THEORY AND APPLICATION OF PULSE INTERPOLATION TO LIQUID METER PROVER SYSTEMS

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PULSE INTERPOLATION

Pulse interpolation, by definition, is the ability to estimate values of (a function) between two known values. Therefore, pulse interpolation enables pulse counts to be made to a fraction of a pulse, thus greatly reducing the rounding - off errors that occur when pulse counts are made to the nearest whole number; which always happens in the absence of Pulse Interpolation.

INTRODUCTION

The flow meter has long been established as the industry "cash register". With the high cost of producing and the reduced selling price of products, the accuracy of the meter becomes increasingly important to ensure profitability. To this end regular "proving" of the meter is essential. Liquid meter proving is carried out by placing a Meter Prover in series with the meter under test; the prover having a calibrated base volume. Proving of the meter is by comparing the quantity recorded by the meter with the calibrated quantity displaced by the prover.

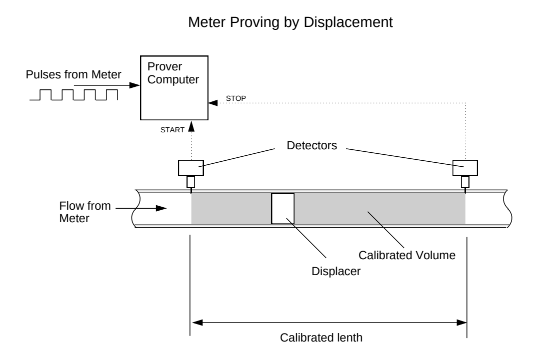


FIG. 1

When sizing meter provers one of the main criteria is that counting meter pulses during the proof run must not contribute more than 0.01% to the overall uncertainty of the proving results. This requires a minimum resolution of 1 part on 10,000.
Traditionally this has required sizing and designing the prover to have a volume between the detector switches that allows the flow meter being proved to generate a minimum of 10,000 pulses between the switches.

For any conventional pulse counting technique, the counter can only discriminate to one pulse irrespective of the number of pulses counted. This results from the fact that the "start" and "stop" detector switch signals occur randomly along the meter pulse train.

The effects of the random start and stop are illustrated in Fig.2 (Pulse train A and B) where for the same pulse train either 7 or 8 pulse cycles can be counted depending upon the relationship of the start and stop signal with the trigger point of the pulse. In this case the rising edge. Pulse train C illustrates that the actual number is somewhere in between. In this example 7.255 pulses.

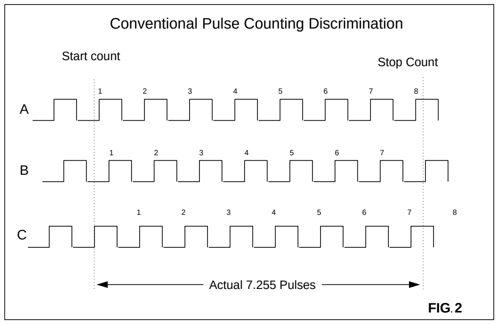


FIG. 2

This has in the past dictated that the volume between the detectors must be sufficient to generate 10,000 pulses from the meter under test.

1 Pulse in 10,000 = 0.01%

This paper will discuss the different methodologies for maintaining accurate flow meter proving while collecting fewer than 10,000 pulses from the flow meter and conform to the industry acceptance of 0.01% uncertainty.

< 10,000 PULSES

The introduction and acceptance of small volume provers has resulted in the requirement for a pulse counting technique that can discriminate to fractions of a pulse and still meet the requirement to limit the uncertainty to 0.01%.
The use of this counting technique has also been extended to allow proving of low frequency output meters such as to helical turbine meters, and the reduction in size of some conventional ball provers, as long as the required length between detectors is maintained. This counting technique is generically referred to as PULSE INTERPOLATION.

REQUIRMENTS

The requirement for any pulse interpolation is to count the actual full meter pulse cycles between the detector gates and to interpolate any partial pulse cycles at the start and end of the counting cycle.

This is illustrated in Fig. 3 where conventional counting will total 350 pulses while pulse interpolation will result in 0.150 + 349 + 0.015 = 349.255 pulses, thus eliminating a potential error of 0.21%. .

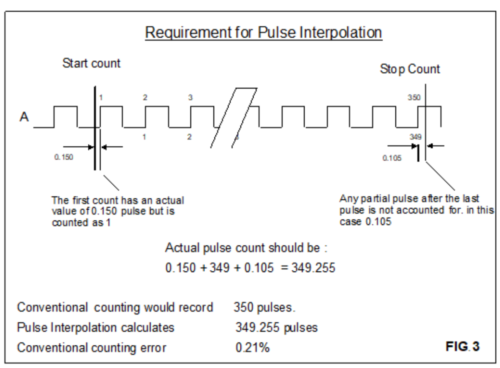


FIG. 3

METHODOLOGY

There are currently 3 main approaches to pulse interpolation:

1) Dual Chronometry (or Double Timing)

As its name implies this approach utilizes two timers, one times the interval between detectors, and the second times the interval between the nearest integer of meter pulses.

The interpolated number of pulses between detectors is derived from the ratio of these times. This is by far the most common method in use and is the only method detailed in API Chapter 4, Section 6. Proving Systems- Pulse Interpolation.

The times T_1 and T_2 are derived from the same high frequency oscillator (1 Megahertz). The sequence is:

Timer 1 is started when the first detector switch is actuated.

Timer 2 is started by the leading edge of the next flow meter pulse after the first detector switch is actuated.

The pulse counter starts on this same pulse.

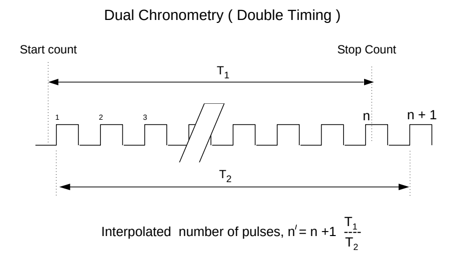


FIG.4

Timer 1 is stopped when the final detector switch is actuated (This is the time for displacing the known
calibrated volume.)

Timer 2 is stopped with the leading edge of the next flowmeter pulse after the final detector switch is actuated.

The pulse counter stops on this same pulse and therefore records the number of pulses received from the flowmeter during time 2; this is an integer n+1

We can state that if n+1 pulses were generated by the flowmeter in T_2 Secs then the number of pulses generated by the flowmeter for the calibrated volume in T_1 Secs. is:

$$n' = n+1 * T_1 / T_2$$

Thus if: n+1 = 658,
T_1 = 0.64579 sec.
T_2 = 0.64719 sec.

Then interpolated pulses:

n'= 658 *0.64579 / 0.64719 = **656.57662** pulses

It follows that
n' / volume = K-factor.

In practice we would calculate as:

$$K = \frac{T_1}{Vol} \times \frac{n+1}{T_2}$$

The interpolated number of meter pulses provides a pulse resolution greater than the 1 part in 10,000 required.

2) <u>Quadruple Timing</u>

This method is also based upon timing; four times are required; the interval between successive pulses, near the start and also near the finish of each pass. The intervals (fractions of a pulse) between the operation of a detector and an immediately adjacent pulse. The ratio between the pulse interval and the fractional pulse interval, gives the interpolation with the full number of pulses counted.

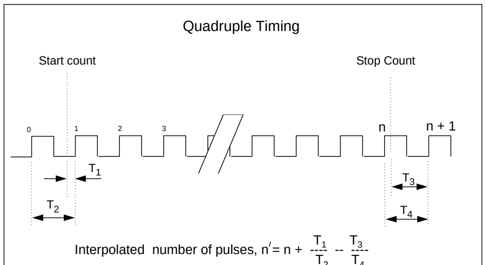


FIG. 5

Times T_1, T_2, T_3, and T_4 are derived from the same high frequency oscillator.

Timer 1 records the time from the first detector switch actuation to the leading edge of the next flowmeter pulse.
The pulse counter starts on this same pulse.
Timer 2 is timing the pulse intervals and records the time for the pulse coincident with the first detector switch
Timer 3 records the time from the final detector switch actuation to the leading edge of the next flowmeter pulse.
The pulse counter stops on the on the leading edge of the next flowmeter pulse after the final detector switch. This is an integer n+1
Timer 4 is timing the pulse intervals and records the time for the pulse coincident with the final detector switch.

We can see that for the first flowmeter pulse counted as 1 this in fact was fraction of 1 pulse (T_1 / T_2). For the last flowmeter pulse counted as 1 was in fact too great by a fraction of 1 pulse (T_3 / T_4)
Therefore the number of pulses generated by the flowmeter for the calibrated volume was

$$n' = n + (T_1 / T_2) - (T_3 / T_4)$$

3) <u>Phase-Locked-Loop</u> Figure 6a
This method does not involve timing but instead senses the frequency of the current meter pulses and generates a parallel train of pulses at higher frequency using a fixed constant. The number of high frequency pulses is counted between detectors and the resultant number is divided by the constant to give the interpolated pulse count.

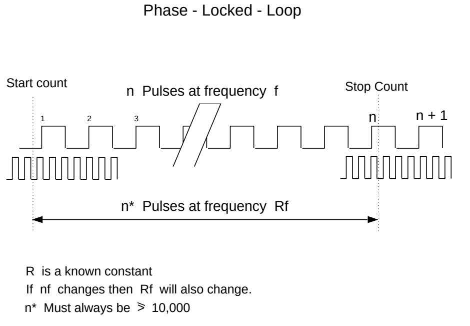


FIG. 6a

A frequency Rf is generated which is a fixed constant R above the flowmeter frequency. The pulses of Rf are counted between the actuation of the first detector and the final detector. The totalized pulses are then divided by R to obtain the interpolated pulses.

$$n' = \frac{n^*}{R}$$

Thus if $n^* = 10{,}500$
$R = 30$

then $n' = 350$

As the pulses of Rf are counted by conventional technique the factor R must be high enough to result in pulses counted exceeding 10,100.

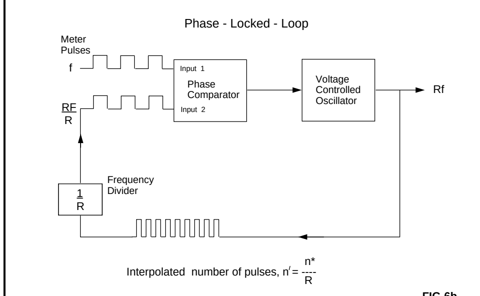


FIG.6b

For each flow meter pulse, the voltage-controlled oscillator generates R number of pulses at a frequency Rf. As the flow meter pulse frequency, or pulse period, can change with flow fluctuations or from non-uniform pulse trains, the frequency Rf must remain in the same ratio with the flowmeter pulse frequency f at all times, thus for any flowmeter pulse period, R number of pulses are generated. To meet this criteria the generated pulse output Rf is divided by factor R and, as this should now be the same frequency as the flowmeter pulses f, the phase comparator compares this with the flowmeter pulses. Any discrepancy in phase between these two pulse trains is detected and the Voltage controlled Oscillator adjusts Rf to maintain the two pulse trains in phase.

APPLICATIONS

In sizing conventional provers, 3 main criteria are considered:-

A. Distance between detectors.
B. Volume between detectors.
C. Displacer velocity.

A. With intrusive sphere detectors the uncertainty of the sphere position is typically 1mm.

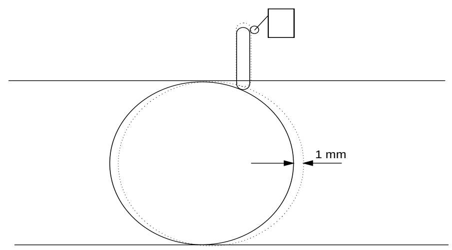


FIG.7

As this uncertainty applies to both the first and final detectors the total uncertainty is typically 2 mm.
As this uncertainty must only contribute only 0.01% to the total uncertainty, this dictates a minimum distance between detectors of 20 meters.

B. With conventional pulse counting, as illustrated in the introduction, irrespective of the number of pulses counted, the uncertainty is 1 pulse. Therefore, a minimum of 10,000 pulses are required to be counted between detectors

1 Pulse in 10,000 = 0.01%

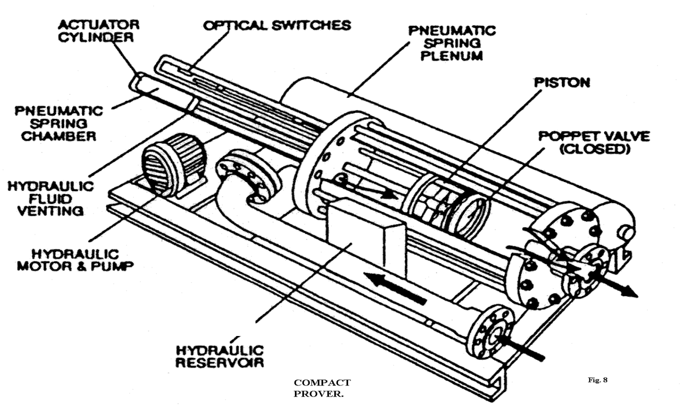
C. The Displacer velocity must meet the recommendations of API.

Compact Provers - Figure 8

The most significant feature of the Compact prover is the precise detection of displacer position using opto-electric detector switches. This results in the calibrated volume being far too small for the flowmeter to generate the required 10,000 pulses, thus requiring the use of Pulse Interpolation.

Low Frequency Meters

Pulse interpolation now allows both Compact and conventional ball provers to cover the calibration of flow meters with a low frequency output. For example helical turbine meters.



Compact Prover Fig. 8

Reduced Volume Provers – Figure 9

Another application of Pulse Interpolation is in reducing the volume of conventional ball provers.

Pulse interpolation overcomes the need for the prover volume to be sufficient for the flowmeter to produce 10,000 pulses.

While this, in theory, can greatly reduce the ball prover volume, the sizing of the prover must still meet the requirements for distance between detectors and sphere velocity

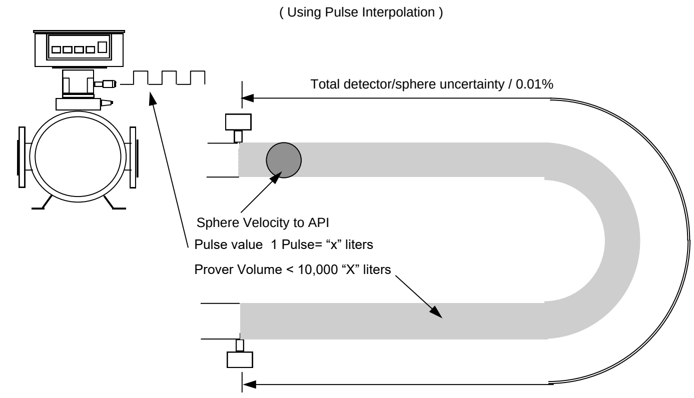


Fig. 9

CONCLUSION

Pulse Interpolation has proven to be a reliable technique for resolving fractional pulse counts to a high degree of accuracy. While only the Dual Chronometry method is illustrated in the API Manual of Petroleum Measurement Standards, this does not preclude the use of other methods, as long as they meet the criteria and test procedure of Chapter 4.6.

Compact Provers utilizing pulse interpolation has allowed us to redefine field proving and reduce our cost of calibration. Pulse interpolation greatly reduces the size of the prover and has been the basis for the world wide acceptance of Compact Provers world-wide and for extended usability of conventional Ball Provers.

REFERENCES

American Petroleum Institute (API) Manual of Petroleum Measurement Standards.

Chapter 4.1 Introduction.

Chapter 4.2 Displacement Provers.

Chapter 4.6 Pulse Interpolation.