www.sensorsportal.com

Sensors & Transducers

http://www.sensorsportal.com

Design and Analysis of Magnetic Flux Leakage Capsule

[1] Maliki IBRAHIM, [2] Zulkarnay ZAKARIA, [2] Ali Aiman MUSTAPHA, [1] Marisah NORHASAN, [2] Mohd Nasir AYOB, [2] Ibrahim BALKHIS, [3] Ruzairi ABDUL RAHIM

[1] School of Manufacturing Engineering, Universiti Malaysia Perlis, 02600 Arau, Perlis, Malaysia

[2] School of Mechatronic Engineering, Universiti Malaysia Perlis, 02600 Arau, Perlis, Malaysia

[3] Process Tomography and Instrumentation Research Group (PROTOM-i), INFOCOMM Research Alliance, Faculty of Electrical Engineering, Universiti Teknologi Malaysia, 81310 Skudai, Johor Bahru, Malaysia

E-mail: maliki@unimap.edu.my, zulkarnay@unimap.edu.my, Ali_Aiman_Mustapha@yahoo.com, marissa.norhasan@gmail.com, nasirayob@unimap.edu.my, Ibrahim_balkhis@gmail.com, ruzairi@fke.utm.my

Received: 25 January 2013 /Accepted: 25 August 2013 /Published: 30 September 2013

Abstract: Magnetic flux leakage (MFL) is among the current in-line non-invasive popular technique applied in pipeline condition control and monitoring. This paper discussed on the design and development of magnetic flux leakage capsule prototype which involve design, fabrication and analysis. This paper discussed three proposed design concept and had gone through scoring and screening process in selecting the best development concept. *Copyright © 2013 IFSA.*

Keywords: Magnetic flux leakage capsule, Design, Development, Analysis.

1. Introduction

Magnetic Flux Leakage (MFL) is the oldest and most commonly used magnetic method of non-destructive testing used in In-Line Inspection (ILI) method for detecting any strange in the inner surface of the pipes such as corrosion, crack or other symptoms which is bad to the pipe condition in transmission pipelines [1]. MFL can reliably detect metal loss due to corrosion and sometime gouging. The basic principle is that a powerful magnet is used to magnetize the steel. At areas where there is corrosion or missing metal, the magnetic field "leaks" from the steel [2]. Therefore, the "leaks" helps user by giving the information on the location, sizes and also the level of potential damage area in the pipeline.

The term pipeline refers to a long line connected segments of pipe, with pumps, valves, control devices, and other equipment/facilities needed for operating the system. It is intended for transporting a fluid (liquid or gas), mixture of fluids, solids, fluid-solid mixture, or capsules (freight-laden vessels or vehicles moved by fluids through a pipe). The term also implies a relatively large pipe spanning a long distance [3].

Article number P_1329

The area of this research is to study, design and develop magnetic flux leakage capsule which suitable in detecting defect of the inner side of steel pipe or steel tank structures. Therefore this project considers the shape of the capsule, the moving mechanism of the capsule, and also the characteristic of the pipeline that can affect the performance of the capsule.

1.1. History of Magnetic Flux Leakage Capsule

Magnetic flux leakage technique was used as early as 1868 by the Institute of Naval Architect in England, where defects in magnetized cannon tubes were found with a compass [4]. In 1918, Magnetic Particles Inspection was accidentally discovered [5]; magnetic particles (ion shavings) were held in place by a local change in magnetic flux at the surface near the defect. The development and commercialization of magnetic particles inspection followed soon after [6, 7].

MFL inspection system is based on the same principle as magnetic particles inspection. The main differences between MFL and MPI is the used of sensors. MFL sensors, which were developed in the 1920's and 30's measure the magnetic field around a defect. MFL sensors allow a quantitative measurement, rather than the more qualitative information provided by MPI [8].

The first MFL in-line inspection tool for pipelines was introduced in 1965 by Tuboscope [9]. Since 1965, MFL tools have gain acceptance by the gas-transmission industry. As a result, MFL tools are some of the most widely used and effective tools available for in-line inspection of gas-transmission pipelines [8].

2. Working Principle

The MFL had developed time to time since principle of MPI. MFL was first used commercially to inspect pipeline in 1964. Today it is the most commonly used in in-line inspection method for pipelines [10, 11]. MFL technology can successfully overcome the physical and practical inspection challenges presented by transmission pipelines. The system can be designed to remain functional in an abusive pipeline environment for long distance and at product flow speeds. The permanent magnets used in this inspection technology need no energy source during an inspection, and the sensors and data recorders require reasonably low power to operate. The magnetic flux naturally enters the pipe and distributes evenly to produce a full volumetric inspection. Often various deficiencies of MFL system are highlighted, but the attributes described above keep MFL at the forefront of pipeline inspection technologies. There are two widely used implementations of MFL that can be differentiated by the orientation of the magnetization terms of axial or circumferential direction [12].

The MFL inspection Pipeline Investigation Gauge (PIG) uses a circumferential array of MFL detectors embodying strong permanent magnets to magnetize the pipe wall to near saturation flux density. Abnormalities in the pipe wall, such as corrosion pits, result in magnetic flux leakage near the pipe's surface. These leakage fluxes are detected by Hall probes or induction coils moving with the MFL detector.

3. Moving Mechanism

Pipeline Investigation Gauge (PIG) is designed so that sealing element for example as shown in Fig. 1 provides a positive interference with the pipe wall. Once inserted into the line, PIGs are driven through the line by applying pressure in the direction of required movement as shown in Fig. 2. A pressure differential is created across the PIGs, resulting in movement in the direction of the pressure drop. In operational lines, this pressure is applied by the line product, whereas, in un-commissioned lines the propelling medium can be chosen to suit the task being carried out [13].

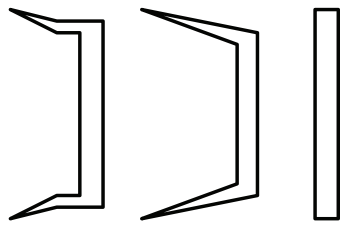

Fig. 1. Types of seal element used in PIGs.

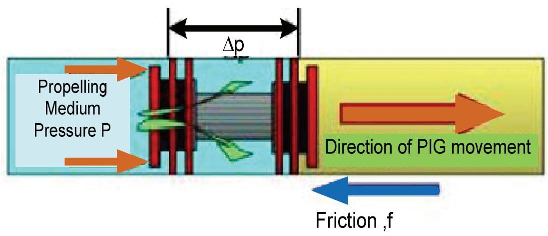

Fig. 2. Movement mechanisms inside a pipeline of a PIG

Sufficient flow required to ensure PIG movement at suitable velocity. Once the force behind the PIG becomes greater than the opposing frictional force, the PIG will move in the direction of the applied force (pressure).

The pressure at which the PIG begins to move is known as the "break-out" or "stiction" pressure. This tends to be greater than the pressure required maintaining movement and is characterized by a pressure rise followed by a pressure drop to a plateau for the PIG launching operation.

The movement of the PIGs are depends on the sealing element design. Pigs can be run in single direction, either backwards or forwards through a line. Pigs that can only run in one direction are known as unidirectional PIGs, and have polyurethane sealing elements of the cone or cup design. Sealing elements in bidirectional PIGs are flat, providing an identical seal in either direction and therefore, giving more adaptability in previously unpigged lines. Additional sealing element might be added to PIGs, leading to better sealing properties along with higher pressure differential required to drive the PIG.

4. Pigging Medium

Pigging medium are used to move the capsule from one end to another. There are three pigging mediums that commonly used:

a) Liquid
   Liquid are the most preferred medium for propelling PIGs in an incompressible liquid. Incompressible liquids provide maximum control over PIG speed as well as lubrication for the PIG seals, minimizing wear and maximizing seal effectiveness and life. Liquids such as water, crude oil or process product and chemicals can be used as propelling mediums. Care should be taken to ensure sealing element materials are compatible with fluid medium and prevailing pressure and flow condition.
b) Gas
   As gasses are compatible, the amount of stored energy behind a PIG propelled with gas is far greater than that of a similar PIG propelled with liquid. Appropriate consideration should be given to safety implications resulting from this stored energy. Pig movement can also be affected by improper use of a compressible gas as a propulsion fluid. Failure to deliver adequate quantities of gas required to maintain sufficient pressure behind the PIG can result in a stop-start motion of the PIG. This effect can be minimized to some extent by sizing equipment properly and maintaining a constant back pressure on the PIG to minimize velocity changes.
c) Multiphase fluid
   Multiphase is the commingled flow of different phase fluids, such as water, oil and gas. Multiphase fluid flow is a complex factor, important in understanding and optimizing production hydraulics in both oil and gas wells. Four multiphase fluids flow regimes are recognized when describing flow in oil and gas wells, bubble flow, slug flow, transition flow and mist flow [15].
   Multiphase fluid safety consideration should give as high as pigging operation using gas propelling medium. Extra care should be taken to consider effect if slugging and the associated forces at the receiving end. Any temporary pipe work should be secured and permanent facilities and equipment should be rated for multiphase flow [13].

5. Pipeline

Pipelines are used to transport all manner of powders and fluids from one point to another. From the food industry to oil and gas transportation, millions of lives are affected by the ability to maintain flow through pipelines that cross over land and undersea to deliver a product [13]. Pipelines can be categorized depending on the commodity transported. According to fluid mechanics or type of flow encountered, pipelines can be classified as single-phase incompressible flow (such as water pipelines, oil pipelines and sewers), single–phase compressible flow (natural gas pipelines, air pipelines, etc.), two-phase flow of solid-liquid mixture (hydrotransport), two-phase flow of solid – gas mixture (pneumotransport), two-phase flow of liquid-gas mixture (oil gas pipelines), non-Newtonian fluid, and finally the flow of capsules [3].

6. Concept Generation and Development

After analyzing existing MFL Capsule, a new design of MFL Capsule developed using an Orthographic analysis as shown in Fig. 3. Orthographic analysis present two or three attribute of a problem in a graphical two or three dimensional array. The possible solutions to be explore by means of combination, permutation, interpolation or extrapolation (technique for problem reduction and expansion). There are three concepts of the design have been developed and will go through concept screening and concept scoring. Several selection criteria listed which used as the references to choose the best concept.

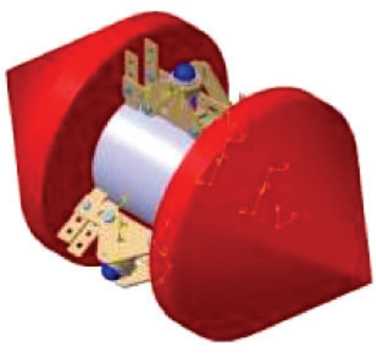

Fig. 3. MFL capsule model developed using ANSYS.

7. Analysis

Engineering analysis of this project divided into two parts. There is capsule analysis using calculation as shown in Fig. 4 to find the minimum pressure require to push the capsule forward and also contact body interaction analysis using explicit dynamic workbench in Computational Fluid Dynamics (CFD) software.

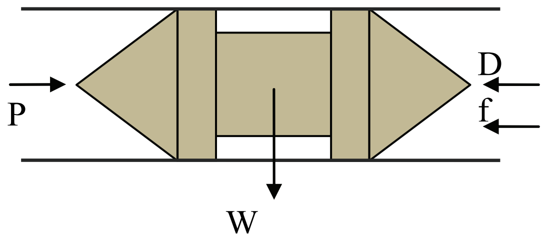

Fig. 4. Free body diagram of the MFL capsule.

$$F - F_D + F_{clearance} > (w.f. = F_{friction}) \quad (1)$$

To find the drag force of the capsule, pressure drop is required

$$F_D = A\Delta p_C = AC_D \frac{\rho(v - v_C)^2}{2} \quad (2)$$

$$\Delta p_C = C_D \frac{\rho(v - v_C)^2}{2} \quad (3)$$

$$C_D = \frac{2k_D}{\left(1 - k_D^Z\right)^Z} \quad (4)$$

$$k_d = \frac{D_d}{D}, \quad (5)$$

where C_D, ρ, v, v_c, D_d and D are drag coefficient of the capsule drag, air density in the pipe, bulk velocity of fluid (air), capsule velocity, sealing element diameter and pipe inner diameter respectively.

8. Result

8.1. Capsule with 400 mm Diameter

The minimum forces required to allow the capsule with diameter of 400 mm to moves forward in the pipe;

$F - F_D + F_{clearence} > (w.f = F_{friction})$
$F - 0.5434N - 0.0056F > (321.688\ kg \times 9.81\ ms^{-1)} \times 0.18$
$0.9944F > 1.11177\ kN$
$F > 1.1177\ kN$

$$p > \frac{F}{A} = \frac{1.1177kN}{0.12576m^2} > 8.8919kPa$$

8.2. Capsule with 500 mm Diameter

The minimum forces required to allow the capsule with diameter of 500 mm to moves forward in the pipe;

$F - F_D + F_{clearence} > (w.f = F_{friction})$
$F - 0.8293N - 0.1124F > (469.6968\ kg \times 9.81\ ms\text{-}^{1}) \times 0.18$
$0.8876\ F > 1.6578\ kN$
$F > 1.8687\ kN$

Therefore the minimum pressure of the capsule in the pipe;

$$p > \frac{F}{A} = \frac{1.8687kN}{0.1963m^2} > 9.5172kPa$$

From the analysis of the capsule with 400 mm and 500 mm diameter, results show that the minimum force to allow the capsule with sealing element diameter of 400 mm is bigger than and minimum force to allow the capsule with sealing element diameter of 500 m. The differences of force value in allowing the starting motion of the capsule because of the difference of its diameter of sealing element other than difference in normal force of both capsules. For capsule with approximate 400 mm sealing element having 321.688 kg of mass with 3155.7593 N normal force, while capsule with approximate 500 mm sealing element have a mass of 469.6968 kg with 4607.7256 N normal force act to the capsule body. Results also show that there is a difference in pressure drop value of both capsules. Capsule with smaller diameter of sealing element experienced larger pressure drop than the capsule with larger diameter of sealing element. This state influenced by the velocity drop of the capsule due to surface area and normal force of the capsule's body. According to the calculations that were made, the leakage flow ratio visible to experience marked contrast where the smaller sealing element capsule only have 0.563 % of leakage compared to the larger sealing element capsule that have 11.24 % of leakage flow ratio. This condition also may influence by the velocity movement of the capsule and the fluid of pigging medium, while the value of velocity influence by normal force value and area of the contact surface. Therefore, to decrease the larger diameter capsule leakage flow ratio, the points can be controlled are the weight of the changeable sealing elements and the diameter itself. In comparing the drag coefficient value produce by formula using Kasugi's Equation and using fluid flow analysis using ANSYS both value differ so much this is because the Kasugi's Equation had already known that can predict Drag Coefficient with 20 % error besides it only consider the drag on the surface of capsule that touching with the pipe inner surface compare with fluid flow analysis using ANSYS that considering the drag on the fully body of the capsule. Therefore, this cause visible marked contrast on the result.

8.3. Analysis Result on ANSYS

8.3.1. Pressure Distribution

The red area in Fig. 5 shows the highest pressure contour 1.607×10^4 where the air pressure supply to the capsule to move forward. The green and blue region shows the medium and low pressure contour. The figure clearly show that the high pressure area only at one side where the pressure inlet supplied.

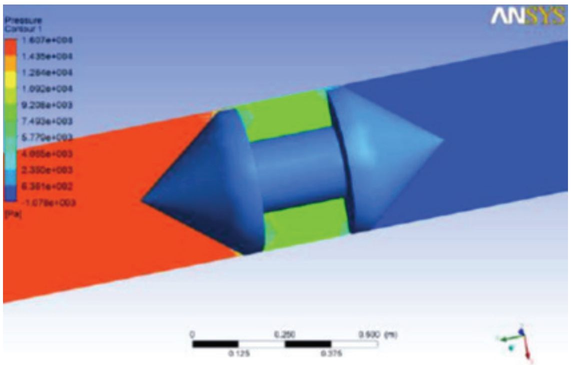

Fig. 5. Pressure distribution exists on the developed capsule.

8.3.2. Steamline

It is found that, the developed module is capable in reaching the highest velocity which is up to $5.687 ms^{-1}$ as shown in Fig. 6.

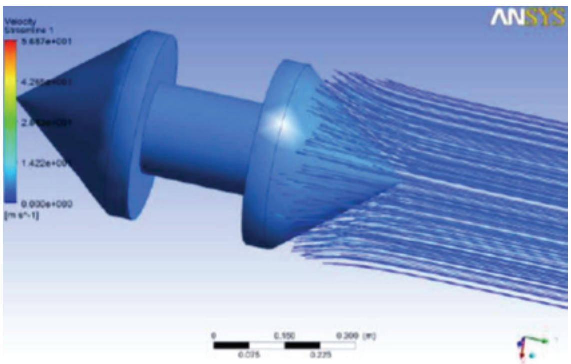

Fig. 6. Steamline simulation result of the developed capsule.

8.2.3. Velocity Vector on the Capsule

The area in Fig. 7 that circled in red shows the vector that acts counters the inlet pressure resulted leakage due to clearance between capsule and inner pipe diameter.

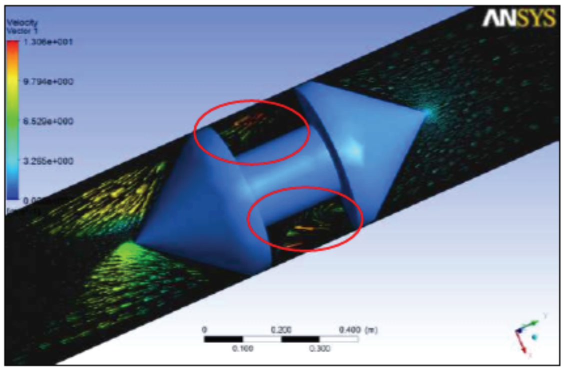

Fig. 7. Velocity vector which acts on the capsule.

8.2.4. Pressure Distribution

The red area shown in Fig. 8 is the highest pressure contour $1.607\ x10^4 Pa$ where the air pressure supplied to the capsule to move forward. The green and blue region shows the medium and low pressure contour. The figure clearly shows that the high pressure area only at one side where the pressure inlet supplied.

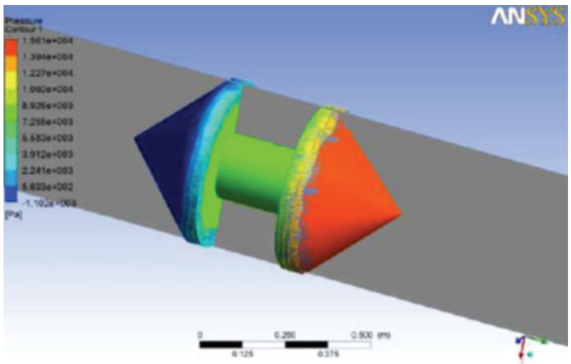

Fig. 8. Pressure distributions of the module in 3D view.

9. Conclusion

In conclusion, the objective of the project on design MFL capsule that can flow through different sizes of pipe ranging inner diameter from 400 mm to 500 mm analyzed motion of MFL Capsule flow using calculation and Computational Fluid Dynamic Software had been achieved. The MFL capsule is designed with a changeable sealing element which enable capsule to flow in 400 mm and 500 mm pipe's diameter. The analysis of obtaining the minimum force require by the capsule to move forward had resulted a minimum of 1.1177 *kN* air pressure to enable the capsule flow for 400 mm diameter sealing element and 1.8687 *kN* of air required to enable the capsule of 500 mm diameter sealing element capsule to flow. So, the listed element had proved that the objective of the project had achieved.

Acknowledgment

This work was supported in part by the Malaysian Government under FRGS Grant 9003-00285.

References

[1]. T. A. Bubenik et al., Magnetic Flux Leakage (MFL) Technology for Natural Gas Pipeline Inspection, Battelle, Report Number GRI-91/0367 to the *Gas Research Institute*, November 1992.

[2]. Magnetic Flux Leakage Retrieved 11 November 2011, (http://en.wikipedia.org/wiki/Magnetic_flux_leakage).

[3]. H. Liu, Pipeline engineering, Vol. 1, *Lewis Publisher*, United States of America, 2003.

[4]. M. L. Nayyar, Piping handbook, 7th edition, *McGraw-Hill*, 1999.

[5]. G. Dobmann, P. Holler, Physical analysis method of magnetic flux leakage, in *Research Techniques in Nondestructive Testing*, Vol. IV, edited by R. S. Sharpe, *Academic Press*, 1980.

[6]. W. Hoke, Principles of magnetic particle testing, edited C. E. Benz, *Magnaflux Corporation*, Chicago, 1967.

[7]. A. V. Deforest, Magnetic testing of iron and steel, *Iron & Steel Engineer*, Vol. 9, 1932.

[8]. F. B. Doane, Magnaflux inspection for cracks and seams, *Iron Age*, September 1933.

[9]. Batelle (http://www.battelle.org/pipetechnology/mfl/LinksMFLHistory.htm).

[10]. G. J. Posakony, V. L. Hill, Assuring the integrity of natural gas transmission pipelines, *GRI Report* 91/0366, 1992.

[11]. J. B. Nestleroth, T. A. Bubenik, Magnetic flux leakage (MFL) technology for natural gas pipeline inspection, Batelle, Report Number GRI-00/0180, *Gas Research Institute*, February 1999.

[12]. G. Dobmann, P. Holler, Physical analysis methods of magnetic flux leakage, in Research Techniques in Nondestructive Testing, Vol. IV, edited by R. S. Sharpe, *Academia Press*, 1980.

[13]. J. B. Nestleroth, Implementing current in-line inspection technologies on crawler systems (Technology Status Report), Batelle: *Gas Research Institute*, April 2004.

[14]. R. Davidson, An introduction to pipeline pigging, *Pigging Products and Services Association,* p. 9, 2002.

[15]. McGraw-Hill Professional (http://www.mhprofessional.com/downloads/products/0071743898/0071743898ch1.pdf).

[16]. P. Guieze, A. Scheffler, V. Afanasyev, B. Theuven, B. Pingue, Multiphase fluid samples: a critical piece of the puzzle, p. 39, 2009.

[17]. M. R. Baxter, Product design, Cheltenham, *Stanley Thornes*, UK, 1999, pp. 76-79.

[18]. Y. A. Cengel, J. M. Cimbala, Fuild mechanics fundamental and application, 2nd Edition, *Mc Graw Hill*, 2010.

[19]. Computational fluid dynamics (http://en.wikipedia.org/wiki/computational_fluid_dynamics#PDF_methods, (8 October 2011).

[20]. K. Oenoki, Forces and Newton's Law, *ORACLE ThinkQuest*, Vol. 2012, 1997.