Design & Development of Ruggedized Mechanism for Detection of Rotating Metallic Objects Using Inductive Proximity Switches

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ABSTRACT

We describe a sensing arrangement for detection of a metallic body rotating at high revolutions per minute (rpm) operating in dusty and muddy environment. For such an environment, the sensing range, switching frequency & ruggedness of proximity switch are key parameters. When an electrical conductor, such as a metal target enters the electromagnetic field, eddy current starts circulating in the conductor. This eddy current draws energy from the field. Presence or absence of metallic objects can be detected by measuring the energy deficit because of the eddy current. An inductive proximity switch based system was developed for detection of rotating metallic objects. Experiments were carried out in the simulated dusty & muddy environment to check the functionality of the system. It has been planned to install the inductive proximity switch based system for detection of metallic objects rotating at high rpm in military application.

KEYWORDS: Inductive proximity switch, Switching frequency, Sensing range, Eddy current, IP protection

I INTRODUCTION

Detection of rotating metallic objects is a critical activity in heavy industries and military applications. It is an important factor for performance enhancement of the equipment, where heavy metallic bodies are required to be rotated at a high rpm to diffuse the explosives in battlefield and also in size reduction of minerals of soft to medium-hard consistency[1]. High *switching frequency* and large *sensing range* are the two major parameters to be considered for sensing of objects rotating at high rpm. When application calls for sensing of rotating metallic targets that falls within an inch of the sensing surface, the proximity sensor fits nicely into design criteria. Capacitive, inductive, magnetic, ultrasonic and photoelectric sensors are few examples of proximity switches. The conventional technique to detect the rotating metallic objects is to use a Hall Effect sensor or magnetic pickup sensor. For our application the problem with these types of sensors is that they have very less sensing range of around 1 to 2 mm and require fine tuning of the sensor.

Devices for metal detection for specific purpose have been developed in the past. Metal detectors operating on a radio wave principle are commercially available from C & G Technology, Inc., Phoenix, Arizona.[2] Hinged hammer designs often used in size reduction of coal, coke, gypsum, limestone or other minerals of soft to medium-hard consistency are commercially available in the market as Horizontal Shaft Impact crusher[3].

In the design, the non-contact type inductive proximity switches are used for detection rotating metallic objects. An inductive proximity switch contains a coil and a ferrite core. Together, these two components form the portion of an LC tuned circuit which drives an oscillator. The coil and core set up a very low-energy electromagnetic field that is radiated from the sensing face of the switch. When an electrical conductor, such as a metal target enters this field, eddy current begins to circulate in the conductor. This eddy current draws energy from the field. At a very precise point, the eddy current is so large that the amplifier cannot output sufficient energy, due to which oscillation stops and the field collapses. The oscillations amplitude is converted into a switching signal. This operating principle permits detection of all metals irrespective of whether they are rotating or not[4]. The inductive proximity switch data is collected using a data acquisition system at regular intervals automatically. Satisfactory trial of the working model of proximity based system was conducted under the simulated dusty & muddy environment at R&DE (E), Pune, India.

II SENSOR SELECTION

Experiments on the five different sensors were carried out. The *capacitive* proximity switch was found good for detection of metallic as well as non-metallic objects but it could not be used in this particular application as they are not suitable for dusty & muddy environment. *Photoelectric* sensor was also tested. Even though it's sensing range is large and it can detect any object, this sensor works only in clean environment and fails in dusty surroundings. *Ultrasonic* sensor could not be incorporated in this system as it has very low switching frequency. *Magnetic* sensors can work in dusty and muddy environment but it can detect only magnets. This sensor is not a good choice as magnetizing the metallic object is not feasible for

our application. The *inductive* proximity switch can easily detect metallic objects and can work in dusty & muddy environment with a moderate sensing range. After testing all these proximity switches, it was decided to use inductive proximity switch ID5055 IFM make as it fulfills all the system requirements. ID5055 has a sensing range of up to 50mm in ideal conditions, switching frequency of 70 Hz, operating voltage of 10 to 36 VDC and with IP67 protection[5]. The selected inductive proximity switch is shown in figure 1.

Figure 1: *Inductive Proximity Switch*

III METHODOLOGY

The experimental model for detection of rotating metallic objects was fabricated with channels and plates as shown in figure 2a. This support structure was fabricated out of standard channel sections. At the bottom, six cushy mounting pads were provided to absorb the vibrations during the operation. The support assembly was mounted on the concrete base and bolted on the M20 studs. The pedestals with bearings were mounted for supporting the rotor shaft. The strengthening was done by providing the gussets.
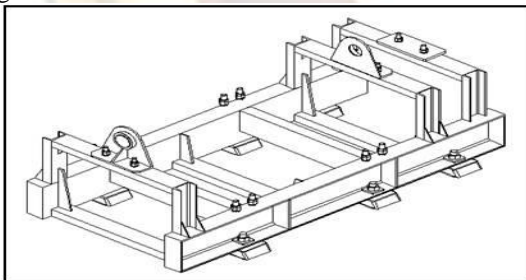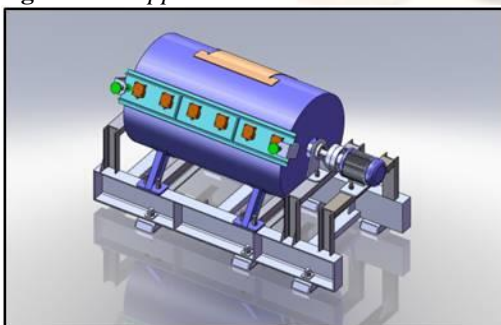

Figure 2a: *Support structure*

Figure 2b: *Rotor drum with support*

The frame was fabricated with channel section was welded at the end of support assembly for mounting of the motor.The length of the rotor was 1300mm and diameter was 800mm. The plate thickness was kept at 6mm.

The rotor drum as shown in figure 2b was prepared by rolling 6mm thick MS sheet and was closed at both the ends. The diameter of drum was kept 800mm. The rotor shaft was fabricated with MS material. The shaft was hollow (OD 60mm and ID 52mm) and the ends of the shaft were solid with 40mm diameter for mounting the bearings. Single row deep groove ball bearing of medium duty with Bearing Number- 6308 having 40mm mounting diameter and 90mm outer diameter was used. The dynamic load capacity of the bearing was 41kN. Pin bush type flexible Love joy coupling was used to compensate any misalignment in rotor shaft and motor shaft. Six metallic objects- EN19 were used as shown in figure 3.

Figure 3: *Metallic Object*

Objects were mounted on the rotor shaft. Rotor shaft was supported on both the sides by mechanical structure. Proximity switches were mounted on the adjustable screw mechanism. The distance of the objects from the sensor was adjustable with the help of screw mechanism. The purpose of designing a cylindrical structure was to create dusty & muddy environment by filling sand and mud inside the drum. 3-Phase induction motor was used to rotate the shaft on which metallic objects were mounted. Motor having 15 KW power and max rpm of 1460 with supply voltage of 415 volt was used[6]. The mechanical setup is as shown in the figure 4. Two separate power supplies were used, one for switches & another for microcontroller circuit. The reason for using two different power supplies was to isolate the sensor power supply from the microcontroller supply. Motor drive was used to control the speed & torque of the induction motor. Electronic circuit setup is as shown in figure 5.
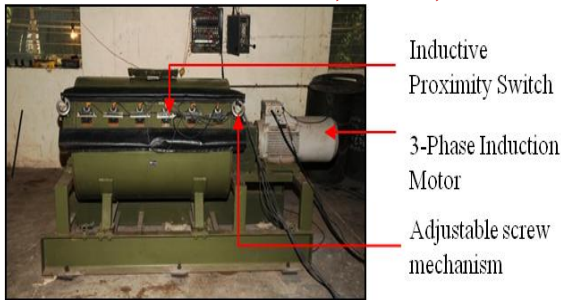
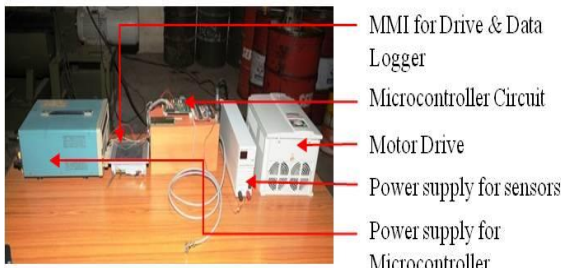**Figure 4:** *Mechanical Experimental setup*

Figure 5: *Electronic circuit setup*

The electronic system consisted of 6 inductive proximity switches which were used to detect the metallic objects. The opto-isolator ILQ74[7] was used for signal conditioning & isolation. It shifts the voltage level and provides isolation between input & output. Incoming proximity signal is applied to the input terminal of the opto-isolator. The photo transistor was configure d in common emitter mode. The circuit of opto-isolator is given in figure 6.

Re-triggerable monostable multivibrator CD54HC4538[8] was used for increasing the duty cycle of the input pulse coming from sensors. The input & output of the re-triggerable monostable multivibrator is shown in the figure 7.
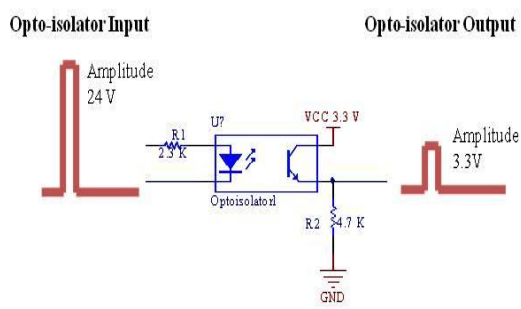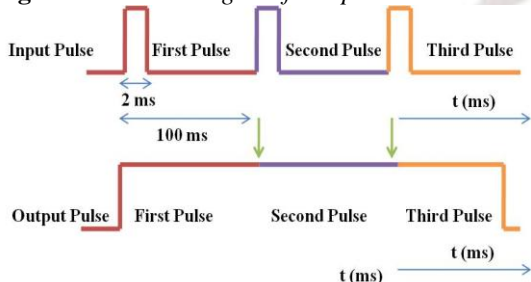

Figure 6: *Circuit diagram for Opto-Isolator*

Figure 7: *Input & Output of monostable multivibrator*

The microcontroller LPC2148[9] was used for decision making and data acquisition. The electronic system block diagram is shown in figure 8 and the microcontroller circuit is shown in figure 9.
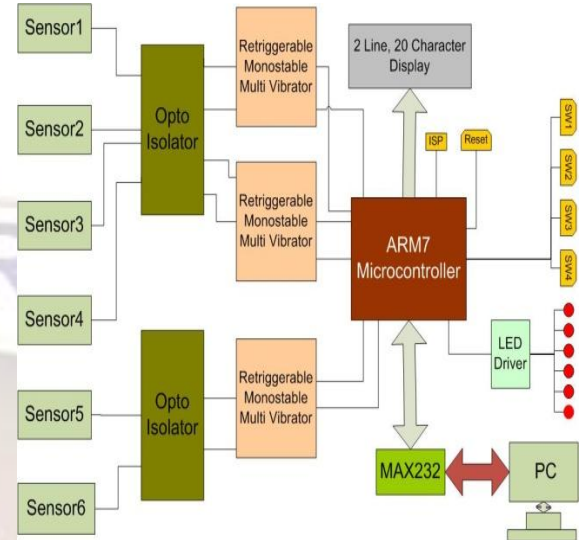

Figure 8: *System block diagram*

A modular software was written in C language for ARM7 based LPC2148 microcontroller. The software scans the input ports for sensor data at predefined interval and gives suitable indication to user/operator about the presence or absence of metallic objects through LEDs & LCD. Software had the provision for logging the sensor status information over a serial port for offline analysis. A timer of 100ms was implemented for periodic scanning of sensors input. An ISR executes whenever the 100ms timer expires. Timer flag is set in the ISR which indicates expiry of 100ms time. The flowchart as shown in figure 10 was implemented to conclude the presence or absence of metallic objects.
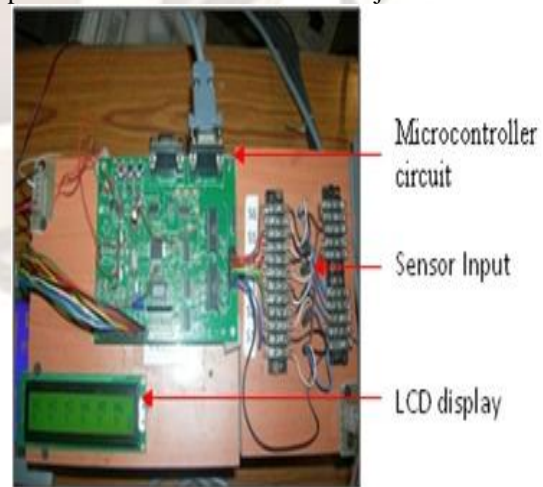

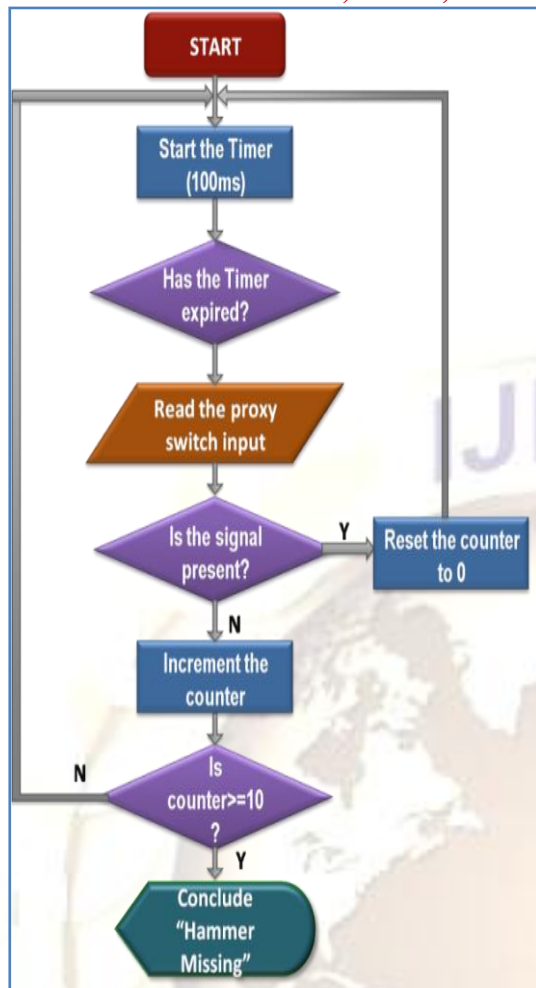**Figure 9:** *Microcontroller Circuit*

Figure 10: *Flow Chart*

IV   RESULTS & DISCUSSIONS

The experiments were carried out to check the proper functioning of the system for detection of metallic objects rotating at a high rpm using inductive proximity switches. Based on the algorithm developed, the data was collected. Experiments were carried out at different motor speeds ranging from 50 to 600 rpm. Also, the tests were conducted with all the six objects present and then removing objects at random. The detail of the experimental data collected is given in table1. Figure 9 shows the absence of objects 4 & 6 as per Sr. No. 7 of Table1. Experiments were also carried out to select the optimum sensing range of the switch. It was found that the switches work up to a maximum range of 30mm. The object distance from the switches for the data shown in table1 was kept 30mm. The same distance was achieved when the environment was dusty and muddy. This concludes that there is no effect of the environment on the sensing range of the inductive proximity switches.

The dimension of the sensor used was 92mm x 80mm. The size of the sensor was quite large because of the requirement of high sensing range. The size of the sensor selected cannot be more than the size of the object to be detected, as it will increase the chances of false triggering by the adjacent objects. Therefore, it is required that object size and distance between the two adjacent objects is sufficient enough so as not to false trigger.

V   CONCLUSION

We have successfully developed a ruggedized mechanism for detection of rotating metallic objects which can work in dusty & muddy environment. Results obtained from the experiments give satisfactory results. We found that the inductive proximity switch is a reliable solution when application calls for detection of rotating metallic objects in dusty & muddy environment.

VI   ACKNOWLEDGEMENT

Table1. Experimentally generated data

Sr. No.	RPM	Sensor No.1	Sensor No.2	Sensor No.3	Sensor No.4	Sensor No.5	Sensor No.6	Remarks
1		Y	Y	Y	Y	Y	Y	All objects present
2		Y	Y	Y	N	Y	Y	Object No. 4 is absent
3		N	Y	N	Y	Y	Y	Object No. 1 & 3 are absent
4	400	N	N	Y	N	Y	Y	Object No. 1, 2 & 4 are absent
5		N	N	Y	N	Y	N	Object No. 1, 2, 4 & 6 are absent
6		Y	N	Y	Y	N	Y	Object No. 2 & 5 are absent
7		Y	Y	Y	N	Y	N	Object No. 4 & 6 are absent

REFERENCES

[1] http://www.miningonlineexpo.com/mining_hammer_mill_crushers_crushing.html

[2] http://www.skk-banjaluckapivara.com/inventMeans for detecting metal objects by Most, Lynn W.; Most, Allen F

[3] http://www.skkbanjaluckapivara.com/invent/container_with_drinking_tube/means_detecting_metal_objects.html

[4] http://www.ifm.com/ifmind/web/techlex.htm

[5] Ifm electronic gmbh • Friedrichstraße 1 • 45128 Essen —GB — ID5055 — 06.03.2003

[6] Data Sheet Oxford 3 Phase Induction Motor

[7] Data Sheet Seimens Quad Channel ILQ74 Phototransistor Opto coupler

[8] Data Sheet Texas InstrumentsCD54HC4538 High-Speed CMOS Logic Dual Retriggerable Precision Monostable Multivibrator

[9] UM1039 LPC 2148 user manual Volume 1: LPC214x User Manual Rev. 01