Feasibility Study of Using a Coupler Skate Encoder System for Monitoring the Real Time Status of Lift Door Operation

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Abstract. This work presents a proof-of-concept study of the encoder system developed for monitoring the health of coupler skate assembly used in automatic door header system of lifts. The motivation of developing a coupler skate encoder system is to provide real-time information on coupler skate status and its performance which could be further used for developing a preventive maintenance program of door header system.

The coupler skate encoder system consists of a Hall effect-based sensor, microcontroller board, and power supply unit. The Hall effect sensor measures the real-time angular rotation of coupler skate assembly. The microcontroller is flashed with the firmware which evaluates the time series data, and as a result, it sends a digital signal in case of any deviation in expected performance of coupler skate assembly. A benchtop sensor calibration set up is constructed to prepare a look-up table for calibrating analog voltage signal against angle in degrees.

The coupler skate encoder system is tested on automatic lift door test jig for evaluating its various parameters like accuracy and repeatability of sensor and real-time data analysis by the microcontroller. The results obtained from the experiments are found to be encouraging such that the coupler skate encoder system resolves the smallest angular rotation which is required to detect an erroneous condition of coupler skate assembly operation.

The proof of concept study highlighted in this document introduces a new concept of real-time monitoring of sub-assembly of door header system, which could be a guiding document in developing preventive maintenance technologies specially designed for lift automatic doors. The preventive maintenance technologies of such kind as discussed in this paper would be a significant development for smooth and error-free operations of lift doors.

1 INTRODUCTION

1.1 Background

A lift is sometimes described as the driverless vehicle, transporting passengers on a fixed route i.e. along the fixed trajectory. To perform such an autonomous driving function, typically, a microprocessor based lift controller uses multiple electro-mechanical subsystems (assemblies) with real-time monitoring of safety sensors. In the case of a lift, one of the important "electro-mechanical" subsystems is an automatic door assembly. The automatic door assembly involves large numbers of linkages and parts (i.e. mechanical and electrical parts) which work in a synergic manner. For a lift to make a successful ride from one floor to the other floor, it is of paramount importance to have robust and well maintained automatic door assembly.

The automatic door assembly of a lift can be considered to be made up of two parts i.e. car door assembly and landing door assembly. The car door assembly is a power-operated mechanism while the landing door assembly is driven by car door assembly. Simultaneous movement of car door and landing door is made possible by the mechanical interlocking mechanism. The mechanical interlocking consists of pair of fins (also known as coupler skates) fixed on a car door assembly (See figure 1-1) and a pair of rollers fixed on a landing door lock assembly (See figure 1-2). The main role of the interlocking mechanism is to act as a link between car and landing doors. When the car door arrives in the unlocking zone, during the lift door operation (i.e. opening and closing of doors) coupler skates located on a car door spread out such that landing lock rollers are pressed causing the landing lock to open. As soon as the car door is power operated through door drive for a door opening or closing command, landing door mechanism follows the car door movement i.e. the car door horizontal movement is transmitted to the landing door through interlocked coupler skates and landing lock rollers. The opening and closing of car and landing door mechanisms are monitored through electrical safety switches.

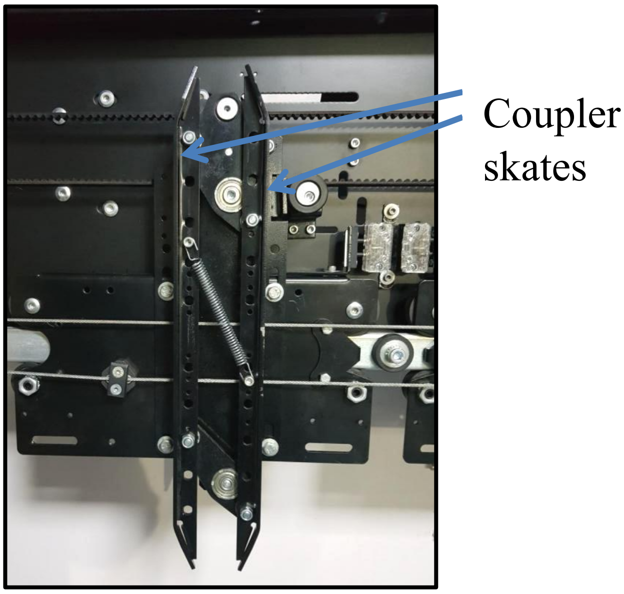


Figure 1-1 Picture of car door coupler skate assembly

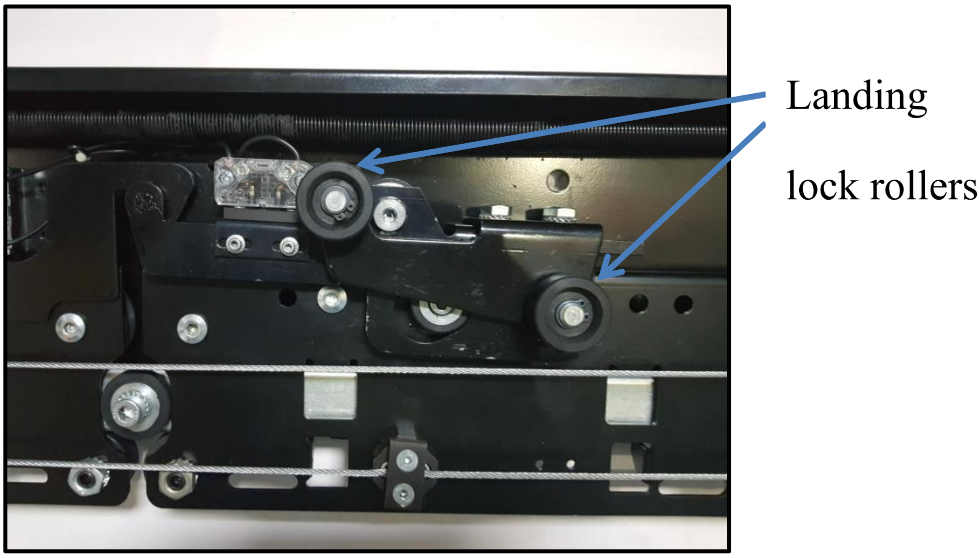


Figure 1-2 Picture of landing door lock assembly

The working principle of automatic door assembly discussed in this article is the most commonly used design by elevator companies. In general, most of the door assemblies will have a similar working principle but they might be different in terms of material specification, size, duty cycle and many other functional parameters which depend upon the application for which it is to be used. Readers are also referred to three articles published in the book "Educational Focus" by Elevator World magazine [1,2,3]. These articles provide a comprehensive introduction about the basics of elevator automatic doors.

One interesting point to be highlighted about the working principle of automatic door assemblies discussed in this article is the "driver" role played by car door mechanism and the "driven" role of multiple landing door mechanisms installed at various stops. For a lift to successfully open the doors, the car door mechanism should always be healthy and in a perfect operating condition such that it can align itself correctly at every floor for the mechanical interlocking to take place; followed by simultaneous movement of car and landing door. It is imperative to always maintain door assemblies and operator wear and tear-free and also in a healthy condition for the error-free operation of automatic doors which will lead to minimum lift breakdowns. Indeed, it has been a challenge for many elevator companies as the maximum number of breakdowns in a lift are typically encountered in the door assemblies. Some of the principal reasons for door related break downs are highlighted in the reference [1] such as dirt, grease and oil accumulation on rollers, pulleys, cables, switches and other sub-assemblies. Also, change in the adjustment of mechanical components and assemblies due to wear and tear over the time of normal usage can cause a breakdown.

Considering the intricacy of the door assembly, the elevator companies need to have a preventive maintenance program. A proof of concept is presented in this article, wherein a sensor is used to monitor the functional accuracy of one of the door sub-assembly which would aid in taking preventive actions rather than reactive maintenance efforts. The function of the sensor described in this document is to monitor the correct working of coupler skate assembly, its wear and tear and the change in dimensional settings during opening and closing operation of the car door assembly. The idea here is to keep monitoring the health of a car door sub-assembly and whenever the data shows a deviation from a threshold value, a flag is raised by the onboard firmware to indicate the need for initiation of preventive action. Note that, the preventive maintenance idea described in this article is a "proof of concept" study, so the experiments and its scope is limited to only coupler skate pre-failure detection scheme. But, for the preventive maintenance program of a complete door assembly to be effective, a comprehensive system should be developed with multiple sensors for monitoring various sub-assemblies of a door.

1.2 Objectives:

The main focus of the work mentioned in this article is to provide a proof of concept of a car door mounted coupler skate pre-failure diagnostic system. In this regard, following are some of the questions that are addressed through this paper:

1. What type of sensor would monitor the health of coupler skate assembly?

2. What is the working principle of proposed "Coupler skate encoder system"?

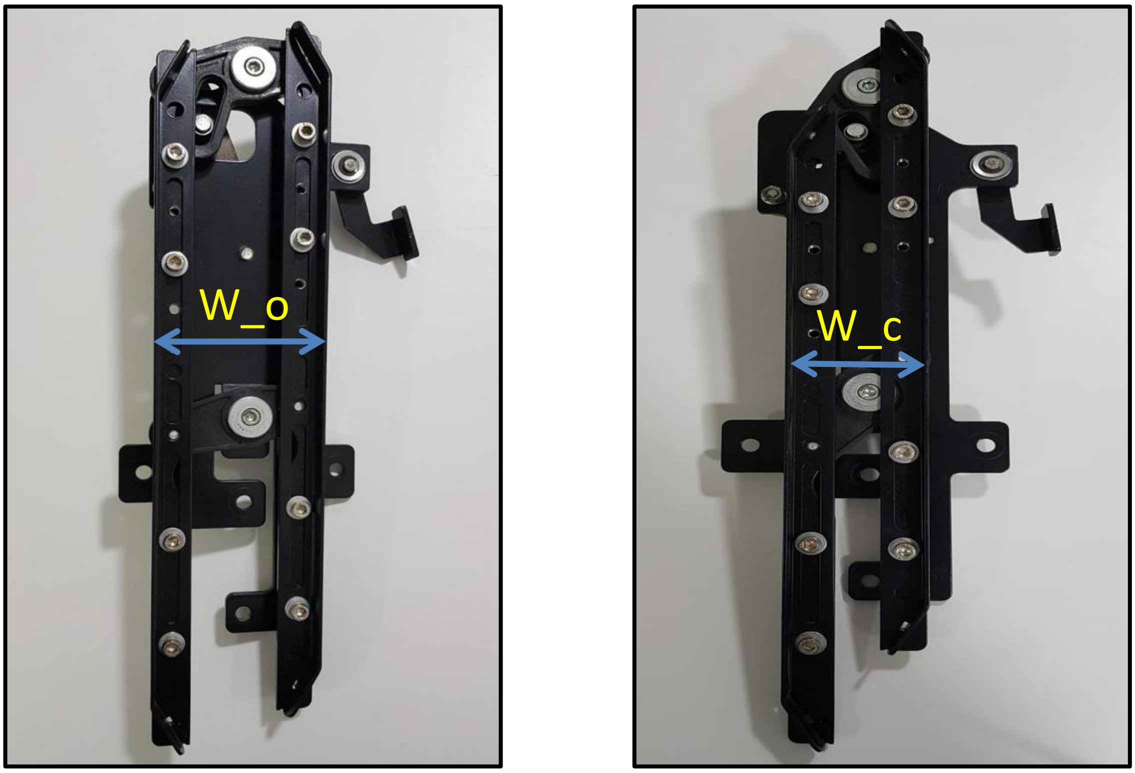
3. Is the coupler skate encoder system sensitive enough to diagnose the deviation in the working of coupler skate assembly?

4. What are the results from the proof of concept experiments of "coupler skate encoder system" in regards to its application to detect coupler skate assembly pre-failure condition?

The paper is organized such that the details about the coupler skate sensor design, experimental set-up, results and conclusions are described in sections 2, 3, 4 and 5 respectively.

2 DESIGN OF COUPLER SKATE ENCODER

The coupler skate studied in this document is shown in figure 2-1 (a, b). As discussed in the introduction section, during the opening of the door, coupler skates (vanes) spreads out to open the landing lock and close-in at the end of the door closing motion. The assembly of coupler skate is designed in such a way that if we connect a linkage connecting both the skates of a coupler, the linkage will be seen making rotational movement about a fixed point. By tracking the rotational motion of the linkage connecting the skates using a sensor, we can monitor the degree of movement of the coupler skates. This concept is the basic working principle of the "Coupler skate encoder" system demonstrated in this document.



(a) **(b)**

Figure 2-1 Picture of the coupler skate assembly ; (a) Coupler skate open condition (b) Coupler skate close condition

Figure 2-2 shows the CAD drawing of the angle position sensor installed on a coupler skate assembly. The angle position sensor (Asahi Kasei, make EM-3242 IC) uses the Hall effect principle to measure the angle. The sensor and the magnet are assembled such that sensor IC PCB is fixed on the coupler skate assembly base plate while the magnet is fixed on the linkage connecting both of the coupler skates. The magnet is oriented and placed in such a way that the rotating magnetic vector from the magnet is in the parallel plane to the sensor IC which is the essential condition for the sensor to measure the degree of rotational motion. During the door operation, as the coupler skates spread out, a proportional rotation is made by linkage which is measured in real-time by the angle position sensor. The analog voltage data measured by the sensor is fed to a microcontroller board (Arduino Uno) which is powered by a DC power supply (Meanwell, Model PSC-60-R4) module. The microcontroller board performs the signal conditioning process to amplify the signal as well as to filter out the noise. The lookup table i.e. analog voltage signal against angle is utilized by a microcontroller to convert the measured sensor signal into the units of "degrees".

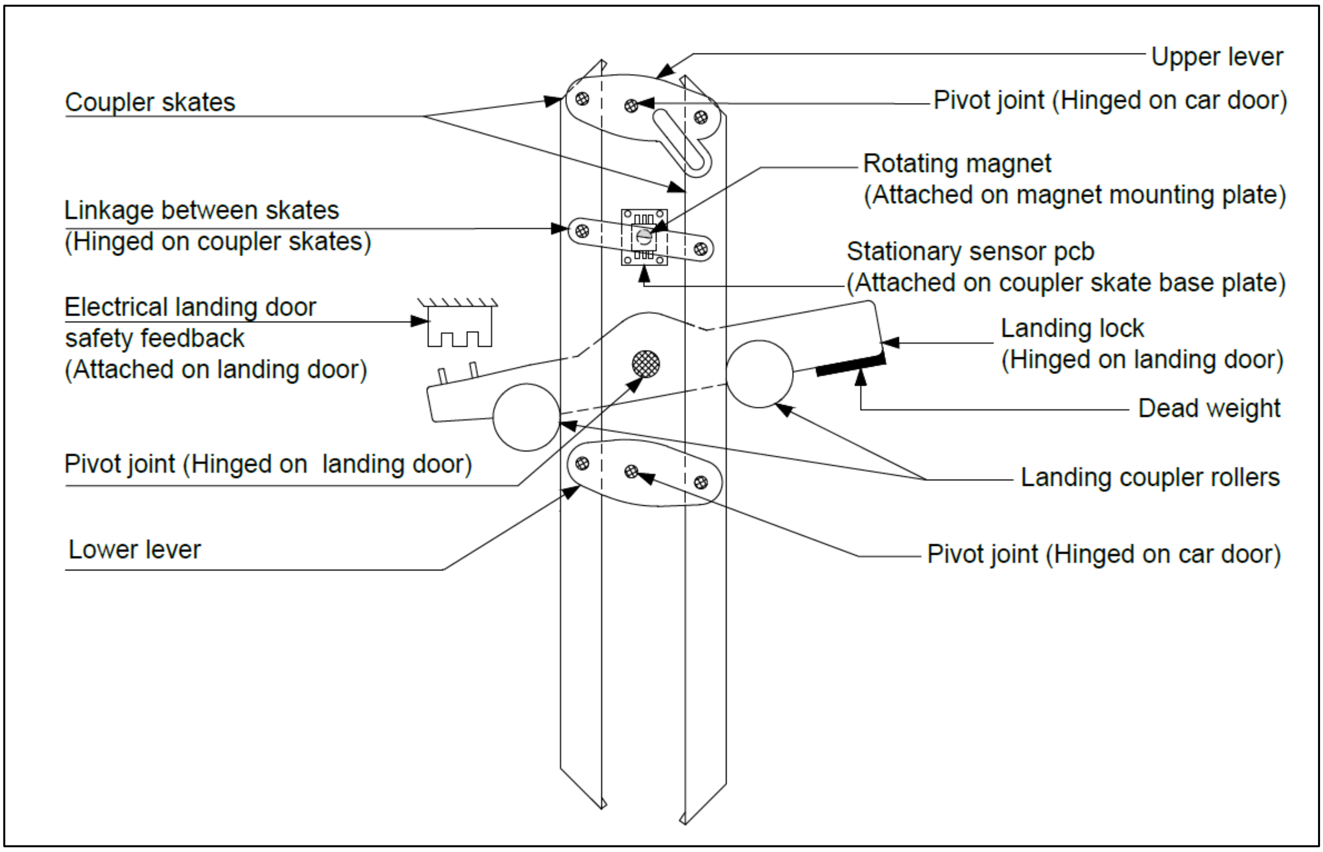


Figure 2-2 CAD drawing of coupler skate encoder system installed on coupler skate assembly

To detect any deviation in coupler skate assembly desired performance level, an algorithm is embedded in the microcontroller to signal the preventive maintenance flag. The desired performance of the coupler skate assembly is defined such that coupler skate assembly should spread out during door open command and the distance between the skates (vanes) should be observed in the range W_o = 87.5 to 90 mm. Similarly, during the door close operation, the coupler skate assembly should close the skates wherein the distance between the vanes should be in the range W_c = 63 mm to 65 mm. Based on these threshold values of W_o and W_c, corresponding angles (θ_o, θ_c) are calibrated and saved in the microcontroller memory. The preventive maintenance algorithm is designed in such a way that whenever the threshold angles (θ_o, θ_c) are not achieved by the coupler skate assembly during the door operation, a flag is raised by the microcontroller signaling a need for preventive maintenance of the coupler skate assembly.

Note, that the optimum working range of W_o = 87.5 mm to 90 mm and W_c = 63 to 65 mm is defined through an independent characteristic study of coupler skate assembly and landing lock assembly wherein the said threshold values of W_o and W_c ensures smooth opening and closing of landing locks. If the threshold values are not met, the landing lock unlocking and locking operation is not smooth and also sometimes it's unsuccessful.

3 EXPERIMENTAL SET UP

3.1 Sensor calibration set up

The sensor EM-3242 is a non-contact angle positioning IC used in the coupler skate encoder system to detect instantaneous angle. The EM-3242 provides an absolute position in the units of "voltage". To convert the angle data from the units of "voltage" to the units of "degree", a calibration set up is constructed. Figure 3-1 and 3-2 highlights the calibration set up. The calibration set up is constructed such that a rotating magnet is placed in parallel plane of the IC so that a rotating magnetic field is generated above the sensor IC. Whenever a known rotation of magnet is made in degrees, a corresponding voltage is measured as an output from the IC. This forms the basic idea for creating a calibration lookup table for the sensor IC.

The construction of a calibration unit is such that the angle measurement scale is fixed on the mounting table (see figure 3-1 and 3-2). The sensor PCB is fixed on top of the angle scale supported by studs. A magnet is held above the sensor IC using a lever which can be freely rotated in the clockwise and anticlockwise direction. Any rotation made by the lever or say magnet is measured by eyeballing the angle pointer fixed on the lever. The angle pointer rotates above the angle scale through which degrees of magnet rotation can be easily measured. The analog voltage signal of the sensor IC for the calibration experiments is measured by an oscilloscope (Tektronix, Model - TBS1000B, Vertical resolution 8 bits). The results of the sensor calibration and its characteristics are discussed in section 4.

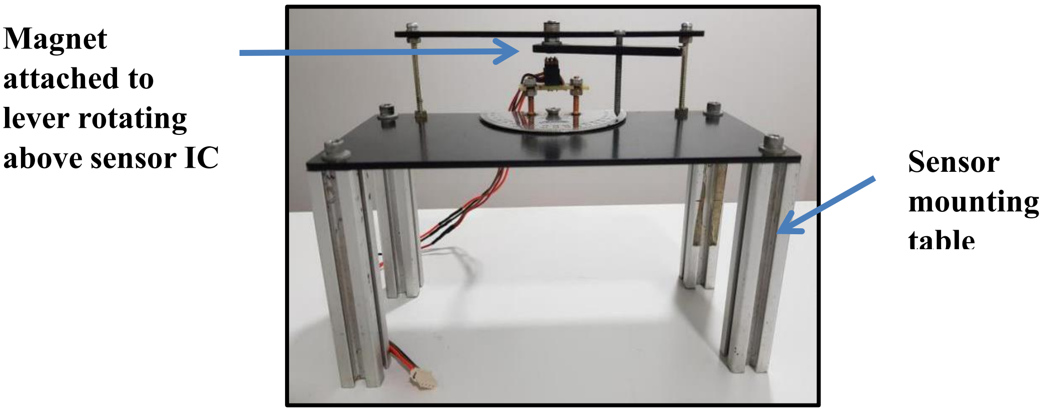


Figure 3-1 Sensor IC EM-3242 calibration set-up

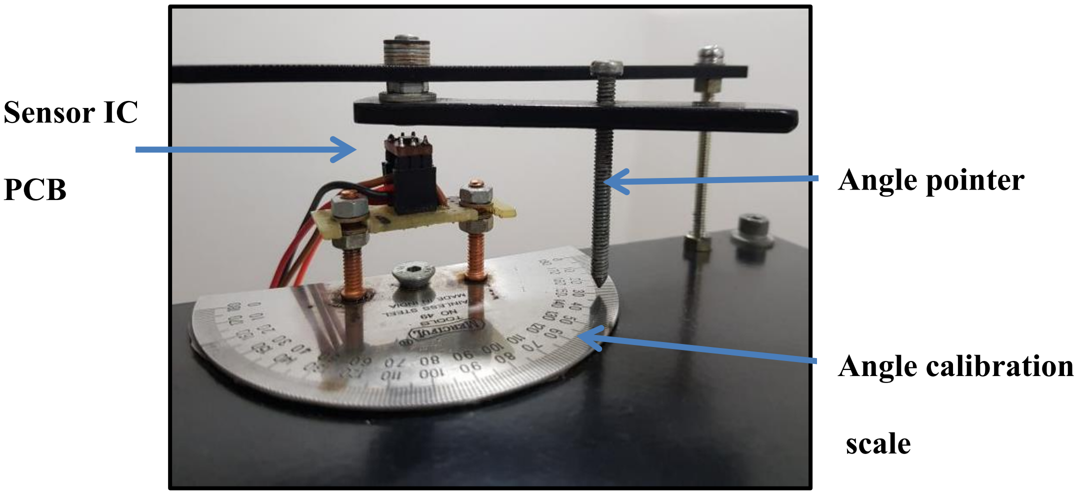


Figure 3-2 Sensor IC EM-3242 calibration set-up (close-up view)

3.2 Elevator automatic door test jig

An automatic lift door test jig is used to evaluate the working of the coupler skate encoder system. On this test jig, landing header and car header are mounted with their respective door panels attached through hangers. Car door header assembly is operated through a door drive unit and the coupler skate system of the car door assembly drives the landing door assembly, simulating the closest possible automatic door operation typically seen for elevators.

To simulate the erroneous operation of the coupler skate assembly, an adjustable screw-based obstruction is provided on the coupler skate assembly. Through the obstruction screw, the spread-out distance between the skates (W_o) is restricted which simulates the faulty operation of the coupler skate assembly during the door opening cycle. The proof of concept of coupler skate encoder system and the fault detection algorithm is verified by performing experiments using obstruction screw attached to an above-mentioned test jig. The results of the experiments are discussed in section 4.

4 RESULTS AND DISCUSSION

The results and discussion section describes the outcome from the calibration experiments and the proof of concept experiments performed on the test jig.

Figure 4-1 depicts the sensor (coupler skate encoder) calibration data which is obtained using a calibration set up described in section 3.1. The figure 4-1 shows the degree of rotation of the magnet on the x-axis while the sensor output analog voltage signal is highlighted on the y-axis. The calibration experiment was performed such that the sensor is calibrated for the angle in the range 0 to 100 degrees. The magnet angle was incremented in the step of 2 degrees. To minimize the random error and to get statistically accurate reading, the calibration for each angle increment was repeated 10 times. Thus, each data highlighted in figure 4-1 through the red colour symbol is an average of 10 experiments.

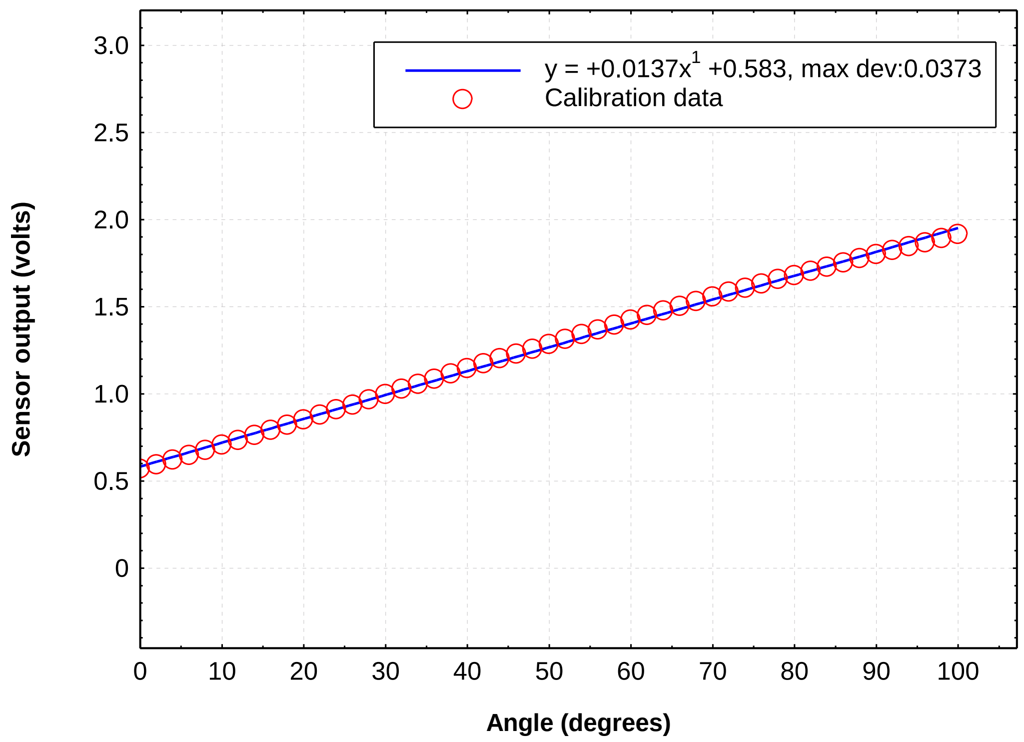


Figure 4-1 Calibration curve of coupler skate sensor (angle against analog voltage signal)

A linear response of the sensor output is observed for rotation of magnet in the range 0 to 100 degrees (see figure 4-1). This result concurs with the behaviour described in the data-sheet of the sensor (EM - 3242). As the sensor shows the linear behaviour a linear equation based data fitting line is also highlighted in figure 4-1. The linear equation obtained through the fitting line enables the conversion of sensor output voltage signal to the units of angle in degrees.

The AKM sensor EM-3242 is a very accurate sensor such that its accuracy is defined in the datasheet as 0.36 deg [4]. For the experiments described in this document, the accuracy is limited by the least count of the calibration angle scale. Thus, considering the least count of the calibration scale as 1 deg, the accuracy of the coupler skate encoder system for the experiments described here is ±0.5 deg.

Figure 4-2 highlights the coupler skate width against the angle measured by the coupler skate encoder system during door opening and closing operation. Here, the angle refers to the angle of rotation made by the linkage which connects the coupler skates (see section 2). The data depicted in figure 4-2 was obtained by performing experiments on the automatic lift door test jig wherein the coupler skate encoder system was installed on the coupler skate assembly. For the case wherein doors are fully closed such that the coupler skate width is W_c = 65 mm, the angle measured by the coupler skate encoder system is 32.20±0.5 deg. When the doors are fully opened and the coupler skate width is W_o = 90 mm, the angle measured by the coupler skate encoder system is 0±0.5 deg. The doors fully open condition i.e. coupler skate width W_o = 90 mm is the reference condition, thus the sensor angle 0 deg is set at W_o = 90 mm. From figure 4-2, it is observed that the coupler skate encoder system measures the angle of the linkage in the span of 0 deg to 32.20 deg for doors being in fully open and fully closed conditions. Figure 4-2 demonstrates the basic working of the coupler skate encoder system to measure the angle of rotation of coupler linkage during door opening and closing operation.

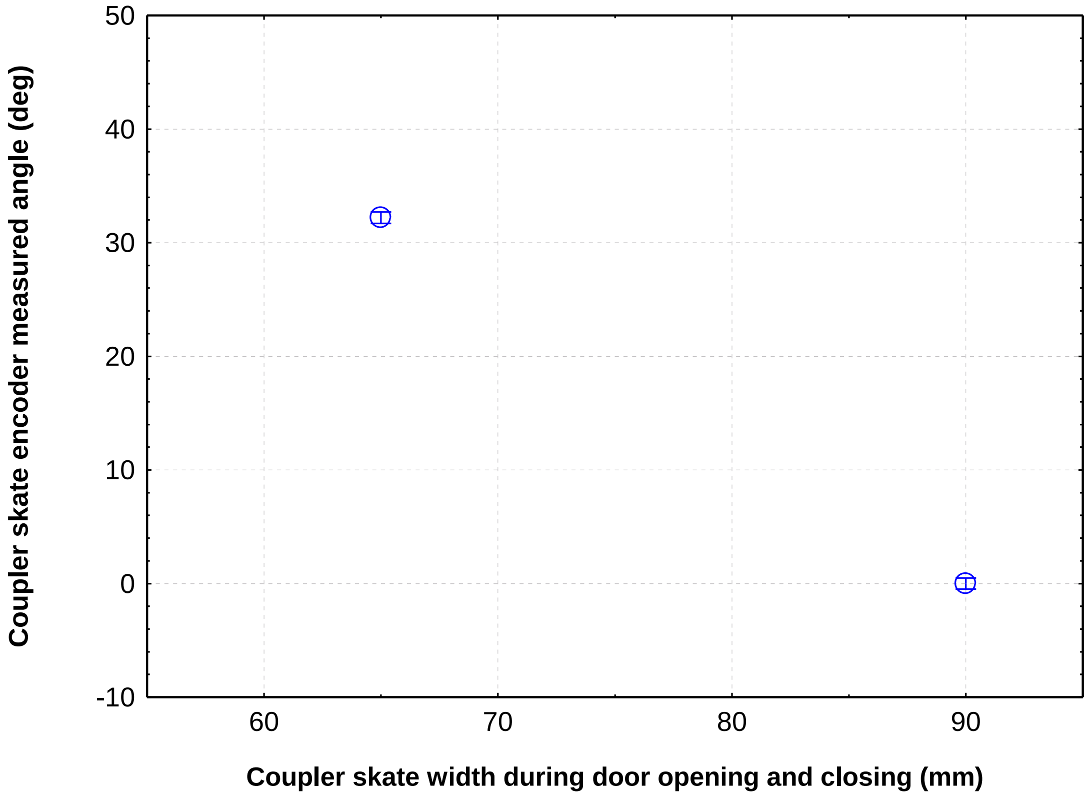


Figure 4-2 Coupler skate encoder system data for doors fully opened and closed condition

Figure 4-3 depicts the coupler skate encoder data for various configurations of coupler skate opening width during door opening operation. The coupler skate opening width was adjusted through a screw-based restriction mechanism such that W_o was varied in the range 90 mm to 87 mm. For every unique W_o value, the door open command was given and the corresponding coupler skate linkage angle was measured using a coupler skate encoder system. A specific range such as W_o = 90 mm to 87 mm was selected for these experiments since it is known from an independent study that coupler skate assembly operates successfully at W_o = 90 mm (healthy condition) while it fails to operate the landing lock at W_o = 87 mm (unhealthy condition). At W_o = 87.5 mm, the coupler skate assembly operates intermittently and it becomes unpredictable; it means that W_o = 87.5 mm can be considered as the flag-raising condition i.e. a threshold condition or an indication at which preventive maintenance should be performed.

As highlighted in figure 4-3, the angle measured by the coupler skate encoder for W_o = 90 mm is 0 deg while the angle measured for W_o = 87.5 mm is 5.05 deg and for W_o = 87 mm it is 5.9 deg. It can be observed that the span of a rotation angle of coupler linkage for the coupler skate assembly to transform from being healthy to unhealthy is 5.05 deg. Considering the accuracy of the coupler skate encoder system as ±0.5 deg, it can be concluded that the coupler skate encoder system developed and discussed in this article is capable enough to detect any deviation in the performance of the coupler skate assembly even before the complete breakdown kind of situation occurs. In other words, in-case any situation arises wherein the coupler skate width decreases to W_o = 87.5 mm (instead of W_o = 90 mm), the coupler skate encoder system can easily detect the deviation to help the microcontroller system raise the flag for the need of preventive maintenance even before the breakdown occurs.

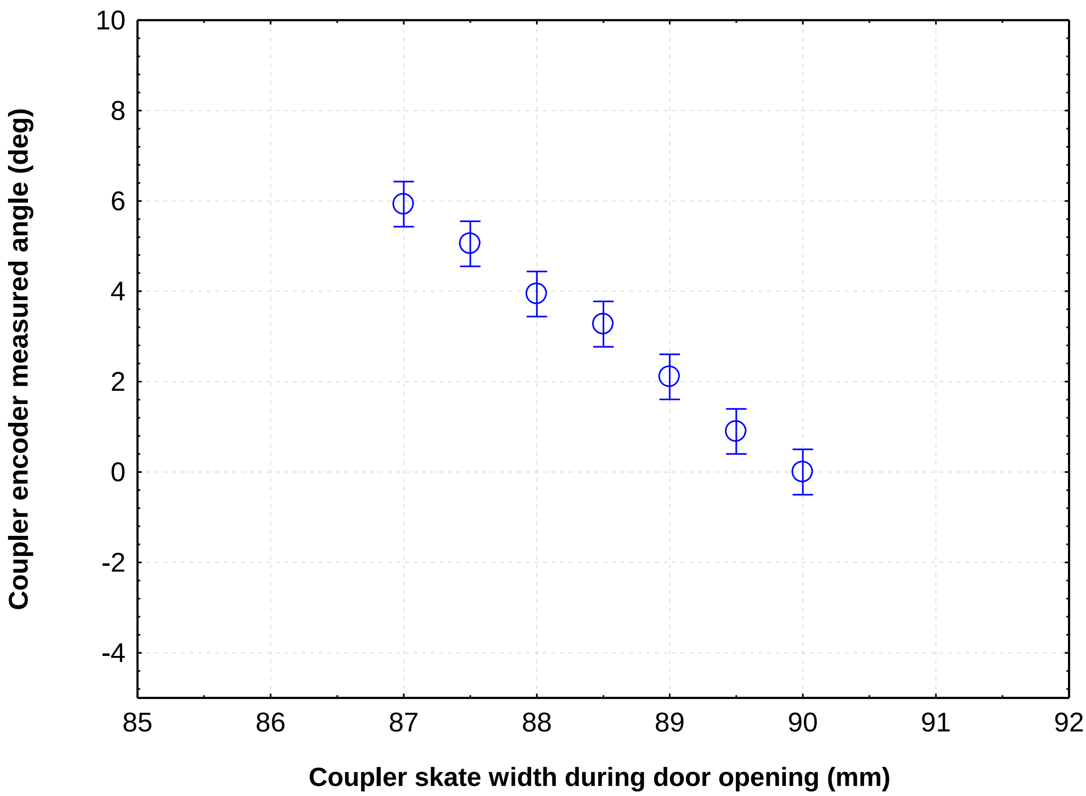


Figure 4-3 Coupler skate encoder angle measurement data versus various coupler skate opening widths

Figure 4-4 and 4-5 demonstrates the proof of concept experiment results (refer section 3.2 for information about experimental set up). Figure 4-4 and 4-5 highlights the coupler skate encoder data against the time in seconds. These experimental data were obtained during door open and door close operation. Also, depicted in the figure 4-4 and 4-5 is the status of flag signal from the microcontroller during door open and close operation. The microcontroller was embedded with an algorithm such that for healthy coupler skate condition the flag signal will remain low (value ~ 0 volts) while for unhealthy coupler skate condition the flag signal value would be high (value ~ 5 volts). Note that, for the demonstration purpose, the unhealthy and healthy condition of the coupler skate assembly was evaluated based on the look-up table fed to the memory of the microcontroller for the door open condition only.

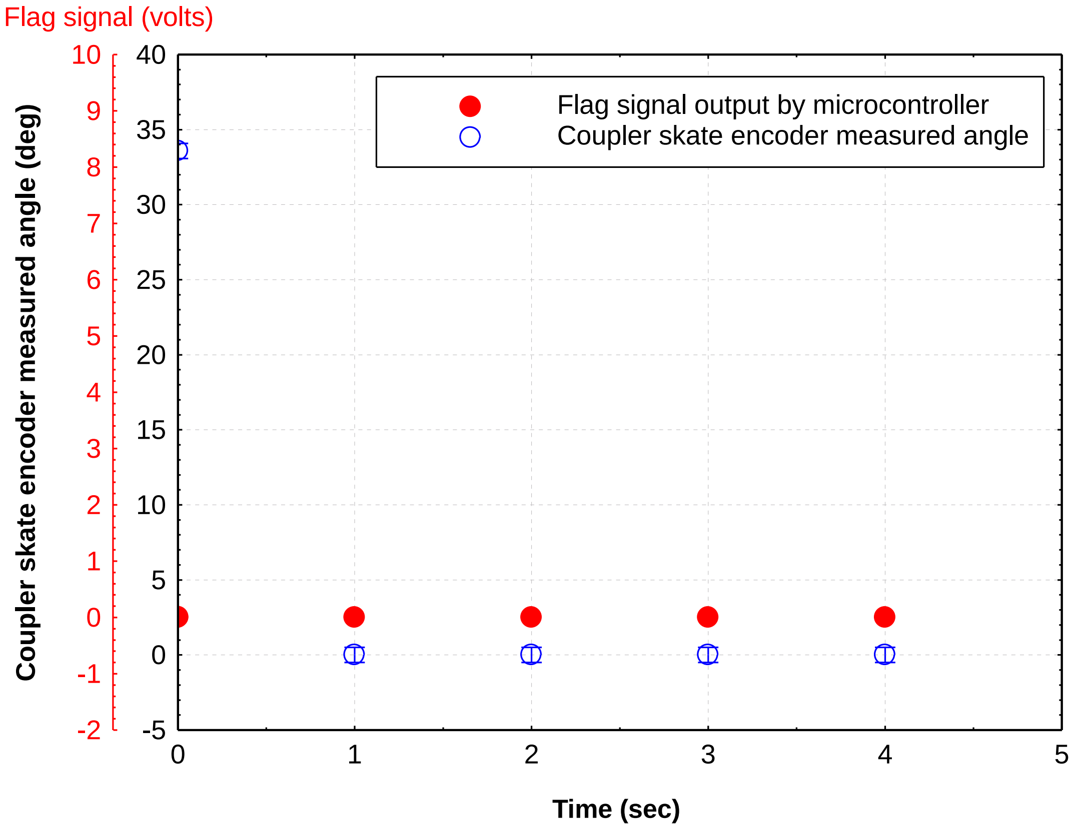


Figure 4-4 Coupler skate encoder angle measurement and microcontroller flag signal data for door opening and closing operation (Coupler skate assembly in healthy condition)

Figure 4-4 data corresponds to the experiment wherein the coupler skate assembly was maintained healthy i.e. (W_o = 90 mm, 0 deg). Here, the coupler skate encoder data measured during the door open condition had no deviation from the target value saved in the microcontroller memory, hence no flag signal was indicated by the microcontroller i.e. the output of the microcontroller flag signal remained low.

Figure 4-5 data depicts the experimental results wherein the coupler skate assembly opening width was reduced to W_o = 87.5 mm to simulate an unhealthy condition. Due to reduced coupler skate opening width, the coupler angle measured by coupler skate encoder was 4.37 deg while the expected angle for a healthy coupler skate assembly is 0 deg. Due to the deviation in angle measured by the coupler skate encoder; a high signal (value ~ 5) is flagged by the microcontroller indicating an erroneous operation of the coupler skate assembly. Thus, the results highlighted in figure 4-4 and 4-5 demonstrates the possibility of using coupler skate encoder (sensor) to detect abnormal functioning of the coupler skate assembly in real-time.

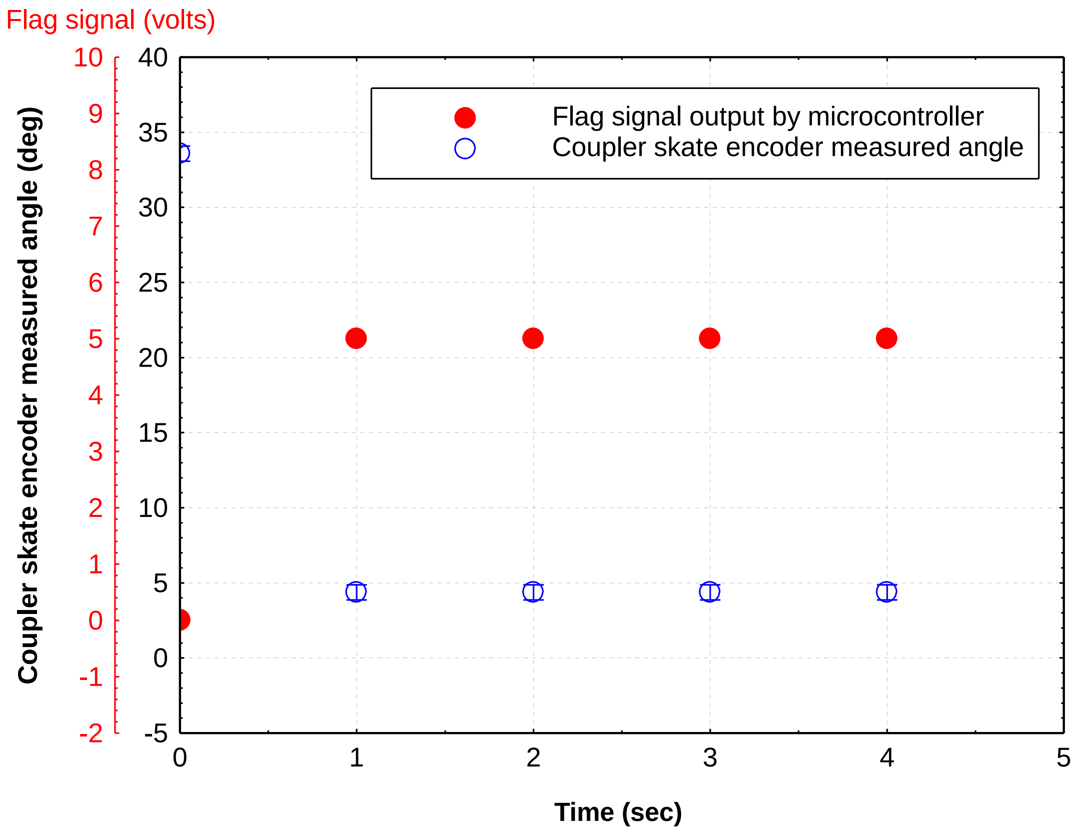


Figure 4-5 Coupler skate encoder angle measurement and microcontroller flag signal data for door opening and closing operation (Coupler skate assembly in unhealthy condition such that W_o = 87.5 mm)

5 CONCLUSION

A proof-of-concept study of the coupler skate encoder system for monitoring the health of coupler skate assembly (used in automatic door header system of lift) was investigated. In this study, a Hall-effect based sensor was utilized to measure the degree of rotation of coupler skate assembly. The data obtained from the sensor was fed to the microcontroller board to make a necessary decision (i.e. to raise a flag) in the event of any deviation against the known expected value. To evaluate the working principle of the coupler skate encoder system, experiments were performed on an automatic lift door test jig. The results obtained from the experiments are encouraging such that the coupler skate encoder system designed is accurate enough to resolve and detect the smallest degree of deviation in the performance of coupler skate assembly.

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BIOGRAPHICAL DETAILS

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