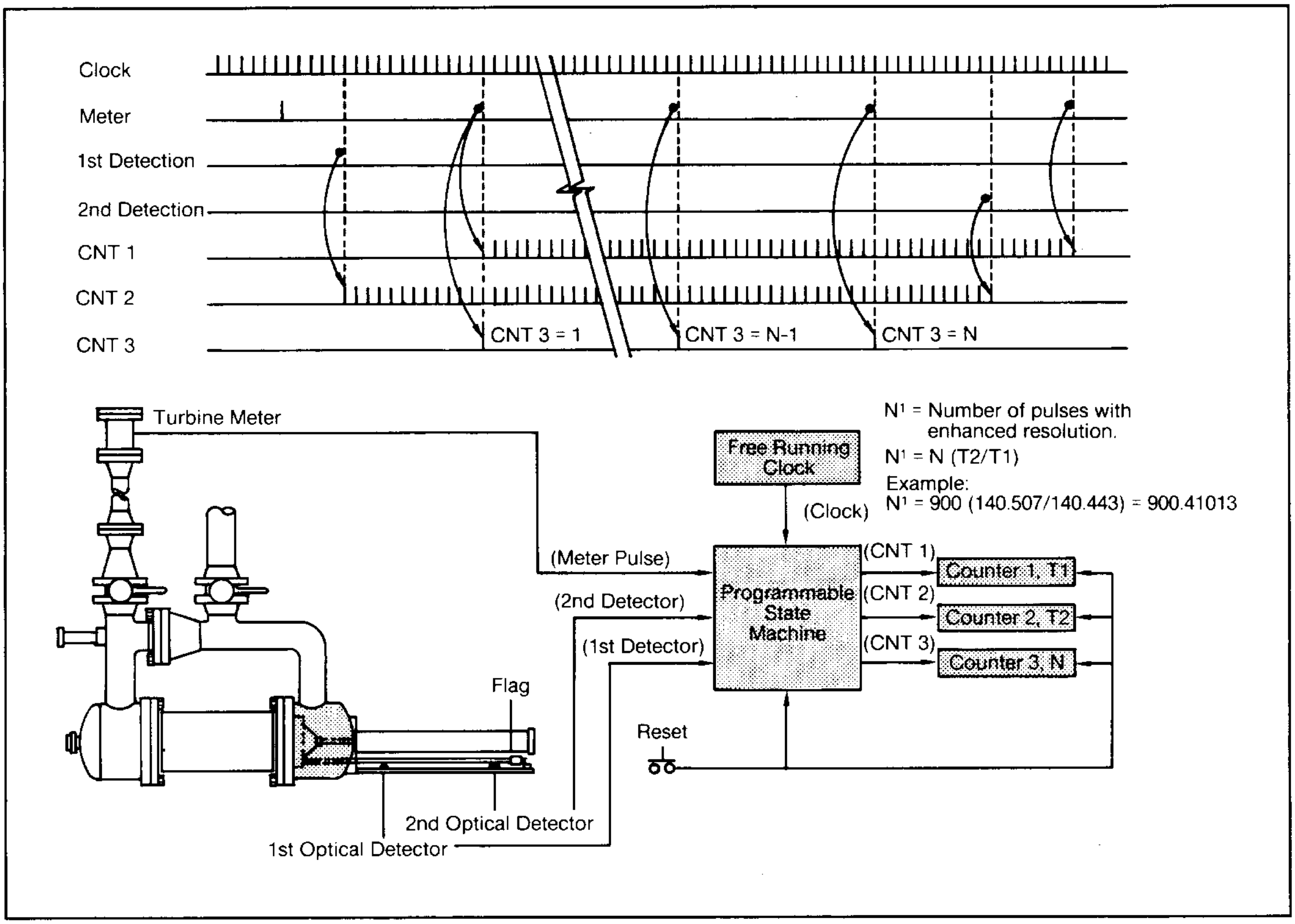


Figure 5 — Dual Pulse Chronometry Pulse Interpolation

The electronics package for the small volume prover must not only receive the meter and the detector switch signals and do the pulse interpolation calculation as previously explained, it must also control the entire sequence of operations in order to repeatedly operate the small volume prover. Microprocessor-based equipment is well suited to the application and is normally used. The control system must withstand the ambient temperature variations in the area used and be suitable for hazardous areas as defined in the National Electric Code.

What Are Code Requirements Applicable to Small Volume Provers?

Meter proving equipment usually must meet a number of national and local codes. The measurement accuracy requirements are specified in the API Manual of Petroleum Measurement Standards and National Bureau of Standards Handbooks.

Design, fabrication, and inspection of the pressure retaining parts are specified in ASME/ANSI Standards B31.3 for Refinery Applications and B31.4 for Pipeline Applications. These standards reference the ASME-Boiler and Pressure Vessel Code Sections IIA, IIC, V, VIII, and IX, and API Standard 1104.

Electrical safety requirements for hazardous areas are covered by the National Electric Code and National Fire Protection Association Publications.

For applications overseas the corresonding national codes would apply. For ship-mounted equipment the American Bureau of Shipping, U.S. Coast Guard, Det Norske Veritas, Lloyds, Bureau Veritas, or other standards would be applicable.

Conclusion

Pulse interpolation techniques combined with present electronic, optical, mechanical, and hydraulic technology have allowed small volume provers to be technically and practically feasible. All requirements of the API Manual of Petroleum Measurement Standards Specifications can be met. Small volume prover performance is equal to, or superior to, that of conventional uni or bidirectional provers, and they offer a large number of advantages over their predecessors because of compact size and speed of operation. As with any other precision measurement device, the small volume prover must be properly specified and applied.

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