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Vortex Bladeless Wind Energy Conversion System: Calculation of Magnetic Force of Permanent and Electromagnet with the Study on its Influence on Stator Coil

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ABSTRACT: Vortex Bladeless is an alternative and innovative way to produce energy from wind, with different and exciting characteristics which makes it a revolution in wind power generation. Nowadays, conventional wind turbines have shown that the wind is an excellent source of energy. However, some of its characteristics do not make them suitable for some applications. Vortex technology uses no blades, getting energy from wind through oscillation. Its design makes it a nice alternative for a greener on-site generation.Basically, bladeless technology consists of a cylinder fixed vertically with an elastic rod. The cylinder oscillates on a wind range, which then generates electricity through an alternator system. In other words, it is a wind turbine which is not actually a turbine. Vortex wind generators are more similar in features and cost-effectiveness over time to solar panels than to regular wind turbine. Electromagnetic induction is also one of the available strategies to transform the energy of the oscillatory movement into electricity.Our bladeless wind turbine captures the energy from the wind by a resonance phenomenon produced by an aerodynamic effect called vortex shedding. Vortex shedding is a phenomenon of vorticity. In fluid mechanics, as the wind passes through a blunt body, the flow is modified and generates a cyclical pattern of vortices. Once the frequency of these forces is close enough to body's structural frequency, the body starts to oscillate and enters into a resonance with the wind. This is also known as Vortex Induced Vibration.

I. INTRODUCTION

Wind energy has become an essential part of the global renewable energy landscape and dependence on it is anticipated to increase in the foreseeable future. At present, wind turbines are the most commonly used machines for converting wind energy into electrical energy, with the movement of the blades fuelling an electricity generator. The wind turbines in use at present have blades that rotate due to the force exerted by wind and convert the rotational mechanical energy into electricity.

The efficiency of renewable energies has grown significantly in recent years and wind energy has been one of the most important responsibilities. The increasing size of wind turbines is making wind power to be one of the most relevant energy sources. Wind turbines with blades have their own advantages and disadvantages. Instead of deliberating on the advantages, it is more important to highlight the disadvantages associated with the use of blade technology.

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These problems are compelling innovators and engineers to look at bladeless wind turbines. Vortex bladeless turbine antiquates the conventional wind turbine and adopts a radically innovative and novel approach to captivate the moving wind energy. This device effectively captures the energy of vorticity, an aerodynamic instability condition. As the wind passes a structure, the flow steers and cyclical patterns of vortices are generated.

A windmill is a device which converts the kinetic energy of wind into electrical energy. There are two ways of producing the energy from windmill which is through rotational windmills and oscillation windmills. Oscillation type windmills are used to produce less amount of electrical energy that's why it is not used in commercial applications. Its main advantage is that it has less moving parts, less space is required for installation, light in weight and cost is also less because it is bladeless and gearbox is also absent.

To understand the reason behind it, we have to understand the working of oscillation type windmills. This type of windmill is based on the theory of vortex induced vibrations (VIV). Vortex bladeless is a vortex induced vibration resonant power generator. It harnesses wind energy from a phenomenon of vorticity, called vortex shedding effect. Clearly bladeless technology consists of a cylinder fixed vertically on an elastic rod, instead of tower, nacelle and blades which are the crucial parts of a conventional wind turbine.

The demand for energy increases day by day as our world is developing every second, when the energy consumption increases the dependence of human on exhaustible energy sources also increases and being engineers it was our responsibility to think of new energy sources which are renewable. As we know there are many renewable resources like wind, solar, geothermal, tidal etc. The wind energy is one of the mostly used type of renewable energy resource. Since it is one of the existing technologies to generate electricity, we think of ways which can eliminate the disadvantages of the conventional wind power generation system and we came to a novel technology that can generate electricity with wind power without the usage of any moving parts in the open atmosphere

The present discusses the generation of electric energy by transforming the kinetic energy of an oscillating structure, induced by the vortex shedding as it is immersed in a fluid flow, commonly known as the VIV or Vortex Induced Vibrations. In this work, we have done calculation of magnetic force of permanent and electromagnet with the study on its influence on stator coil. It is found that the Biot-Savart law can be used for finding the magnetic force and the theoretical magnetic force for the ring and round magnets are founded using the Biot-Savart law.

When wind passes one of the turbines, it shears off the downwind side of the cylinder in a spinning vortex. The KE of the oscillating cylinder is converted to electricity through a generator similar to those used to harness energy. It consists of a conical cylinder vertically with an elastic rod. The cylinder oscillates in the wind, then generates electricity through a system of coils and magnets.

II. PRINCIPLE RELATED

The main principle behind bladeless wind generators is the conversion of linear oscillation of mast to rotational motion. As the mast is subjected to wind energy, it tends to oscillate due to the vortices formed around the structure of the mast, which can be converted to rotational force to generate electricity. In the bladeless wind system configuration, the mast is fixed with respect to the ground and the rib structure at the top of the mast consisting of thread arrangement is used for pulling the threads attached to it.

This concept is based on fluid dynamics. In vortex-induced vibrations (VIV), the motions carried by the body due to an external fluid flow starts to oscillate. For example, the VIV of a cylinder(see Fig 3.1) which is placed into air having definite velocity and these air strikes in the perpendicular direction to the center axis of a cylinder. Hence the fluids always having some viscosity, when the flow comes in contact with the cylinder then will be slowed down and forming the boundary layer[1].

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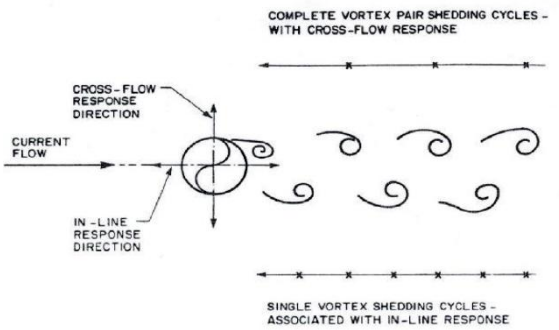


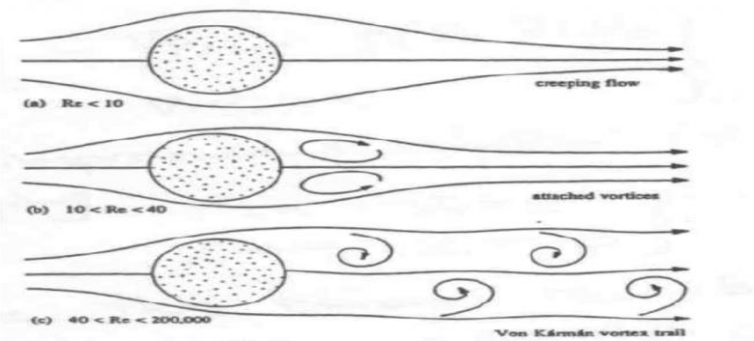
VIV of a cylinder

Due to excessive nature of curvature of body, the boundary layer will be separated at some point. Vortices are then formed changing the pressure distribution along the surface. When the body is not formed symmetrically around to its mid-plane then due to this reason different lift forces were developed on each side of the body, hence it tends to converts motion transverse to the flow. This motion changes the nature of the vortex formation in such a way as to lead to limited motion amplitude.

VORTICES AND VORTEX SHEDDING EFFECT

Vortex shedding is an oscillating flow that takes place when a fluid such as air or water flows past and bluffs (As opposed to streamlined body at curtained velocities, depending on shape and size of the body. In this vortices are created at the back of body and detach periodically from either side of body. Vortex shedding behind a circular cylinder. In this animation, the flows on two sides of a cylinder are shown in different colors, to show that the vortices from the two sides alternate.

Vortex Bladeless is a vortex induced vibration resonant wind generator. It harnesses wind energy from a phenomenon of vorticity is called the Vortex Shedding (see Fig 3.2). Basically, bladeless technology consists of a cylinder fixed vertically with an elastic rod. The cylinder oscillates on a wind range, which then generates electricity through an alternator system. In other words, it is a wind turbine which is not actually a turbine.Vortex wind generators are more similar in features and cost-effectiveness over time to solar panels than to regular wind turbines[2].



Vortex shedding effect

STRUCTURE & GEOMETRY

The outer cylinder is designed to be largely rigid and has the ability to vibrate, remaining anchored to the bottom rod. The top of the cylinder is unconstrained and has the maximum amplitude of the oscillation. The structure is built using resins reinforced with carbon and/or glass fiber, materials used in conventional wind turbine blades[3].
The rod's top supports the mast and it's bottom is firmly anchored to the ground. It is built of carbon fiber reinforced polymer, which provides a great fatigue resistance and it has a minimal energy leak when oscillating.

Naturally, the design of such wind turbine is quite different from a traditional turbine(see Fig 3.3). Instead of the usual tower, nacelle and blades, our device has only a mast made of lightweight materials over a base. This reduces the usage of raw materials and the need for a deeper foundation.

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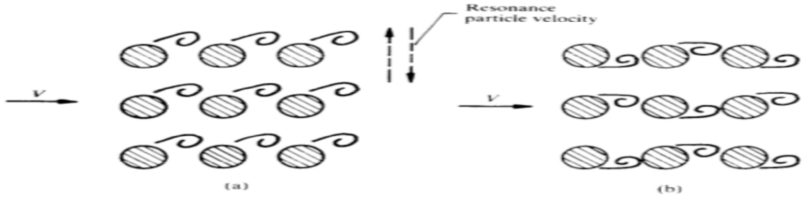
Structure of vortex bladeless wind turbine

RESONANCE

One of the most well known events produced by aerodynamic resonance is the collapse of the Tacoma Narrows bridge . Resonance phenomenon arises when an oscillation is reinforced by a periodic movement(see Fig 3.4). In aero elasticity, the air can induce an oscillatory movement in a body if its natural resonance frequency and the vortex shedding's wake frequency are similar[4]. The vibrations induced in a body by vortices are known as VIV phenomena. The vortex shedding happens with periodicity, with forces perpendicular to the incident wind flow direction. There is a constant of proportionality *St* between the average velocity of the incident wind flow *v*, the inverse of its characteristic length *Φ* and the frequency of vortex shedding *f*:

$$f = St \cdot v \quad \Phi \quad (1)$$

The resonance phenomena often appears associated with the normal mode of oscillation.



Resonance

VORTEX'S ALTERNATOR

Currently, Vortex generates electricity through an alternator system, made by coils and magnets, adapted to the vortex dynamics, without gears, shafts or any rotating parts. Our Vortex generator is currently considered a "small wind turbine".Alternators are a well-known technology, although the way Vortex is using it is innovative and patented. This design allows reducing maintenance and eliminates the need for greasing.

Frequency tuning

The frequency of the Vortex shedding is proportional to the windstream's velocity, however each structure has its own natural vibration frequency. To match wind frequencies with a device's natural frequency you should modify the body mass (the more mass the less natural frequency) and the rigidity (the more rigidity, higher frequencies), among other parameters. Therefore, you would need complex mechanisms to vary the natural frequency of that device.

To avoid this, Vortex design uses instead a magnetic confinement system with permanent magnets that increase the apparent stiffness of the system according to their degree of flexion. The degree of flexion grows as long the wind intensifies. We call this "tuning system".

VON KARMAN VORTEX EFFECT

The Vortex Street effect or Vortex Shedding effect was first described and mathematically formalized by Theodore von Karman, the genius of aeronautics, in 1911. This effect is produced by lateral forces of the wind on an object immersed in a laminar flow[5]. The wind flow generates a cyclical pattern of vortices, which can become an engineering challenge for slender structures, such as towers, masts and chimneys

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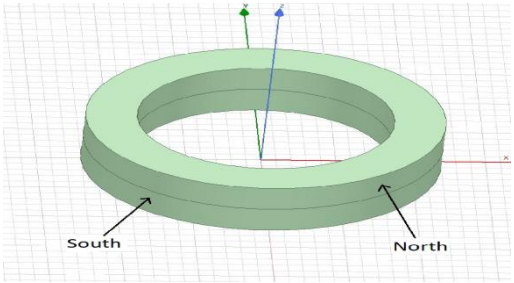
III. MAGNET DESIGN AND ANALYSIS

PERMANENT MAGNET DESIGN

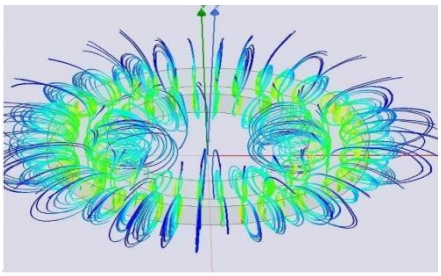
The mast body can move in any direction depending on the direction of the wind. Hence, a ring magnet with the coils (on mast body) placed in the middle of the ring has the advantage of being symmetric in all directions and can give the output without imposing any constraint on mast body to move in a particular direction. However, in a ring type magnet, the magnetic flux is highly concentrated near the surfaces and very little in the middle where the mast body typically makes the oscillations(see Fig 5.1). Hence, the coil may not sense a significant change in the magnetic flux linked to it unless it almost reaches the inner surface of the ring magnet which is only possible with abnormal wind speeds. Thus, the voltage generated would be small using ring magnets [17].



Ring Magnet

The same is the case with two bar magnets placed on either sides of the mast body as shown in Figure. The field lines are mostly concentrated next to the surfaces. Also, the voltage generated will be maximum for only one direction of wind speed. To get a uniform field for all wind directions, a systematic arrangement of multiple magnets in circular fashion
could be helpful.

The arrangement gives a better flux change than the ring magnet(see Fig 5.2). However, it is not an efficient system because a strong field is expected in the axial direction of the magnet system. As the flux leaves north pole of a magnet and enters the south pole of another magnet, the field will be maximum in circular direction where the magnets are placed rather than at the centre where the mast body is placed. Hence, there wouldn't be enough field in the region of oscillation which may lead to small induced voltages.



Streamline diagram of ring magnet

Streamline diagram of ring magnet

The magnets can also be arranged radially. In this arrangement, there is more flux change observed as compared since the flux lines from north pole to south pole pass through the mast body(see Fig 5.3). However, this is also effectively like two bar magnet arrangement and results in maximum voltage induced for one particular direction of wind parallel to the field. As the airflow can be in any random direction so is the oscillation of the mast body, this arrangement cannot favour in all cases. Hence, it is desired to have a field system which not only works for all wind directions evenly but also aids in generating maximum voltage by giving maximum flux change in the coils placed in the mast body during its vibration[17].

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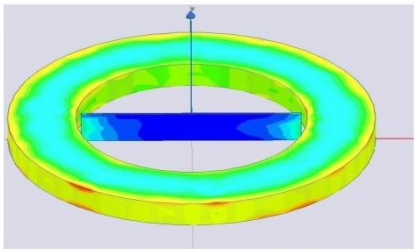


Flux density magnitude diagram of ring magnet

Flux density magnitude diagram of ring magnet

The round magnets are used for the development of the design of alternator(see Fig 5.4).

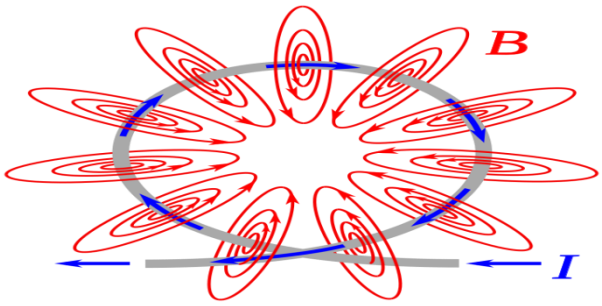
Flat Circular Round Magnet

DESIGN OF ELECTROMAGNET

An electromagnet is a type of magnet in which the magnetic field is produced by an electric current. Electromagnets usually consist of wire wound into a coil. A current through the wire creates a magnetic field which is concentrated in the hole, denoting the centre of the coil(see Fig 5.5). The magnetic field disappears when the current is turned off. The wire turns are often wound around a magnetic core made from a ferromagnetic or ferromagnetic material such as iron; the magnetic core concentrates the magnetic flux and makes a more powerful magnet.

The main advantage of an electromagnet over a permanent magnet is that the magnetic field can be quickly changed by controlling the amount of electric current in the winding[18]. However, unlike a permanent magnet that needs no power, an electromagnet requires a continuous supply of current to maintain the magnetic field.

Electromagnets are widely used as components of other electrical devices, such as motors, generators, electromechanical solenoids, relays, loudspeakers, hard disks, MRI machines, scientific instruments, and magnetic separation equipment. Electromagnets are also employed in industry for picking up and moving heavy iron objects such as scrap iron and steel



Electromagnet magnetic field

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AMPERE'S LAW

The magnetic field of electromagnets in the general case is given by Ampere's Law:
which says that the integral of the magnetizing field around any closed loop is equal to the sum of the current flowing through the loop. Another equation used, that gives the magnetic field due to each small segment of current, is the Biot–Savart law. Computing the magnetic field and force exerted by ferromagnetic materials is difficult for two reasons[19]. First, because the strength of the field varies from point to point in a complicated way, particularly outside the core and in air gaps, where *fringing fields* and *leakage flux* must be considered. Second, because the magnetic field B and force are nonlinear functions of the current, depending on the nonlinear relation between B and H for the particular core material used. For precise calculations, computer programs that can produce a model of the magnetic field using the finite element method are employed.

DEVELOPMENT OF ELECTROMAGNET AND ITS INFLUENCE

An electromagnet is a type of magnet in which the magnetic field is produced by an electric current. Solenoids are spring-shaped coils of wire commonly used in electromagnets. If you run an electric current through a solenoid, a magnetic field will be generated[20].The magnetic field can exert a force on charged particles that is proportional to its strength

Force = charge x velocity of the charge x (magnetic constant x number of turns in solenoid x current).

IV. SAMPLE CALCULATIONS

1V.1 CALCULATION OF MAGNETIC FORCE BY ELECTROMAGNETS

Force = $\left(\frac{(n\ x\ i)^2\ x\ magnetic\ constant\ x\ a}{(2\ x\ g)^2}\right)$

F = force,
I = current,
g = length of the gap b/w solenoid and metal
a = area
n = number of turns in the solenoid
Magnetic constant = 4 x π x 10^{-7}

n - 1000
I - 10 ampere
a - 0.5 meters
g - 1.5 cm

F = $\left(\frac{(n\ x\ i)^2\ x\ magnetic\ constant\ x\ a}{(2\ x\ g)^2}\right)$

= $\left(\frac{(1000\ X\ 10)^2\ X\ (4\ X\ \pi\ X\ 10^{-7}\ X\ 0.5)}{(\ 2\ X\ 1.5)^2}\right)$

= 14 Newtons (N)

Note: The above all are assumed values.

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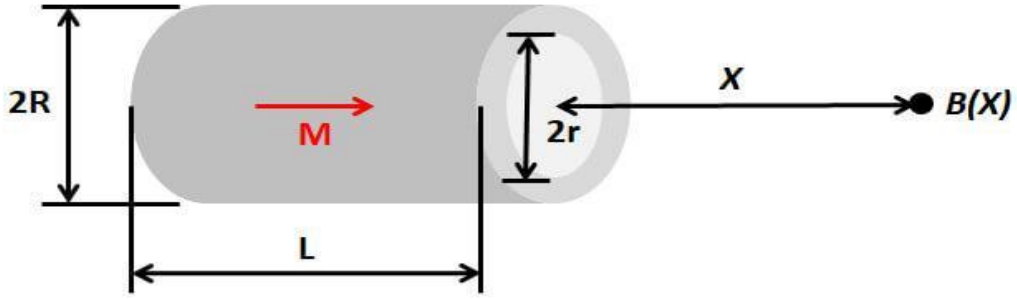
IV.2 MAGNETIC FIELD OF RING MAGNET



Ring Magnet

$$B(x)=\frac{Br}{2}\{(\frac{L+x}{\sqrt{r2+(L+x)2}}-\frac{L+x}{\sqrt{R2+(L+x)2}})-(\frac{X}{\sqrt{R2+x2}}-\frac{X}{\sqrt{r2+x2}})\}$$

Br = residual induction of magnet
X = air gap between testing point and magnet surface

For flat circular round magnet:
Br = 3500 gauss

For circular ring magnet ,
Br - 3500 gauss
R - 4 cm
L - 2 cm
X - 1 cm
r - 2 cm

According to BIOT SAVART LAW, field strength is,

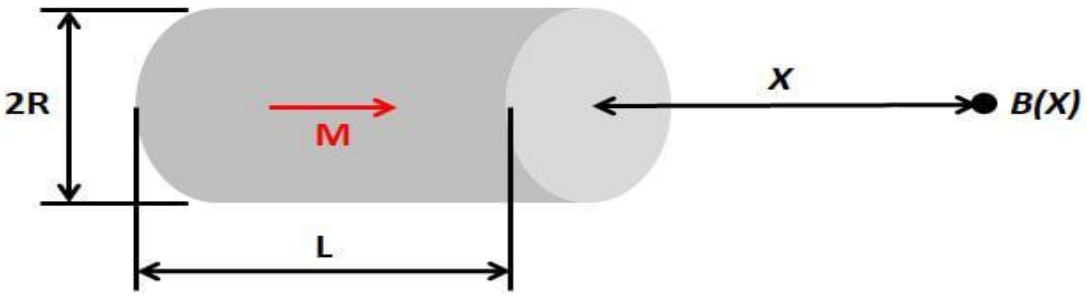
$$B(x)=\frac{Br}{2}\{(\frac{L+x}{\sqrt{r2+(L+x)2}}-\frac{L+x}{\sqrt{R2+(L+x)2}})-(\frac{X}{\sqrt{R2+x2}}-\frac{X}{\sqrt{r2+x2}})\}$$

Br of ferrite magnet is 3500 Gauss

$$B(x)=\frac{3500}{2}\{(\frac{2+1}{\sqrt{(\frac{4}{2})2+(2+1)2}}-\frac{2+1}{\sqrt{(\frac{8}{2})2+(2+1)2}})-(\frac{1}{\sqrt{(\frac{8}{2})2+(1)2}}-\frac{1}{\sqrt{(\frac{4}{2})2+(1)2}})\}$$

= 1750 x 0.4363
=764.27 Gauss = 764.23 x 10^{-4} Tesla

IV.3 MAGNETIC FIELD OF FLAT CIRCULAR MAGNET



Flat circular magnet

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$B(x)= \frac{Br}{2}\{(\frac{L+x}{\sqrt{R2+(L+x)2}}) -(\frac{X}{\sqrt{R2+x2}})\}$

Br = residual induction of magnet
X = air gap between testing point and magnet surface

For flat circular round magnet,
Br - 3500 gauss
R - 1 cm
L - 0.5 cm
X - 1 cm
r - 2 cm

According to BIOT SAVART LAW, field strength is,
$B(x)= \frac{Br}{2}\{(\frac{L+x}{\sqrt{R2+(L+x)2}}) -(\frac{X}{\sqrt{R2+x2}})\}$

Br of ferrite magnet is 3500 Gauss
$B(x)= \frac{3500}{2}\{(\frac{0.5+1}{\sqrt{(2)2+(0.5+1)2}} - \frac{1}{\sqrt{(2)2+(1)2}})\}$
= 1750 x 0.1527
=267.37 Gauss = 267.37 x 10^{-4} Tesla

V. CONCLUSION

In this study we are able to determine that,
1) Magnetic force of an electromagnet: 14 Newton
2) Magnetic force of flat circular magnet: 267.37 X 10^{-4} Tesla
3) Magnetic force of ring magnet: 764.23 X 10^{-4} Tesla

NOTE- The values determined are purely theoretical.

Among the permanent magnets, the permanent magnet with the strongest magnetic force is the artificial permanent magnet while the magnetic force of natural permanent magnets is much weaker. Therefore, the magnetic force of the permanent magnet usually does not reach the level of the electromagnet magnetic force.

We can adjust the magnetic force of the electromagnet by changing the current according to actual needs. However, the magnetic field strength and magnetic force of the permanent magnet are fixed and difficult to adjust.

In this research, we found that using permanent magnet is better as it is the one that could be used for model type. Electromagnet is useful in large scale production. Hence it's found that the Biot Savart law can be used for finding the theoretical values for magnetic force of ring and round magnet.And here we have done the study on the influence of magnetic force of permanent and electromagnet on stator coil.

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