Intelligent inspection technology for cross-country buried petroleum pipelines

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A case study is presented here on the continued development efforts at the Bhabha Atomic Research Centre on instrumented pipeline inspection gauge for Indian Oil Corporation Limited over the last two decades. A marvel of technology involving challenges of non-destructive testing techniques, mechanical, magnetism, electronics, data processing and analysis, operational safety requirements and portability, qualifications of the tools and characterization of defects with acceptable accuracy were achieved to be at par with the internationally available tools. These tools are being extensively deployed in the field. The homegrown technology for in-line inspection has brought down the cost of the tool and that of the services per kilometre. Different technologies are now being pursued to ensure that the in-line inspection work in the country is carried out in an 'Atmanirbhar' way.

Keywords: In-line inspection tools, MFL technique, Odometer, oil companies, petroleum pipelines.

Introduction

A network of thousands of kilometres of buried pipelines exist in India to transport petroleum products, crude oil and natural gas. It is immensely important to maintain these pipelines in a healthy condition for safe operation over a prolonged period, thus protecting the people, environment and the national asset. Inspection of these pipelines at regular intervals without loss of throughput is necessary to monitor their health and this is only possible by means of in-line inspection (ILI) tools, popularly known as instrumented pipeline inspection gauge (IPIG)[1]. There are a few international companies that provide pigging service at premium prices without actually selling the inspection tool. The home-grown technology for in-line inspection has not only curbed the monopoly of these foreign service providers but also strengthened the integrity management programme of our country's energy lines. Moreover, the development has strategic importance in respect of safety, security and integrity of India's energy lines.

Indian Oil Corporation Limited (IOCL), the largest integrated oil company in India approached Bhabha Atomic Research Centre (BARC), Mumbai for the development of ILI technology. In the interest of the nation, BARC has developed magnetic flux leakage (MFL)-based ILI technology and deployed a fleet of commercial IPIGs for various pipe sizes ranging from 12 to 24 inch. The 12 inch IPIG, the first of its kind was developed under a first MoU signed with IOCL on 17 April 1995. The successful inspection run in commercial pipelines took place in June 2003 in 161 km of Mughalsarai–Allahabad section of the Barauni–Kanpur pipeline (BKPL). Thereafter, several hundred kilometres of inspection runs were carried out in commercial pipelines. For bringing the technology to a mature state by incorporating latest advances and to develop a range of next-generation IPIGs, a second MoU was signed on 21 October 2005. After successful delivery of the developed IPIGs to IOCL and completion of the second MoU, IOCL again approached BARC with a requirement to develop new-generation IPIGs with latest technologies. Upon mutual agreement, a third MoU was signed on 10 July 2019.

The developed tools are compliant to the specifications laid down by the Pipelines Operators' Forum (POF). Hybrid sensing technology for better defect detection and characterization, online data compression and compact, rugged and low-powered electronics for greater length of pipeline inspection at one go are some of the advanced features incorporated in the indigenously developed tools. This is the direct outcome of BARC's strength in multidisciplinary R&D activities in the area of spin-off technologies.

The IPIG works on the MFL principle. It has the capability to inspect ~300 km length of pipeline in a single stretch, negotiating critical pipe features like tees, bends, valves, etc. The hybrid sensor system collects information at a high rate, stores the acquired data on a customized DSP–FPGA-based hardware platform, processing them using real-time data screening algorithm. The odometer system gives location accuracy within ±1 m from the nearest reference (magnetic marker placed at every 2 km). During the inspection run, movement of IPIG is compulsorily tracked by monitoring a low-frequency radiofrequency (RF) signal continuously transmitted by a device call pig locator

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placed as a part of IPIG. After the inspection run, data of hundreds of kilometres acquired over 50–60 h are downloaded and analysed offline to provide inspection report for pipeline operators. Based on the results, pipeline operators take up the necessary post-pigging mitigation action for damage control. The indigenously developed tools inspected around 10,000 km of oil pipelines of IOCL and other Public Sector Units (PSUs) reporting severe defects, pilferages and trends of corrosion growth.

MFL technology

The MFL technology, a passive, time-tested and highly reliable inspection method has scored over other competing methods like those using variants of ultrasonic transducers (UTs). For Indian pipelines particularly carrying crude petroleum products, filling up of defect sites with muck restricts the use of UT inspection technology. Furthermore, deployment of MFL technology is economical compared to other methods.

Magnetic design

The MFL technique is used for detecting metal loss, corrosion and discontinuities in ferrous materials. The magnetizer unit of the IPIG tool houses rare-earth magnets to axially magnetize a section of the pipe to the onset of magnetic field saturation. The level of magnetization is customized for the steel used in Indian pipelines. Any reduction in section thickness and/or discontinuities in the pipeline cause magnetic flux to fringe into the surrounding medium. The magnitude and spread of the leakage flux is a direct estimate of the volumetric metal loss in the pipeline. Primary Hall-effect sensors are placed at the magnetic neutral plane to detect any leakage flux in case of wall thinning. Discrimination of defects, whether they are on the inner or outer diameter is done by another set of sensors called secondary sensors. This distinction is of paramount importance with regard to the corrective measures taken by the pipeline operators. Secondary sensors could either sense residual flux or they can be of eddy current-type. Figure 1 shows a schematic view of the principle of working of the magnetizer unit.

Design requirements of the magnetizer assembly: The magnetizer consists of an optimized magnetic circuit comprising permanent magnets, iron brushes, backing iron offering high magnetic susceptibility and Hall-effect sensors. Keeping in view the volumetric constraints inside a mobile inspection tool, the magnetizer needs to be compact in order to allow the inspection tool to safely navigate various pipeline features, including tight bends, tees, valves, etc. The magnetizer also needs to ensure adequate magnetization in varying thickness of pipe-sections, an inevitable requirement in cross-country pipelines going under roads and over bridges, etc.

The geometry of the magnetic circuit is heterogeneous, comprising both hard and soft magnetic materials having nonlinear properties. As a result analytical closed-form expressions for estimating magnetic flux and other parameters in the circuit are not available. Hence computer aided design (CAD) tools based on finite element analysis (FEA) have been used for field analysis and design optimization (Figure 2). This analysis helped in estimating the signature of the leakage magnetic field for a known irregularity in the pipe section. Later during calibration of the tool in the test sections/loops, these findings were benchmarked.

Magnetic materials: Pipeline steels are hardened/tempered medium carbon steels having average magnetic properties. Analytical closed-form expressions for estimating magnetic flux and design parameters of the circuit are not available; hence the backing iron needs to be of soft-grade magnetic alloy having very high magnetic permeability to avoid any ampere-turns drop in the backing iron region. Wire brushes connect magnetic flux to the pipeline section while offering suitable manoeuvrability and soft magnetic path. Power and space constraints precluded usage of electromagnets to meet the ampere-turns requirement of the magnetic circuit. Rare-earth permanent magnets have been used to drive the magnetic circuit owing to their high energy density, high coercivity and high remanence. This ensures lowest volume of permanent magnet in the circuit, thereby meeting the critical design requirement of a compact magnetizer. Magnet design was optimized to ensure high permeance

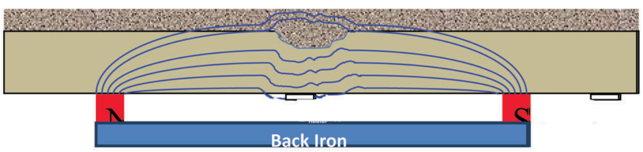

Figure 1. Schematic view of the MFL principle.

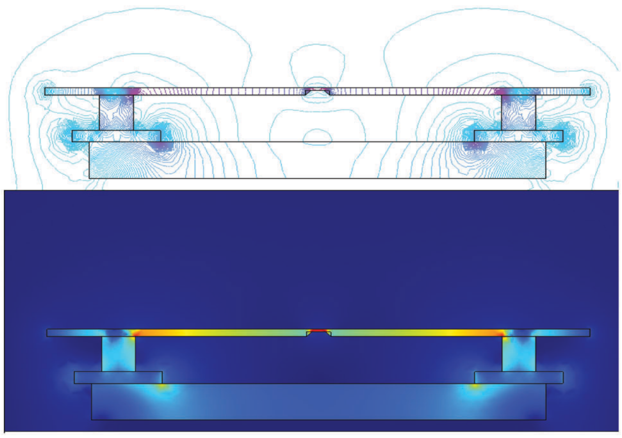

Figure 2. Finite element analysis of the magnetizer unit.

Table 1. Key magnetic parameters of various types of permanent magnets

Material	B_r (kg)	H_c (KA/m)	H_{ci} (KA/m)	Curie point (°C)	Maximum working temperature (°C)	Temperature coefficient B_r (%/°C)	Temperature coefficient H_C (%/°C)	Maximum energy product (kJ/m^3)	Density (g/cm^3)
Ferrites	3–4	300	400	450	200	–0.2	0.4	36	4.8
Alnico	11–12.5	48	50	750–900	250	–0.02	0.02	44	7.3
$SmCo_5$	10	756	1700	740	250	–0.045	–0.25	192	8.2
Sm_2Co_{17}	11.5	820	1592	>850	350	–0.035	–0.2	248	8.3
Sm_2Co_{17} (low temp. coeff. grade)	10.4	756	1194	>850	350	–0.01	–0.2	208	8.4
NdfeB	12.8–13.2	995	1592	300	150	–0.12	–0.70	340	7.4

coefficient of the permanent magnets. This ensured stable magnetic field in the pipe during changes in its section thickness. The high permeance coefficient also provided immunity against loss of magnetization due to temperature, external demagnetizing fields, shock and vibrations.

Table 1 shows a comparison of key magnetic parameters of various types of permanent magnets.

Neodymium–iron–boron (NdFeB) magnets have been selected for their superior magnetic properties compared to other permanent magnets. Since NdFeB magnets have poor corrosion resistance, these were suitably coated before use in the magnetizer assembly.

Optimization of magnetic circuit: Magnetic properties (*B–H* curve) of each material in the magnetic circuit were measured for usage in the design software. The soft magnetic materials were measured in compliance with IEC 60404-4 and ASTM A341, while the permanent magnets were measured according to IEC60404-5 and ASTM A977 at in-house facilities of BARC. Parametric studies were carried out for correlating the magnitude of leakage flux to volumetric loss of the pipeline material.

Mechanical design

The indigenously developed IPIG tool is capable of inspecting around 200–300 km of pipeline at one go without interrupting the throughput. During every inspection campaign, the tool travels through rough terrain and hostile environmental conditions. It is imperative and mandatory to inspect the pipelines without doing any damage to the pipeline assets and the costly inspection tool as well. The robust and rugged mechanical design of various modules/ systems and components of IPIG takes care of hostile environment inside pipelines, like change in cross-section, geometrical irregularities, bends, dents, steep slopes of riser and down-comer at bridge/river crossings, main line valves at various locations and, last but not the least, the high-pressure petroleum cargo being transported. Some components will also experience excessive wear and tear due to continuous rubbing with the inner surface of the pipe.

The mechanical systems/components of IPIG are categorized into three groups: pressure-retaining components, kinematic components and abrasion resisting components (mainly involving polyurethane). Pressure-retaining components are designed and analysed according to the intent of ASME Section-VIII boiler and pressure vessel code. Conventional mechanical design approach is followed for the kinematic and polyurethane components. Design is qualified for vibration and shock according to the requirements of IEC571. All pressure-retaining components are helium leak tested followed by hydrostatic pressure tested to qualify for design pressure. Elastic damping materials are provided at appropriate locations in the modules of IPIG to isolate individual components, wherever necessary. Also IEC-qualified industrial-grade electronics COTS and SMD components are selected.

Major mechanical components/systems: Major mechanical systems comprise of magnetizer unit, MFL sensing system, data acquisition system-cum-power supply module (pressure-retaining components), odometer system, tow links and polyurethane (PU) cups for sealing and support purpose.

Magnetiser unit: This unit is supported by PU cups to keep it coaxial to the pipe and create differential pressure across the unit for propulsion of the tool inside the pipelines. The spring-loaded magnetizer unit is capable of getting compressed or squeezed diametrically by approximately 17–18% of its original dimension to move through the pipelines with known and specified irregularities. Modular collapsible design of the magnetiser unit as shown in Figure 3 is capable of negotiating 3D 90° bend and other constraints like ovality, dents and change in pipe thickness.

MFL sensing system: This system employs MFL (works on the principle of Hall effect) sensors encapsulated and rigidly secured on a sensor carriage. The MFL sensors capture the leakage flux signatures and store the same in the data acquisition and storage unit. There is a specified number of sensor carriages (depending on the size of the tool) arranged at equal spacing in a circular array to cover the entire internal periphery of the pipe. The spring-loaded sensor carriage ensures that sensor capsules always remain in contact with the pipe wall and parallel to the pipe surface throughout the inspection run. It also maintains integrity

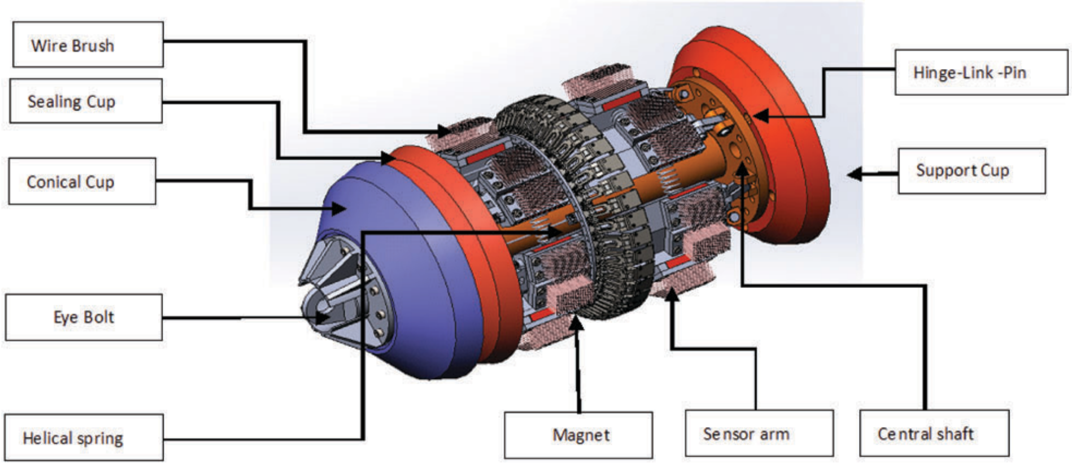

Figure 3. Magnetizer unit.

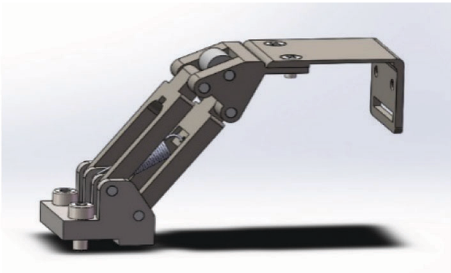

Figure 4. Sensor carriage.

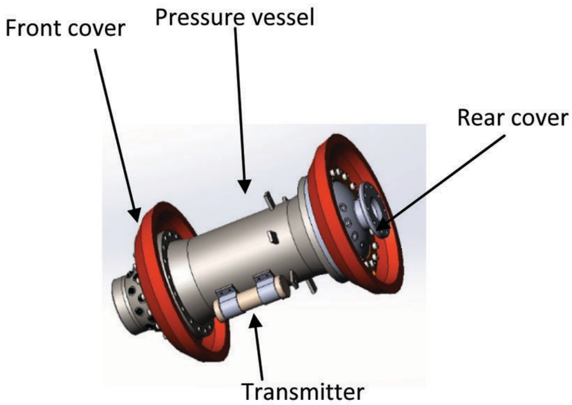

Figure 5. Data acquisition system-cum-power supply module.

and wear resistance of the top surface for a travel of 250–300 km run inside the hostile environment of the pipeline (Figure 4).

Data acquisition system (DAS)-cum-power supply module: This module is a pressure-tight sealed vessel with front and rear covers which houses the electronics and storage system, and the power supply unit containing battery packs (Figure 5). Components of DAS-cum-power supply unit, viz. front and rear covers, pressure vessel and cable connectors are designed primarily to withstand external pressure of 120 bar besides meeting other constraints due to the pipeline geometry and features. The material of the vessel and its covers are chosen such that the assembly is also capable of shunting the flux coming from the preceding magnetizer unit, thus preventing it from reaching the electronics systems inside the assembly. The design basis of this module is mainly (according to the intent of ASME Section VIIII) protection against plastic collapse and protection against collapse from buckling (ASME B & PV Code, Sec VIII Div1 and 2). The material properties and allowable stress values have been obtained from ASME Section II Part D to check the developed stresses against the allowable limit.

Odometer system: This is mounted at the back of IPIG tool, and estimates the location of the tool within a specified accuracy from a nearest known reference during its travel in the pipeline (Figure 6). The odometer system consists of a stainless-steel wheel crowning with toothed PU rim and mounting arm with tension springs. Three such assemblies are mounted on the rear cover of the DAS-cum-power supply module in a circular array, 120° apart. Each wheel is pressed to the inner wall of the pipe by a pair of tension springs to ensure sufficient frictional torque for rotation. The wheels are encased in a PU ring to avoid damage to the pipe. Force on the wheel is calculated optimally to avoid wear out of PU.

Polyurethane (PU) cups: These are attached at both front and rear ends of each section of the tool. Three types of PU cups commonly used in IPIG are conical cups, sealing cups and support cups (Figure 7). Conical cups are located at the nose of the tool to guide it inside the pipeline terrain. Sealing cup is attached at the front of the first section of the tool, which is usually the magnetic module. The basic function of sealing cups of IPIG is to provide sufficient sealing with the pipe inner diameter and in turn create differential pressure across the tool. The differential pressure generates the driving force to propel the IPIG tool inside the pipelines. The support cups have holes in their faces to facilitate passage of oil; they take the weight of each section or module and maintain the tool coaxial with the pipeline. However, the support cups also create certain amount of sealing. The selection of the grade of PU material is such that it has high abrasion resistance to make the tool capable of inspecting greater length of the pipeline in one stretch. PU has good material compatibility with petroleum products.

Bend negotiability of IPIG: Optimized design of individual sections of the IPIG tool, tow links and PU cups ensures the 3D 90° bend negotiability of the tool. This is schematically shown in Figure 8. In general, the IPIG tools for inspection of smaller-diameter pipes have two or more articulated sections, whereas large-sized IPIGs are single-module tools. The sections of small-sized tools are connected with each other using a universal coupling commonly known as tow links. The sealing cup of the front module provides the necessary pulling force due to differential pressure across it and these links facilitate the tool to smoothly negotiate the pipeline features like sharp bends, valves, tees, riser/down-comer at river and bridge crossings. The indigenously developed tow links have unique design features – swivelling in all directions and also push–pull mechanism in a single unit. This is achieved by a link chain-type coupling moulded in PU as shown in Figure 8.

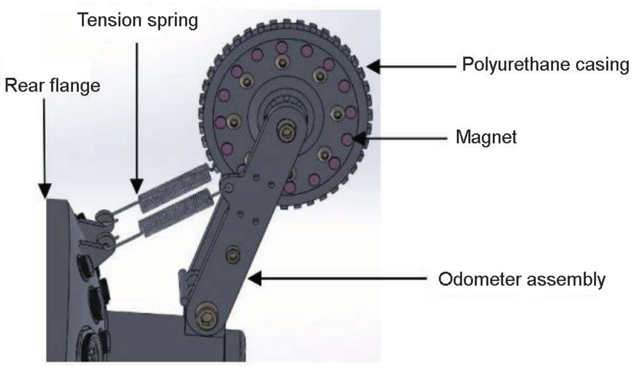

Figure 6. Odometer system.

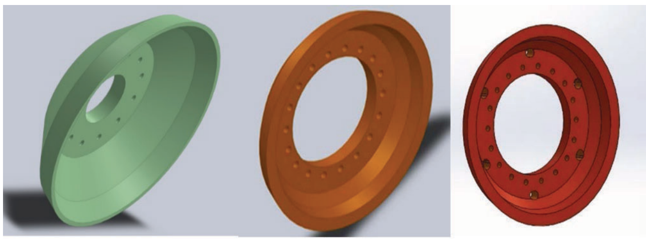

Figure 7. Various types of PU cups.

The link chain provides the necessary pulling force, whereas PU takes care of compression.

Data processing: The IPIG gathers huge volume of data from even a single inspection run. Most of this is noise arising from nominal pipeline condition. Signal due to a defect or a pipe feature is almost always a short-lived phenomenon submerged in noise and is typically as difficult to detect as a needle in a haystack. Moreover, according to the terms of inspection, the inspection report is sought soon after the run. This calls for unsupervized processing of the data with minimum human intervention. The first step to data preprocessing is decompression if an on-line compression algorithm has been employed while collecting the data. Noise removal or denoising is the next step that improves the signal-to-noise ratio and as a consequence probability of detection (POD). A multiresolution framework has been suggested for the first time that works best for the detection and even for characterization of MFL signals[2]. The proposed methodology of MFL signal analysis has been extensively adopted by many researchers globally since then. As the processing involves multichannel data, equalizing channel response functions also helps[3]. A surface image of the pipeline is developed from the reconstructed clean multichannel signal, where the extent of thinning and percentage wall loss are indicated by varying grey levels (Figure 9). The image is subjected to segmentation and automatic detection of signal features.

Defect characterization from the MFL signal essentially precipitates to finding defect parameters – length, width and percentage wall loss. Typically we seek a solution of an inverse problem that maps MFL signal features to defect parameters (Figure 10). The mapping is known to be multivariate and nonlinear. To complicate the problem further, the forward mapping is 'many-to-one'. For example, for a wide–shallow defect, the effect of blooming (flux spread outside the defect boundary) is less significant than a narrow–deep defect of the same length. As a result, these two types of defects may give rise to the same primary signal features causing under-sizing of the narrow–deep defect. Empirical relationships defining the inverse mapping from radial MFL signal to defect parameters have been derived from experimental observations that seem to work for a wide range of defect sizes[4]. Three primary features extracted from the bipolar radial MFL signal sensed over a rectangular defect are (1) temporal/spatial span from first to second peak, (2) number of sensors sensing the defect and (3) the maximum peak-to-peak flux density. The issue of non-unique mapping may be resolved by considering secondary signal features (like shape of circumferential flux distribution across the sensors) in the feature space.

It is rather useful to model a complex corrosion defect (also called a river-bottom defect) as a combination of a general area of corrosion 'patch' with pits of deeper depth inside the patch boundary. The assessment method then decides whether the defect behaves as a single irregular

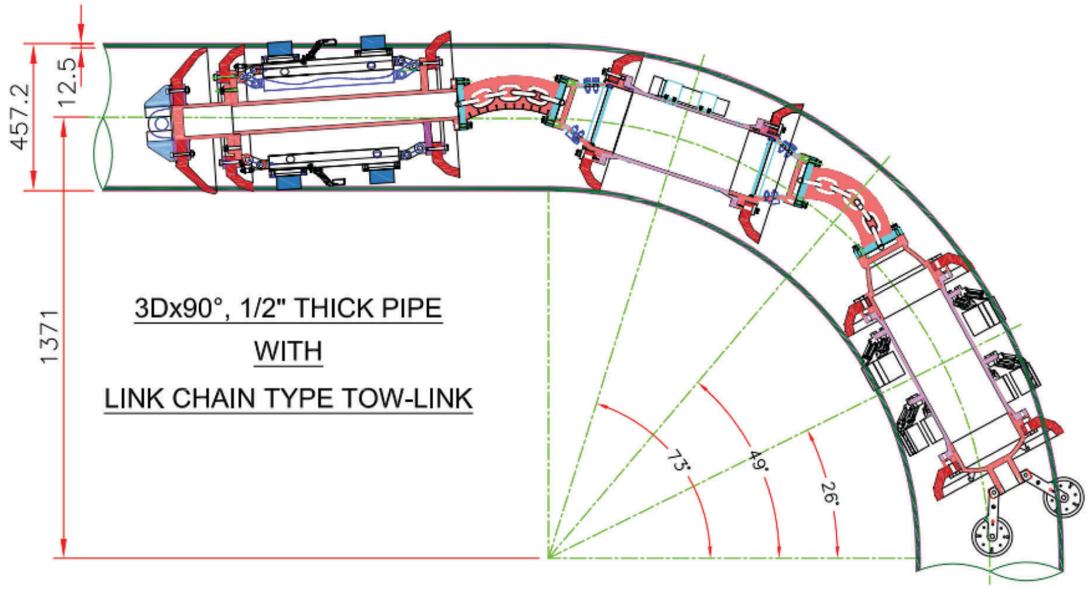

Figure 8. Three-dimensional bend negotiability of IPIG.

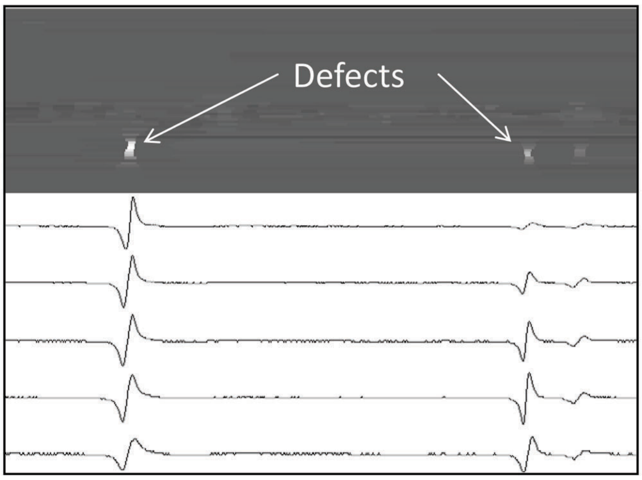

Figure 9. Surface image of a pipeline showing defects.

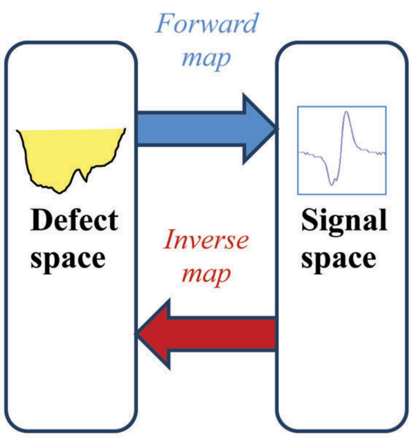

Figure 10. Forward and inverse mapping for defect characterization.

'patch', or if local 'pits' within the patch govern the failure pressure. It is also important to assess the interaction between the pits. Characterization of river-bottom defects having varying wall loss and irregular surface extent has been attempted using a partially time-varying model[5]. The scheme maps the projections of MFL signal (on wavelet basis) to those of the defect shape, and selectively employs time-varying and time-invariant models in different frequency bands to estimate the exact defect shape. Shape reconstruction uses alternate projections that converge to minimum norm solution. Once defect sentencing is done, maximum allowable operating pressure (MAOP) for a pipeline is decided according to ASME B31G or DNV-RP-F101 guidelines. Odometer readings corrected by coordinates of magnetic markers and known pipe tally are used for estimating locations of the defects with required accuracy. Subsequently, excavation and repair of the corroded section of the pipeline are undertaken, if required.

Data acquisition electronics of an instrumented pig collects leakage flux data from an array of Hall sensors disposed on the inner periphery of a pipeline. A large part of these data does not contain any useful information and need not be stored. Online compression economizes the use of electronic resources. A DSP–FPGA-based parallel architecture is conceived for acquisition and compression of data in real time. The architecture is designed around a high-performance DSP processor. The data acquisition hardware blocks consisting of control logics and FIFO are implemented in FPGA. FIFO interconnects DSP with the acquisition hardware, running acquisition task in parallel for achieving maximum throughput. The data compression algorithms based on a statistical measure of variance, namely mean absolute deviation (μAD) are implemented on the DSP[6]. Further, a multivariable dimensionality reduction technique can be employed for compression across sensors. For this, the principal component analysis (PCA), a well-established dimensionality reduction technique has been suggested[7]. Finally, a wavelet-based technique that exploits the correlation within a single sensor's reading as well as denoises the data is recommended.

Prototyping and validation experiments in linear pull through/wet test loop facility

The tool design has gone through several iterations to meet the target specifications. Rigorous validation experiments were conducted at test rigs built to simulate actual pipeline conditions whenever any design modification was made. Some of these test rigs are static and some mimick the motion of the tool relative to the pipe. Figure 11 shows the test rig used for high-pressure hydrostatic testing of the modules and electrical connectors. Figure 12 shows a rotary drum test rig built to test repeatability of measurements and endurance of components under dry running condition[1]. In this rig an arrangement is made to keep the magnetic module(s) and the sensing system stationary over a rotating carbon steel drum, emulating the movement of IPIG.

The linear pull through and wet test loop established at IOC R&D Faridabad has riser and down comer, tees, stiff bends, etc. that are commonly encountered in an inspection run (Figure 13). Repeated runs of the tool in the test loop/facility confirms endurance under harsh pipeline conditions, thus simulating travel over greater lengths of the pipes. The tests not only proved the functional capabilities of the integrated system, but also the field worthiness of the tool.

Data collected from the experiments were used as baseline data for developing defect analysis and sentencing software. Figure 14 shows reference defects created on a pipe

Figure 11. Rig for pressure testing of modules.

Figure 13. Linear pull through and wet test loop at Faridabad.

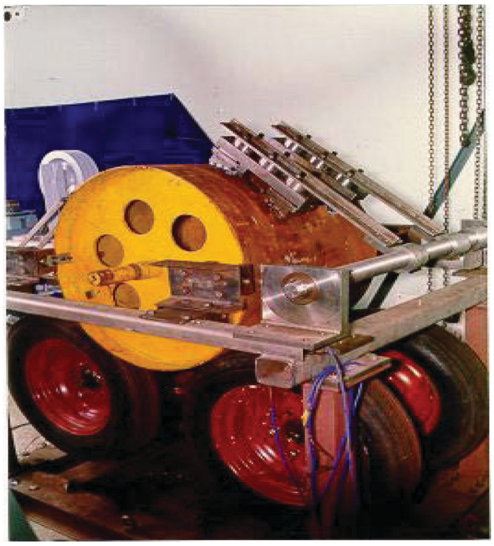

Figure 12. Rotary drum test rig.

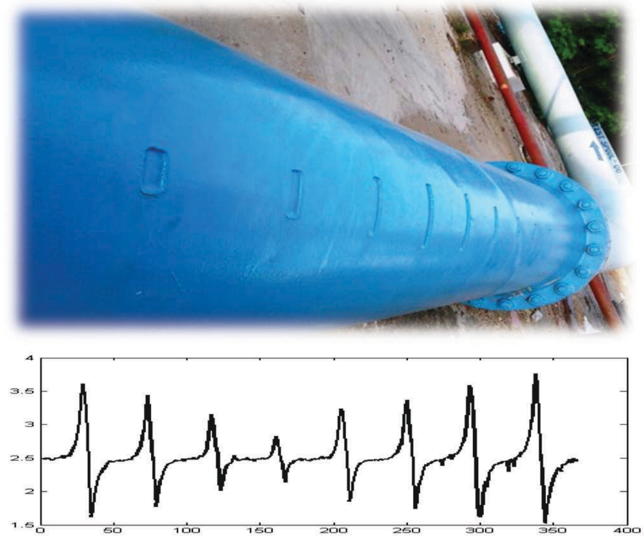

Figure 14. Reference defects and signals recorded on them.

section and the recorded signature thereon. Parameters of the empirical relationships were estimated from the noisy records of the defect signatures. Moreover, uncertainties in the measurement could be statistically modelled from the data collected from repeated runs. Once the noise characteristic is known, design of denoising scheme becomes easier.

Deployment of field-worthy tools for inspection of domestic commercial pipelines

The indigenously developed tools (Figure 15) have already been used for inspection of around 10,000 km of cross-country pipelines of IOCL and other PSUs reporting severe defects, pilferages (Figure 16) and trends of corrosion growth. The reports have been used extensively for repair of pipelines, wherever necessary. It was observed that defect characterization results met the accuracy envisaged in the POF document. The developed technology has generated great confidence among pipeline operators on indigenous capability.

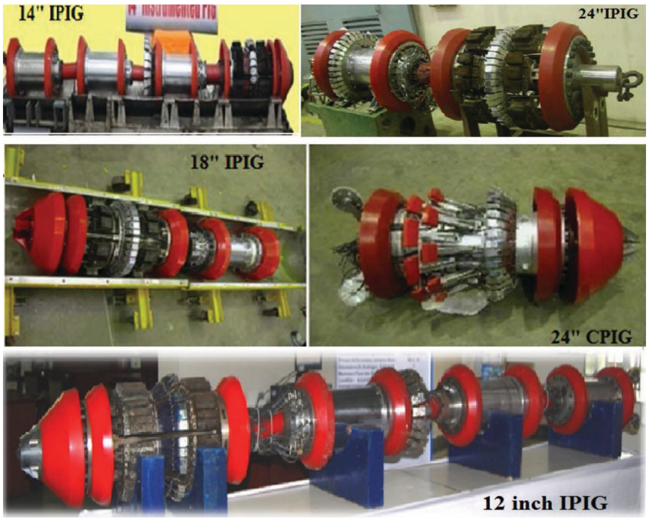

Figure 15. Different sizes of indigenously developed ILI tools.

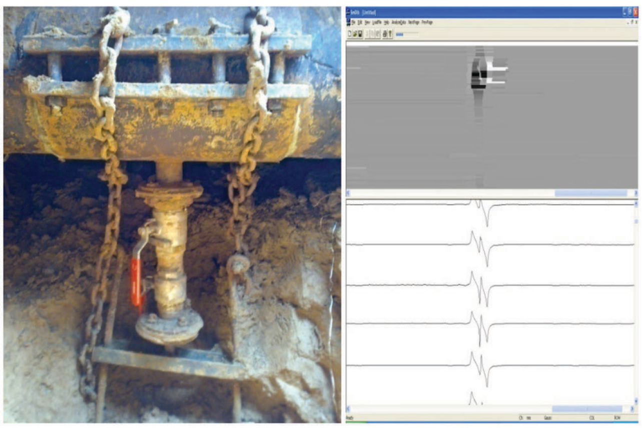

Figure 16. Pilferage points detected by IPIG.

New developments

Development of a number of technologies has been taken up to meet the specific requirements of Indian industry[8]. The following two examples demonstrate the steps towards capability building that would make the tool state-of-the-art and competitive in the open market.

External PIG – a novel tool for inspection of pipelines from the outside

So far all indigenously developed IPIGs carry out inspection from inside the pipelines where proper tool insertion and retrieval arrangement is in place. However, there are pipelines in oil refineries, process industries and power plants (conventional and nuclear) where inspection from the inside is not feasible due to the small diameter of the pipes, and also because accessibility and special provision for launching and retrieval of the tools cannot be made. Inspection of such pipelines would only be possible from the outside. Till date the health assessment of such pipelines is mostly done by spot thickness measurements, which are localized and intermittent.

Using the expertise and domain knowledge in the area of in-line inspection, BARC has developed a novel inspection tool known as external PIG (EPIG) based on MFL technology[9]. This tool is capable of inspecting full periphery and full-length pipelines from the outside. During each inspection campaign, besides conventional recording of inspection data, real-time MFL data can also be recorded, which gives the inspector an advantage to critically look into a particular section of interest on examining the signal.

In-house developed EPIGs inspected 6″ and 10″ CS pipe sections at Dhruva, BARC, 6″ and 250 m long liquid waste discharge pipeline at the Integrated Fuel Fabrication Facility (IF3), BARC and 6″ fire water line for ITFT at R&D Centre, NPCIL, Tarapur (Figure 17). Based on the preliminary

Figure 17. EPIG tool for 6″ NB pipe inspection.

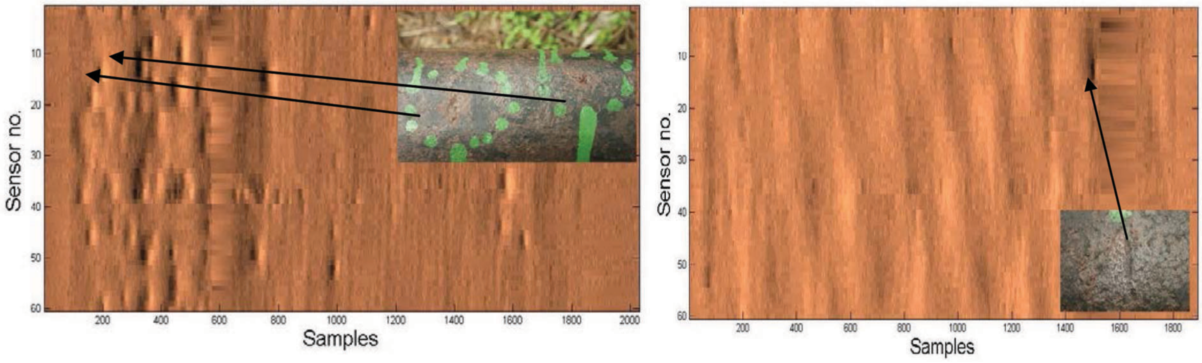

Figure 18. C scan and actual defects of pipeline at IF3.

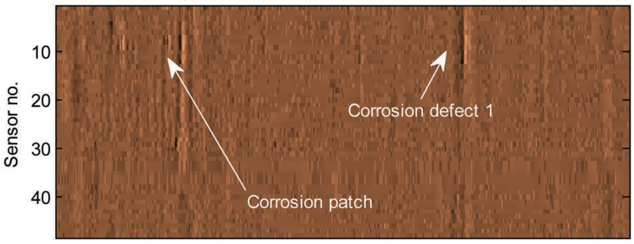

Figure 19. C scan showing corrosion patch and isolated defect of fire water line.

analysis report, verification of a few defects was carried out (Figures 18 and 19). The site verification of defect showed good match with parameters estimated from the analysed data.

Eddy current sensing technology for IPIG

Eddy current technology is based on the principle of electromagnetic induction and a new secondary sensor system has been developed by BARC. When an alternating current is passed through a coil (eddy current probe), it produces an alternating magnetic field which, if placed in close proximity to a conducting surface, induces current in it that flows in small circles (eddies). This current (eddy current) is strongest at near surface and penetrates to a very short distance in the material. Hence only near wall defects are detected. The eddy current generates its own magnetic field opposing the one provided by the eddy current probe. As a result, overall inductance of the probe decreases. Also, as the eddy current dissipates energy, resistance of the probe increases. In the presence of cracks and surface defects on the conducting surface, the eddy currents will face sufficient resistance in their path which will be reflected as a change in the opposing magnetic field. This in turn would affect the impedance of the probe coil. Thus change in the impedance measurement of probe coil indicates the presence of irregularities on the smooth metal surface. The developed probe consists of two differentially connected, identical SS coils placed in a single sensor module. Internal defects with a minimum size of 18 × 18 and 20% wall loss are detected by these sensors (Figure 20). External defects with wall loss less than 80% are clearly distinguished from the internal defects[10].

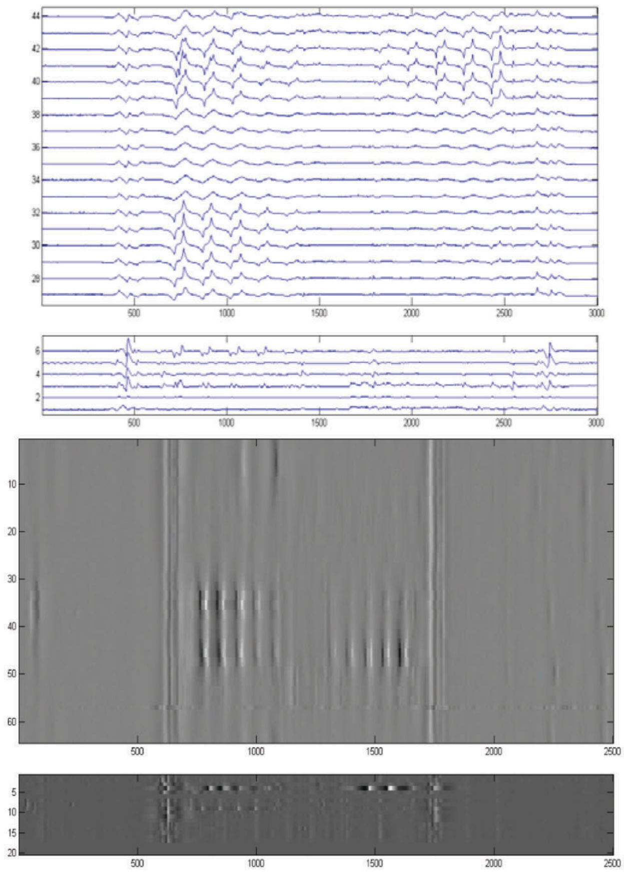

Figure 20. Internal defects detected by MFL and eddy current sensors.

Summary of achievements and future scope

The oil and gas industry in India has reorganized significantly since the beginning of the development of IPIGs due to frequent upheavals in the global market and ensuing policy changes in the country that called for expansion of pipeline networks as well as safe and economic transportation of petroleum products to meet the increasing demand. As a consequence, the need for more accurate estimation of defect sizes has been emphasized for better planning of repair and restoration of corroded sections of pipelines, particularly in relatively inaccessible stretches such as in congested cities or under a riverbed. Development of new-generation IPIG tools using dual technology (MFL and UT) for improving the probability of detection and accuracy of defect characterization has been undertaken by BARC. Work has started on the development of 18″ combo IPIG based on MFL and ultrasonic technology and 18″ IPIG tool for gas pipeline with bypass mechanism for speed control. We can proudly say that the sustained efforts towards this successful indigenous development that involved a large team of researchers, academicians and industry personnel over a decade is a confident step towards 'Atmanirbhar Bharat'.

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