Multi-Diameter Pipeline Inspection Gauge for Lang Distance Industrial Application

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ABSTRACT: This paper presents an innovative approach for the design and development of Pipeline Inspection Gauge (PIG) which can inspect pipes from 15" up to 30" with a simple change of shirts using the latest technologies such as Electromagnetic Acoustic Transducer (EMAT) sensors as well as Remote Field Eddy Current (RFEC) sensors for oil pipes inspection, through the creation of a simulation tool capable of generating simulated images from pipeline using Inertial Navigation System (INS) for highest accuracy and precision inspection to protect the environment and equipment from any unexpected accident. There are several dynamo motors utilized to regenerate green efficient power from the flow of the medium inside the pipeline to elongate the distance of investigation by the mean of reduction of the number of individual pigging processes to save time and cost for companies. The INS uses accelerometers and gyroscopes of the type "Integrated Micro Electro-Mechanical Systems" (iMEMS), to carry out the mapping corresponding to the inspected pipes. Fluid hammer effect is another factor which has been considered during designing this pig. To avoid such case to occur the design has been revised and several arms have been devised around the robot to maintain the speed and position of pig all the way through the pipeline.

Keywords: Pigging, Pipe Line Inspection Multi Diameter Pipes, Remote Field Eddy Current, Hydraulic Transient

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1. INTRODUCTION

Pipelines are considered to be the safest way for transportation of large amounts of liquid and gas over large distances. Pipelines are one of the cornerstones of modern civilization constituting an essential part of the infrastructure. More than 3 million kilometers of pipelines connect the reservoirs of oil and gas, the ports of shipment, the refineries and the storage facilities today. Non-destructive testing of the pipeline system by means of in-line inspection using intelligent pigs has become an important part of this system in ensuring its safe and economic operation. In order to prevent pipeline failure, any defect that may become critical has to be detected early enough. As most of the pipelines are buried and also covered by a protective coating, a complete inspection can only be done from the inside. This is achieved with in-line inspection using automated inspection systems called intelligent pigs (or smart pigs). The ultimate goal of this type of inspection is to detect a certain type of defect with a high Probability of Detection (POD) and to provide high resolution data that allow precise sizing of the detected defects [1].

Intelligent pigs are automated inspection systems which are usually designed such that one inspection tool is looking for a specific type of defect utilizing one technology. Table 1 shows an overview. The main inspection methods that are used are Magnetic Flux Leakage (MFL) and Ultrasonics (UT).

Table 1: overview of the current inspection technologies utilized for PIG

Task	Inspection Tool	Inspection Principle	Comment
Geometry Inspection	Caliper Tool	Mechanical Deflection	
Metal Loss Inspection	MFL Tool Ultrasonic Tool	Magnetic Flux Leakage Wall Thickness Measurement (Piezoelectric)	Liquid and gas line; indirect measurement Requires liquid coupling; direct measurement
Crack Inspection	Ultrasonic Tool	45° shear wave (piezoelectric) EMAT guided waves	Required liquid coupling; axial & circumferential Fluid testing stage

2. PROBLEM STATEMENT

Low-flow or low-pressure situations in oil/gas pipelines can be problematical in a sense that the PIG can get stuck in the middle of operation. This causes a system failure which can lead to serious damages to the structures such as spoiling the suction pumps. Some pipelines have no access, meaning launcher and receiver are missing or there are vast distances between them. Multi-diameter pipelines, telescoping pipelines or plug valves can also be addressed with current tools. The required expertise to develop and

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deploy these tools increase from conventional in line inspection (ILI) technology towards bi-directional, tethered, low-flow /low-pressure, or complex multi-diameter tools. Still, many pipelines cannot be inspected. Most of these so-called unpiggable pipelines have never been cleaned before which is also a challenge for internal inspection. These pipelines must be examined from a self-propelled motion platform. There has not been any specific research regarding the effect of fluid hammer on the pipelines caused by pigging process. As it is comprehended, the size of the pig is relatively high due to its function of cleaning the interior surface of the pipeline. Furthermore because of the possible disfigurations in the pipe; the movement of the pig may not be smooth with constant velocity all the way in pipeline. Therefore these sudden changes in the speed of the pig causes fluid hammer effect which may break the pipeline at any weakened or cracked point.

Purpose of the Study

The main purpose of this study is to develop an innovative design for Pipeline Inspection Gauge to enhance the inspection process of the robot and eliminate the commonly confronted problems which make the system to be known as unpiggable. Also by utilizing EMAT as well as Eddy Current sensors with latest signal processing techniques, it is possible to gather high resolution information regarding the status of pipelines merged deep under the ground. The unpiggable pipelines have the highest POD (probability of defect) and are considered as one of the most critical branches in the oil and gas industry to be kept well maintained to prevent damages and defects. Thus the result of this study can help the oil and gas companies to keep their pipelines clean and safe. Furthermore by reducing the POD of pipelines and upgrading the inspection systems, there will be a high impact on the sustainability and waste reduction which ethically and commercially can benefit the industries in this field. In addition, there are very few researches regarding the fluid hammer effect of currently existing PIGs on pipelines. The fluid hammer as one of the most destructive effects in pipelines can cause failure for the system, and the very first areas which will be directly affected by this phenomenon are the weakened parts of the pipeline due to corrosions and deformations. Thus the result of this study can create a better design for future PIGs and be used as reference for future researches.

3. METHODOLOGY

The proposed inspection technique for this research is to use EMAT to detect the metal loss due to corrosion as well as Eddy Current to detect cracks inside and outside of the pipelines. Hence to achieve this objective the first step is to design the sensors. The sensor must be made out of highly durable rustproof material; furthermore in a case where as the PIG is used for Oil pipe inspection, the sensors must be waterproof.

After identifying the proper sensor, the initial experimental readings derived will have numerous amount of undesirable interferences such as variety of noises and overshoots; hence to stabilize the signals, noise cancellation filters as well as signal processing techniques needs to be implemented. Matched filter is a famous type of filter utilized in many researches to eliminate noise of inspection sensors. Barker codes on the other hand is a signal processing technique which allocate an autocorrecting sharp peak to the input signal which by converting the received signal to its original, will be off charted and can be eliminated.

Subsequently, the information is needed to be stored in an external HDD because the internal ram of most of the Processing Units (PUs) is insufficient to be utilized as storing component for a long inspection application. Even the biggest capacity HDD might run out of space hence HUFFMAN algorithm is used in many applications to compress the data by a factor approximately 30%.

The software used to implement signals processing techniques to PU is commonly Matlab, but the reading results from the software does not have any graphical user friendly interface, hence to represent the stored data from inspection, Labview can be utilized to design the GUI. The integration of Matlab and Labview makes interchanging of the two software easy and the available libraries for Labview makes it capable of communicating with almost all the available sensors.

Locating the defects is as important as detecting them. Inspection of pipelines requires a mapping system to accurately locate the position of weakened point with respect introduced origins. The mapping system is responsible to show the three axis coordination position of defect as well as its distance from the origin and its depth from earth surface. To detect the coordination and depth of system, IMEMS Gyroscope & accelerometer are commonly used and to detect the objective distance from origin, Odometers are the most famous components universally utilized in many industries.

The system of PIG does not limit to inspection and mapping sensors. There are varieties of other sensors which are required to build in in order to get as much as possible information from a single inspection run. Sensors such as temperature, pressure, humidity and flow-rate meter must be integrated with mapping system and inspection system to delicately show the location of variation in any of the mentioned parameters.

The required system can implement SMC or CAN bus for integrating the signals or in the other hand, Wavelet method can be utilized in programing of sensors to get flawless readings from each sensor with respect to another. After assembling and programming the controller to integrate the readings of sensors, further testing and analysis can be conducted to improve the accuracy and precision of inspection.

The other objective of this research is to develop the system such that it can inspect multi-diameter pipelines with the least impact on the flow of fluid inside it. Any sort of effect from the movement of PIG can cause change in the speed of fluid which ultimately causes fluid-hammer effect.

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The design considerations for implementing adjustable arms can be tricky. The design must fundamentally have the strength to withstand a pressure of approximately 80bar inside the pipeline, also the arms must be able to adjust to environmental condition and apply adequate force to pipeline walls to control the speed of PIG. To analyse the design, simulating software such as Creo or Solidwork are widely used in the market. These software are capable of visualizing and simulating the real time effects and reactions of variety of stress factors on different components, hence by using them it is possible to improve the design to prevent system's imperfection while inspection.

After validating the design, the prototype can be constructed and mechanical analysis on the system can be conducted. Final testing of system which includes the testing on delivered outcomes from inspection and mechanical activity of system to cope with environmental condition can validate the authenticity of results. In the case of improvement needed, the system can be reconstructed.

4. DESIGN

As the mechanical aspect, it is necessary to determine the minimum size that can have a shirt or module, in such way it does not get jammed or damaged the structure of the inspected pipe. Also as the goal of this research to reduce the effects of water hammer on pipe it is vital improvise chasms for the fluid to pass from inside of PIG. It is necessary to mention that these tools use the pressure and the fluid as means to travel for the interior of the pipe. For what uses disks that work as stamps, traction calls, they are built in base of a polymer whose malleability allows sealing the space between the PIG and the internal wall of the pipe, impeding the damage to this (Figure 1).

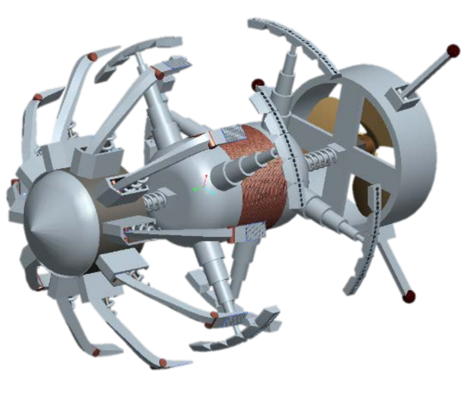

Figure 1:3D design of the prototype using Creo

The designed prototype consists of three main bodies. Each part has different attribute which ultimately makes up the inspection system according to the predefined criteria to fulfill the objective of research. The first part of prototype (the Head) is facilitated with a ball bearing to rotate freely. Cleaning brushes are attached at the top of rotatable and compressible handles. The handles are architected to create a rotational force as the flow of fluid pass its orientation There are springs with high stiffness such that, it can apply a high pressure in different pipe radius at all the time (Figure 2).

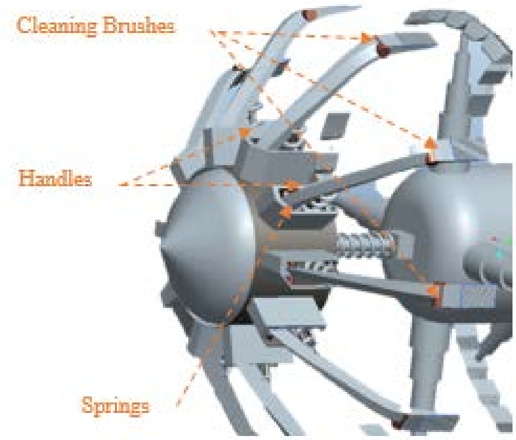

Figure2**:** PIG's head 3D design

The middle part of the prototype is where the electronic parts are placed mostly. The PU with the communication system and the supplementary sensors such as temperature and pressure are located in this part. The adjustable arms are also attached to this part of system which subsequently can compress and expand according to the diameter of pipeline. At the pot of arms, the EMAT and Eddy Current sensors are devised with adjustable positioning system to cope with variety of pipeline diameters (Figure 3).

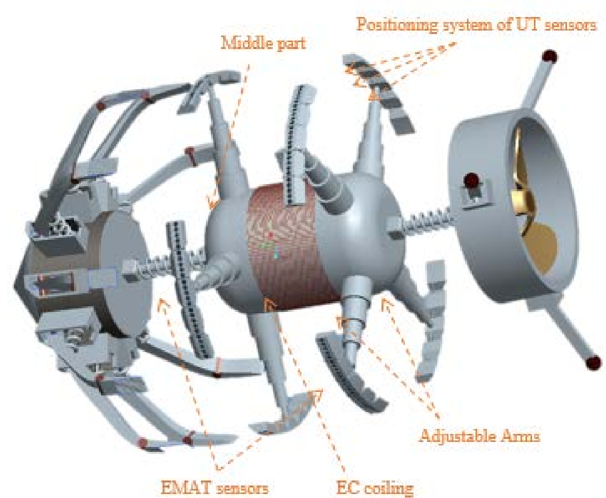

Figure 3: PIG's inspection and controlling body 3D design Illustrates the placement of arms

At the back of the designed PIG, the Dynamo as well as Odometer sensors are placed. Batteries are polarized with internal transformer ICs and Odometers are located with 120 degree angle difference to cover the full area of pipeline as well as stabilize the position of back part. The Odometers are connected to handles which with the aid of spring will have all time connection to pipeline wall. The figure 4 illustrates a closer look at the system.

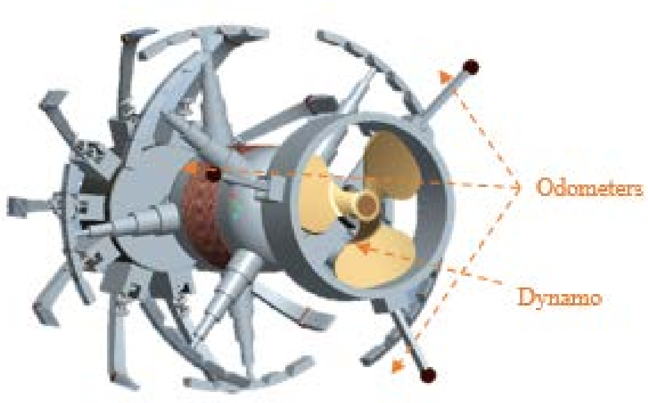

Figure4: PIG's back and dynamo 3D design

Table2 shows the mechanical specification of the robot. The specification of designed robot has been picked by investigating various similar researches.

Table2: Technical Specs of designed PIG

Specifications	Data
Weight	60kg
Length	900mm
Number of bodies	3
Total length	approx. 1m
Inspection speed for full axial resolution	15~20mm/s
Minimum bend radius	1.5 D
Maximum Pressure	100bar
Temperature Range (oC)	5~60

5. Results

The resultant program is undoubtedly more complex than a standard operation utilizing one intelligent PIG. Additionally, there are extra costs associated with the running multiple PIGs for the inspection and cleaning. However, this additional cost was estimated to be greatly functional for other purposes of companies therefore investment in such inventions can be vastly benefitting for industry. The benefits of the additional information that will be obtained from the composite inspection are significant and are considered to outweigh the costs associated with obtaining it.

The additional data obtained from the composite inspection will be used to categorically remove the uncertainly regarding laminations and/or metal-loss defects in this pipeline. As well as the brushes and dynamo which can help controlling the movement speed, the arms are devised to maintain a steady movement for the pig through the pipeline.

The approach described is considered to be a significant move forward where pipelines are known to contain defects that are difficult to conclusively characterize. This approach has been useful for the operator of the pipeline described in this paper and is expected to prove useful for other pipeline operators faced with a similar situation.

The design is advised such that the robot has sufficient contact with the surface for cleaning, as well as speed maintaining purposes but simultaneously it minimize the fluid hammer effect and the nozzles devised on it, guides the fluid through the dynamo at the end of it, hence maximum efficiency of impulse being conveyed to the PIG and energy being regenerated for the electrical circuit of robot to reduce the battery consumption.

As it was explained previously this development was made according with norm of PEMEX, NRF-060-PEMEX-2006, here in the table below it shows the full characteristics which must be met according to this regulation. According to the data represented n table 2, the maximum pressure applied on the robots arm is 1000 psi under the worst case scenario condition which the robots arms are fully starched to cover the circumferential area of 30 inches pipeline with excessive applied pressure of the off-shore pipeline.

In figure 5 the stress analysis as well as the bending analysis conducted on the design is presented and as it is illustrated the designed parameters can withstand the overwhelming pressure of 1000 psi under précised design developments (Figure 5).

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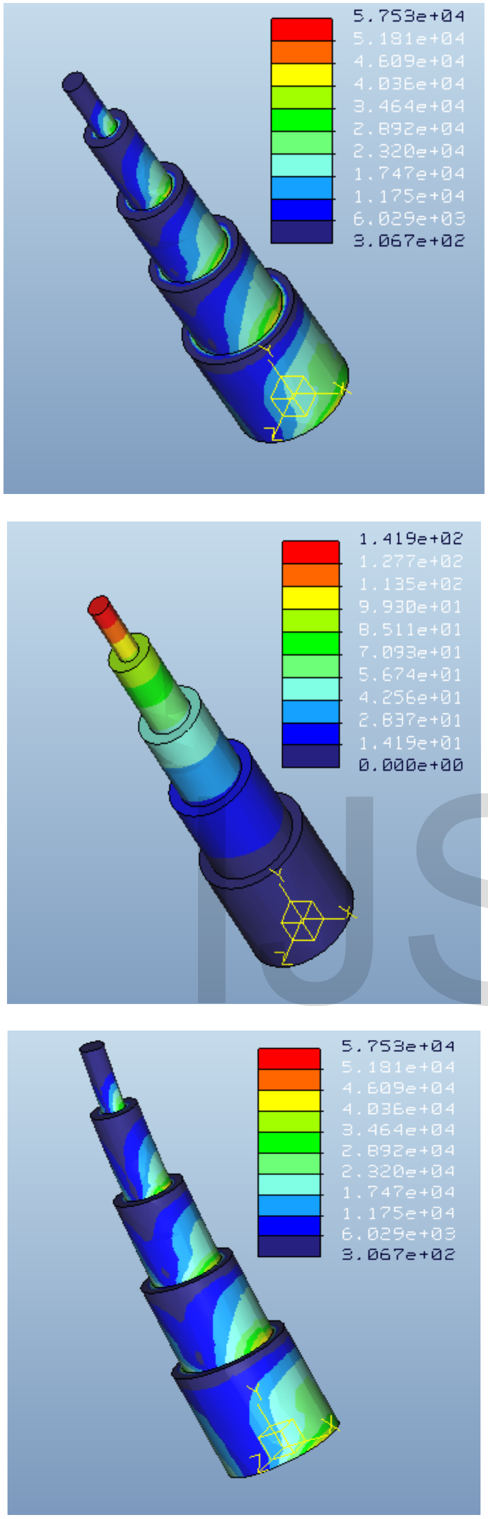

Figure5: Stress Analysis using CREO software to calculate the alloable stress and pressure of pipeline

6. CONCLUSION

This research can help the oil industry companies to maintain their pipeline system safe and clean. It significantly improves the pigging process as well as vastly reduces the pigging operational costs due to its technological advantages. The design has precisely been devised to prevent the destructive effects such as fluid hammer. The proposed design is a combination of cleaning as well as inspection PIG, therefore it has a multi-purpose functioning ability which has not been experienced in the previous devices. This article can be further investigated and expanded due to its market needs and capabilities.

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