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OPERATION & PROBLEMS ASSOCIATED WITH PROVER DETECTOR SWITCHES
Class #4100

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INTRODUCTION

In many parts of the petroleum industry, sphere provers are used to dynamically calibrate volumetric meters. In order to accomplish this, sphere provers are required to be accurate and repeatable. This accuracy and repeatability is largely dependent on performance of the prover sphere detector. Any operational or design problems associated with the prover detector will affect the prover's performance. This paper will review critical parts of a prover sphere detector that must be checked in order to obtain accuracy reliability and repeatability. The areas that will be covered are:

- Prover detector accuracy.
- Prover detector mechanical repeatability.
- Prover detector electrical repeatability.
- Prover detector performance due to prover sphere contact length.
- System accuracy and repeatability.

PROVER DETECTOR ACCURACY

Prover detector accuracy is one of the parameters that governs the performance of a prover system. Small imperfections or variations in the detector's dimensional tolerances can have a significant impact on the prover's volume. In addition, changes in these tolerances due to normal operations impacts the prover's ability to accurately determine a meter factor. Therefore, it is very important to have a program or procedure to check the dimensional tolerances of each detector component or to check the overall dimensional tolerance of the complete detector. This is necessary on initial detector installation and subsequent calibrations.

Sphere type prover detectors typically use some type of plunger or probe inserted into the pipe that contacts the sphere as the sphere passes by the detector. When the sphere first contacts the detector, the plunger or probe starts moving the electrical switch. Typically, the switch point is usually somewhere between initial contact with the sphere and the point where the rod or probe reaches the edge of the prover pipe. In order to understand this relationship, we need to review the equation that governs the sphere verses detector movement. This equation is,

$$\Delta X = \sqrt{(D+d)(I_1) - I_1^2} - \sqrt{(D+d)(I_2) - I_2^2}$$

Where:

D = Diameter of Sphere or Inside Diameter of the pipe prover

d = Diameter of actuator detector probe

I_1= maximum detector actuation depth

I_2 = minimum detector actuation depth

I_1-I_2 = Range of detector actuation repeatability

ΔX = sphere position repeatability or range of sphere positions

The subscripts 1 and 2 represent the switch maximum and minimum switch points. The difference between these two points is the range of detector repeatability. A visual representation of the sphere to detector relationship can be found in Figure 1.

As seen from the equation, the key variables that impact the sphere to detector relationship are prover sphere diameter, detector plunger diameter, and plunger insertion depth. When these values are known, this equation can be a very useful tool for determining a prover's sensitivity to changes in detector dimensions. When a detector is replaced with a new style of detector, the equation can also give an estimate of the new prover volume.

When a detector is chosen and the dimensional tolerances are known, the mechanical repeatability of the detector can be used to determine the prover accuracy. By using the equation above, we can calculate the linear accuracy of the sphere from the detector repeatability. Once the linear accuracy of the sphere with respect to the detector is known, the accuracy of a prover can be determined from the equation:

$$P_a = \frac{\Delta X \sqrt{N_{Det}}}{L}$$

Where:

P_a = Prover Accuracy

N_{Det} = number of times a detector is actuated during a calibration run (unidirectional = 2 for a single pass, bidirectional =4 for two passes)

L = Length of the calibrated section of the prover

Conversely, if the desired prover accuracy is known, the minimum prover length for a given detector accuracy can be determined by:

$$L \min_{Det} = \frac{\Delta X \sqrt{N_{Det}}}{P_a}$$

Where:

$L\min_{Det}$ = Minimum calibrated section length based upon the prover detectors

Due to the mathematical relationship between the sphere and the detector, several important points should be noted. First, to minimize proving error caused by detector uncertainty, the detector actuation depth should be as long as practicable without interfering with the movement of the sphere. A graph showing the importance of detector insertion depth is found in Figure 2.

One important relationship the equation provides is detector error and its impact on sphere position repeatability and minimum prover size. A detector with a given repeatability error can increase the sphere position repeatability by several times depending on the insertion depth. With most provers, this range is between 3 - 6 times greater. In addition, as the detector insertion depth is decreased, the sphere position repeatability error is even greater. This will require the prover length to be increased in order to obtain a resolution of 1 part in 10,000. A graph of this can be found in Figure 3.

The real value of this equation becomes evident when trouble shooting prover system accuracy and repeatability problems. If a proving system is not performing properly, the detector actuation variance can be checked and used in the above calculation to determine if the error is greater than 1 part in 10,000 of the prover volume. If it is, a detector with a higher precision and closer tolerances is necessary.

PROVER MECHANICAL REPEATABILITY

Prover detector mechanical repeatability is determined by the detector's physical dimensions (mass), the number of its interconnected parts, and its construction tolerances. During a typical meter calibration, prover spheres will travel between 2.5 and 10 feet per second. When the sphere actuates the detector at these speeds, the detector is required to travel from its resting to its activating position in a few milliseconds. If the detector is designed to be light and of few moving parts, the true position of the sphere will be detected. However, if the detector is massive with many moving parts, the dynamic effects of the additional mass may impact the true position of the sphere.

Many interconnected parts or special actuation geometry increase the overall dimensional tolerance of the detector. In most cases, increases in dimensional tolerances will decrease the detectors ability to determine the sphere's true position. Based on the equation in the section above, additional detector dimensional tolerance will result in an error that could be larger than the minimum resolution of the prover. In new prover design, large dimensional tolerances may require a larger prover volume. The goal of a good detector design should be to reduce the number of parts thereby reducing the detector tolerance error.

Construction dimensional tolerances also have a significant impact on a prover's repeatability. A detector designed with adequate clearances and the capability to flush debris from the moving parts will likely provide many years of service. If this is not the case, the true position of the sphere will be misrepresented due to the detector binding or trash preventing switch actuation. In switches where the detector plunger passed through the detector body to actuate an electrical switch, if the plunger or the seal wears, leaks could occur which could cause environmental problems.

Another factor that can affect detector mechanical repeatability is the type of materials used to construct the detector. Parts that contact each other and that are under high impact loads should be case hardened or made out of a harder material. Lower cost mild steel components wear faster and should not be substituted for case hardened parts. In one case, as mild steel parts wear form normal use, the detector tolerance went from .016" to .125". This resulted in a significant change in the prover volume.

Even though any prover detector will work if the prover is large enough, a prover designer or measurement technician will usually obtain better proving results and less maintenance problems with a detector that has fewer moving parts, close dimensional tolerances, and higher quality materials.

PROVER DETECTOR ELECTRICAL REPEATABILITY

Though often overlooked, prover detector electrical component repeatability can have a significant impact on prover repeatability. The switching time for both detector electrical switches and any switch relays (electronic or electro-mechanical) connected between the detector and the flow computer or prover counter, should have a total switching time less than 1 part in 10,000 of the total time for the proving run. If not, then at a minimum, any replacement switches should be selected and tested to insure their switch times do not vary more that 1 part in 10,000 from the parts they are replacing. An equation that can be used to determine the time component is,

$$T_s = L / 10{,}000 \times V_{Sph}$$

Where:

T_s = Switch Timing

V_{Sph} = Maximum velocity of the sphere

L = Length of the calibrated section of the prover

A good practice is to test each component's time constant and mark the constant on each component before installation on a prover. Then, if a component needs replacing, a component with a similar time constant can be chosen. One test method that the writer has found successful is described below using detector switches and relays with double throw switches:

- Connect a signal generator to the detector switch and a high speed counter. The circuit should be wired so that the signal to the counter is shorted through the switch except when the switch is in transition from normally open to normally closed.
- Set the signal generator to a fixed frequency, (20-30 kHz) and activate the detector switch.
- Record the number of pulses and divide by the signal generator frequency to determine the time for the switch to change position
- Test each component and mark the pulse count on the component.

Using components tested with this procedure will reduce the chance of the switching speed of the electrical components affecting the prover calibration or meter proving.

PROVER SPHERE CONTACT LENGTH

Prover sphere contact length can be very important to the performance of a sphere detector. In order to understand the affect of the sphere contact length, imagine a sphere inflated to a diameter equal to the prover internal diameter. At this inflation only a very small band of the sphere a few thousands of an inch wide would be contacting the pipe wall. As the sphere is inflated, the width of the band contacting the pipe wall increases. The relationship between the sphere inflation and contact length can be determined from the equation below.

$$L = 2/3d[(1+i\%)^3 - 1]$$

Where,

L = contact length

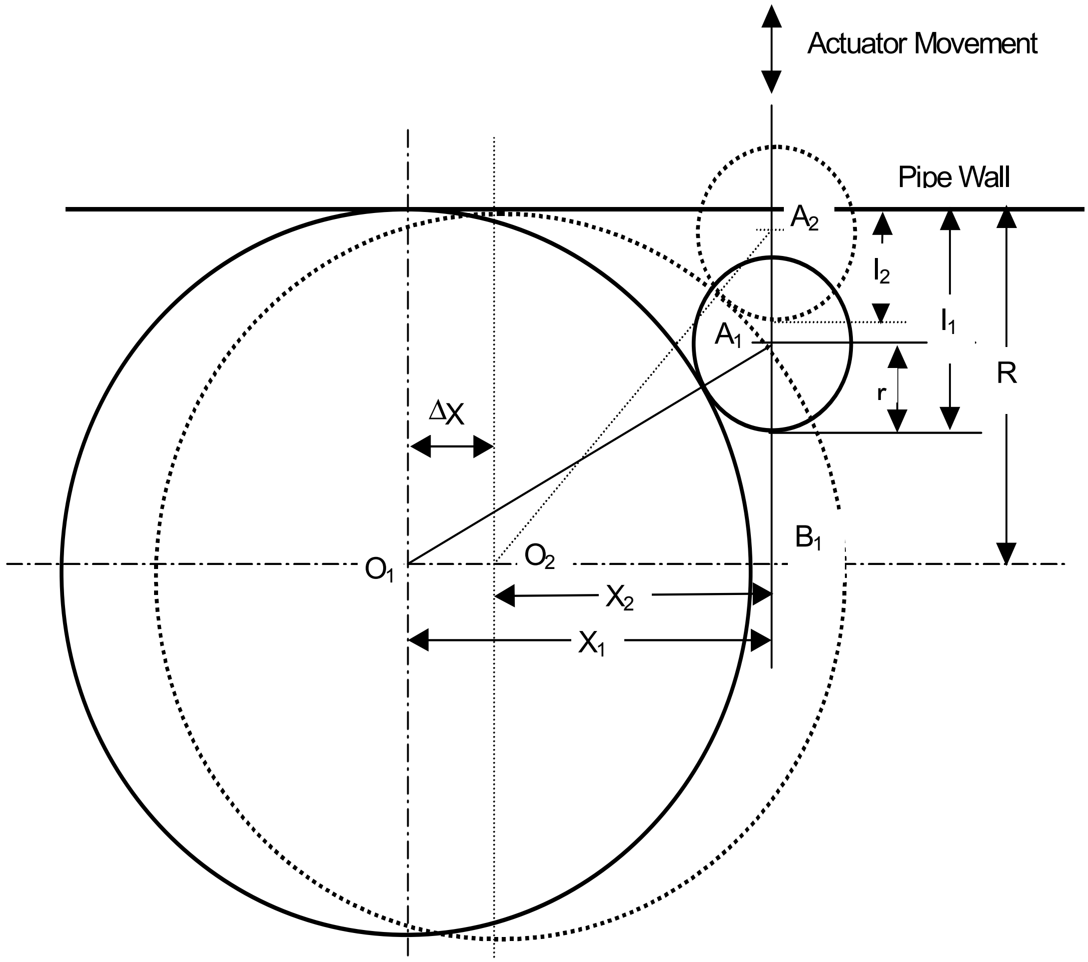
d = internal diameter of pipe

$i\%$ = percent increase in sphere diameter and/or circumference (e.g., 2% = 0.02)

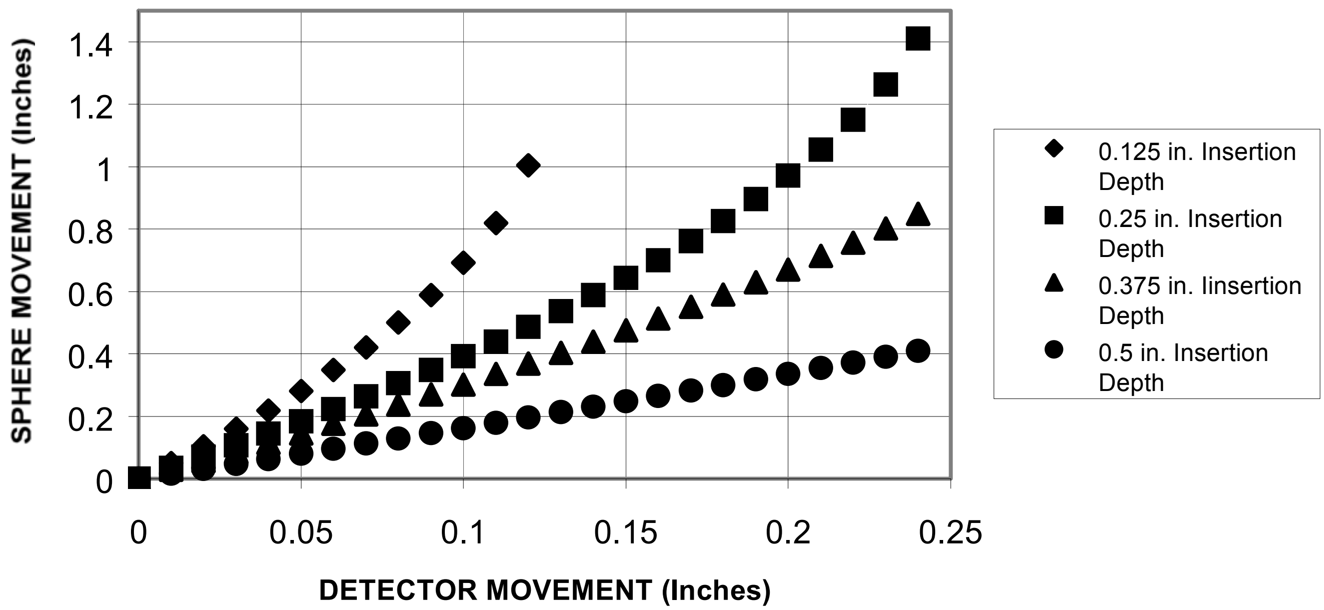
On a typical 16 inch sphere at 2% inflation, the contact length with the pipe wall is approximately .622 inches. However, the average size hole for a prover detector is approximately 1.25 inches. Since the sphere contact length is less than the diameter of the detector hole, leakage past the sphere will occur. Under normal operations the amount of time for this leak to occur is very small. Therefore, the amount of leakage will be negligible. However, if this leak occurs when the prover is water drawn, the very slow movement of the sphere as it approaches the detector can greatly increase the leakage rate.

CONCLUSION (SYSTEM ACCURACY AND REPEATABILITY)

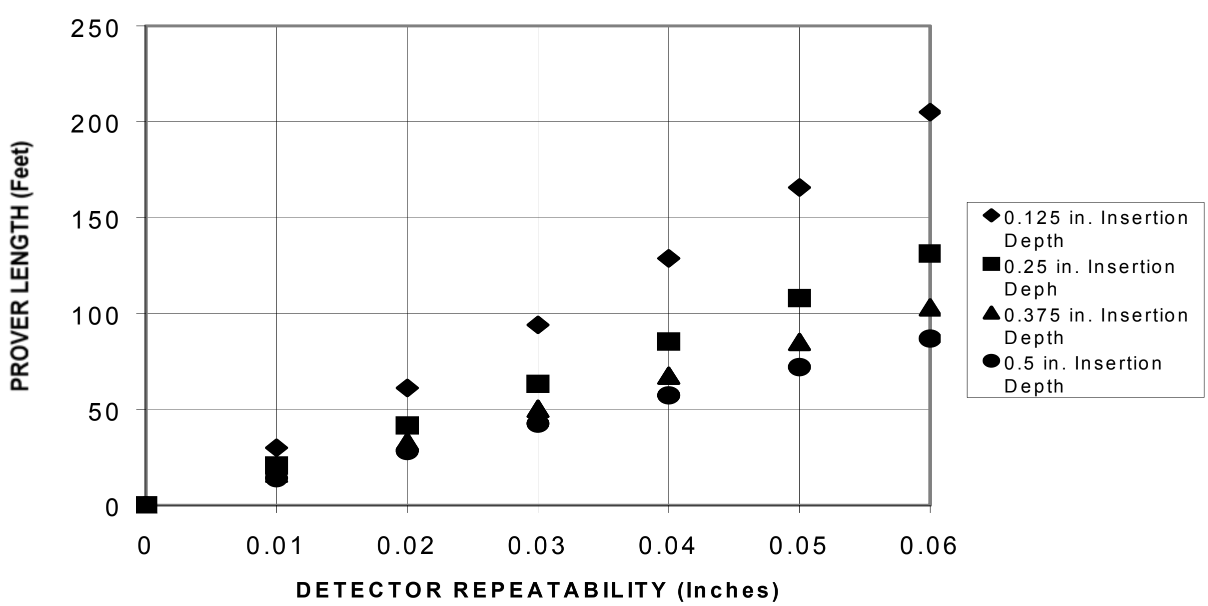
In the above text, we covered specific areas that would affect the performance of a proving system. The equations provided can be used to determined component error that would affect the proving system resolution by 1 part in 10,000. These should be very useful tools in analyzing prover detector problems. However, it is important to note that when examining proving system performance, the affect of all of these components combined should be used to determine a prover’s overall performance.



(Figure 1) Detector position versus sphere linear position



(Figure 2) – Sphere versus Detector Relationship at Various Insertion Depths for a 12" Prover with a 0.75" Diameter Detector Ball



(Figure 3) Prover Length versus Detector Repeatability at Various Insertion Depths for a 12" Unidirectional Prover with a 0.75" Diameter Detector Ball