Real Time Tracking and Monitoring System for Pipeline Pigging Analytical Study on Distance of Magnetic Module with Pig

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***Abstract* — In order to track a pig inside a pipeline and sending the data in real time, it is highly important to have a magnetic module that is strong enough to saturate a section of the pipeline. The issue is to specify the exact location of where the module should be placed to achieve the best tracking results to transmit the data. This paper describes the setting up of the experiments and their finding that has been carried out to examine the relationship of the distance between the magnetic module and the pig with respect to the magnetic field strength detected at gradiometer. Detail analysis of the result shows that the strength of the magnetic force field would lessen by half if the module sticks to the pig.**

***Index Terms* — Pipeline pigging, RT tracking and monitoring, Magnetic Module Distance, Gradiometer.**

I. Introduction

Pigging is needed in every stage of pipeline life. Cordell et al [1] and Hiltscher et al [2] listed 26 various reasons to pig a pipeline which mainly occurs during pipeline construction, operation and decommissioning. Pipeline obstruction may cause loss of man hours and production down-time. Thus, it is essential to monitor pigging operations at close intervals. Acoustics method, radioactive sources and magnetic transmission methods have been used to detect the movement of pigs over the years, which often led to inaccurate analysis due to errors resulting from manual operations. Manual data input necessitate the training of on-site workers on: how to interpret data, allow time for its input, and include error assumptions in final reports and obviously all this at the expense of the pipeline operator. Considering the real needs of pipe-liners, digital data collection is necessary to compile an inspection history of an area without human intervention, and in a short time.

We develop a Real Time Tracking and Monitoring System for Pipeline Pigging (RTTMPP) to overcome some of mentioned problems. It provides similar functionality to the Intelligent Transport System (ITS) [3][4]. It shows different pigs location in different sections or pipelines and at the same time allows an interactive input, query or update of information. The real time data stream will enables: real-time information and data analysis capability on-the-fly, support detailed analysis of pipeline data from present or historical inspections, and provide spatial information for graphical output (either to the screen or a plotter) for reports and further analysis. There are three main challenges we deal with by introducing the framework for RTTMPP.

First, the selection of detection methods: Introducing devices to be welded to the pipeline may increase potential for corrosion in the pipeline [5]. Thus make magnetic transmission technique the most suitable method to be used for detection. However, oil and gas pipelines are normally made of steel or carbon steel which acts as a protective shield for electromagnetic waves. Thus, if magnetic transmission is to be used to detect the pig inside the pipeline; a strong and effective transmitter needs to be used since pipelines can be buried considerable feet below ground level.

Second, the pipelines might be located in environments where no (phone, Internet or any traditional telecommunications service is available), thus the actual transfer of information may reveal to be another problem by itself. Thus adequate wireless telecommunications technology needs to be sought.

Third, since the system is proposed to function like an ITS, a suitable Geographical Information System (GIS) tool need to be selected. Various open source and commercial GIS software are available on the market which should match the technical and business aspect in oil and gas industry. Thus, commercial GIS tool with wide data sharing, support and off the shelf functionality to decipher the data transmitted and display the status of the pig at real time need to be look for. To realize the Real Time Tracking and Monitoring System for Pipeline Pigging, it was decided that magnetic flux would be ideal for detecting the pig; however, the introduction of a magnet close to the pig itself means that undesirable results might occur if the magnet is not properly attached to the pig. These discrepancies or lack of efficiency of the magnetic strength might take place due to the fact that the majority of the pig body is normally made up of conductive material (iron) and therefore magnetic flux prefer to pass through the pig body rather than saturate the pipeline wall and flow outside of the pipe [6]. Thus, considerations need to be taken regarding the location of where the magnetic module should be placed in relation to the pig itself. This paper discuss the issue of whether the magnetic module should touching the pig, or should be placed as far as possible from the pig, and the exact location of where the module should be placed to achieve the best tracking results. The hypothesis, experiment setup and the experiment result will be discussed in the following section.

II. RTTMPP Architecture

The RTTMPP architecture framework was design after considering the constraint mentions previously. The system was proposed to comprise of three layers; Data Acquisition layer, Communication Layer and Presentation Layer as in Figure 1.

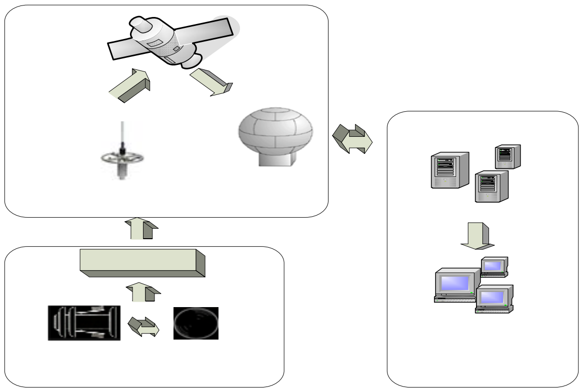

Figure 1: Proposed architecture framework

Data Acquisition Layer (figure 2) is concern with detecting the pig and transmitting the inspection data with time stamp, pig location (XY-Coordinate) and the Speed.

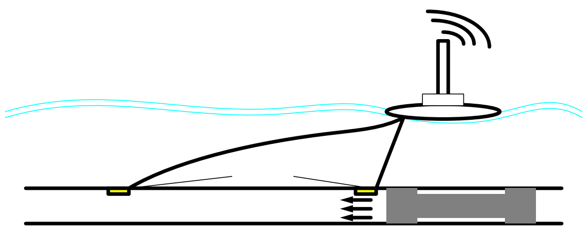

Figure 2: The data acquisition layer setting

The detection will be done via magnetic flux technique in which the magnetic module attach to the pipeline pig will magnetized a sections of the pipeline which then detected by sensors located along the pipeline. The sensors will be connected to data loggers which consists of microprocessor, storage device and communication module so as to process the data and transmit the message via communicator to the satellite link when requested. The data logger is to be operated using solar panel to avoid running out of battery situation. For offshore pipelines the data loggers is to be placed on a buoy.

This paper will focus on doing experiments to determine the suitable distance between the magnetic module and the attached pig.

III. Proportionality Investigation

This experiment studies and analyzes the relationship of the distance (*d*) between magnetic module and pipeline pig with respect to the magnetic field strength (*M*) detected at the gradiometer from outside the pipe. There are four probable relationships which can be predicted between these two variables which are:

- i They are directly proportional
- ii They are inversely proportional
- iii They are exponentially proportional or
- iv The relation between them are ambiguous

If *d* is directly proportional to *M* ($d = kM$), thus the result would be as *d* increases, the *M* variable increases and vice-versa and this relationship should repeat itself for different points along the line. If *d* is inversely proportional to *M* ($d = k/M$), this means that when one variable increases by a certain ratio, the other decreases by the same ratio. Meanwhile If *d* is exponentially proportional to *M* ($\log_m d = k$) then, the plotted graph of the experiment result should follow a particular pattern. If the result does not meet all of the above relation, then it can be concluded that the relation is ambiguous and need to be further analyze.

Since the target area of this project is the oilfield and pipeline industries, thus the same set of materials that are used throughout everyday job within these two specific industries have been used. The magnetic module is made of Neodymium Iron Boron (NdFeB) which provides highest magnetic output at up to about 150^0C respectively speaking. However other magnets like Samarium (SmCo), Copper-Nickel-Iron (CuNiFe) and Ferrite magnets can also be utilized but the result achieve will be differs [7]. While to measure the magnetic force field between the magnetic module and pig, a fluxgate gradiometer is used [8].

IV. Experiment Setup

This experiment is divided into five phases in which, Phase 1 to Phase 4 is to collect the data for interaction between magnetic module and pipeline pig at varied distance meanwhile phase 5 is to get the readings of ambient noise in the settings.

To set the experiment, both magnetic module and pig were aligned in respect to each other and ruler was placed parallel to the magnetic module. The distance between the ruler and the pigging equipment was set as 1.2 meter. The positioning of the ruler was in such a manner that one always started taking readings from the magnetic module side. Figure 3 below shows the top view of the equipment set-up.

For phase 1 to 4, magnetic module was position respectively at d= 1.5 m, 0.9m, 0.75m and 0.6 m away from the pig. Then gradiometer readings were taken every 0.15 meter starting from 0 meter and moving to the 2.4 meter measurement. This means that a total of 17 records were collected for every recorded *d*. Once the readings were recorded, the pig was placed in its original position and the magnetic module was moved accordingly so that readings for phase 2 until 4 can be taken.

Note that when the magnetic module was 0.6 m away from the pig it was close enough for both bodies to experience a force of attraction. For this reason, the two wooden strips were inserted between the magnetic module and the intelligent pig. This gave the possibility to obtain gradiometer counts when the magnetic module was very close to the intelligent pig frame but not close enough to touch it.

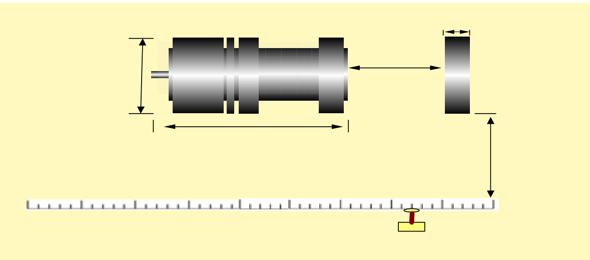

Figure 3: Experimental Setup

After the whole set of distance were recorded, the magnetic module and the pig were removed from their original location and placed far away from the site leaving the measuring stick and gradiometer at their place. Then, the gradiometer readings were recorded from the exact location and intervals as in above i.e. from 0.15 m to 2.4 m. This is to record the ambient noise data should they exist. The experiment result and the analysis are provided in the next section.

V. Assumptions

Before analyzing the data, it is important to mention the basic assumptions that were taken throughout the whole sets of experiments. Perhaps the most obvious one is the fact that at no point in time during the experiments a pipe was used. Obviously, there was no need for a pipe due to the fact that the magnetic module is designed in such a manner so as to saturate a complete section of the pipe. Therefore, the excess magnetizing field will bounce off the pipeline wall and gets detected by the sensors attached with the Base Station. Moreover, to compensate for this, the gradiometer sensitivity was put to low. Thus, if the magnetic module is strong enough to saturate the section of the pipe wall and reach the sensors on the Base Station, no tracking problems will crop up.

Another important assumption is that the liquid viscosity and density of the product traveling with the pig along the pipeline does not interfere with the strength of the magnetizing force field. Thus, during this experiment the medium through which the magnetic field traveled was air. In real life situations, the density of the material traveling inside the pipelines is far denser than air. Thus, pigging operators or engineers should be fully aware about the medium within which the pig and the magnetic module are expected to travel.

One should also consider the possibility of locating the gradiometer and its sensors at different positions. For these experiments, the sensors of the gradiometer were always placed 18 cm above the ground. Different results might be recorded if these sensors are placed above or below the 18 cm height. However, it is assumed that the ratio will be retained.

Finally, there were instances when the gradiometer readings went out of range and In order not to loose any trends during the analysis of the data, it was decided to put a 100AT/m figure to represent these out-of-range situations.

VI. Experimental Result

It is important to note that the gradiometer provides valid readings. This can be confirmed by taking several readings in succession in one location without moving anything, and note the repeatability. Under certain circumstances however, even successive readings repeating to within several amp turns/meter may still represent noise. Thus, once the ambient noise was measured, the data gathered was subtracted from all readings so that the readings recorded will only represent the magnetizing force field of the magnetic module in relation to the pig. Table 1 shows the four set of readings that have been taken.

Table 1: Gradiometer readings with magnetic module placed at a distance of 'x' away from pig

Distance (meter)	Gradiometer readings (amp-turns/m)			
	1.50 meter	0.90 meter	0.75 meter	0.60 meter
0.0	-34	-16	-14	-4
0.15	-37	-23	-19	-6
0.30	-35	-30	-26	-11
0.45	-17	-37	-33	-14
0.60	0	-43	-41	-17
0.75	18	-47	-48	-22

0.90	30	-45	-54	-27
1.05	36	-36	-55	-31
1.20	40	-18	-46	-27
1.35	35	5	-28	-24
1.50	25	20	-13	-19
1.65	18	35	10	-2
1.80	14	44	33	13
1.95	11	35*	35*	23
2.10	8	28*	28*	27
2.25	2	26*	26*	27
2.40	4	30	36*	28

**Results are derived from the '100' figures, which implied that the gradiometer went out-of-range.*

From the experiment, the result obtained was plotted in Figure 4 and the peaks of every set of readings are shown.

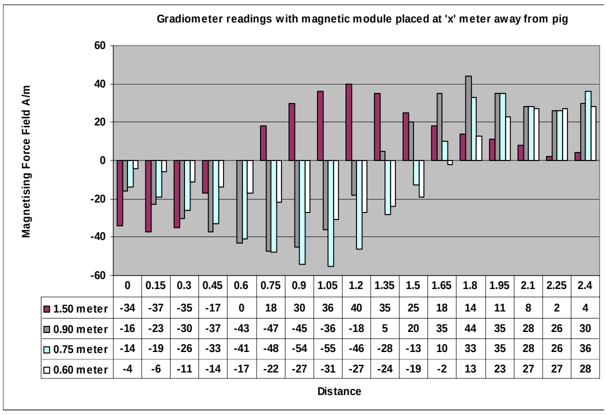

Figure 4: Graph readings

Thus, brief analysis of the data in Figure 4, yields the result in Table 2 which indicates the distance of the peaks for every set of readings.

Table 2: Positioning according to peaks

Distance d (meter)	Peak Magnetizing Force Field (M) (A/m)	Position
1.5	40	3rd
0.9	47	2nd
0.75	55	1st
0.6	31	4th

As Table 2 clearly denotes, the highest readings were achieved when the magnetic module was very close to the pig but was not touching it. This means that ideally, pigging operators and engineers should place the magnetic module as close as possible to the pig body, but no form of direct contact with the conductive parts of each of the two objects should take place. Therefore, some insulated material that prevents both bodies from sticking to each other should separate the magnetic module and the pig.

Table 3: Percentage distribution of results

Distance (m)	Peak MMF (A/m)	Distribution of M (%)	Differential Distribution
1.5	40	73	27
0.9	47	85	15
0.75	55	100	0
0.6	31	56	44

Table 3 continues to emphasize the findings and notes that the 100% mark was reached when d was 0.75 meter; only 56% was reached when d was 0.6 meter. This means that there is a differential distribution of 44% between the two. When one notes that this percentage difference took place with the movement of the magnetic module by just 0.15 meter, the results are quite alarming. Thus, pipeline operators need to be 100% sure that the magnetic module is not directly touching the pig.

If both stick to each other than the desirable results may not be achieved because this might lead to serious difficulties in locating the pig if it gets stuck. Furthermore, it might also be difficult for the Base Station that are located along the pipeline to detect the pig once that it passes close to them since the Magnetizing Force Field will be very low.

In order to proceed with the analysis, the data needs to be studied in more detail and further calculations need to be carried out. Figure 5 below needs to be used to derive further information. Previously, we only compares data by grouping the magnetic force field, *M*, readings with a particular distance, *d*, now it necessary to group the distances, *d*, and derive the magnetic force field from the graph.

For this exercise, the distance d was taken under consideration and readings at the 0 AT/m magnetic field force was taken as the origin and adding readings of ± 0.15 meter for every distance d.

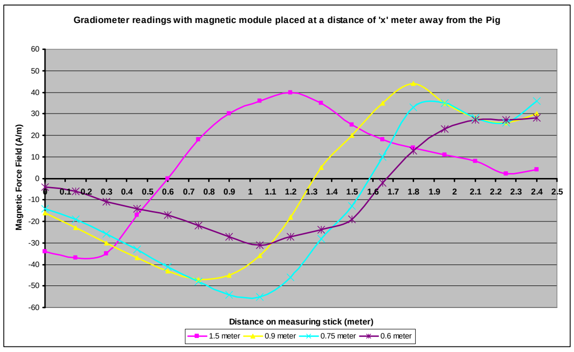

Figure 5: Combination of gradiometer readings

Although much has been discovered on the relationship between d and M, no analysis has been carried out to investigate about the mention hypothesis. In order to proceed with the analysis, the data needs to be studied in more detail and further calculations need to be carried out.

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Table 4: M and D at 0.15 meter intervals

1.5m	MFF A/m	0.9m	MFF A/m	0.75 m	MFF A/m	0.6m	MFF A/m
0.30	-35	1.02	-38	1.28	-36	1.37	-23
0.45	-17	1.17	-21	1.43	-20	1.52	-17
0.60	0	1.32	0	1.58	0	1.67	0
0.75	+18	1.47	+18	1.73	+22	1.82	+14
0.90	+30	1.62	+32	1.88	+36	1.97	+24

In order to simplify the data and make it possible to superimpose all the readings in one graphical output, Table 4 was compressed and all relevant data was included in Table 5 below.

Basically, the distance columns were grouped into one. Instead of viewing the actual distance, a relative distance field was created since the 'origin' was always taken at point where M = 0.

Table 5: *M* and *d* grouped together

Distance (meter)	MFF (A/m)			
	d = 0.50 m	d = 0.90 m	d = 0.75 m	d = 0.60 m
-0.30	-35	-38	-36	-23
-0.15	-17	-21	-20	-17
0	0	0	0	0
0.15	+18	+18	+22	+14
0.30	+30	+32	+36	+24

Table 5 was converted into graphical format to be able to visualize any relationship (if present).

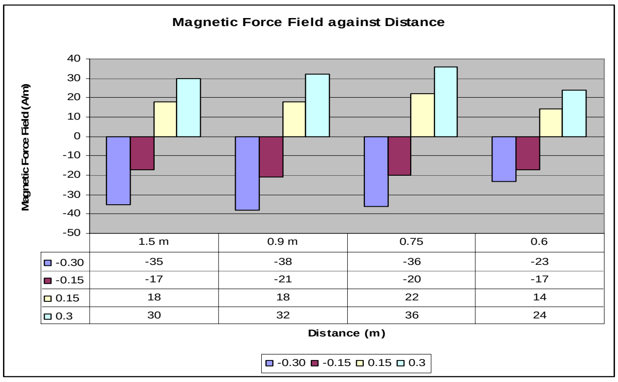

Figure 6: Magnetic Force Field against Distance (column graph)

Figure 6 and 7 gives an initial indication of the results. It is difficult to find a common relationship between the two variables. The resultant only gives us some general information about the strength of the Magnetic Force Field for that magnetic module and pig at that particular instant, but no other sort of other information (either general or specific) can be derived. Upon studying these results in further detail, one can conclude that *d* is neither directly proportional to *M*, nor inversely proportional or exponentially proportional. Therefore the relationship between these two variables is ambiguous.

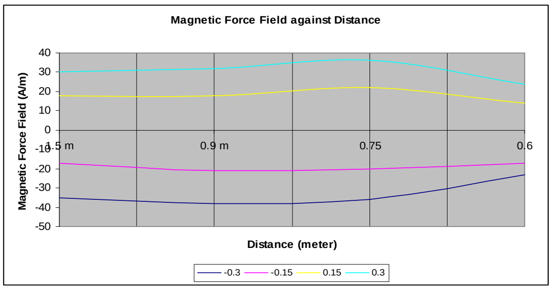

Figure 7: Area under a curve

VII. Conclusion

Data acquisition and transmission is a critical part for the success of RTTMPP system. The relationship between the magnetic field strength (*M*) and distance (*d*) (between magnetic module and pipeline pig) is very important for such system, so further experiments are needed to determine the suitable location of magnetic module that gives a maxim detection of pig. This paper shows these experiments and its results. Analysis of results shows that the magnetic module should be as close as possible to the pig body but not touching it. It also shows that the strength of the magnetic force field would nearly lessen by half if the magnetic module sticks to the pig. Therefore, pipeline pigging operators and engineers should be fully aware of these results to make pig tracking more efficient, effective and reliable.

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