Title of Innovation: Robotic Internal Inspection Machine

Nominee(s): Russ Langley, James Huggins, Michael O’Neill, Dale Davis, Darrell Davis, J. David Carter, David Paulley

Category: Integrity Assessment

Dates of Innovation Development: 2009 ~ Current

Web site: www.coatingrobotics.com

Summary Description:

The inspection machine is a robot-based electrical system with multiple inspection features and applications. It locates coating defects such as holidays within new construction coated steel pipe. The Inspection Robot includes onboard camera visual inspection, measures dry film thicknesses and detects holidays after coating the internal field joint, allowing any necessary repairs to be made immediately, on site, and prior to product being introduced to the pipe. The internal inspection may also be applied to the entire length of the factory-applied coating using a removable circumferential brush. The high-quality video feature can be used to detect faulty welding, display weld bead contours, faulty field-applied couplings, debris, parent coating damage, etc. Detection and repair prior to introducing product in the pipeline eliminates or greatly minimizes the chance of internal corrosion anywhere in the pipeline. This corrosion prevention innovation is a vital step in pipeline integrity management and corrosion mitigation.
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The Inspection Robot does three critical corrosion prevention jobs in one: dry film thickness testing, high-voltage holiday inspection and visual inspection. It also uses a laser beam to detect unacceptable weld beads.
Full Description

CRTS has designed, tested and built internal pipeline inspection robots that enhance the pipeline industry’s current internal corrosion management techniques used both onshore and offshore (see Figure 1). The primary purpose of the Inspection Robot is to detect flaws in pipeline coatings before any product enters the pipeline. This internal corrosion prevention opportunity paves the way for better internal corrosion management when the pipeline is actually in production. Internal corrosion is minimized with coating integrity.

The many features and applications of the Inspection Robot include visual inspection with an onboard 360° camera; dry film thickness (DFT) measurement; and a rotating brush used for high-voltage holiday inspection. It also has a removable circumferential holiday-detection brush that locates coating defects along the entire pipeline. It can be used in conjunction with the robot’s other inspection tools to detect debris, parent-coating damage, field-applied coupling failure, unacceptable weld bead contours and any other anomalies. The Inspection Robot can be used with liquid epoxies and fusion-bonded epoxies for onshore projects, and fusion-bonded epoxy powders for offshore projects.

Figure 1 An offshore project requires a train of robots to clean, coat and inspect factory-coated pipe and internal field joints. The Inspection Robot second from right shows the removable circumferential brush.

The Inspection Robot does not interfere in any way with industry methods or standards; rather, it precedes those methods and provides a foundation for optimum internal corrosion management. Although cost savings vary with each project, the overall savings of preventing internal corrosion are achieved in the pipeline’s longevity, product purity, reduced friction, decreased leaks and ruptures, and reduced operating and maintenance costs. And while inspecting the pipeline and/or internal field joints adds an element of time to construction, the Inspection Robot can be configured to work simultaneously with welding and nondestructive testing processes both onshore and offshore. Its untethered design enables it to enter the pipeline only once for internal field joint and full-length inspections.
How does the innovation work?

In new pipeline construction, the Inspection Robot is part of a robotic system that (1) cleans, coats and inspects internal field joints (measures dry film thicknesses and locates holidays) or (2) locates holidays along factory-coated pipes using a circumferential brush only (see Figure 2). It contains technology to view and record the radial location of any coating holidays, and can also display parent-coating damage, debris, failed field-applied couplings and other anomalies. The Inspection Robot contains the following features:

- 1 rotating camera with zoom, focus and exposure options
  - Allows visual inspection and monitors the electronic DFT probe
- 1 rotating camera to monitor the holiday brush as it sweeps the internal field joint
- 1 fixed camera to view potential hazards in the pipeline that could damage the Inspection Robot, e.g., large debris
- 2 brass brushes
  - One rotating brush
  - One attachable circumferential brush (optional)
- 1 electronic (DFT) probe
- 1 laser beam to ensure weld bead contours meet specification of project

The Inspection Robot can transmit data to the operator from at least 6,600 feet (2,000m) inside the pipeline when used in conjunction with other robotic equipment.

Figure 2. An onshore pipeline project can be inspected using just a Crawler and an Inspection Robot. It locates parent-coating damage, debris, failed field-applied couplings and other anomalies prior to any product entering the pipe.
A. FACTORY-COATED PIPELINE INSPECTION CAPABILITY

The Inspection Robot inspects the length of a factory-applied internal coating as it is strung together (onshore). A circumferential high-voltage brush is pushed or pulled through the pipe, extending to the interior factory-coated pipe surface, sweeping the coating (see Figure 3). If a holiday is detected, the robot sends an on-screen message to the operator’s monitor detailing the position of the holiday. The message is recorded for the pipeline owner/operator. The owner/operator may then repair the holiday prior to any product entering the pipeline, thus nearly 100% mitigating internal corrosion (Figure 4).

![Figure 3](image1.png) The Inspection Robot features a removable circumferential brush for detecting holidays in factory-coated pipe.

![Figure 4](image2.png) A field-applied coupling failure was located by using an Inspection Robot for a recent onshore project. With no product in the pipe, the owner can repair and thus prevent future leaks or ruptures into the environment.

B. FACTORY-COATED PIPELINE INSPECTION DETAILS

New construction pipe sections are placed end-to-end and welded together to form a continuous pipeline. A circumferential (i.e., non-rotating) brush is attached to one end of the Inspection Robot and positioned to make contact with the inner circumference of the pipeline (see Figure 3). During inspection, the brush maintains constant contact with the interior of the pipe while moving through it. In this manner the entirety of the internal coating of the pipeline may be rapidly inspected.

C. INTERNAL FIELD JOINT INSPECTION CAPABILITY

At the internal field joint, the dry film thickness (DFT) is measured in each quadrant with an onboard electronic probe to ensure the corrosion prevention coating meets design specifications. The measurements are transmitted wirelessly to the operator for confirmation and recorded for the pipeline owner/operator. A rotating brush then sweeps the coated internal field joints to detect any holidays (see Figures 2, 6). If a holiday is detected, the robot sends an on-screen message to the operator’s monitor detailing the radial location of the holiday. Lastly,
a visual inspection is conducted using the laser beam, an onboard rotating camera with operator-controlled zoom, focus and exposure. This inspection allows the operator to detect any visible anomalies such as weld spatter/slag, coating blisters holidays and foreign objects. The owner/operator may then repair any holiday or anomaly prior to any product entering the pipeline, thus nearly 100% mitigating internal corrosion.

D. INTERNAL FIELD JOINT INSPECTION DETAILS

The ends of each pipe joint (i.e., "coating cutback") are typically not coated at the factory because the coating would be destroyed or corrupted by the welding process. Thus, there is a gap in the coating between the two pipe sections at their junction (see Figure 5). New construction pipe sections are placed end-to-end and welded together to form a continuous pipeline. The welding at the internal field joints (i.e., a "girth weld") is subject to imperfections that might have been created during the welding process: weld spatter, weld slag or even foreign objects. The bare metal can be protected with epoxy coating inside each pipe after welding and before beginning to move fluids (to include gasses) through the pipeline, and that operation must be performed from inside the pipe (see Figure 1). Failure of a pipe section could result in release of its contents into the environment and/or could necessitate a costly repair or replacement of that section, halting production.

After cleaning and coating robots supply coating protection to the internal field joint, the Inspection Robot begins its vital role. An operator triggers the DFT probe at each quadrant to ensure the coating meets project requirements. Then, using the onboard camera, a high-voltage holiday detector is aligned over the coated area to sweep the coated field joint 360° (see Figures 6-7). If any anomalies or holidays are located, the weld may be repaired by re-abrading the coating and then recoating (the pipeline owner may choose to not repair or to repair any time prior to introducing the product). The cleaning and coating cycles are adjusted to maintain the millage specifications. The inspection process is then repeated for verification via live feedback. Figures 8-9 demonstrate the visual inspection camera and inspection video capabilities.
When and how was the innovation developed?

Years ago, CRTS attempted internal inspection techniques using camcorders, but no measuring devices were on board the robot. In approximately 2009, at the request of Saudi Aramco, CRTS engineers developed prototype robots with inspection tools that gave precise measurements and data. These inspection services are now a highly recommended quality control aspect of our complete robotic services.

How or why is the innovation unique?

First, no other Inspection Robot with the described capabilities is known to us. The Inspection Robot performs dry film thickness testing, visual inspection and high-voltage holiday inspection with a single-entry into the pipeline. The Inspection Robot performs these functions internally via remote operation for both onshore and offshore applications. The operator and the pipeline owner can immediately make cost-saving decisions about pipeline corrosion prevention and future maintenance, repair and rehabilitation.

Second, because the Inspection Robot is remotely operated, there is no need for cables to be dragged inside the pipe. Typical high-voltage holiday detection requires a ground wire to be connected between the high-voltage supply and bare steel of the pipe. Depending upon the customer’s requirements, the Inspection Robot can be configured to operate in two configurations: the typical manner described, or untethered. The untethered configuration
replaces the ground wire with a conductive pad or brush. When this pad or brush contacts the coated interior surface of the pipe, it establishes a capacitively-coupled ground path. Specialized electronics detect any holidays. This innovation is critical for the efficient operation of the Inspection Robot in offshore environments where a trailing ground wire is impractical due to the presence of the line-up clamp.

Third, preventing internal corrosion via robotic inspection helps the energy industry achieve its need for internal corrosion prevention solutions. Coatings are known to counteract the corrosive effects of oxygen, carbon dioxide, hydrogen sulphide and other corrosion agents, but internal coatings must be teamed with internal inspection to ensure 100% effectiveness. The innovative nature of inspecting the interior surface of pipelines prior to introducing fluids in the pipe will hopefully become the standard rather than the exception.

What type of corrosion problem does the innovation address?

Preventing internal corrosion is the primary purpose of the Inspection Robot. A common complaint when seeking internal corrosion integrity is that coatings often disbond from the pipe surface, or they have pinholes that allow corrosion cells to develop. The Inspection Robot identifies the pinholes (or other problems) before product is put in the pipe, allowing the operator/owner to eliminate and prevent this cause of internal corrosion. Some common corrosive factors are:

1. Potable Water. Potable water is adversely affected by pH, alkalinity and buffer intensity. “The most corrosive agent in most pipelines is water. Any pipeline that has water or has a flow media contaminated with water” is an appropriate candidate for this technology.¹
2. Temperature. In oil and gas pipelines, temperature accelerates electrochemical and chemical corrosion and flow may be affected by the presence or absence of protective scale formation.²
3. Impurities in the product being transported.
4. Erosion and cavitation.³

This is clearly not an exhaustive list, but simply identifies some of the most common potential internal corrosion issues the Inspection Robot can help identify.

What is the need that sparked the development of the innovation?

Internal corrosion is one of the energy industry’s primary enemies, and it causes many financial, operational, environmental and human catastrophes. Only health care and real estate exceed annual corrosion costs to the US, and the direct costs of corrosion between January and June 2013 were approximately USD $500.7 billion. A 2008 “Pipeline Corrosion Final Report” found that 97% of corrosion failures in offshore gas transmission lines were caused by internal corrosion. Clearly, corrosion control is a worthy opponent to fight. Internal robotic inspection of factory-coated pipe and/or coated internal field joints helps ensure corrosion integrity, by:

a. Detecting potential corrosion spots that require repair.
b. Delaying corrosion and its accompanying repair, rehabilitation and cost.
c. Protecting the environment from leaks and ruptures.
d. Enhancing owner/operator confidence that the protective coating has been properly applied via real-time video feedback and recording of each pipe length and/or internal field joint.
   1. Offshore pipeline projects especially benefit from corrosion prevention design. With lay barge costs easily reaching $500,000 daily to construct a pipeline that must last a certain lifetime, internally inspecting the coated pipe and its internal field joints is the only way to correct internal coating problems prior to product entering the pipe.
e. Protecting human life.

This short list is the foundation upon which corrosion management should stand. There are, sadly, many incidents detailing human loss due to pipeline corrosion. An example of the importance of internal corrosion control is recalled in the tragic El Paso Natural Gas Company (El Paso) pipeline rupture near Pecos River in 2000 (this example is used to demonstrate the need for corrosion prevention design rather than to implicate).

After 11 campers were fatally burned by the explosion, the National Transportation Safety Board (NTSB) reported and made recommendations to NACE International and the Research and Special Programs Administration about the “major safety issues identified in this investigation … design and construction of the pipeline, the adequacy of El Paso Natural Gas Company’s internal corrosion control program,” and more (see Figure 10 for example of poor management communication among designers, engineers, contractors, etc.). For instance, other El Paso gas lines had been inspected with a “smart pig” (internal inspection tool) and found no evidence of internal corrosion that needed repairs, “but a visual inspection of the pipeline in the

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immediate area of the rupture found an area of internal corrosion, which was repaired. Could the loss of life incurred been avoided with adequate inspection processes?

Are there technological challenges or limitations that the innovation overcomes?

The Inspection Robot has the option of using untethered remote control (telemetry), one of the most important technologies for cleaning, coating and inspecting onshore and offshore pipeline construction. The telemetry handles all the wireless data to and from the coating inspection robot, as well as the inspection video. Telemetry is crucial in offshore pipe laying operations because of the presence of the line-up-clamp and any other additional equipment between the robotic machinery and the open end, such as root-bead inspection devices, plasma machines, etc. Even without the presence of the line-up-clamp, telemetry eliminates the need for handling an awkward tether, spool, or other mechanisms.

For onshore pipeline projects, telemetry allows for long distance wireless operation (particularly tie-ins) without the awkwardness of additional equipment. The Inspection Robot can operate from at least 6,000 feet within a pipeline.

What are the potential applications of the innovation?

The CRTS Inspection Robot has been successfully used on new pipeline construction in the following onshore and offshore environments and projects:

ENVIRONMENTS

- Desert, mountain, horizontal directional drilling (river crossings), onshore, offshore

PIPELINE PROJECTS

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- Water lines: potable, mine tailings, sewer, water injection, desalinated water, hot (160°F+)
- Gas: natural, offshore, onshore production, wet/sour gas, sour gas
- Sour oil
- Factory-coated pipe
- Pipelines with field-applied couplings
- Clad pipe in new construction pipelines
- Pipelines that require internal field joint coating

How does the innovation provide an improvement over existing methods, techniques, and technologies?

The Inspection Robot capabilities precede and strengthen existing methods, techniques and technologies because most corrosion management begins after the product enters the pipe. Whether the new construction will be coated or use other corrosion management design, the Inspection Robot plays a significant role in delaying internal corrosion. Without inspection and subsequent repair (if necessary), there is still a chance for corrosion to invade.

CORROSION PREVENTION DESIGN

The most convincing improvement is enabling the integrity of the pipeline by designing it to be built with protective coating intact. The accepted method of applying protective coating has a demonstrated 10-20% increased throughput as a result of reduced friction, and maintenance is reduced because less rust is in the pipeline. This prevention technique will likely fail if there are unseen defects in the coating, preventing the coating from doing its job. However, all the prevention in the world is useless if the coating is not properly applied to a properly prepared surface.

Many pipelines are inspected for corrosion using inline inspection techniques, but many pipelines cannot be “pigged” due to tight bends, etc. Another inspection technique is to use coupons, sacrificial metal strips that are weighed and then placed in a pipeline for a period of time. The coupon is then removed and reweighed to determine how much loss occurred in hopes of identifying internal corrosion. Unfortunately, coupons are not always placed where corrosion is growing and there is no way to assess whether the corrosion was rapid or slow-growing.

An example of design improvement is that sacrificial walls are unnecessary with intact, inspected coating. Documented corrosion management recognizes that coating pipelines and their internal field joints reduces “surface roughness, and thus internal friction...reduce[s] the

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pressure drop between compressor stations, and thus allows installing less power and consume less fuel,” leading, at a minimum to lower CAPEX.  

The Inspection Robot helps improve pipeline safety by minimizing internal corrosion, and safety is an important factor to the public. The Interstate Natural Gas Association of America reported that “a permanent, non-invasive system could improve safety. The best safety program is damage prevention, and if you can address corrosion before it is an incident, that is the best way to deal with the issue.” This statement succinctly represents CRTS’ commitment to provide internal corrosion prevention services.

What type of impact does the innovation have on the industry/industries it serves?

Table 1 explains the gap between pipeline owner and public interest.

<table>
<thead>
<tr>
<th>Pipeline Owner Interests:</th>
<th>CRTS Bridge:</th>
<th>Public Interests:</th>
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<tbody>
<tr>
<td>Safe Transportation</td>
<td>Revolutionary Robotic Technologies for Applying Protective Coatings to Internal Field Joints</td>
<td>Consistent Supply</td>
</tr>
<tr>
<td>Sound Investment</td>
<td></td>
<td>Environmental Sensitivity</td>
</tr>
<tr>
<td>Brand Name Protection</td>
<td></td>
<td>Brand Trust</td>
</tr>
<tr>
<td>Risk Management</td>
<td></td>
<td>Personal Safety</td>
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</table>

CORROSION PREVENTION DESIGN

The impact of designing pipelines for internal corrosion prevention means savings in energy costs, improved transportation infrastructure, reduced pipeline friction, smaller footprint and little to no need for corrosion allowance. Planning ahead for maintenance and reduced rehabilitation and repair costs can lower the environmentally-disastrous factors of microbiologically influenced corrosion, erosion corrosion, pitting, crevices and many more factors. Engineers can specify preventive coatings in new pipelines and with the addition of internal inspection, the source of many leaks will be eliminated. Once the pipe is coated and inspected, the benefits translate into lower prices for private and commercial sectors, less compressor usage, minimized pipe diameter, and overall environmental protection for the owner and the public.

CORROSION MANAGEMENT

Preventing internal corrosion is a sound method of corrosion management in an industry that suffers from 25% failure due to corrosion (oil and gas) and incurs costs of $1 trillion annually. Pipeline owners are naturally eager for innovative corrosion prevention technology.\(^{10}\)

Inspecting internal coatings, whether on the internal field joint or the factory-coated pipe, is corrosion management at its best. Pipeline integrity is assured with internal corrosion prevention measures, coupled with aggressive management. Incorporating corrosion prevention into the design of new pipelines prequels the important management techniques that occur after a product enters the pipeline.

**Does the innovation fill a technology gap? If so, please explain the technological need and how it was addressed prior to the development of the innovation.**

There is a technology gap in some current methods of corrosion prevention technology. A typical pipeline anti-corrosion methodology is as follows: The pipe strings are internally coated with an epoxy-based coating to reduce friction and protect from corrosion. An external coating is applied over the pipe to prevent external corrosion. Engineers specify sacrificial anodes and sacrificial wall thickness to accommodate inevitable corrosion. The external field joints will be coated and then covered by a heat-shrink sleeve. Assuming no sleeve failures, everything but the weakest link, the internal field joint, has been protected.

In offshore work, a gap in inspection technology is highly significant. Internal corrosion is difficult to rehabilitate and repair. The Inspection Robot not only provides internal corrosion prevention, the service itself does not slow the lay barge because welding and weld inspection operations are being performed simultaneously.

**Has the innovation been tested in the laboratory or in the field?**

Yes. All robotic equipment undergoes rigorous testing during R&D and prior to every project. R&D testing consists of a minimum of 500 cycles of testing in our shop, simulating field conditions such as temperature and angle. All instrumentation is calibrated and certified in accordance with our ISO 9001:2008 standards. Table 2 shows recent inspection services around the world.

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\(^{10}\) Ossai, C. 2012. Advances in asset management techniques: an overview of corrosion mechanisms and mitigation strategies for oil and gas pipelines. DOI: [http://dx.doi.org/10.5402/2012/570143](http://dx.doi.org/10.5402/2012/570143).
Table 2. CRTS, INC. ROBOTIC INSPECTION SERVICES

<table>
<thead>
<tr>
<th>YEAR</th>
<th>LOCATION</th>
<th>PROJECT STATISTICS</th>
</tr>
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<tbody>
<tr>
<td>2013</td>
<td>USA</td>
<td>Ongoing inspection of couplings (onshore)</td>
</tr>
<tr>
<td>2013</td>
<td>Canada</td>
<td>366 welds, two customers (onshore)</td>
</tr>
<tr>
<td>2012-</td>
<td>Brazil</td>
<td>1,754 welds, 154 offshore. Both inline and line-travel inspection requested by same customer. Seawater injection pipeline (onshore/offshore)</td>
</tr>
<tr>
<td>current</td>
<td>Saudi Arabia</td>
<td>Onshore spool work.</td>
</tr>
<tr>
<td>2012</td>
<td>Chile</td>
<td>6,391 welds at a desalination project. (onshore)</td>
</tr>
<tr>
<td>2011</td>
<td>Saudi Arabia</td>
<td>1,032 welds (onshore)</td>
</tr>
<tr>
<td>2009-</td>
<td>International</td>
<td>Multiple internal field joint inspection projects and some full-length pipe inspections (onshore and offshore)</td>
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<td>current</td>
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**2009-CURRENT INTERNAL FIELD JOINT INSPECTION SERVICES**: 10,000+ welds  
**2009-CURRENT OTHER INSPECTION SERVICES**: Ongoing

Is the innovation commercially available?

The inspection service with this Inspection Robot has been used since 2009. CRTS is a service company; we do not sell our robotic equipment. We build or customize our robots to project specifications, test them with the customer’s requested coating, then send our field technicians to operate them as they clean, coat and inspect internal field joints and/or factory-coated pipe.

Are you aware of other organizations that have introduced similar innovations?

To our knowledge, there are no comparable remotely operated devices for internally inspecting pipelines on any of the continents we serve.

Are there any patents related to this work?
