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DESIGN, CONSTRUCTION AND EVALUATION OF A MAGNETIC POLE DETECTOR USING A SIMPLE ' AND' CIRCUIT.

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ABSTRACT

A simple, low-cost electronic system based on logic "AND" gate circuit arrangement capable of detecting magnetic field polarity has been designed, constructed and tested. The system incorporates a magnetic sensor (MS), which is a tiny permanent iron magnet. The sensor designed to function as a key or switch was used as an input in the logic "AND" gate arrangement. The sensor aligns itself along the field of any externally applied magnet, responding differently to different magnetic poles. It was observed that on sensing a North Pole an output was obtained, but on sensing a South Pole no output was produced. The combinations of the input and output of the electronic system gave the exact truth table of an AND gate. Various magnetic fields were tested and their polarities determined. This method provides a simple digital way of determining magnetic field polarity. The complete field polarity sensing circuit is presented and described.

Keywords: Magnetic – sensor, AND – gate, field, polarity.

INTRODUCTION

Magnetic fields are encountered almost in our everyday life. They occur in nature as well as in electrical and electronic appliances used everyday. Maxwell and Gauss (Halliday, and Resnick 1978) showed that single magnetic poles (Monopoles) do not exist. Knowledge of the polarity of a magnet is important and very useful especially for scientist working in the areas of magnetism and magnetic effects of current.

To the best of my knowledge there are four methods which are popular for determining magnetic field polarity in our local environment.

The first is the directional current flow method applied in solenoid when a magnet is being produced. If the direction of current flow is anticlockwise when observed from one end of the solenoid (Webster, 1982), the bar at that end will assume a North Pole. If the direction of flow is clockwise, that end will assume a South Pole. This method applies well for the manufacturer who has the privilege to make this observation. If the polarities of the bar were not previously indicated the user of such a magnet cannot apply this method.

The second method is based on the magnetic field of the earth. A freely suspended magnet dips downwards at some angle to the horizontal. Such an angle constitute the angle of dip or inclination (Nelkon, and parker, 1979). Usually the North-seeking pole points upwards while the South-seeking pole points downwards. This method is applied in identifying magnetic polarities of a bar. (Okiwelu, 2001) pointed out that in areas around zero latitude (Magnetic field is horizontal and the angle of dip of the earth's field is no more than 15^0.

The third method is the use of magnetic compass to test the polarity. According to the fundamental law of magnetism the North Pole of the magnet will attract the South Pole of the compass while the South Pole will attract the north pole of the compass.

The fourth method is the use of a standard bar magnet, when the pole of the bar in question is brought close to that of the standard magnet, attraction or repulsion observed is used to determine what pole it is.

The above methods are time consuming. Therefore the aim of the work reported in this paper is to develop a simple, accurate, reliable and time saving method of determining magnetic field polarity.

THEORETICAL BACKGROUND

One of the ways of producing temporary and

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permanent magnet is by inserting the material to be magnetized in a solenoid of a given length and passing steady current through the solenoid for a short time. During this process, the end of the material where the current flow in the solenoid is anticlockwise will assume a north polarity while the opposite end where the flow is clockwise, will assume a south polarity (Webster, 1982).

The magnetic induction B produced in such a coil of length L and N turns when a current I flows through it (Nelkon, and Parker 1995) is given by:

$$B = \mu_0 NI/L \qquad (1)$$

Where μ_0 is the permeability of air. With an iron core of permeability μ, the induction B becomes:

$$B = \mu NI/L \qquad (2)$$

Also the force due to this flux is given as

$$F = BIL \qquad (3)$$

Like poles of a magnet repel while unlike poles attract. Magnetic field lines are outwards in a North Pole while they are inwards in a South Pole (Nelkon, and Parker 1995). Existence of magnetic poles provides a basis for which lines

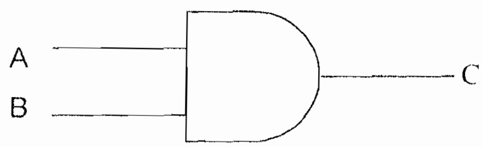

Fig 1: Circuit symbol for a two – input AND gate.

of force emanate from the North Pole and terminate at the South Pole. This makes magnetic field properties analogous to those of the electrostatic field (Carpenter 1997), in which the field lines terminate on the source charges. However atoms can be ionized and positive and negative charges can be isolated but no one has isolated magnetic pole. That is magnetic monopoles have not been detected. When a magnet is broken each fragment exhibits a magnetic dipole. The side of the fragment that assumes a North Pole or a South Pole can be determined precisely using a digital circuit. That is the essence of this work.

When two of such poles of strength M_1 and M_2 are placed a distance γ apart in space, the force that exist between them (Weber, et al, 1980) is given by Coulomb's law as:

$$F = \mu_0 M_1 M_2 / 4\Pi\gamma^2 \qquad (4)$$

Where M is in Ampere – metre and μ_0 in Weber per Ampere – metre. This force is one of repulsion between like poles and attraction unlike poles. The equation (4) applies to long, thin magnets with well – separated poles.

The magnetic sensor designed for this work contains an iron pin, which is ferromagnetic. Such materials have very high susceptibility (Nelkon, and Parker 1995), which range between 10^2 and 10^{15} (Weber et al 1980) and hence of equally high relative permeability. In such materials, magnetization is in the direction of the applied field. Thus the iron pin in the sensor aligns itself along the field of any externally applied magnet, responding differently to different poles. The monitoring of the responses of magnetized iron pin to different magnetic poles can be digitally implemented using a circuit arrangement based on AND gate (figure 1).

Table 1: Truth table for a two – input AND gate.

Input		Output
A	B	C
1	1	1
1	0	0
0	1	0
0	0	0

An AND gate has the logic characteristic of producing an output only when a signal is present in all its input terminals. A series circuit containing switches represents the electrical equivalent of an AND gate and the circuit cannot be complete except all the switches are on. Table 1 is the truth table for a two – input AND gate showing its possible inputs with their corresponding outputs.

In table 1, "1" represents an output while "0" represents no output under the output column. Also "1" represents an input and "0" no input under the input column. From here observe that such an AND gate will produce an output only when the two inputs have a signal each.

DESIGN, CONSTRUCTION AND TESTING OF THE SENSING CIRCUIT

The novelty in this work is in the construction of a magnetic sensor MS designed to function as a key. It contains a tiny permanent ferromagnet produced using a coil of length 7cm and 76 turns and iron pin. The pin responds differently to field from north and south poles of an external magnet. It rests in a vertical position on a wooden slab W (fig. 2) and thus can be displaced vertically when a magnetic field of suitable polarity is brought close to it. The pin is soldered to connecting wires, which form part of the circuitry. The head of the pin is a South Pole (S) while the tip is a North Pole (N). The cap of the sensor C is a non-magnetic conductor (Copper plate) attached to the other connecting terminal. The arrangement provides a kind of magnetic switch; (fig 2).

When an external North Pole (N) is brought close to C an attraction force according to equation (4) is experienced whose magnitude depends on the strengths of the magnetic poles. The force lifts the pin vertically to remain in contact with C. the circuit is then complete and current flows through MS. If the external field is removed the pin slips back to the wooden slab thus breaking the contact with C. However if an external South Pole (S) is brought close to C a repulsion force is now experienced which fixes the tip of the pin on W, so that no contact is made with C. Therefore the circuit remains broken without any current flowing through MS. Thus only a north pole (N) can switch the circuit on.

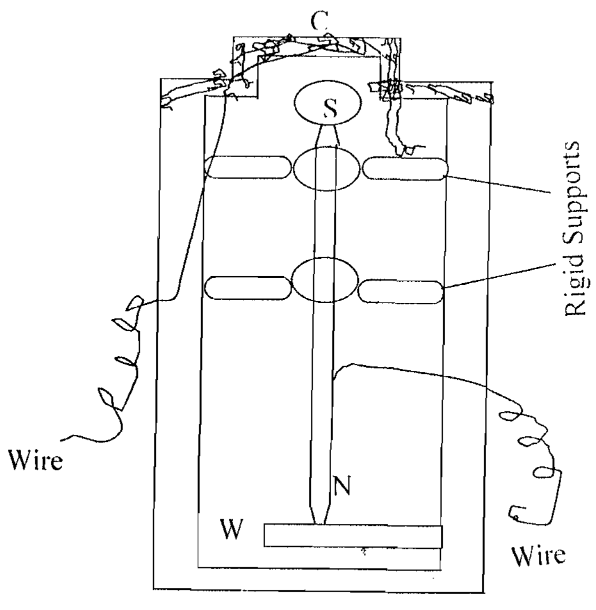

Fig. 2 Diagram of the Designed Sensor

For sensing circuits, various output media such as sound, visible screen etc are used. For this work, an electric bulb was employed as the output device. The lighting and extinguishing of the light from the output bulb convey the specific information of the presence of a north pole N and a South Pole S respectively. The sensing circuit used, which is shown in fig. 3, is the electrical equivalent of the electronic AND gate. B is the battery that powers the circuit, L is the output indicator lamp while the key K together with MS act as the two input terminals analogous to that of electronic AND gate shown in fig. 1. Therefore for the lamp to light, K and MS must be closed. This represents a logic condition. With K closed and open various magnetic poles were tested at the sensor by bringing them close to C and the outputs of the circuit observed.

Since both MS and the Key, K. have only two possible states in the circuit, that is off or on, the values 0 and 1 were assigned to these two states respectively. The same was applied to the output indicator lamp. MS being On, means current goes into the lamp and being off means it does not.

Similarly, K being On, means current goes into the lamp and being off means it does not. Also the lamp being On means it is receiving current and being off means it is not receiving current.

SENSITIVITY OF THE SENSOR

The mass of the tiny pin used was 1.0×10^{-4}kg and the current passed through the coil to make the pin a permanent magnet was 10A. Sensitivity depends largely on the weight of the pin. Applying equation (1) we notice that the minimum magnetic field required to lift the pin in a vertical position is obtained from the relationship.

$$F = mg = BIL \quad (5)$$

$$\text{Therefore } B = mg/IL \quad (6)$$

Where m is the pin mass and g is acceleration due to gravity. Since length of coil was 0.07m, using g = $10ms^{-2}$ and substituting values in equation (6), we obtain that B = 1.43×10^{-3} T. Thus the sensor will respond to a field as weak as 0.001T. However additional measures that can increase the sensitivity include reducing the mass of the pin, use of higher current and longer coil in

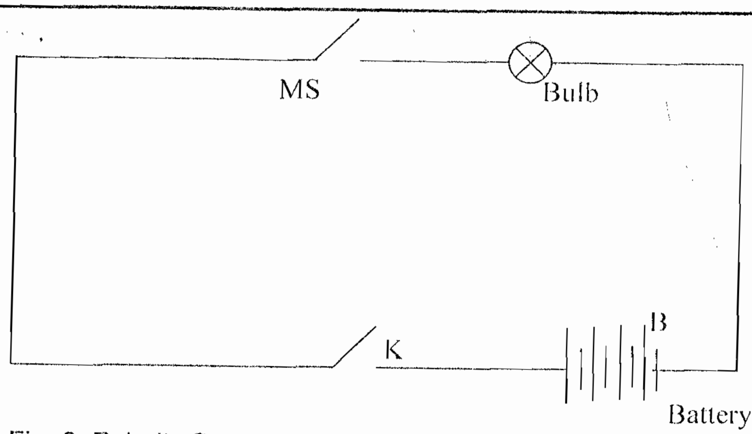

Fig. 3: Polarity Sensing circuit.

magnetizing the pin and making the gap between the "pin head," and the MS cap very negligible.

RESULTS AND DISCUSSION

The results of performance tests on the sensing circuit showed that:
With K On (K = 1) and a north pole brought to the sensor, an output was obtained. This is because the attraction force which now exist between the N – pole and the MS pin (S- pole) lifts the pin vertically to make contact with the MS cap. Thus the sensor as a key switches on, allowing current pass on to the bulb. The bulb then lights. This is shown in the first row of table 2.

With K still On (K = 1) and a south pole brought to the sensor, no output was obtained. This is because a repulsion force now existing between the S – Pole and the sensor pin forces the pin to remain fixed on the wooden slab and no contact is made between the pin and the MS cap (an open circuit). The sensor as a switch therefore remains off blocking the current from reaching the bulb. This is shown in the second row of table 2.

With K off (K = 0) and a north pole brought to the sensor, no output was obtained. Here the presence of an N –pole switches MS. On as in the first observation but flow of current is cut off by the key K. Therefore there is no output. This condition is shown in the third row of table 2.

With K still Off (K = 0) and a south pole brought to the sensor, no output was obtained. This is due to two reasons. The repulsion force between the S –pole and the sensor pin maintains MS in an off state while the electric current to both MS and the bulb is cut off by the key K. This is also shown in the fourth row of table 2.

In summary, if K is on, and if a pole present at MS produces an output, then it is a north pole but if otherwise, it is a south pole.

Table 2: Truth table for the sensing circuit.

INPUT		OUTPUT
K	MS	BULB
1	1	1
1	0	0
0	1	0
0	0	0

CONCLUSION

A simple electronic circuit has been designed using locally available components (2.4A, 3V bulb, switch etc) which is capable of determining the polarity of a piece of magnet. It incorporates a sensitive magnetic sensor capable of responding to a weak magnetic field of 0.002T, which is lower than most of the magnetic fields we come across in everyday life.

The output device can be a buzzer or simply an electric bulb as used in this work.

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