Design and Development of Pipeline Inspection Gauge (PIG)

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***Abstract*– Oil pipeline maintenance has always been considered a problem of importance to oil companies. Before leakage happens, it must be detected, and preventive action must be taken to avoid oil losses and environmental problems. Corrosion in the lower portion of the pipeline due to the accumulation of water and other corrosive chemicals is one of the major causes of oil pipeline leakage. One of the techniques used to verify the conditions of the oil pipelines is the running of a data collection system throughout the whole length of the pipeline (which could be kilometres) to gather data about the corrosion and its location inside the pipeline. This system is commonly referred to as the Pipeline Inspection Gauge (PIG) which performs automatic pipeline inspection with Non-Destructive Testing (NDT) technologies such as ultrasonic and magnetic flux leakage. The ultrasonic probe helps experts to calculate the thickness of the wall of the pipeline through the Time of Flight Diffraction (TOFD). The aim of the investigation included in the research presented is to design and develop an ultrasonic PIG to be suitable for entry into the carbon steel pipe with a 323.85 Millimetre diameter. The PIG has 18 ultrasonic transducers to cover the whole area, an orientation system, a support system, a storage system, a support system, and a storage system.**

Keywords — Ultrasonic, NDT, PIG, Maintenance, Corrosion.

I Introduction:

Petroleum, as the main source of energy powers a large number of vehicles as well as ships, aircraft, and railway locomotive. This implies that it is extremely profitable because its global market demand is very high regardless of whether it is a non-renewable energy source. Many offshore pipelines in a variety of fluid transportation applications are becoming relatively aged. In the meantime, the concern over environmental issues resulting from pipeline failure is becoming increasingly important. Pipelines even with optimized design and maintenance conditions would suffer from defects as it progresses through its lifetime. Therefore, pipeline operators are in urgent need to actively clean and periodically inspect the pipelines to determine the validity of the Pipeline [1]. The challenge for engineers is the checking and maintenance of the underground pipelines without disrupting or stopping the flow of the product. To define pigging is a process in which a suitably sized device, be it spherical or cylindrical, is propelled through a pipeline by controlling the pressure and flow of the current media (fluid or gas) with the specific purpose of cleaning, inspecting, distributing an inhibitor and or as a plug to isolate a pipeline's section. A PIG now can be defined as a device (or gadget) that moves through the inside of a pipeline to clean, dimension, or inspecting, usually while the line is in service, to inspect a pipeline to decrease the chance of pipeline failure [2]. Depending on the nature of the job requirements, a PIG can be used in a variety of pipeline industries, such as gas or other related fields, such as utility PIGS, inline inspection tools, gel PIGS, and plugs. Due to technological advancements, PIG improvement led to the design of smart PIGS, also known as In-Line Inspection (ILI) tools or intelligent PIGS, which are electronic devices designed to flow inside of a gas/liquid transmission pipelines, usually while the line is in service, to inspect a pipeline to reduce the risk of pipeline failure [3].
Ultrasonic methods require a liquid interface; this sometimes causes difficulties in gas transmission lines but works extremely well in oil and other liquid-type pipelines [4]. PIGs may be divided into various groups. These operations include debris removal, wax, rust, and dirt washing, tasks such as pre-installation dewatering, hydro test pipeline flooding, identification of irregularities and leakages, as well as other physical damage as a means of inspection.
The pigs used to perform these tasks can be divided into three main categories [5]:

- Utility PIGS, which are used for cleaning, separating, or dewatering functions.
  Based on their fundamental function, utility pipeline pigs can be categorized into two group

Figure 1 Cleaning PIGs

a. Cleaning PIGs:

Cleaning Pigs that are used to clear from the pipeline solid or semi-solid deposits or debris as shown in Figure 1.

b. Sealing PIGs:

Sealing pigs that are used to provide a good seal to either sweep liquids off the line or provide an interface inside the pipeline between two dissimilar products [6].

- In-Line Inspection Tools have many types which provide information on the condition of the line, as well as the extent and location of any problems. The most common types are:

a. Magnetic-Flux Leakage ILI PIG (MFL):

Which MFL, ILI tools operate is by comparing it to the well-known horseshoe-shaped magnet as shown in figure 2.

To retain its power, the magnet is fitted with a 'keeper'. This is simply a metal bar which carries the flux from one pole to the other. If the cross-sectional area of the keeper at any point is insufficient to contain the flux, then leakage will occur [7].

Figure 2 Magnetic-Flux Leakage (MFL) PIG

b. Ultrasonic ILI PIG (UT):

Unlike magnetic flux leakage equipment, ultrasonic instruments for metal loss detection provide quantitative wall thickness measurements of the inspected pipe wall. The metal loss (corrosion) defect data is given as a grid of measurements of wall thickness with a very high axial and circumferential resolution. Along with the fact that the "river-bottom profile" is also provided for each corrosion, the high precision and trust level of such data make UT ILI data suitable for the most advanced defect assessment algorithms [8].

Figure 3 Ultrasonic (UT) PIG

II PIG DESIGN AND DEVOLOPMENT

A. Work Methodology:

We will follow this methodology, to work plan be systematic, organized and clear, and the first phase would be the collection of data as part of the pigging process, the study of the pipeline to be pigged through a vital qualitative examination prior to the design. When this information on the pipeline has been collected, a field survey is carried out to launch and retrieve locations along the pipeline, resulting in quantitative data, which is to check cracks and corrosion in the pipelines in which there is a lot of bends. The design depends mainly on the ability of the PIG to pass flexibly through these bends inside the pipeline, the datasheets and schematic drawings of the pipeline are then generated and the pig is constructed on the basis of this knowledge. PIG design requires the drawing and testing of prototypes using CAD, so theoretical calculations created need to be compared with those produced by the machine in order to refine and scale the final solution, which would be the last step in the design process.

The datasheet compiled below is the result of the qualitative collection of pipe information that collected during the visit to Petroleum Pipelines Company (PPC) and based on ASME/ANSI B36.19 Carbon Steel Pipe (schedule No.40) 12' pipeline [9][10]. The information contained will be used for the calculation, analysis and design Ultrasonic PIG.

Table 1

Parameters:	Value:
Flow-rate(s) :	100 000 L/hr. - 300 000 L/hr.
Length of pipeline, L :	20 km
Outside diameter, OD:	323.85 mm
Inside diameter, ID:	303.22 mm
Nominal thickness, t:	1.0312 mm
Pipe bends :	5D bends
Interior condition:	Smooth
Pipe material**:**	Carbon steel
System pressure, P**:**	40 bars

Pipeline Data

B. CAD Design

The PIG is designed and developed based on studying the designs of previous researches and designs for the commercially available PIGs. The design was done based on the inner diameter of the pipe and the dimensions of the bend.

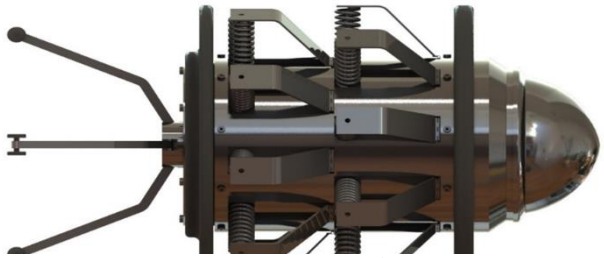

Figure 4 CAD DESIGN of PIG

As shown in Fig 4, the design consists of a cylindrical body with 18 slots to attach the hangs with sensor carriers. Sensor carriers are consist of fins and springs.

Fins consist of a diagonal part and a straight part. Also fins have housing for the UT sensor supported by spring to absorb shocks from dents to keep ultrasonic sensors save.

The Cylindrical body also consist of legs with wheel that hold the odometer to calculate the distance that the PIG will be

traveled in the pipeline and help us to know where the crake located in the pipe. The PIG material is selected to be stainless steel 304 as it doesn't react with crude oil so it's suitable for this medium.

Cylindrical body is supported by two rubber discs which keep the body centered in the pipeline and serve the purpose of blocking the fluid to propel the PIG. The rubber material is selected to be polyurethane.

C. Stress Analysis

To analyze the stresses applied on the pig a Finite Element Analysis (FEA) software "ANSYS" was used.

The stress distribution resulting from applied pressure is shown in Fig.6. These stresses are within the range of the factor of safety.

The stresses on the PIG are calculated through running the model and the maximum stress calculated is 82.325 MPA as shown in the figure below, which is lower than maximum stress of the stainless steel 304 material.

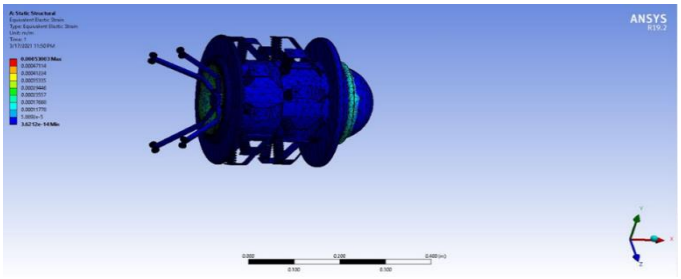

Figure 5 Von-Mises Stress on the PIG

Equivalent elastic strain is (0.00053003) as shown, which means a small deformation of the PIG body under hydrostatic load.

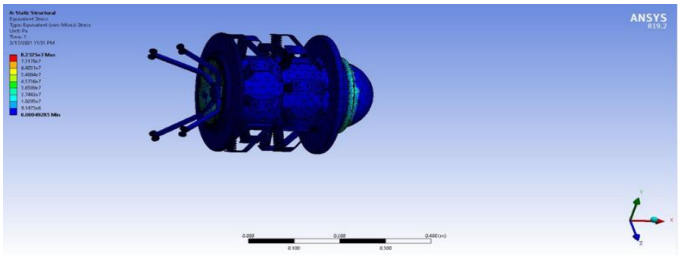

Figure 6 Equivalent Elastic Strain on the PIG

Total Deformation is 0.12849 mm as shown, which means a small deformation on the PIG body under hydrostatic load.

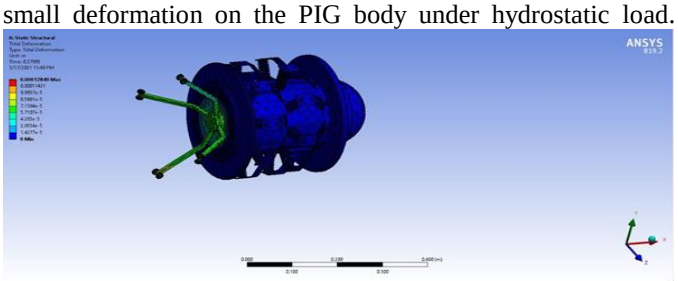

Figure 7 Total Deformation on the PIG

D. MATHEMATICAL MODELING OF THE PIG

Behavior of the PIG model in steady state motion is analyzed.

The working assumptions are listed as following:

- Most friction is due to the sliding contact of the seals and the pipe wall, as most of the PIG weight is directed to the seal discs.
- The fluid inside the pipeline is incompressible.
- The pressure drop across the PIG is assumed constant and that pressure drop across seals is equal.
- The wall force is assumed to be related to real oversize of the sealing disks as their design offers zero or little resistance to the flow.
- The coefficient of the friction between PIG and pipeline is constant.

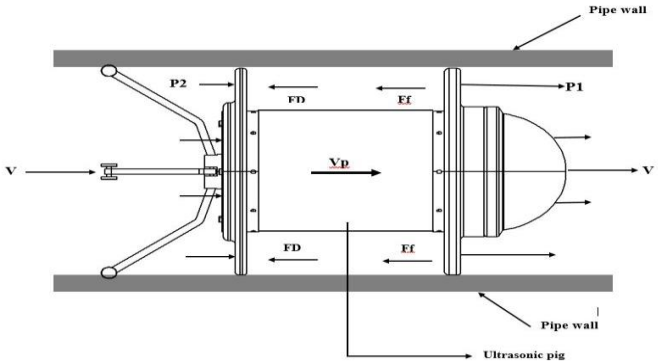

Figure 8 PIG motion analysis

- The dynamic equations of the PIG derived from Newton's second law:

$$F = ma \qquad [11]$$

The PIG motion with the fluid flow in the pipeline is obtained through a force balance as follows. This equation is based on calculations of the forces acting on PIG in the present study:

$$M \frac{d \dot{V}_{pig}}{dt} = \Delta P.A - FD - F_{fr}$$

Where:

M: The mass of PIG

V_{PIG}: The velocity of PIG

P: Pressure difference across the PIG

A: The cross-section area of pipe

FD: The drag force on the PIG

F_{fr}: Is the axial contact force acting on PIG with the inside surface of the pipe known as the contact friction force.

E. ELECTRICAL SYSTEM AND SENSORS SELECTION

After choosing the appropriate design for the pig to inspect the pipeline, we move to the stage of selecting the suitable components for this operation, such as sensors, and suitable GPS to determine the position of the pig and corrosion or deformation.

- Scanning Module (Ultrasonic sensor):

The ultrasonic transducers (Dakota T-101-3000), as shown in Figure 9, were chosen based on the design of the sensor carrier and the acoustic attenuation of the medium of propagation allowed for the application. To get greater resolutions, so the transducer frequency should be great to get wavelength shorter. At the same time, the acoustic attenuation in the fluid increases exponentially with the rise in frequency [12].

Figure 9 Dakota T-101-3000

- Distance Module (odometer):

The odometer used for knowing the position of cracks and corrosion after the PIG scanned the pipeline. This distance measurement is based on a sensing magnetic impact as the idea of Hall Effect sensor. We will know information about both to understand the technology used to determine the distance [13].

- Positional Module:

Transmitter and Receiver is suitable for underground pipeline inspections so it used for tracking the PIG during the inspection operation and determining its position [14].

- Controller module:

The main job of the controller to make all components are connected to and determine (size, position, and distance from beginning) for cracks, corrosion, or any deformation in the pipeline. Tiva TM4C129X Microcontroller was selected for this mission. Tiva TM4C129X has CPU speed up to 120MHz, Up to 1MB Flash, Two 12-bit ADCs up to 2MSPS, and a microSD card slot [15].

- Rotation Identifier Module:

IMU sensor used for rotation identifier in the pigging operation, As IMUs work by detecting rotational movement of the three-axis, commonly known as Pitch, Roll, and YAW. To achieve such, it relies on the functionality of Accelerometers, Gyroscopes, and Magnetometer [16].

- Support System:

The support system consists of a hermetically sealed cabin and a power supply. Rechargeable Li-ion battery pack acts as power supply. Because the inspection operates with pressure in the oil and water, so sealing the inspection system is necessary.

III CONCLUSION

This paper introduces the design and development of an ultrasonic PIG used for oil pipeline inspection. The developed structure will assist the pig to fluctuate with dents and deformations during the pigging operation. The Ultrasonic transducers were chosen based on the design of the sensor carrier and the acoustic attenuation of the medium of propagation allowed for the application. The IMU sensor with ultrasonic transducers and an odometer device will improve the data acquired and inspection capabilities during the operation by indicating the angle of PIG operation and specifying the exact location of defects. They will assist in defining the internal pipeline surface profile and can be used to improve the baseline data for an integral predictive maintenance system in pipeline systems.

IV Recommendations for future work:

In addition to the inspection system, the PIG structure will include a cleaning system.

A dual-purpose cleaning and inspection PIG system will reduce the pigging operation cost.

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