Simple Solenoid as a Linear Actuator

Anthea K. Fernandes
UG Student
Department of Electronics and Telecommunication Engineering
Don Bosco College of Engineering, Fatorda-Goa, India

Cimona Pereria
UG Student
Department of Electronics and Telecommunication Engineering
Don Bosco College of Engineering, Fatorda-Goa, India

Chetana Patil
UG Student
Department of Electronics and Telecommunication Engineering
Don Bosco College of Engineering, Fatorda-Goa, India

Nimha Nadesan
UG Student
Department of Electronics and Telecommunication Engineering
Don Bosco College of Engineering, Fatorda-Goa, India

Sanjila Gaonkar
UG Student
Department of Electronics and Telecommunication Engineering
Don Bosco College of Engineering, Fatorda-Goa, India

Abstract

The following paper describes how a simple solenoid can be used a linear actuator, and how the linear actuator in turn can be used for various simple functions.

Keywords: Solenoid, Linear actuator

I. INTRODUCTION

A. *Ampere's Law*

The law states that "the line integral of magnetic induction for a closed path is equal to $\mu_\circ$ times the net current i, passing through the area bounded by the curve.
Thus, mathematically, this law can be expressed as

$$\int_c \mathrm{B}.dx = \mu_\circ i$$

Where,
B= magnitude of magnetic induction
$\mu_\circ$ = relative permeability
i = total current passing through a coil
What it means is that for any closed loop path, the sum of the length elements times the magnetic field in the direction of the length elements is equal to the permeability times the electric current enclosed in the loop.

B. *Solenoid*

A solenoid is a coil of wire wound on a long straight core. Using Ampere's law as stated above we can conclude that, when a current passes through a solenoid, a magnetic field is produced according to the following expression:-

$$B = \mu_\circ N i$$

Where,
N= Number of turns per unit length in a solenoid

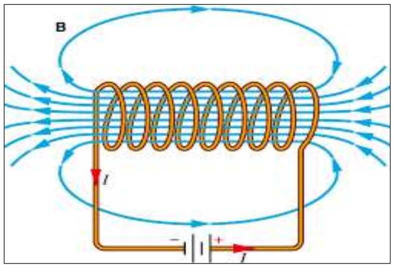

Fig. 1: Magnetic field lines of a solenoid

As seen in the figure above, the magnetic lines are approximately straight and parallel to the axis of the solenoid showing a uniform magnetic field, until they reach the ends where they begin to diverge. It is experimentally observed that in a solenoid, the magnetic field outside is very small compared to the field inside

C. *Linear actuator*

An actuator is typically a mechanical device that converts energy into motion. A linear actuator creates motion in a straight line. The movement of this linear motion can be managed by a simple control system.

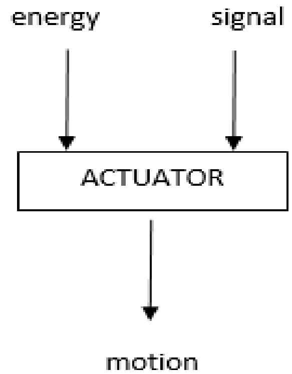

Fig. 2: Block diagram of an actuator

II. SOLENOID AS A LINEAR ACTUATOR

The above properties of a solenoid allow it to be used as a linear actuator as will be shown below.

III. CONSTRUCTION

1) Take a hollow insulator and wrap a wire around it.
2) Make sure the ends of the wire is 'sticking' out.
3) Tape up the body of the hollow insulator with the wire wrapped around it so that it is easier to work with.
4) Keep a long conducting material (eg:nail) $1/4^{th}$ inside the wrapped hollow insulator as shown in the figure bellow.
5) Remove the buffer coating from the two ends of the wrapping wire.
6) Place a battery between the two ends of the wrapping wire.

NOTE:

- The magnetic field strength is directly proportional to the number of turns.
- Depending on the physical dimensions of the conducting material placed inside the hollow insulator, increase or decrease number of turns of wrapping wire so as to in turn increase the force of the magnetic field strength.
- If the number of turns is too less and compared to the physical dimensions of the conducting material, then even after the introduction of a magnetic field, there might be no change in position of the conducting material.
- Thus, both quantities have to be of a comparable number.

NOTE: For easier understanding 'hollow insulator' will be referred to as a 'cylinder' and 'long conducting material' will be referred to as 'nail' as we are using a nail for illustration purposes.

Fig. 3: Hollow cylinder wrapped with wire and ends sticking out

Fig. 4: Open circuit with nail in cylinder

IV. COMPLETE THE CIRCUIT

Touch both the ends of the wire to the respective polarities of a battery to complete the circuit.

V. WHAT HAPPENS THEN?

We notice that as soon as we complete the circuit, a force is felt on the nail and it gets pulled in all the way into the cylinder.

Instead of a nail if we use a magnetic material eg: a thin magnet bar, then we notice that once we complete the circuit, the magnet bar is pulled into the cylinder, and if we reverse the polarity of the battery, the bar magnet gets pushed out.

Fig. 5: Closed circuit, showing nail pulled inside as soon as voltage is applied to circuit

The direction in which the magnetic bar moves is determined by the direction of the flux produced by the solenoid.
The direction of the flux produced by the solenoid is in turn determined by the Right Hand Rule, which states :-

"An electric current passes through a solenoid, resulting in a magnetic field. When wrapping the right hand around the solenoid with the fingers in the direction of the conventional current, the thumb points in the direction of the magnetic north pole."

What happens is the wire that is wrapped around the cylinder acts as a solenoid. When the circuit is complete we are basically providing a voltage source to the solenoid and a current i, flows through the wire.

According to the extension of Ampere's law for a solenoid, as stated above, when current is flowing through a solenoid it produces a magnetic field according to the above stated expression. The magnetic field lines are strongest inside the cylinder.

The area inside the cylinder acts as magnet and introduces a magnetic force on the nail. Due to this magnetic force on the nail, it gets attracted to the inside of the cylinder and as a result it gets pulled inside.
The intensity and strength with which the nail gets pulled inside is defined by two quantities:-

1) *Magnetomotive force (m.m.f.)*

- The magnetomotive force drives of tends to drive flux through a magnetic circuit and corresponds to electromotive force (e.m.f.) in an electric circuit.
- The m.m.f. of a coil is the product of current in the coil and the number of turns.
- It has the unit of Ampere Turns (AT).

2) *Magnetic Field Strength (H)*

The magnetic field strength (H) is defined as the magentomotive force (m.m.f.) per metre length of magnetic circuit and is given as:

$$H = \frac{NI}{l} \text{ AT/m}$$

Where;
N =number of turns of a coil,
I= current (A),
l= length of magnetic circuit(m).

By adjusting these physical quantities along with the dimensions of the cylinder and nail, we can we can push/pull varying lengths (dimensions) of nails/ bars.

VI. Conclusion

The energy from the battery was successfully used in making the nail move in a linear path with the help of a simple solenoid. Thus, we can conclude that a simple solenoid can be used in making a simplified linear actuator.

References

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