Uluslararası İleri Doğa Bilimleri ve Mühendislik Araştırmaları Dergisi
Sayı 7, S. 273-281, 9, 2023

Araştırma Makalesi

IJANSER
https://as-proceeding.com/index.php/ijanser
ISSN: 2980-0811

International Journal of Advanced Natural Sciences and Engineering Researches
Volume 7, pp. 273-281, 9, 2023

Research Article

A Novel Safety Sensor Design for Elevator Leveling and Early Door Opening Applications Considering Signal Integrity

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(Received: 27 September 2023, Accepted: 13 October 2023)

ATIF/REFERENCE: Bozkurt, B., Atakay, D., Koca, B. & Altan, İ. (2023). A Novel Safety Sensor Design for Elevator Leveling and Early Door Opening Applications Considering Signal Integrity. *International Journal of Advanced Natural Sciences and Engineering Researches*, 7(9), 273-281.

Abstract – The elevators are a common part of our life and day by day being increased the elevator abilities to rich the fast of day. High level passenger elevators have special traffic control strategies such as high speed, low noise and more to save time and energy. New elevators need high performance level sensors to move in safe and obtain high reliability in case of early door opening and leveling procedure. On the contrary, many elevators model uses reed relay based magnetic sensor to run. Moreover, magnetic sensing sensor has only two contacts and not electronically device inside it to obtain safe. Aim of this study is to reduce elevator accident related to sensor based. Unreliable and ordinary sensors could lead accident because of sensor behavior. In this study, a new generation infrared radiation sensor was designed and implemented for real applications by performing a risk analysis, considering the elevator electrical connection diagram. In this study, designed novel sensor has two sensing section to decide the right signal evaluation. Designed sensor has two channel outputs for the control boards and control boards evaluate the elevator situations in safe.

Keywords – Elevator, Early Door Opening, Infrared Light Transmitter, Levelling, Sensor, Signal Integrity Level

I. INTRODUCTION

Today, elevators are one the indispensable facility in the world. Elevators transport human and good to achieve the life speed. Day by day new rules and moving strategies can be seen literature to obtain high performance. On the contrary, elevator safety is another problem to come over without decreasing the elevator performance. Generally waste time during the parking and leveling abilities are directly related to elevator quality and performance. High class elevator must execute the leveling and early door opening to avoid the waste time. Much of the wasted time occurs during the waiting the door opening on the floor level. Thus, door can be opened early during the end of the elevator travelling. Another subject related to elevator comfort is not lose stopping level during the elevator landing under different load characteristics. Any missing the floor level elevator must come back. Car and floor level must be at same line for especially for obstacle person or any loading executing. Avoid the wasted time and

making leveling executions are made under door opened. Before the elevator landing end door begins to open and in case of losing the floor level elevator must be reverse act to find the correct level. On the contrary, door opened moving cannot be possible according to elevator standards such as EN-81.xx and ASME. To be moved the elevator during the early door opening and leveling procedures, security chain are made as short circuit to fake door closed signal for control boards in short distance. Door opened acting only can be executed 20 cm up and down from the floor level. During the door opened scenario, elevator control board must be trust the sensor signals. In case of any sensor malfunction elevator can move door opened. Unexpected moving during the door opened can cause elevator accident and personal injuring. In this study, a novel safety sensor was designed and used in real elevator applications for early door opening and leveling executions. Novel sensor was based on modulated infrared light as obstacle sensor considering common elevator electrical connections and well structure. Infrared light is non-visible light has low wavelength in electromagnetic spectrum. On the receiver side, filtering and protecting the modulated infrared light can be easily recovered against the day light noise. Instead of dry contact magnetic sensor, a novel infrared based double sensing sensor was offered and used in real applications.

II. MATERIALS AND METHOD

Describe Today, elevators are a part of modern life and generally used as vertical transporting. Related to technology, elevators have different abilities such as high speed, two cars in same shaft and duplex or triplex application to improve passenger transporting. Moreover, new strategies point not only speed and more cars using same shaft, but also support smart tricks to increase control abilities. Early door opening and leveling are two ways to improve elevator moving. Early door opening saves time and increase numbers of passengers at per day. Leveling is one of the famous abilities especially for disabled person must use elevator to move. Smooth and non-obstacle moving can be possible at only floor level equals to car level. Any missing the level point during stopping or changing related to any load, control board leveling the car position and make car stop at right position. Elevator applications are strict with many official rules do not lead any unsafe moving. European standard, EN-81-1-2-3 and American ASME, regulate elevator safety and installation and many countries obey EN81.xx or ASME rules [1-2]. According to EN-81-1, Electrical rules forces two breaking points for motor control directly connected to safety circuit. During the elevator moving, any opened door directly cut the safety circuit and makes the elevator stop [1-2]. So, early door opening and leveling application is not possible in normal elevator acting. At the floor level for short distance, safety circuits can be bridged to execute leveling and early door opening procedures. Bridged safety circuits can be dangerous in case of wrong using. So, this short area for leveling and early door opening are needed extra protection methods as electrical and software. The conflict between early door opening and strict rule written in EN 81-1 forces companies to find their ways to improve the strategy without leading any weakness at safety circuit. During the leveling or early door opening, elevator safety is bridged, and risk of failure must be checked. Risk degree can be expressed via Signal Integrity Level (SIL). Signal Integrity Level can be defined as a relative level of risk-reduction via safety function or reducing risk related to specify target [3,4]. IEC 61508 specifies 4 levels of safety performance for a safety function [5]. SIL level is grouped as 4 sections from 1 to 4 to define the risk. Grouped questions lead to find the SIL level. Questions are severity, exposure time, possibility, and probability, respectively. Fig. 1shows list of answer related to questions to obtain SIL level. End of the chart, W_n determine the SIL level according to predilection. For the severity section, C_2 was chosen. Frequency of elevator accident was accepted as C_2. Through the technology and safety components abilities, reliability of elevators is improved and day by day trustable. On the contrary, any malfunction of sensor may lead to an accident. It must be emphasized that sensor may lead any accident, but sensor cannot be accepted as only one guilty. On the contrary, sensor is a main cause for any unexpected act. It is fact that from mechanical to electronics are responsible any accident or malfunction.

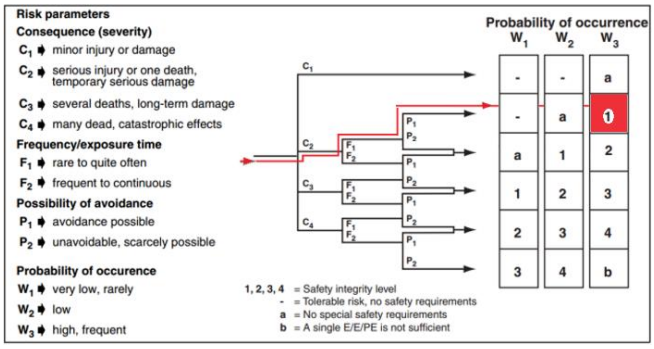


Fig. 1 Signal Integrity Chart to obtain SIL level.

But sensors are the heart of any systems to be carry on in healthy. For ordinary elevator sensors called mono-stable and bi-stable, have no power supply to improve their characteristics without changing the body or inside structure. This is why sensor level must be upgraded and associated to strict rules such as SIL. According to chosen answer (C_2, F_1, P_2, W_3), level of SIL-1 is adequate. Ordinary elevators have no sensor regarding any SIL levels. Fig. 2 shows common elevator sensors and its inside structure. Magnetic sensitive dry contacts and low voltage current capability are significant poor sides. To define a new sensor for elevator, infrared based sensing was used and designed "E" shape form for easy installation. Infrared light is invisible light and has 700 nm – 1 mm wavelength has many application areas such as medical, military and etc [6-8]. Infrared light is easy to generate only infrared light emitting diodes and widely used in many applications such as night viewing, remote controls and more [9-11]. Infrared light sensors are easy to protect from day light only using dark glass in front of the receiver. Dark glass is a kind of optical filter to protect environmental visible light [12-14].

In this study, novel sensor based on modulated infrared light was designed and implemented for levelling and early door opening for elevator applications. Implemented sensor tested in real elevator application.

A. Conventional Sensors for Elevators

In elevator application, any sensor can be used as position sensor, there is not any special strict to use determined sensor for elevator. Moreover, only dry contact reed relay-based sensor is used as conventional method. Reed relay-based sensor has no protection inside it and easily can be damaged due to inductive load characteristics and low current capability [15]. Especially inductive load is highly effective to damage the dry contacts and makes the sensor life reduce dramatically [16, 17]. Any ordinary elevator sensors, named are bi-stable and mono-stable, has no special features such as short circuit protection, thermal protection, or high voltage power input range to obtain useful and long life. Dry contact sensors such as mono-stable and bi-stable are widely used because of their low costs and easy to install. Fig. 2 shows an ordinary elevator sensor based on magnetic sensing.

Fig. 2 Bi-stable sensor and its structure.

Bi-stable and mono-stable sensors have not any electronically device their inside and any protection structure. Moreover, dry contacts have determined number of running cycle. Besides of advantages, maintains and periodically checking must be executed. Other side, electronic sensors have unlimited running cycle as much as precaution suit switching and with extra protection methods, their life span is expandable and their efficiency can be increased [18, 19].

Especially for automobile, railway and flights, sensors and their protections method are not easy and not ordinary. High input power supply range, reverse voltage protection and voltage suppressor protections are some useful methods to improve the life span of electronic device. But sensors are very sensitive to environmental changing. Included protections may lead to decrease sensitivity of sensor. For any infrared receiver, In order to decrease environmental light effects, infrared light beam was modulated at determined frequency which related to receiver and transmitter sensor response frequency.

Power supply is an important subject for any electronics device to obtain long life cycle. power supply is responsible the device running at normal situation via regulating the voltage and current. high voltage spikes and noise from air or cable force to power stage before the device core. Thus, robust, and wide range voltage input for the power supply has much importance to provide long life for the electronics device [20, 21]. In this study, dual way infrared based safety sensor was designed and implemented with wide range power supply,

thermal and DC short circuit protection for heavy duty applications.

III. PROPOSED SYSTEM

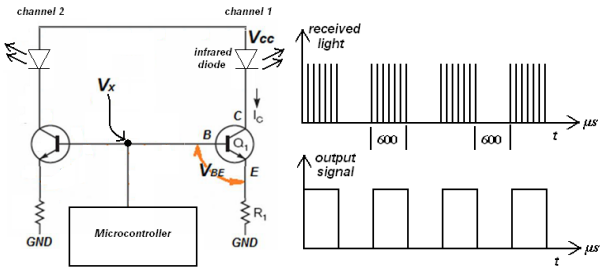
The proposed sensor structure was designed in three sections to obtain maximal reliability and robustness. In first, sensor was based on double infrared transmitters and receivers. The second, proposed system was protected against over voltage, thermal and DC short circuit situations. The last protection is related to standards to avoid unexpected elevator moving. Opened door leveling and early door opening procedures were limited for strict possibility and logical combination.

A. Infrared Sensor

Infrared light has bigger wavelength and lower frequency than the visible light. Infrared light is widely used in many devices such as remote controller to night vision systems for aerospace, food engineering, military, and medical applications [22-24]. Moreover, infrared sensor is widely available in markets. For lights sensors and applications, the light must be modulated to avoid environmental lights interference and especially it is easy to protect from day light [25-26]. In this study, infrared light modulated at 38 KHz to prevent stability running. This frequency is determined according to receiver response which is determined in the datasheet. Infrared transmitter emits at 38 KHz. Unfortunately, all light sensors have life related to light emitting performance. So the designed was balanced distance and 10 years life span according to light emitter diode data [27-28]. To improve light emitting life span, transmitter current was characterized according to current curve and life span. Current controlling was based on BJT (Bi-junction transistor) rules showed at Equ. 1. For BJT transistor, Emitter current only can be changed according to based voltage (V_x), as much as R_1 is constant [29,30].

$$I_B = (V_x - V_{BE}) / R_1 \quad (1)$$

Today, where, V_x is control voltage and for designed circuit, is constant as 5V comes from microcontroller, V_{BE} is voltage drop between emitter and base pins. V_{BE} changes from 0.55 to 0.65V according to environmental temperature and accepted as 0.65V. R_1 is emitter resistor; it leads to prevent emitter current at stabile value. Increasing the temperatures, IE has increasing direction. But same time transistor base current decrease because of the increasing voltage drops at R_1 due to increasing IE, these two situations balance the IE current at constant point at variable temperatures [31-32]. Transmitter can prevent same lighting current for different temperatures. Due to same current, efficiently light distance and expected life span can be carrying on. Fig. 3 (a) shows temperature compensated constant current structure for infrared light transmitter stage. Two stage transmitting left and right side support from same modulated 38 KHz carrier signals. Two receivers based on same response frequency accorded at 38 KHz and transmitted light beam line as left channel right channel. Receiver has inside low pass filter centered at 38 KHz and open collector output to connect to microcontroller for evaluation. Only carrier frequency is not adequate to obtain secure data from receiver. Other unexpected transmitters or light noise at 38 KHz may lead to wrong answers at outputs of the receivers.



(a) (b)

Fig. 3 (a) Infrared light emitting stage powered with transistor (b) Modulated infrared light.

To avoid to misunderstandings, carrier frequency was modulated NULL data at the transmitting side was shown at Fig. 3.b. Receivers have low pass filter to eliminate carrier frequency at output. At receiving side, Microcontroller evaluates the received signals to generate logical one or zero. Modulated IR light can be obtained same characteristic at receiving infrared diode. Microcontroller controls the signal acquisition real time. At valid two periods, microcontroller decides the logical output as one vice versa is zero.

B. Generating carrier frequency and data

Microcontroller was programmed using Pulse Width Modulation (PWM) structure to obtain simple carrier frequency and determined suitable data for infrared receiver. Infrared receiver, TSOP4038 was determined according to carrier

frequency and low distance gap [33]. TSOP4038 is widely used for telecommunication at infrared area for TV, radio or home appliance products and includes low pass and optical filters inside the structure. In addition to filters, ready to use infrared receivers have automatic gain unit and logical output as an open collector. Microcontroller generates PWM signals at determined center frequency to obtain valid logical output at transmitter side. Following codes at Fig. 4. shows 38 KHz settings as data and carrier.

```
void main()
{
   setup_adc_ports(NO_ANALOGS|VSS_VDD);
   setup_adc(ADC_OFF);

setup_timer_0(RTCC_EXT_L_TO_H|RTCC_DIV_64);
   setup_timer_1(T1_DISABLED);
   setup_comparator(NC_NC);
   setup_vref(FALSE);
   setup_timer_2(T2_DIV_BY_1, 25, 1); → PWM
structure was adjusted at 38kHz.
   setup_ccp1(CCP_PWM);→ PWM register was
adjusted.
   setup_oscillator(OSC_4MHZ);
   set_tris_a(0x00011000);→ port A was
adjusted as requested.
   set_pwm1_duty(13); → related to carrier
frequency.
   output_low(cikis_a);→ channel A
transmitting output.
   output_low(cikis_b);→ channel B
transmitting output.
   output_low(durum_led);→ output of
situation.
   enable_interrupts(INT_timer0); //
activated Timer0
   enable_interrupts(GLOBAL);     // enabled
for activated interrups.
   while(true){
   delay_us(5);→ related to carrier
frequency.
   say=say+1;
if(say<=120){
   set_pwm1_duty(13);→ related to carrier
frequency.
```

Fig. 4 Sample code for Microchip for 38 Khz carrier frequency and data

Two infrared transmitter and receiver were designed as light barrier detector to generate logical output for microcontroller. Fig. 5. Shows basic structure of sensors' running style.

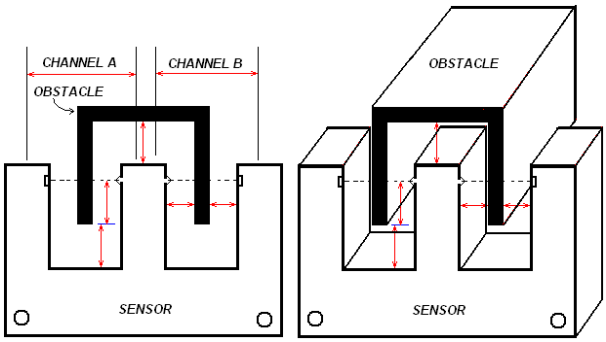


Fig. 5 Novel sensor designed as light barrier

Two barrier light outputs are characterized as one of the outputs is logical on at light off and other output designed as logical off at light off. Left side output and right-side output for two receivers are called Q_1 and Q2 and explained at Section 4.

C. *Elevator signals*

Elevator signals for early door opening and leveling procedures must be characterized correctly. Elevator control board used in this study called PLEIONE and certificated EN-81-1-2 rules by SZUTES. One of signal is related to floor level and other one is related to leveling area. These signals levels are restricted by determined distance according to standards at floor level +-20cm as maximum. Moreover, leveling procedure must be executed maximum 21mm slipping from floor level. Two signals are evaluated as leveling and early door opening area and floor level signals. Two signals must be needed but not adequate. Fig. 6. shows signals positions for control board named PLEIONE.

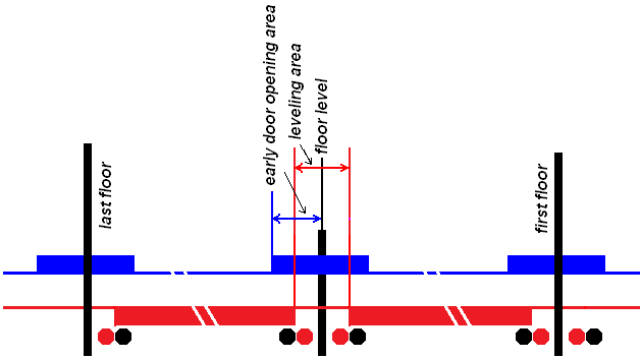


Fig. 6 Signals for the control board through the up and down moving

Early door opening and door opened levelling are dangerous procedures for elevator moving. Normally, during the door opened, elevator can't be moved because of the opened door. Safety circuit for any elevator application cover directly

door connections as a part of security. But during the early door opening or any levelling procedure door connection must be short circuit. Fig. 7 shows any elevator safety circuit validation for EN-81-1-2+A3. As a common, elevator connections are coded with nick numbers [34]. Safety circuit has many switches serially connected each other in a sequence and rules. Safety circuit starts at point 101 and ends at 140 as a turning of door locking.

where, 101 is start point of security circuit. 120 is turning of emergency switches. 130 is turning of door switches. 140 is end of security circuit. Elevator security circuits start point 101 and ends point 140 as turning of door locking unit. From start to point 120 calls emergency stopping situations. Any breaking between 101 and 120 directly related to expert or technicians to fix. But from 120 to 140, according to door opening and before the locking switches may be not closed.

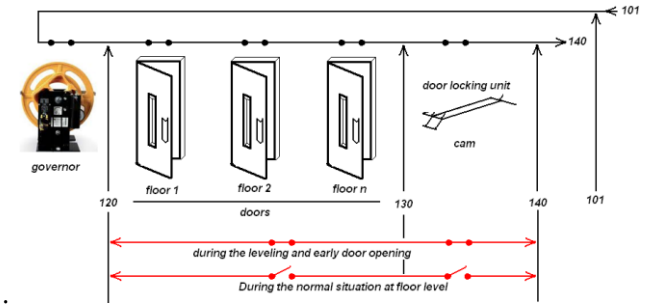


Fig. 7 Elevator security circuit

During the traveling all switches from 101 to 140 are closed and not controlled by electronics device but only sensing to carry on the running. The controller board only senses the switch situations to evaluate the elevator act. But during the early door opening and opened door levelling control board make short circuit from 120 to 140 by controlling another auxiliary board. So, during the execution of levelling and early door opening, controller can't evaluate and door situation and any possible accident. Because of this risk, levelling and early door opening area was restricted as maximum +-20cm according to official rules. Expecting the risk analyse, any unexpected situation makes end the levelling and early door opening procedures to avoid any accident.

In this study, infrared based sensors were used to early door opening and levelling procedure as safety sensor situation for real elevator application. To improve sensor security or reliability two signals have cross check inside the sensor and control board too.

D. Improved Sensor Reliability

Pair of sensors was designed for elevator application to improve early door opening and leveling procedure ability. Created protections were designed two steps as hardware and software. Software protection was embedded inside of the sensor and control board discretely.

Sensor signals change the outputs only in case of any obstacle between transmitter and receiver. This is normal expectation but unexpected situations during the inspection or under direct foreign source lights, sensor may give unwanted signals. To avoid unexpected situations, sensor outputs were evaluated leveling end floor level discretely. Fig. 8 shows barriers positions and logical light outputs.

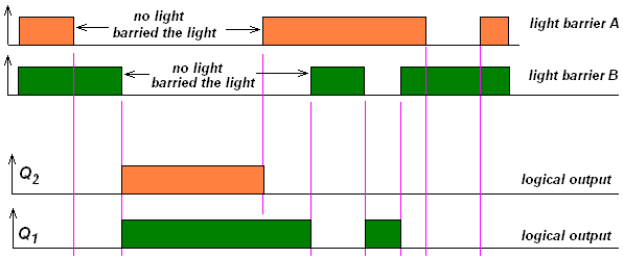


Fig. 8 Behaviour of light barriers

One of output (Q_1) can be evaluated as door level and means of Q_2 has levelling early door opening area (and levelling area). Door level signal (Q_1) has low importance according to early door opening or levelling signal coded as Q_2. Q_2 critical outcome is supported and crosscheck in three stage to improve sensor reliability and sensor security. Although Q_1 and Q_2 are discrete outputs, Q_2 output depends on light of Q_1 and Q_2, together. This is first internal check designed as software inside of the sensor. From Fig. 9, Q_2 behaves as and rule of Boolean between Barrier A and Barrier B. valid Q_2 output can't be obtain only one side barrier. Valid mean of Q_2 can be understand as elevator must have been at floor level and ready to levelling or early door opening procedure. This same checking algorithm was embedded inside of the controller board PLEIONE for second step crosscheck.

Control board evaluates the outputs discretely as if sensor didn't evaluate. These two-protection style are only software protection one of inside of the sensor and other one is inside of the control board. But software is not reliable as lonely. To improve reliability, hardware protections were

designed and evaluated independently from the software.

Hardware protections were designed in two parts. One part was arranged as software protection. Software protection has a checking system about signal timing and sequences to decide real logical output. Software protection is based on two steps as inside and outside the sensor. Inside the sensor is based on modulated light and outside the sensor protection is based checking algorithm to decide valid output. The second protection part is included in the hardware to protect from noise, short and thermal conditions. Thermal condition may relate to overload and short circuit situations. Noise is highly effective parameter reducing the sensor performance to be taken care. Short circuit protection improves the sensor reliability and life span.

Elevator security signals must be short circuit from 120 to 140 points by auxiliary board using safety relay which are designed on strict rules and passed independent official standards. Safety relays offers and guarantees 2mm opened switch gap during the normally open situation. In this design, SCHRACK safety relays SR6B6K12 was used discretely between 120-130 and 130-140 points. SR6B6K12 guarantees 2 mm opening during energized or released time [35]. This security circuit bridging from 120 to 140 includes source and sink electrical connections to improve reliability. Sink mode and source mode connection are basic industrial electrical connections to explain the connection style in electrical diagrams. Source connection is a simple way to apply any load connection to power source. Sink connection is current based connection on current ring way. Fig. 9 shows sink and source connections styles.

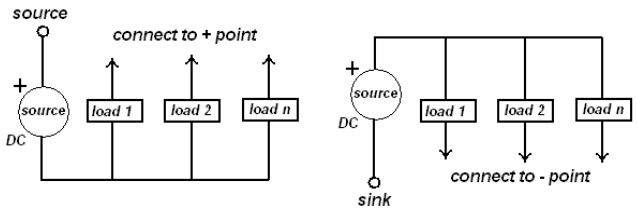


Fig. 9 Sink and source connection methods

Safety relays are connected to sensors output sink and source mode connection to improve hardware protection. Fig. 10 shows safety relays connection to light barriers outputs as sink and source connection mode.

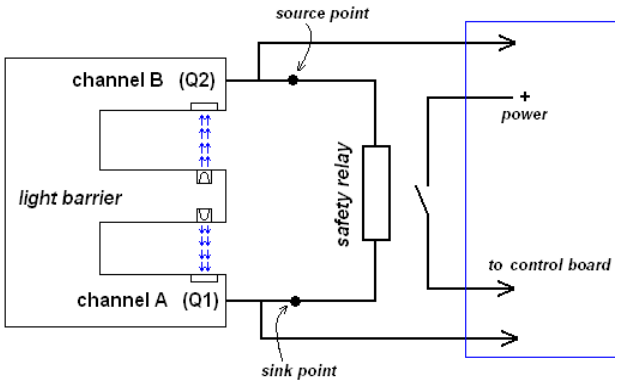


Fig. 10 Safety relay connection to sensor output

Safety relay signal obtained from light barriers were applied to control board to improve evaluation and decide safe decision. Any decision about levelling and early door opening must be pass several checking points as software and hardware.

To improve sensor reliability for heavy situations, DC short circuit and thermal protection were included. Sensor cables directly connected to control board without any serial communications because of having vital importance on elevator acts. Connections between cabin and control panel is made by flexible cables which is travelling all time up and down with cabins' moving. Flexible cables may have broken in time related to tired of cable material and leads to short or open circuits. To protect according to short circuit, thermal protection and DC short circuit protection were designed. Especially DC short circuit protection is used to protect sensor outputs. Thermal protection is activated by long time running under the overload. Sensor was designed for 1 Ampere at 24Volt DC. Overload loading makes the IC heat and close to 150^0C thermal protection is activated. DC short protection is one of the famous methods to protect the IC. Unbroken outputs are very important to carry on signals after turned to normal running mode.

IV. RESULTS

All signals are already evaluated by control board. Before the evaluation control board side, the signals must be sure that all signals are valid and safe. Because of the opened door elevator moving is dangerous at floor level. To overcome unexpected moving, all possibilities come from sensors were evaluated. Table 1. Shows logical combinations and explained the elevator control board acts.

Table 1. Sensor outputs and board reactions

Sensor Outputs		Acts of Elevator Control Board
Q1	**Q2**	**Control board evaluation**
0	0	Elevator is at floor level and no leveling.
0	1	Elevator is at floor level and Leveling procedure can be executed.
1	0	Elevator is not floor level! But inside leveling area. Early door opening could be executed.
1	1	Elevator is not at floor level and outside of the leveling area.

According to Table 1, only one possibility was used to leveling and early door opening. Other possibilities were evaluated as unsafe situations to make bridging for security circuit for elevator. All possibilities except 0-1 combinations are restricted for leveling and early door opening procedure. In case of any sensor output broken or any activation of inside protection breaks the valid possibility for leveling or early door opening execution. Unexpected accidents and unexpected acts were prohibited. Implemented sensor was designed as "U" shape is sized under industrial gape size to improve spreadable for other secure areas such as machinery, aerospace etc [36]. Novel sensor was based on two "U" to obtain "E" shape and flexible using. Fig. 11 shows the sensor and obstacles after produced.

Fig. 11 Sensor and "U" shaped barrier after installation

Sensor was installed at top of the car to follows "U" shaped barriers. Fig. 12. shows installed sensor during passing the U shaped barrier.

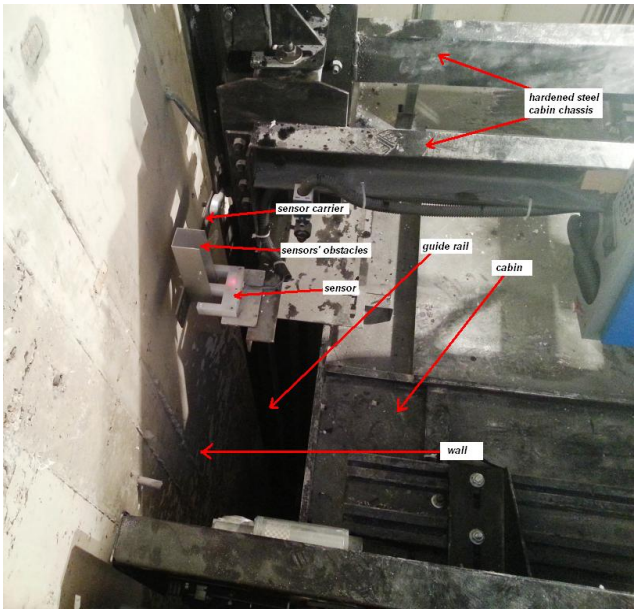


Fig. 12 Installed sensor is under real application

The application was executed at 24 Volt DC and inside of the sensor includes linear voltage regulator up to 60 Volts to improve sensor behaviours and prevent sensor from against too high voltage spikes and noise.

V. DISCUSSION

In this study a novel sensor designed and installed for elevator application regarding elevator safety connections. This application can be executed for different types of elevators such as hydraulic or machine roomless.

ACKNOWLEDGE

Thanks for Emlak Konut Elevator (EKA) for its contributions to us.

VI. CONCLUSION

In this study, Novel optic-based sensor was designed as safety sensor for elevator application. And discussed all possibilities to what happen for sensor and control board behaviours. Especially according to Table 1 and subjected protections sensor was robust and have extra ordinary protection styles as software and hardware methods. for conventional elevator sensors, bi-stable and mono-stable, have no include power supply to run and only has two magnet contacts named dry contacts. Thus, there is no chance to improve ordinary elevator sensor for high reliable level such as SIL. Thus, new body designed as "E" shape and improved optical based electronics sensor to obtain long life and high safety. Because

of the importance of discussed subject, all signals given to control boards or born from sensor were crosschecked more than one time. In this study encourage us to use this optical sensor designed as "E" shape in elevator applications for leveling and early door opening without making weakness elevator security circuit.

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