Two-Terminal Self-Powered Magnetic Sensor with Warning Lights for Elevator Applications

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***Abstract*—Sensors are the heart of any electronic device and make device behaviors robust. Generally, malfunctions are related to sensor errors. Many sensors are based and characterized on nature behavior such as magnetic field, thermal sensing or light sensitivity. Magnetic sensors are widely used in many applications such as automobiles, doors, elevators for triggering, limit switches. Commonly, magnet sensors include a reed switch having contacts that are of magnetic material and the electromagnet acts directly on them without requiring any external device. But reed switch based sensors are not robust in case of any fault in operation such as short circuit or over load. Passive sensor does not require a power supply to run and reed switch is a passive sensor. In this study, self-powered electronic magnetic sensor was designed around the reed switch core. Designed sensor has on-off output capability according to magnetic field presence and although has only two wires, it has ability to show its state with light emitting diodes. In order to obtain long life and robust structure, thermal and short circuit protection has been included. Designed sensor was built and tested in elevator application as real environmental situation. Characterized novel sensor has 250mA current capability at low voltage DC and AC current.**

***Index Terms*—reed switch, elevator, thermal protection, current limiter, vertical transporting, sensor**

I. Introduction

Vertical transporting is a very popular subject and never loses its popularity in the course of time. Crane and elevator applications are installed in many buildings and structures such as ships, mines, ports. Especially for elevator applications, sensors are needed to show the car (cabin) position. Generally reed switch based sensors are very common in elevator and crane world to evaluate the machine position. Reed switch is a simple electrical switch operated by an applied magnetic field. It consists of a pair of contacts on ferrous metal reeds in a hermetically sealed glass envelope. Reed switch has found common use as a sensor in robotics, telecoms and more [1]-[3]. In case of any power down, reed switch based sensors are widely used in elevator sector. Hence, elevator position is never missed by (bi-stable) magnetic sensors. Moreover, bi-stable magnetic sensors are inexpensive and simple to connect. Bi-stable sensor acts as a magnetic switch based on reed switch and ferromagnetic coil. Fig. 1 shows reed switch characteristics according to magnetic field direction. Only North Pole changes the position which was set by South Pole and vice versa. The state set by any pole cannot be changed as long as the other pole is not presented.

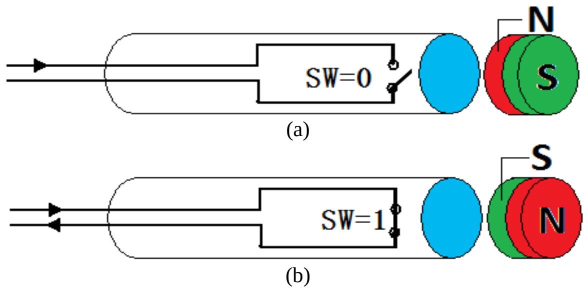

Figure 1. (a) Reed switch state turns to open when the South Pole is close to side of sensor (b) Reed switch changes its state when the North Pole is close to front side of sensor.

Any bi-stable sensor is a passive model sensor and has no electronic inside it. Thus, bi-stable sensors are sealed with an inexpensive plastic cover to protect from impacts. Plastic cover is designed as a screw-nut to improve installation convenience on the cabin. Bi-stable sensors have aluminum or plastics leg to install. Bi-stable sensors are very simple to understand and connect to any device. There are only two wires as dry contacts without polarity. Dry contact means that current can flow bidirectional and thus can be used in AC and DC current [4], [5]. Any special experience is not needed for installation. So two wires, dry contacts, simple structure and installing are all the advantages of the bi-stable sensors. On the contrary, reed switch current capability is so weak to trust with respect to any bi-stable sensor. Every moveable contact has limited and dramatically less lifetime than solid state switch. All dry contacts have a simple problem. Every current flow decreases the contact life dramatically. In order to provide contacts lasting long life period, contacts may have been included silver or platinum according to environmental circumstance. Current is an enemy to damage the contacts. Any current flow causes damaging at the contacts during the opening time. This damaging level is related to current level and inductivity of load. Especially for DC currents, huge inductive loads damage the contacts in short time [6]-[8]. Fig. 2 shows a pair of contacts before and after the damage. Any mechanical switch has to stand current flows and any current flow damage the contacts' surface related to load current in short or long period.

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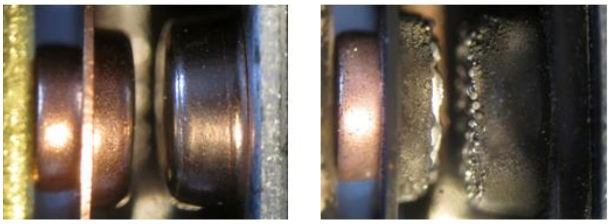


(a) (b)

Figure 2. (a) Healthy contacts (b) damaged contacts by current

Damaged contacts or contacts under overload dramatically lose its ability. On the contrary, solid state contacts have negligible damage on the contacts and their lifetime are close to 25 years provided that protection rules were undertaken [9], [10]. High *dv/dt* and *di/dt*, force the solid state contacts under the opening and closing time same as dry contacts [11]-[13]. Some protection methods must be implemented for semiconductor structure possibly during the manufacturing or installing. In this study, offered protection limitations were explained in the following section. As much as protection rules have been obeyed, solid state switch has longer life than the dry contacts. But mainly, solid state switching is related to one way current flowing. In order to obtain bi-directional current flows, two copied solid state structure must be connected inverse paralleled with each other or full wave rectifier may be added. Solid state structure and dry contact capabilities have been compared in Table I. "yes" or "no" meanings are available or not. "+" or "-" meanings are advantage or disadvantage.

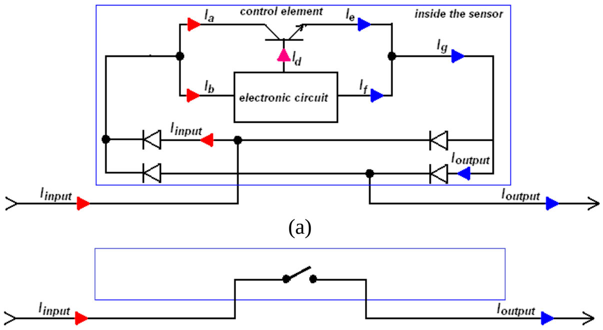
TABLE I. SOLID STATE AND DRY CONTACT FEATURES ARE LISTED

	Dry contact	Solid State contact	Designed sensor
Two wire	(yes) +	(no) -	(yes) +
Long life	(no) -	(yes) +	(yes) +
Short circuit ability	(no) -	(no) -	(yes) +
Short circuit protection	(no) -	(no) -	(yes) +
Run without power supply	(yes) +	(no) -	(yes) +
Bi-directional current flow	(yes) +	(no) -	(yes) +
Voltage drops	(no) +	(yes) -	(yes) -
Movable parts	(yes) -	(no) +	(no) +

From the Table I, solid state and dry contact switch structures have their own unique advantages that cannot be referred to each other. In this study, proposed sensor output merges all capabilities in same structure without decreasing the present advantages. Solid state contact has voltage drop at the contacts and this is one of the weakest aspects of solid state contacts. Dropped voltage leads to power loss during the on time. Voltage drops on the solid state contacts cannot be reduced related to semiconductor structure. In this study, upper current limit has been limited to less than 1 ampere to reduce to power loss multiplier. This sensor has been characterized to carry 250mA as maximum.

II. NOVEL SENSOR STRUCTURE

Position Novel sensor based on two wires has no auxiliary power supply to run. In fact, device needs low current to run and uses little bit of main current. Fig. 3 shows the essentials of inspired idea and basic sensor structure.



(a)

(b)

Figure 3. (a) Inspired circuit (b) equivalent circuit model

From Fig. 3, basic current equations can be written regarding to Kirchhoff's current law.

$$I_{output} = I_g \tag{1}$$

$$I_g = I_e + I_f \tag{2}$$

$$I_e = I_d + I_a \tag{3}$$

$$I_b = I_d + I_f \tag{4}$$

$$I_{input} = I_b + I_a \tag{5}$$

As a result of the sequenced equations, (6) can be written.

$$I_{input} = I_{output} \tag{6}$$

Equation (6) shows that input and output current values are equal and there is no current loss through the path. But inside the circuit, current may have different paths and flow directions. In the end, all current has been superimposed even when the signal is AC. Sensor include full bridge rectifier to obtain bidirectional current flow.

III. SHORT CIRUCIT PROTECTION

Commonly, sensors have no capabilities for short circuit, over current and thermal protection unless any ability comes from its nature. Especially magnetic sensor based on reed switch has no feature to protect itself and carry on the ability under overload conditions. In this study, low impedance positive temperature coefficient (PTC) resistor was used to protect from short circuit and over load. A thermistor is a type of resistor, whose resistance varies significantly with temperature more than the standard resistors. PTC and other similar devices are widely used as inrush current limiters, temperature sensors, self-resetting over current protectors, and self-regulating heating elements. Today new generation PTC based protection method is a common way to protect the circuit because of its simplicity [14]-[16]. PTC and derivatives' are common to protect electronic devices and current path against the short circuit. Fig. 4 shows the change of PTC resistance versus temperature.

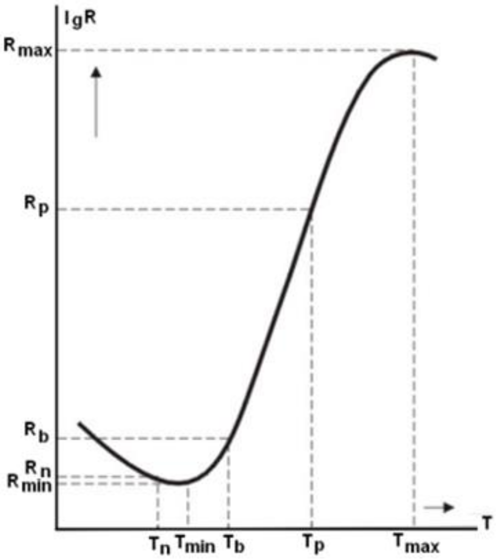


Figure 4. PTC thermistor resistance vs. temperature.

where, n equals to room temperature (T_n=25^0), T_{min}: Min. temperature (at this temperature the zero-power resistance is minimum), T_b is Curie temperature, T_p is poise temperature, T_{max} is temperature which makes R maximum. For T_b point, $R_b=2R_{min}$. At normal conditions, PTC resistance is around the T_n *and* T_{min}. In case of any short circuit, increased current lead to power loss on PTC and temperature increases immediately. Increased temperature lead to increase internal PTC resistance and makes main current limit until decrease the temperature to normal conditions. In this study, novel structure sensor was tested and optimized with 15ohm PTC.

IV. Proposed Circuit

Final designed circuit is shown in Fig. 5. Main current path starts at I_A and ends at I_B. D_1, D_2 and D_3 were used to provide its own supply as self-powered from the main current via dropping adequate voltage. Reed switch is used only to sense the magnetic field presence to switch MOSFET on and off. MOSFET can be controlled by voltage and except switching time, it does not need current for gate input [17], [18]. I_g current on R_3 is negligible especially during the on state of reed switch. D_5 is a green LED to indicate the normal conditions. Normal condition is related to maximum current capability.

R_2 is 15 ohm PTC resistor to protect the circuit for over current and short circuit. T_1 leads to voltage drops at A and B points during the on state of the sensor. Dropped voltage is around 4,2 volts. Dropped voltage is used for supplying power to green and red LEDs to show the states of the sensors. Novel sensor is designed for 12-36 DC-AC applications up to 250mA. Limited current especially under the 1 ampere leads to reduce power loss during the on time. Power loss can be calculated via (7) and (8).

$$P_{loss} = I \times V_{dropp} \tag{7}$$

$$P_{loss} = I^2 \times R \tag{8}$$

For the PTC@15Ω, power loss can be calculated as obtained as 0,9375Watts@250mA via (7). In addition to PTC power loss, voltage drops between A and B (except PTC) must be added to PTC loss. Measured voltage drops 4,2V leads to 1,05Watts and total power loss was calculated 1,9875Watts via (8).

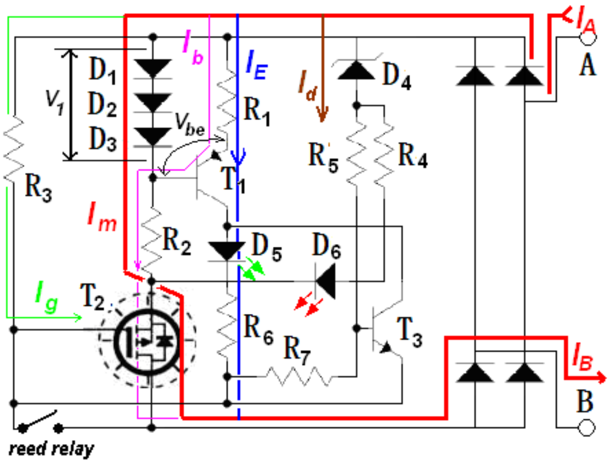


Figure 5. Final circuit for proposed sensor.

During the installation or maintenance, sensor states or any fault can be predicted by the installer. Table II shows the situations for each state of the lights. But color of the light is related to over current (or short circuit) or normal condition.

TABLE II. Meanings of Warning Lights

Green LED	*Red LED*	*Reed swicth*	*Situation*
○	○	Magnet north	Off state
○	●	Magnet south	Over load or short circuit
●	○		Normal condition
●	●		Sensor error

Green LED means that current flow is under the estimated limit but the red light shows that current is high and there is an over load. Under short circuit situation, PTC is activated immediately and sensor protects itself until the PTC turns normal situation. Undetermined diodes located to input side are designed as rectifier to AC current. This ability leads to be used at AC and DC signals.

V. Implementation of Sensor

Novel sensor was simulated using Electronics Workbench 5.12 software. Simulation was used to normalize the components. Designed structure was offered for currents up to 250mA. In order to evaluate the sensor performance at limit conditions, simulation performance was evaluated for different resistors and diodes. In this study, the aim is not only to obtain self-powered sensor but also to design as two terminals. At the same time installing and moving abilities on the x and *z* axis were improved and transparent cover is designed to obtain visible warning lights. Fig. 6 shows PCB after soldered. PTC was soldered on the left side and reed relay for sensing was located on the right side.

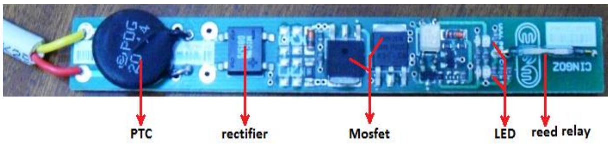


Figure 6. Soldered PCB

In order to be seen warning lights, cover of PCB was designed as transparent plastic cover. Outside of the cover was designed as groove. Thus sensor can move through the y axis. Moving ability and indicating the states make the sensor user friendly. During the installing, it is easy to see sensor states. On the contrary, old style cannot be seen during the operation. Designed sensor for the elevator brings observation and simplicity for installing. Generally elevators are classified in three classes regarding the elevator speeds. Fig. 7 shows the sensor in real application after installation.

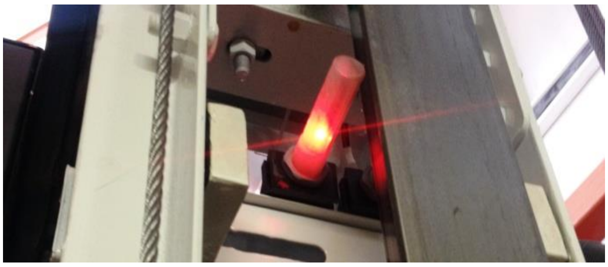


Figure 7. Sensor installed on the cabin and under running

Designed sensor is so useful to reduce maintains time because of the visible warning lights. Rope and rail guide are left and right side, respectively. Fig. 8 shows sensor is ready to use sensor.

Figure 8. Novel sensor for ready to use

During the installing, the best position of the sensing can be accessed via adjusting the two axis moves. A base, carrier, soldered PCB, transparent cover, two nuts and cable holder are parts. Base of the carrier includes teeth to hold the sensor at determined location.

VI. Conclusion

In this study, especially to be used for elevator application, an ordinary bi-stable sensor was improved as novel sensor. Current protection, short circuit and normal and over load warning LEDs were included. Ordinary models have a mechanical switch. Novel structure includes solid state switching element to avoid the contact damaging. Designed sensor was tested for currents up to 250mA capacity, and 36V DC and AC voltages. The most important feature of the sensor is that it has only two wires and it is pin-to-pin compatible with the old style un-transparent sensor. Designed sensor merges dry contact and solid state contacts' benefits at same structure. From Table I, designed sensor has all advantages in same structure except voltage drop. Unfortunately, voltage drop level can be optimized but not disappeared. Voltage drops increase the power loss during the on time. In order to reduce to power loss, current capacity was limited to 250mA and total power loss was characterized less than 2Watts. Designed sensor could be used not only crane or elevator sectors but also can be used for mine or flammable situation because of the sealed cover and solid state contact abilities.

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