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Design of a reliable pressure measurement method for paste backfill pipelines

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Abstract

A key component of underground distribution system (UDS) design for paste backfill is a pressure indicating transmitter (PIT), which allows the pressure at the instrument's location to be measured and used to provide several useful diagnostic functions. These functions include the determination of friction losses and overpressures as well as the detection of pipe breakage or blockage and confirmation of flushing progress. Unfortunately, the usefulness of these PITs can be compromised due to the demanding nature of the application in which the cemented paste will fill up any dead leg in the instrument mounting branch of the pipe spool and prevent pipeline pressures from being accurately measured by the sensor. This requires mounting the PIT close to the pipe's inside diameter, which can lead to sensor damage. PIT accuracy has been found to be unreliable due to these issues, and PITs frequently require cleaning or replacement. This paper discusses a planned PIT mounting spool design that uses a protective liner on the inside diameter of the pipe. The liner allows pressures to be transmitted to the PIT while avoiding the sensor head damage or dead leg build-up problems that currently make PIT usage unreliable.

1 Introduction

Pressure measurement in underground paste backfill pipelines has been problematic at many mines during their operational lifetimes. The author has conducted audits on paste plants and received operational feedback from backfill engineers indicating that PITs can have operational lifetimes as low as three months at many mines. The average lifetime of a PIT appears anecdotally to be approximately one to two years.

Some mines have dealt with this problem by simply not using the PITs or by delaying the replacement of PITs for long periods. This results in operational risk since the PITs are installed for several reasons, including:

- Detection of overpressure
- Leak or rupture detection
- Determination of blockage location
- Calculation of friction losses
- Confirmation of the presence of the flush water or air

If the PITs are unavailable, then the capability above is likewise unavailable. The commensurate risks range from moderate to serious, depending on what is occurring in the paste backfill distribution system.

Some mines deal with the failure of PITs by quickly replacing the PIT (either the entire PIT or the sensor head). Of course, this results in downtime in the distribution system to perform this repair or replacement. And a substantial cost is associated with frequent PIT replacement since they are approximately USD 3,000 to replace an entire PIT assembly.

In addition to outright failure of PITs, some mines have experienced measurement inaccuracy from PITs due to the build-up of material in the dead leg of the PIT branch, thus preventing the paste backfill's pressure from accurately being measured by the sensor head of the PIT.

Figure 1 shows how a dead leg can be filled with cemented paste backfill material. This material, if strong enough, can form a rigid beam that bridges across the sensor head of the PIT and reduces the pressure that the sensor head can measure. The effect is noticeable when the underground distribution system (UDS) is empty, and PITs show residual pressure despite there being no pressure in the system.

Figure 1 Dead leg of pressure transmitter branch filled with cemented paste

In Figure 1, the sensor head is approximately 6 mm away from the inside diameter of the steel pipe. Since this particular pipe is lined with a ceramic lining that is 12 mm thick, the distance of the sensor head to the inside diameter of the lining is approximately 18 mm when the liner is not worn.

2 Failure mechanism

The failure mechanism for the PITs that have experienced premature failure in the field is variable. Some failure mechanisms, like dead leg plugging and residual pressures on the PIT, are apparent and easily verifiable. In contrast, the failure of the diaphragm seal on a PIT is a less understandable problem.

Understanding the potential failure mechanisms is essential in order to identify a solution.

Potential PIT failure mechanisms are described below:

- Dead leg filling with cemented paste results in residual pressures measured by the PIT. This failure mechanism seems clear and results from a thin wafer of cemented paste curing while under pressure during a long pour. When the pressure is removed, the wafer continues applying some pressure to the PIT diaphragm seal (sensor head), resulting in a residual pressure reading of the PIT when no load is applied.
- Dead leg filling with cemented paste results in improper readings measured by the PIT. In this case, the wafer of cemented paste works in reverse compared to the previous bullet item. The wafer acts as a beam which spans the PIT diaphragm and prevents the full load of the pipeline pressure from being applied to the sensor head. As a result, the measured pressure will be reduced compared to the actual pipeline pressure. It should be noted that both a residual pressure reading when the pipeline is empty and a reduced pressure reading when the pipeline is under pressure could apply from the same dead leg plug of cemented paste.
- Abrasion of the PIT sensor head is possible if the PIT is too close to the paste flow in the pipeline. Although it is intuitively obvious that if the PIT sticks out into the flow of the paste in the pipeline (i.e., beyond the inside diameter of the pipe), there will likely be immediate abrasion. It is also likely

that other circumstances will result in abrasion. For example, as the pipeline wears, the inside diameter will enlarge, and the sensor head will be closer to the flow. In addition, eddies due to the discontinuity where the branch meets the main pipeline may result in the flow of paste up into the dead leg, resulting in turbulence and abrasive wear on the PIT. This is especially true during flushing with high velocity and lower viscosity materials flowing through the pipeline. Generally, PITs are located very close to the inside diameter of the pipe to avoid the dead leg build-up described in the previous two bullets, so the potential for error is present. For example, some PITs are installed with a tapered thread coupling, and the degree to which the tapered thread is chased (i.e., the diameter of the taper expanded) will result in significant differences in the final seating location of the PIT sensor head. Obtaining a precise seating of the sensor head can be difficult and not necessarily apparent if the PIT is installed on a closed pipe spool and the inside diameter of the pipe is not visible.

- Infiltration of cemented paste into the PIT sensor head is assumed to be one of the causes of failure. Although the PITs are rated for the pressure in the pipeline, there are sometimes dynamic pressures that peak at a higher pressure than the average pressure. These peak pressures can be due to pump pulsations, free fall-induced water hammer, or other dynamic events. Although it is difficult to pinpoint the reason for PIT diaphragm seal failure or overpressure, infiltration of cemented paste into the PIT sensor head sometimes explains the PIT failure.

3 Historical solutions

There have been many different attempts to solve this problem in the past. Figure 2 shows a PIT with a circular piece of 6 mm rubber lining that is epoxied to the face of the PIT sensor head. While this solution effectively reduces the replacement rate of PITs, it is ineffective at eliminating the dead leg effect.

Figure 2 Rubber-capped PIT

Even with this rubber lining, the life of the PIT was less than expected. This may be because the rubber lining rubbed away from the face of the PIT, with wear on the inside diameter of the pipe, and the offset distance from the rubber lining to the inside diameter of the pipe reduced.

In addition, other backfill system operators have experimented with having the sensor head of the PIT set back further from the inside diameter of the pipeline and using a grease nipple on the PIT pipe branch to allow the PIT branch dead leg to be filled with grease. Anecdotally, this adjustment was considered effective. However, this method required frequent refilling of grease to function correctly.

4 Proposed PIT solutions

In order to solve the problem of PIT reliability, several solutions have been proposed, and the advantages and disadvantages of each option are described below. All three solutions have the same primary concept of isolating the PIT completely from the paste and eliminating the dead leg. The differences between the solutions are focused on how exactly that sensor head and dead leg isolation is carried out.

4.1 Option 1: Urethane spool lining

In this option, a PIT with a 50 mm sensor head is bolted into a 50 mm branch of the paste pipeline so that the sensor head of the PIT is 6 mm away from the inside diameter of the pipe.

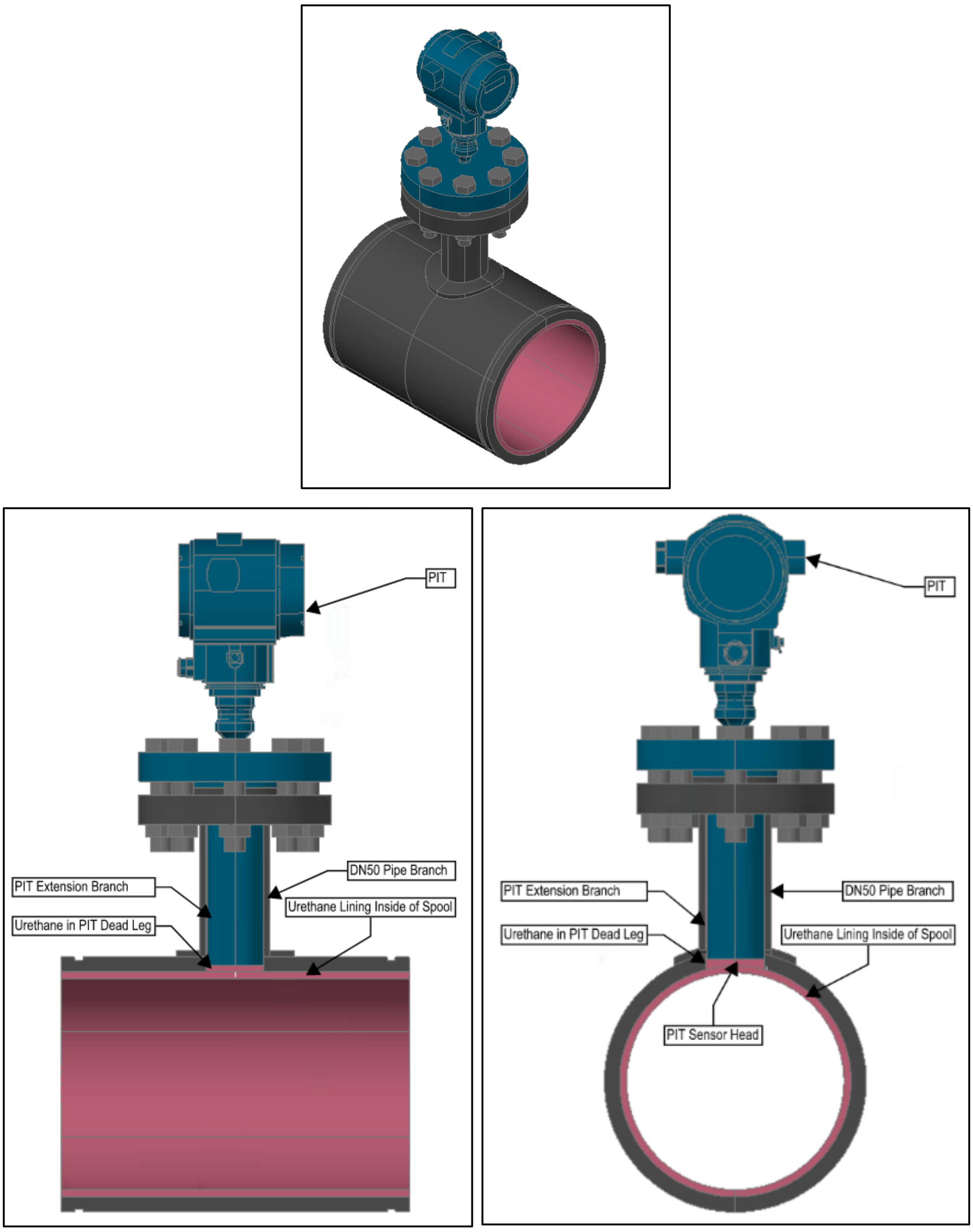

Figure 3 Urethane Spool Lining

With the PIT in place, a spray on urethane liner fills the dead leg in the branch and conforms exactly to the profile of the PIT sensor head and lining the inside diameter of the main pipeline.

This solution creates a seamless spool of moderately flexible material that will allow the pressure of the paste pipeline to be transmitted to the diaphragm sensor head of the PIT with minimal reduction in pressure due to bridging of the sensor head. In addition, no paste can penetrate the diaphragm seal, even with momentary spikes in pressure, which may displace the seal between the diaphragm and the housing.

Advantages:

- A continuous urethane seal makes it impossible for the liner to be breached by paste unless worn through or stripped out of the spool piece.
- Relatively simple fabrication process with a simple application of spray-on liner.
- Urethane generally will not peel off in complete strips; therefore, it will likely not contribute to downstream pipeline blockage if it does.

Disadvantages:

- PIT replacement with a new instrument may not fit precisely with the urethane liner.
- Replacement of the PIT may damage the liner since the PIT sensor head will be stuck to the urethane and may pull the urethane in the branch with it as it is extracted.
- The urethane will fill in the annulus between the instrument and the branch pipe inside diameter, which may make it very difficult to remove.

4.2 Option 2: Rubber with grease

In this option, a paste pipeline spool piece with a 50 mm branch pipe will be rubber lined with the rubber lining spanning the dead leg gap in the branch pipe. The dead leg will have a quantity of grease dropped into the bottom of the branch, where it will sit on the rubber lining. Next, a spool piece slightly smaller than the inside diameter of the rubber-lined spool will be inserted into the rubber-lined spool. This smaller spool piece will serve as a mould and prevent the rubber lining at the branch from being pushed into the inside diameter of the pipe as the PIT is installed. With the spool piece in place, a PIT with a 50 mm sensor head is bolted into the branch pipe, and the excess grease is allowed to squeeze out of the annulus between the branch pipe and the PIT sensor head (via the flange connection) until the flange is fully bolted and torqued. The interior mould spool is then removed.

The resultant rubber-lined spool piece has an incompressible and flexible gap between the PIT sensor head and the inside diameter of the spool piece.

Advantages:

- This method also has a continuous seal layer that cannot be breached unless the rubber lining is peeled off or ruptured at the branch location.
- The PIT will not be stuck to the rubber lining and, therefore, can be removed and replaced without any issues.

Disadvantages:

- The use of rubber lining in paste backfill lines has generally not been successful, with anecdotal evidence of rubber lining peeling off and blocking downstream piping.
- The removal of the PIT may result in a vacuum within the branch piece, which may rupture the rubber lining.
- Installation of a new PIT or reinstalling an old one in the branch may force air against the rubber lining since the PIT head will act like a plunger. Therefore, reinserting the PIT may not be possible unless a mould spool is placed inside the spool piece to prevent the rubber from being forced away from the branch intersection.

- It may be challenging to fill the cavity between the rubber lining and the sensor head and the annulus between the sensor head and the branch pipe inside diameter with grease. In addition, any air in these areas will allow for compression, resulting in the face of the rubber lining deforming and potentially ripping if the deformation exceeds the elastic limit of the rubber.

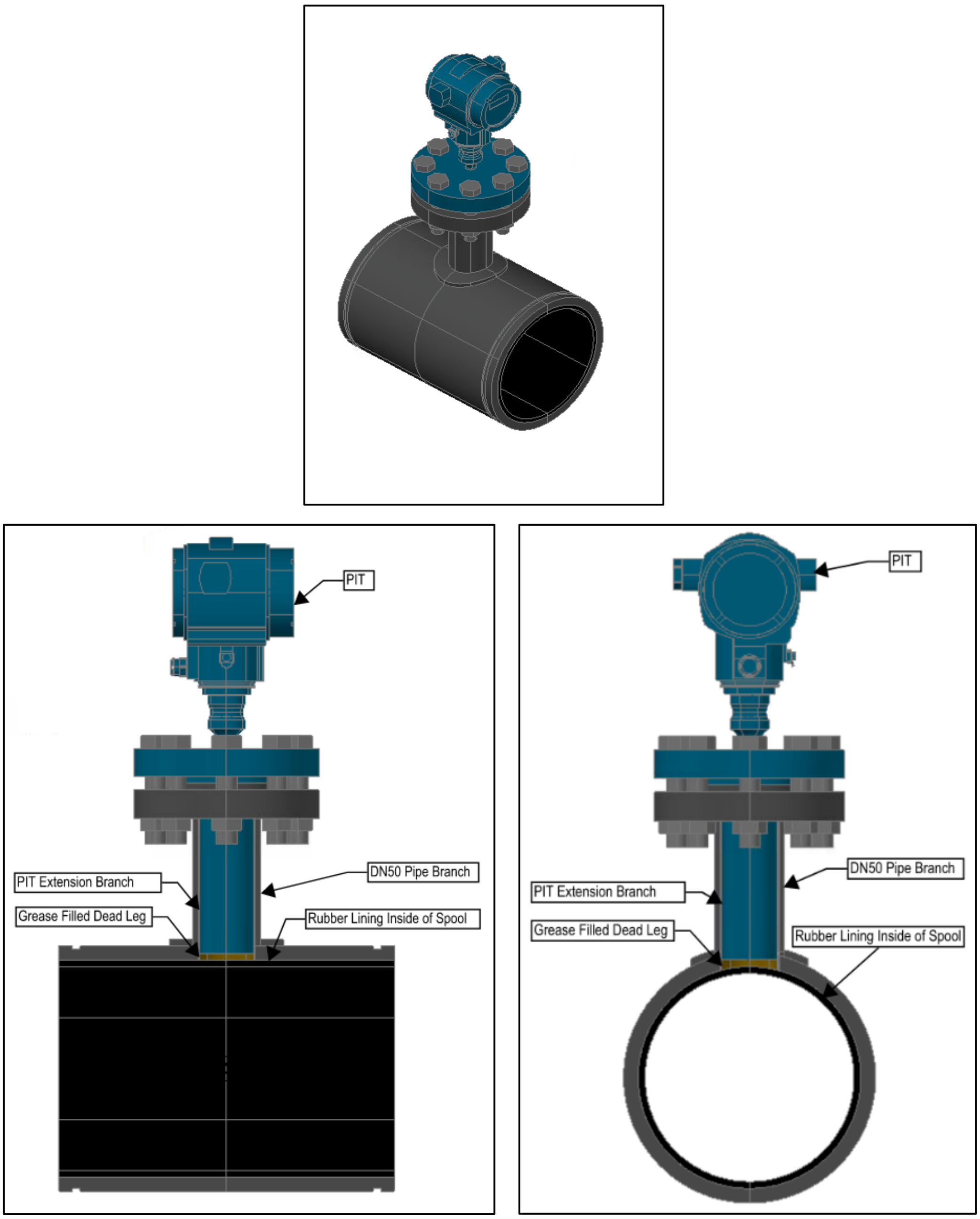

Figure 4 Rubber with Grease

4.3 Option 3: Urethane plug

This option is similar to Option 1, except the urethane lining is applied to the dead leg instead of lining the entire spool piece. The thickness of the urethane lining will be at a 6 mm minimum along the centre axis of the branch pipe. It will be at a larger thickness at the perimeter of the PIT sensor head due to the flat face of the PIT sensor and the curved inside diameter of the paste pipe.

As with Option 1, the PIT will be installed, followed by the urethane lining application.

Advantages:

- Continuous seal of PIT sensor head.
- Relatively simple fabrication process.
- The urethane plug will not block the pipeline if it peels out.

Disadvantages:

- The plug is not as securely anchored in place as in Option 1, and the urethane could be pulled out of the dead leg due to high dynamic flushing forces.
- The attachment surface area primarily consists of the face of the PIT sensor head. Therefore, if the PIT removal with the urethane liner is attempted, it will likely be stuck in the branch pipe. Even if it could be removed without taking the spool apart, it would take the urethane plug with it requiring the plug's replacement.

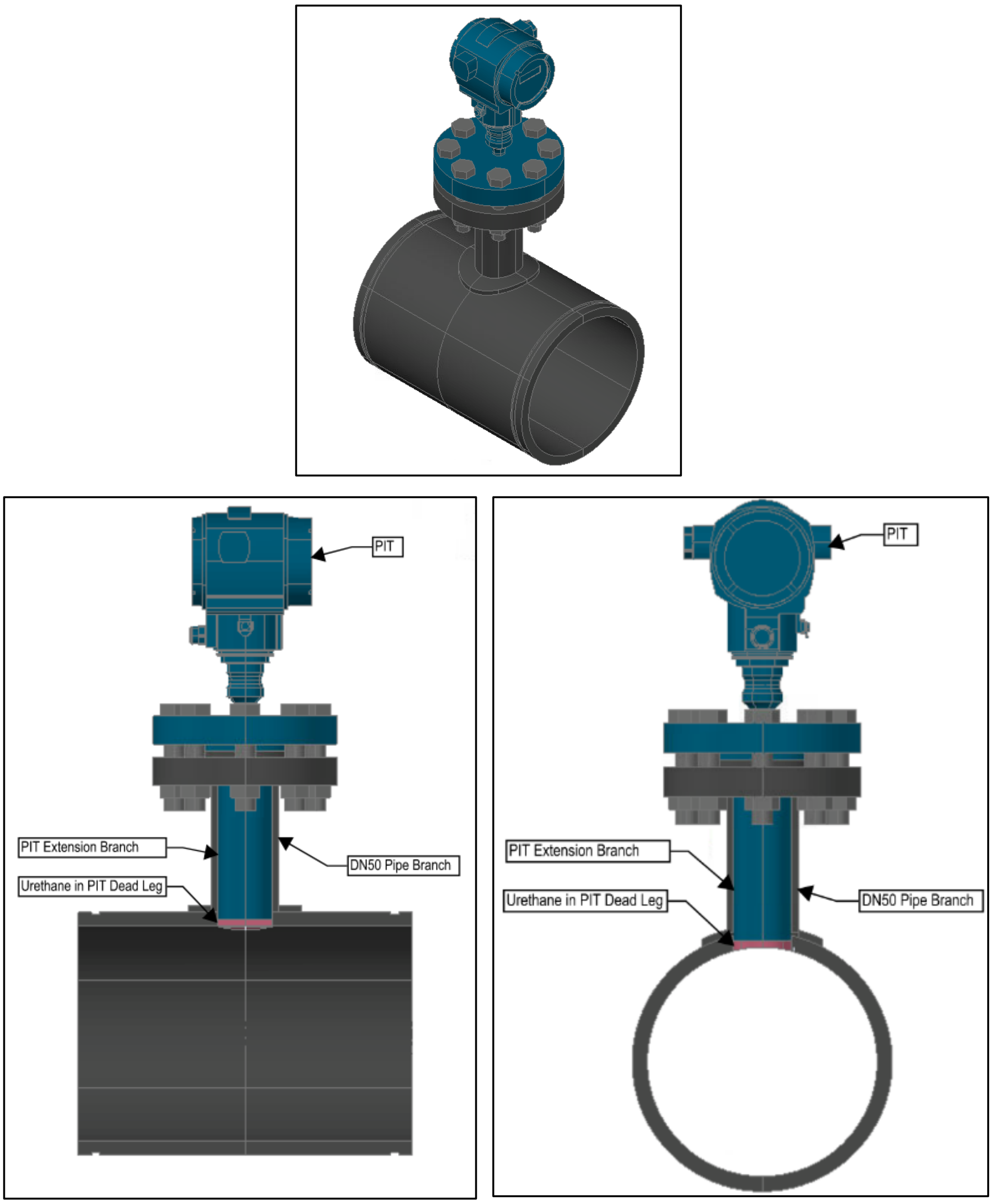

Figure 5 Urethane Plug

5 Conclusion

All three options can potentially address the chronic PIT failure problem. However, each has disadvantages associated with them.

The optimal option for field trial was Option 3 since it posed the least risk for downstream pipe blockage, considered a greater risk than PIT reliability.

Currently, a trial is planned at a Canadian mine where the Option 3 spool will be fabricated and installed in a recently constructed UDS. If the outcome of this trial indicates that the urethane plug stays in place and prevents damage to the PIT, this option will likely be used in future installations.

If the dead leg plug does not reliably stay in place or if the PIT fails due to infiltration of paste into the diaphragm seal, then it is likely that Option 1 will be the next attempt at addressing this problem.

Option 2 is considered the riskiest option since there is precedent for large rubber lining sections to peel off and travel down the pipe. Unless that possibility can be addressed, then it is likely that this solution will not be attempted.