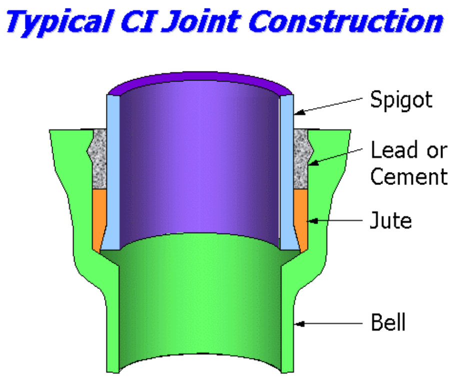
Sealing Large-Diameter Cast-Iron Pipe Joints Under Live Conditions
Technology Assessment

Background

Several older urban areas of the United States still have large amounts of cast-iron gas distribution mains with some 47,000 miles still in service. Individual segments of these mains average between 12 and 20 feet in length and are connected to one another by a bell and spigot joint as shown in the figure. The annular space between the bell and spigot was filled with a jute packing to provide a fluid seal and finished with a lead or cement plug.



In the days of manufactured gas, the jute material was kept moist and compliant by the humidity and higher molecular weight hydrocarbons present in this gas and, as a result, were usually leak free. However, for many years now, the natural gas flowing in these mains is characterized by its low humidity and high methane purity. This has resulted in the jute drying out, causing it to shrink and/or crack which, in turn, produces numerous leaks. The costs of replacing significant lengths of cast-iron mains on a yearly basis are prohibitive due to their large size and location in highly urbanized environments. Instead, local gas distribution companies must extend the useful life of these cast iron mains by findings ways to fix the leaking joints inexpensively.

Technology Being Developed

The industry has responded by the development and use of several different means for repairing cast iron joints both externally and internally. The objective of this project is to develop and commercialize a robotic repair system capable of sealing multiple bell and spigot joints from a single pipe entry point. The proposed system will repair joints while the pipe remains in service by traveling through the pipe, cleaning each joint surface and attaching a steel sleeve lined with an epoxy-impregnated felt across each joint. Sufficient bypass of natural gas around the robot will be maintained during each operation so gas delivery to attached customers is unaffected. The approach will save over both external encapsulation by greatly reducing the number of excavations required to access the cast-iron pipe and over competitive internal repair technologies which either require the line to be taken out of service during the repair cycle or rely on the rejuvenating the original jute material that exists in various (and unknown) stages of deterioration.

The joint-sealing robot will be comprised of four main subsystems. These are: 1) two sequentially run robot trains; 2) pipe access hardware for safely admitting into and removing the robot trains from the live gas-main environment; 3) a coiled tubing delivery system for providing primary locomotion and transmission of command/control signals to the robot from the 4) surface control and display electronics.

The first robot train will have a front mounted pan/zoom/tilt camera which will be used to visually locate each bell and spigot joint. Directly behind this camera is a dual element, counter-rotating brushing module whose function is to remove debris from the cast-iron bell and spigot joint pipe wall. Immediately behind the brushing module is a base module which provides power and control to the two other modules and a supplemental locomotive (tractor).

In operation, the coiled tubing is used to deliver the pipe wall preparation module to the farthest cast-iron bell and spigot joint to be repair from a given launch location (500 – 1000 feet from the single pipe entry point). The brushing module is then activated to clean the joint by slowing moving the abrasive brushes back and forth across the patch site. Proper cleaning of the joint is visually confirmed using the on-board camera. The coiled tubing unit is then used to withdraw the train back to the next joint where the cleaning process is completed. This sequence is continued until all of the joints have been prepared (cleaned) for patching.

The brush module is then removed from the train and replaced with the repair sleeve carrier/patch setting module. The steel sleeve is slid over the carrier along with its polymer gasket and epoxy-saturated felt. The coiled tubing unit is then used to deliver the patch-setting train to the most distant bell and spigot joint. This location is confirmed with both the quadrature encoder footage counter and visually with the camera. Once the camera is located exactly at the bell and spigot-joint gap, the fine resolution odometer on the camera is set to zero. The coiled-tubing unit is then used in conjunction with the camera's odometer to move the patch setting train forward by a known, fixed distance which assures the patch is properly aligned with the bell and spigot joint. A control command is then issued from the surface unit to the base unit to release nitrogen from a stainless-steel pressure vessel on-board the patch setting module into its expandable rubber bladder. This causes the bladder to inflate and locks the stainless-steel sleeve into position via its interlocking, racheting barbs. The epoxy is allowed to cure and reaches full strength within 12 hours. During the interim, a gas-tight seal is assured by the polymer sleeve which has been energized against the joint by the hoop stress of the stainless-steel sleeve. [Note: The volume and rate at which the nitrogen is bled from the inflation bladder results in no appreciable dilution of the BTU-quality of the natural gas.]

The patch-setting module is then pulled back into the access fitting/launch chamber where it is loaded with a new patch. It is then moved to the bell joint immediately in front of the one previously repaired and the next patch installed. This process is repeated until all joints in the segment have been repaired.

Competing Technologies

Bolt-On Repair Sleeves

The simplest repair option is to install a full circle leak clamp over the bell and spigot joint. Each joint location is excavated, the pipe exterior cleaned and the rubber lined, stainless steel sleeve bolted into place. This option is routinely used to spot repair welded steel lines but variations of it have been used to bridge cast iron joints in the past. This repair method is generally not practiced for cast iron pipes as external encapsulation is considered to provide superior sealing characteristics.

External Encapsulation

The most common cast-iron joint repairs involve external encapsulation with several utilities making use of keyhole tools and vacuum excavation to minimize the size (and therefore costs) associated with the excavation and follow on surface restoration. Once the bell joint is fully exposed and its entire circumference cleaned with pneumatic chippers and grit blasters, an encapsulation mold is placed around the joint. The mold is then filled with a synthetic rubber in its liquid state that cures to a flexible material that permanently adheres to the pipe yet allows the joint to move under thermal expansion/contraction cycles without leaking. The system is suitable for low pressure lines.

The primary benefits of the system are its relatively low costs and the ability to test that the leak has been stopped using a simple soap test before closing the excavation. The main drawbacks are the fact that the excavation size is still quite large (and expensive) for larger size pipes (12 inch and up) and the necessity to completely expose and clean the entire joint circumference.

Internal Encapsulation

Several groups are developing internally-applied anaerobic sealant for repairing leaking cast iron joints. Products include the PLCS Mainspray and the EmBridge Energy/Con Edison Cis-Bot joint sealing robot. To date, these systems have experienced limited success and limited usage for a variety of reasons not related to the actual anaerobic sealant used.

For example, those systems which simply spray sealant at each joint location and depend on diffusion to wet the jute often reduce but do not completely eliminate the leak since full wetting of the packing material cannot be guaranteed. In fact, in some situations large amounts of the jute material may have actually broken out and have become displaced from the bell and spigot joint leaving nothing for the sealant to bond to. In addition, low pressure cast iron mains often have significant amounts of debris. As the tethered robot is pushed through the main, this debris can accumulate in front of the tool. This can reduce the operator’s ability to correctly position the robot at the bell and spigot interface due to obstruction of the video camera lens or prevent further forward movement due to build up of a debris wall. It has also been reported that debris can cut and damage the robot umbilical and that premature solidification of the anaerobic material due to its contact with metal ions in the debris.

Cured-In-Place Pipe

Several manufacturers provide cured-in-place pipe liners (CIPP) for rehabilitating sections of damaged piping. These systems consist of a flexible liner, usually made from polyester, that has been inverted (“turned inside out”) prior to installation. The liner is saturated with a liquid thermosetting resin that is made to harden by pumping either hot water or steam inside the liner once it has been placed across the pipe section to be rehabilitated. This process results in a continuous, tight-fitting pipe liner within the existing host pipe. Products are available for both non-pressure and pressurized piping systems operating at pressures up to 200 psig. Once cured, the liner has sufficient mechanical strength to bridge small holes and joints in pressure pipes but still requires the overall host pipe to be mechanically sound. The pipe ID is typically cleaned prior to the installation using high pressure water jetting systems.

As practiced, conventional CIPP liners are not suitable for use in *live gas mains*. The CIPP process blocks the entire pipe cross sectional flow area during the wall installation and curing steps which prevents gas delivery to attached customers. In addition, a camera and cutter head robot are required to cut through the cured liner at each service tap location to re-establish flow communication between the line main and the service lines.

CIPP is used to rehabilitate continuous sections of pipe whereas the proposed research focuses on making spot repairs to only those areas of pipe that have experienced localized corrosion or mechanical damage.

Internal Repair Sleeves

The Link-Pipe repair system comprises a cylindrical stainless steel sleeve surrounded by an outer sleeve constructed of a combination felt/foam liner that is saturated with a liquid resin such as urethane immediately prior to installation. The outside diameter of the sleeve is normally ½-inch smaller than the inside diameter of the host pipe. Sizes are available for repairing pipes from 4- to 54-inches diameter.

The stainless steel sleeve has a series of locking barbs along the longitudinal cut line that "lock" the sleeve against the host pipe wall once the sleeve has been mechanically expanded outward against the host pipe wall using an inflatable air bladder. The sleeve is carried to the repair point by slightly inflating the air bladder to hold the sleeve in place and then moving the wheeled sleeve carrier/inflation bladder through the pipe using push rods or by pulling it into place using cables. A CCD camera is used to observe each step of the installation.

At present, Link-Pipe installations require the host pipe to be taken out of service. As importantly, the Link-Pipe product is not capable of sealing active leaks since there is no pressure seal across the split sleeve. The operational procedure is to clean the pipe wall at each patch location in order to allow the resin to intimately bond to the pipe wall. This is necessary because the resin is relied upon to create the pressure seal. Any voids or channels caused by lack of adhesion represent potential leak paths. Fortunately, the resins used by Link-Pipe swell several-fold. This makes the design quite forgiving with regard to the cleanliness of the pipe - especially when combined with the mechanical compression provided by the sleeve once it is set. In practical terms, this has meant that use of high-pressure water jets to clean sewer lines and wire brushing of steel lines have been sufficient to effect pressure tight bonds. The sleeve is then moved into place and the bladder inflated to 20 - 30 psig to lock the sleeve into place. The resin normally cures in 30 minutes with full cure strength achieved in one hour. Due to the construction of the sleeve, a simple visual observation of the stainless steel sleeve using the CCD camera indicates proper installation. Link-Pipe is now developing products for the gas industry.

Technology Comparison

The advantages and disadvantages of various joint-repair technologies are shown in the table below. The initial comparison shows that the proposed technology based on the robotic approach will save significant costs to repair cast-iron joints.

Comparison of Cast-Iron Pipe Joint Repair Methods

JOINT REPAIR METHOD	MAIN CONDITION	REPAIRS PER EXCAVATION	COMMENTS
External Bolt-on Repair Sleeve	In service, no impact on gas delivery	1	Conventional technique, most common for steel pipes
External Encapsulation	In service, no impact on gas delivery	1	Most common repair technique for CI joints
Internal Encapsulation	In service, no impact on gas delivery	10 –12 repairs each direction	Dependent on condition of jute sealant
Cured-in-Place Pipe	Out of service, interrupts gas delivery	Entire pipe segment up to 40 joint repairs	Rarely used due to length of time main must be taken out of service
Internal Repair Sleeve (Conventional)	Out of service, interrupts gas delivery	Up to 40 joint repairs	Rarely used due to length of time main must be taken out of service
Internal Repair Sleeve (Robotic)	In service, no impact on gas delivery	40 – 80 repairs each direction	Independent of condition of jute; significant savings possible versus other techniques