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Low-Cost Sensor Node for Crack Monitoring of Out Pipes Using Non-Destructive Testing for Process Industries

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In process industries, non-destructive evaluation is an appropriate method of health monitoring. Due to the manual health monitoring system, catastrophic accidents occur at petrochemical plants. Humans lacked the requisite experience to properly generate fresh materials and operate diverse machinery and modes of transportation in the early industrial days, which led to serious accidents. The use of damage detection to detect potential material flaws resulted in a significant boost in machine reliability. By identifying the potential development and manufacturing improvements with extra knowledge, NDT became a fundamental part of early day complex systems. Oil refineries and petrochemical plants have millions of pipes forming a network. These pipes are monitored annually during plant shutdown. The maintenance has been carried out traditionally, therefore it has become a very hazardous, as well as a tedious task. In the present article, we have tested a low-cost crack monitoring device. For this, an Arduino-based system has been developed for crack monitoring of pipelines from outside. The concept of magnetic flux leakage is used to trace any defect in the internal structure of ferromagnetic pipelines. Using the Hall effect sensor, a change in the magnetic field intensity has been located and captured. The current research reduces the limitations of the health monitoring system of process industries. This will promote a safe atmosphere for workers, as well as for society and the environment.

Keywords: Non-destructive testing, Ferromagnetic material, Magnetic flux leakage, Sensor node, Crack monitoring.

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1. INTRODUCTION

Ferromagnetic pipelines are popularly used in process industries. In furnaces or oil & petrochemical plants, pipes of ferromagnetic materials are extensively used. Due to harsh operational conditional ferromagnetic pipes are prone to corrosion and erosion. With aging effect and traditional health, monitoring makes it more difficult for monitoring of thickness and detection of the crack all along the length of pipeline from outside [1].

Leakage detection from inside the pipeline using magnetic flux parameters is popularly being used in the pipeline industry due to its ease of evaluation and hassle-free monitoring of the equipment. The magnetic flux leakage (MFL) technique is being deployed for > 90 % of pipeline industries across the world. The fundamentals of the MFL technique lies in the basic physics employing magnetic induction. Its sensing capability of detecting cracks in the metallic surface made it a suitable choice for pipeline industries application. The flux leakage mechanism is extensively studied to evaluate and monitor the fitness of the pipelines in the petroleum sector. As it presents an accurate analysis from its statistical experimental data sets. This helps in investigating the cracks in the ducts under longitudinal magnetization.

In our proposed model we have presented a novel highly accurate crack sensor-based system which is robust and reliable. In this article, we have tested the MFL with our sensor node and tested it for integrity monitoring of ferromagnetic pipelines.

1.1 Objective

The reduced thickness of metal lining in the pipeline, Corrosion, or surface cracks causes magnetic flux leak into. The literature work has investigated a few neural network optimization algorithms in the pipeline industry [4, 5]. We propose using a Hall effect sensor that provides data that can be further analyzed for any safety standards. Some alternatives to the Hall effect sensor that has been used in the existing literature are Giant Magneto Resistive (GMR), Anisotropic Magneto Resistive (AMR), Giant Magneto Impedance (GMI), Magneto-Optical (MO). Due to the accuracy in results and compact and economical aspects, we have deployed a hall effect sensor in our module. Crack detection studies the MFL method based on two different magnetization arrangements namely circumferential magnetization (CM) and axial magnetization (AM). Axial MFL devices magnetize the core axially and the field generated in its transverse section causing to determine the circumferential defect in the pipelines. Circumferential MFL magnetizes the sample circumferentially, so is used to determine the axial defects.

1.2 Motivation

India's oil reserve is the second largest in the Asia Pacific after China. Due to the large gap between the consumption and production of oil. India is merely dependent upon the import of oil which makes India one of the five largest importers of crude oil in the

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world after the United States and China which is mostly dependent upon the Middle East [2].

The pipeline operates as arteries and vines of the petrochemical plant because of aging infrastructure and in the absence of maintenance of these strategically managed assets they suffer severe corrosion and erosion causing leakage in the pipeline or an overhead tank. Even though the process of maintenance is completely manual and dependent upon scaffoldings, rubbing and monitoring with a probe at limited corrosion-prone locations that too once a year during annual plant shut down.

2. LITERATURE SURVEY

Furthermore, for building a leak detection pipeline mechanism the authors in [3] have deployed a smart pipe for making it leak-prone by enabling a detection mechanism. The work in [4] investigates a model for pipeline gas leakage detection using a global positioning system (GPS) for identifying the location. The setup explores several gas sensors for its operation from which the data is acquainted but the GPS to track the source with precision. IoT-enabled leakage detection and monitoring system for ammonia gas has been explored in [5]. Furthermore, IoT-enabled leak detection for oil pipelines has been used by the authors in [6] where negative pressure wave is used to locate the leaky position. Some other related work focused by researchers in the recent past has been tabulated in this section subsequently.

Table 1 – Literature survey for crack monitoring

Ref. No.	Authors	Monitoring Element	Sensing Technology and tool	Limitations and Research Gap
7	A. Ayadi et al.	Cross country buried water Pipeline	Underground pipeline monitoring using in-pipe sensing using an acoustic sensor	Prone to corrosion and erosion due to soil moisture and soil pH
8	M. Meribout et al.	Oil and Gas Pipeline	Underground pipeline monitoring using acoustic, optical, piezo, and Lidar based sensing and detection	Prone to corrosion and erosion due to soil moisture and soil pH
9	P.E. Bhaskaran et al.	Oil Pipeline	Detect leakage using in-pipe monitoring by employing pressure and flow sensor	Cannot localize the point of leakage
10	M.I. Mohd Ismail et al.	Underground Water Pipeline	In pipe inspection of the pipeline using accelerometer	Unable to locate leak point
11	W.Z. Khan et al.	Oil and Gas Pipeline	IoT based sensing	In pipe scanning used which requires high maintenance

3. PIPELINE ASSESSMENT MODELS

Many mechanisms have been proposed and established for the health monitoring of ferromagnetic pipelines through different intelligent systems. Some of these devices create different types of locomotion methods for robots to move either inside the pipeline or over the pipeline. Primarily these are classified into two broad categories,

(i). In pipe inspection
(ii). Out pipe inspection

3.1 Integrating Sensor Node with MFL Technology

Pipeline for the transportation of gas and oil has been an integral part of the world population. The concern lies in maintaining the pipeline integrity management system for inspecting a defect. Recently MFL probe has been proved to be an emerging tool to check the inline leakage inspection. Inspection is performed using high-power magnets. For non-destructive testing magnetic flux leakage technique is used for the detections of defects and cracks in pipelines. A strong permanent magnet is used to create magnetic flux in the object pipeline to be tested. MFL detection is widely used due to its simple operation and durability. Uniform flux distribution is there in pipeline if no defect is detected. Otherwise, a leakage magnetic flux is obtained at defected region. Hall effect sensors detect the leakage magnetic field in the region of crack. These hall sensors can detect magnetic flux leakage and generate an electric signal proportional to the flux leakage [12].

4. CIRCUIT DIAGRAM

Arduino UNO is a 32-bit microcontroller board with Atmega 328 processor. It has 6 analog and 14 digital input/output pins. There are 6 pins for PWM also. It runs on a clock speed of 16 Mhz. Arduino Uno contains 32 KB of flash memory. Arduino is also equipped with 3 ground pins it can provide 5 V of external power supply. As shown in Fig. 2. Arduino UNO board gets interfaced with the linear hall effect sensor module. The sensor module has 4 pins Ao for analog output, do for digital output, + *Vcc*, and G for ground. This module is capable to detect the north and south poles of the magnet. This sensor module can also provide relative strength of the magnetic field both in analog as well as in digital format.

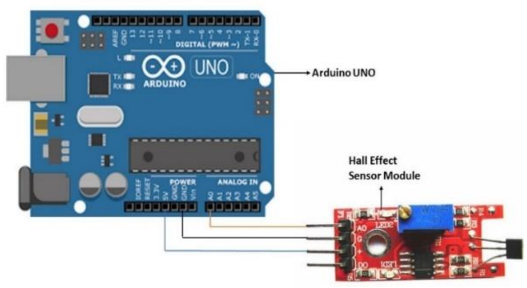

Fig. 2 – Interfacing of Arduino with Hall Effect Sensor

For our experiment, we have connected the ground pin of the sensor with the ground pin of Arduino, the positive pin (+) of the sensor node with 5 V pin of Arduino, and Analog output pin A0 of Arduino to the analog pin in the sensor module.

5. EXPERIMENTAL SETUP

The output of the sensor is directly proportional to the magnetic field strength passing through the pipeline. The output signal from the Hall sensor is termed as "Hall Voltage" If there will be a crack detected on the surface of the pipeline, a variation is obtained in the output of the sensor. sensors named as "Hall Voltage". The array of sensors provides an analog value to the microcontroller module.

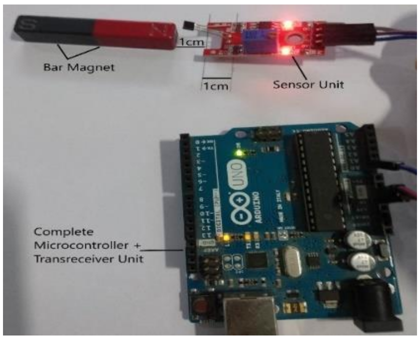

Fig. 3 – Hall Effect sensor at 1 cm apart from magnet

The experimental setup for the design and development of superscribed sensor nodes to capture a crack in the pipe is done in two stages. In the first stage of operation as in the case, the benchmark setup analysis of the sensor has been tested. For the implementation of the initial design at an early stage we carried out our experiment over an 8-bit RISC-based popularly used processor. In this sequence, we used Arduino UNO as a microcontroller unit with the capability of transmitting data to the system via serial communication. Hall effect sensor is used in the sensing unit in both the cases of the experimental setup with the capacity to transmit analog variation in output voltage concerning a change in the strength of the magnetic field.

6. RESULTS AND DISCUSSION

Theoretically, we would benefit from using this sensor. Herewith this sensor we could measure the variation in magnetic field strength. When we apply the system over the pipeline, then by this parameter we will locate where is the leakage in the pipe going to be. We experimented with 2 steps and got the results. In the 1st phase, the hall effect sensor is placed 1 cm apart from the North pole of the bar magnet as shown in Fig. 3. The red side of the bar magnet is the North pole, and the dark side is the South pole. The hall sensor is connected with Arduino UNO is placed at a distance of 1cm from the bar magnet. We get the readings of this experiment in real-time over the integrated development environment (IDE) of the system as shown in Fig. 4.

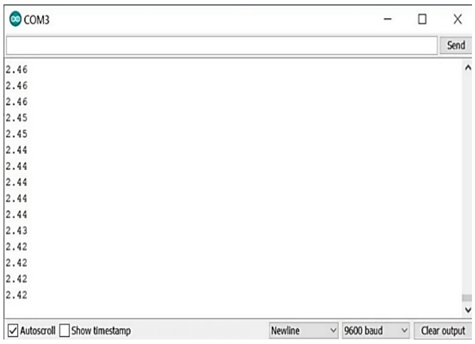

Fig. 4 – The output of the Hall sensor when the magnet is 1 cm apart

The values obtained in the serial monitor of Arduino IDE are proportional to the distance between the hall effect sensor and the bar magnet. A magnetic domain hall effect sensor even works to examine the presence of any magnetic field or as a proximity sensor in terms of strength/ intensity of the magnetic field shown in Fig. 3.

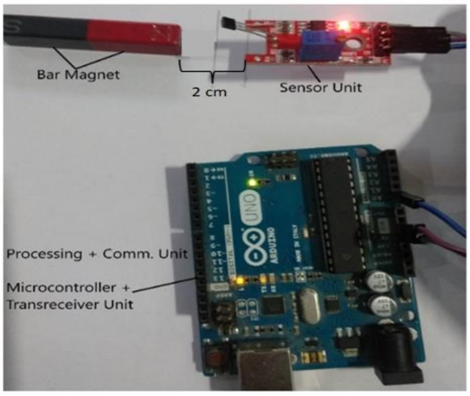

Fig. 5 – Hall sensor at 2 cm apart from magnet

The integrated data sets are utilized to optimize the feature interpretation. The more accurate data sets enable better early alarming and sensing of the severity condition for the pipeline integrity mass assessment. Further, in the next phase of the experiment, the hall effect sensor is placed 2 cm apart from the north pole of the bar magnet shown in Fig. 5 and real-time sensor output is shown in Fig. 6.

In the second phase of the experiment, keeping other parameters constant the hall sensor is placed 2 cm apart from the bar magnet. The real-time output is obtained over the Arduino Integrated Development Environment (IDE). The values obtained are transmitted through the serial port of the microcontroller unit, interfaced with the sensor as shown in Fig. 5.

The output of the Hall sensor when the magnet is 2 cm apart in case 1 the output obtained from the hall effect sensor is placed at 2 different locations as shown in Fig. 6. In the primary test, it is placed at 1cm apart from the bar magnet and in the next part, it is placed at 2 cm apart from the bar magnet. The difference in the output of both the sensors is shown clearly in the graph below. The *X*-axis of the graph shows a real timestamp while the value obtained from the sensor as Hall voltage is represented on the *Y*-axis of the graph.

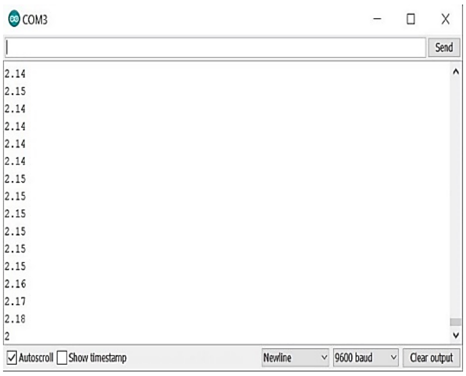

Fig. 6 – The output of the Hall sensor when the magnet is 2 cm apart

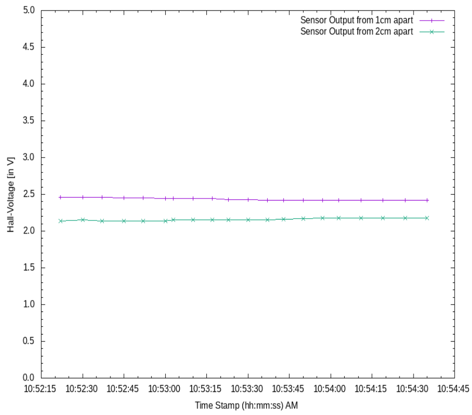

Fig. 7 – Comparison between the output of sensors for both locations

When the sensor is placed closer to the magnet i.e. (1 cm) apart the output obtained has more value in terms of voltage. This value is represented by the purple color in the graph below. The sensor output decreases with the increase in distance between the sensor and the magnet. The green-colored line in the graph below represents the output when the sensor is at 2 cm from the magnet.

7. CONCLUSIONS

In this article, we have focused the research on the development of a cost-effective device for pipeline integrity monitoring. Most of the piping infrastructure of in-process industries like in petrochemical plants are at a height of 40 to 60 meters from the ground level. For a maintenance engineer, it becomes hazardous to monitor the integrity of the pipeline continuously at this height. Therefore, our present experimentation will be helpful to design smart sensor nodes. Further, we will focus on the Internet of Inspection Things for petroleum sensor network (PETS-NET) as a whole new one. It will perform continuous monitoring in the petroleum industry and provide early alerts for leakage and cracks. These smart nodes will monitor prone areas regularly in piping arrangement and provide alerts to the maintenance team. Post-inspection data processing is done by integrating data sets to optimize the feature interpretation. The interpreted data is retrieved by the data acquisition unit, which gives an early alarm for making a leak-proven pipelining industry.

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Недорогий сенсорний вузол для моніторингу тріщин у вихідних трубах з використанням неруйнівного контролю для переробної промисловості

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У переробних галузях неруйнівна оцінка є ефективним методом моніторингу робочого стану обладнання. Через ручну систему контролю за станом обладнання на нафтохімічних підприємствах трапляються катастрофічні аварії. Людям не вистачало необхідного досвіду, щоб належним чином виробляти свіжі матеріали та керувати різноманітними машинами та видами транспорту на зорі індустріальної епохи, що призводило до серйозних аварій. Використання системи виявлення пошкоджень для виявлення потенційних дефектів матеріалів призвело до значного підвищення надійності машин. Завдяки удосконаленням при розробці та виробництві з додатковими знаннями, неруйнівний контроль став фундаментальною частиною перших складних систем. Нафтопереробні та нафтохімічні заводи мають мільйони труб, які утворюють мережу. Ці труби контролюються щорічно під час зупинки заводу. Технічне обслуговування їх проводилося традиційно, тому воно стало дуже небезпечним, а також виснажливим завданням. У статті ми протестували недорогий пристрій моніторингу тріщин. Для цього була розроблена система на основі Arduino для моніторингу тріщин трубопроводів ззовні. Поняття витоку магнітного потоку використовується для відстеження будь-якого дефекту внутрішньої структури феромагнітних трубопроводів. За допомогою датчика Холла була локалізована та зафіксована зміна напруженості магнітного поля. Сучасні дослідження зменшують обмеження системи моніторингу робочого стану обладнання переробної промисловості. Це сприятиме створенню безпечної атмосфери для працівників, а також для суспільства в цілому та навколишнього середовища.

Ключові слова: Неруйнівний контроль, Феромагнітний матеріал, Витік магнітного потоку, Сенсорний вузол, Моніторинг тріщин.