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# НЕКОТОРЫЕ ПРИМЕНЕНИЯ СИЛЫ МАГНИТНОЙ ЛЕВИТАЦИИ ВО ВРАЩАЮЩИХСЯ МАШИНАХ

***Аннотация:*** *Снижение величины механических потерь является проблемой для многих инженеров и исследователей.*

*Возможно, они нашли в силе левитации то, что искали для вращающихся машин, особенно машин с низким КПД, таких как некоторые ветряные турбины.*

*В этой статье мы рассмотрим некоторые вращающиеся машины, работа которых зависит от технологии силы магнитной левитации. Мы узнаем о механизме использования этой силы в некоторых вертикальных ветряных турбинах, а также о ее использовании в вентиляторах и насосах.*

***Ключевые слова:*** *сила левитации – ветрогенератор на магнитной подвеске – вентиляторы на магнитной подвеске – насосы на магнитной подвеске – магнитный подвес.*

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# SOME USES OF MAGNETIC LEVITATION FORCE IN ROTATING MACHINES

***Abstract:*** *Reducing the value of mechanical losses is a concern for many engineers and researchers.*

*Perhaps they found in the force of levitation what they were looking for for rotary machines, especially machines with low efficiency, such as some wind turbines.*

*In this paper, we will review some rotating machines that depend in their operation on the technology of magnetic levitation force. We will learn about the mechanism of using this force in some vertical wind turbines and also its use in fans and pumps.*

***Key words:*** *levitation force – maglev wind turbine – maglev fans – maglev pumps – magnetic suspension.*

## 1-Introduction:

With the increasing global demand for electrical energy, it was necessary to think in two parallel directions

First: Serious work to raise the efficiency of means of generating and producing electrical energy

Second: Work to reduce energy consumption in electrical equipment.

Therefore, the researchers found that the force of magnetic levitation could be a good vsolution in both options.

The force of magnetic levitation was used in vertical wind turbines due to their weak efficiency and because of the vertical position of their axis, which helps more in installing the magnetic system that causes magnetic levitation on the turbine axis.

Here we must distinguish two ways of using the force of magnetic levitation in wind turbines:

1- Use a conventional axial flow generator

2- Use a hybrid axial flux generator

-The use of this technology in fans also had a positive impact in terms of reducing energy consumption and reducing noise.

Also, thanks to this technology, the performance of many types of pumps has been improved in terms of gear wear and other mechanical faults, as well as energy consumption.

Below, all of these topics will be reviewed and explained.

**MAGNETIC LEVITATION PRINCIPLE:**

Magnetic levitation, maglev or magnetic suspension is a method by which an object is suspended above other with no support other than magnetic field. The electromagnetic force is used to counteract the effect of gravitational force. Magnetic Levitation Magnetic levitation is known as maglev and this phenomenon works on the principle of repulsion characteristics of permanent magnets this technology has been mainly used in the railway industry in the Far East to provide very fast and reliable transportation on magnetic levitation trains and with ongoing research its popularity is increasingly attaining new heights. Neodymium magnet pair is used for magnetic levitation and substantial support can be easily experienced. By placing these two neodymium magnets on top of each other on the same poles for making repulsion on each other the magnetic levitation or repulsion will be strong enough to keep both magnets at a distance away from the each other. Repulsion force or levitation is also used for suspension purpose and its strong to balance the weight of an object depending on the verge (threshold) of the magnets in this project we expects to implements this technology from the purpose of achieving vertical orientation with our rotor as well as axial flux generator or motor.

**An introduction to applying the concept of magnetic levitation in wind turbines**

The rotation of the propellers powers an electric generator and then generator supplies a home with electric current. To simplify the process the wind rotates the blades, the rotation causes a shaft to spin, and the shaft connects to a generator to make electricity. Maglev wind turbine has several advantages over conventional wind turbine. For instant they are able to use winds with starting speed as low as 1.5m/s, also they could operate in winds exceeding 40 m/s. currently the largest conventional wind turbines in the world produce only 5 MW of power. However, one large maglev wind turbine could generate 1 GW of clean power, enough to supply energy to 7, 50,000 homes. It also increases generator capacity by 20% over conventional wind turbine and decreases operational cost by 50%. The maglev wind turbine will be operated for about 500 years, but the wind will blow only intermittently and unpredictably. Therefore, it is necessary to store the electricity produced when the wind is blowing and then release it at a steady rate to maintain a steady supply of electricity to the consumers hence for this purpose it's can also be used in conjunction with hydroelectricity. An area may have some water but not enough to generate a large amount of electricity continuously. Maglev wind turbines can be installed to pump the water from the lower level reservoir to the upper level reservoir during the night so that there will be enough water to activate the electric generators during the day. Such combination of wind turbine and hydroelectric generation could supply electricity to many towns and cities.

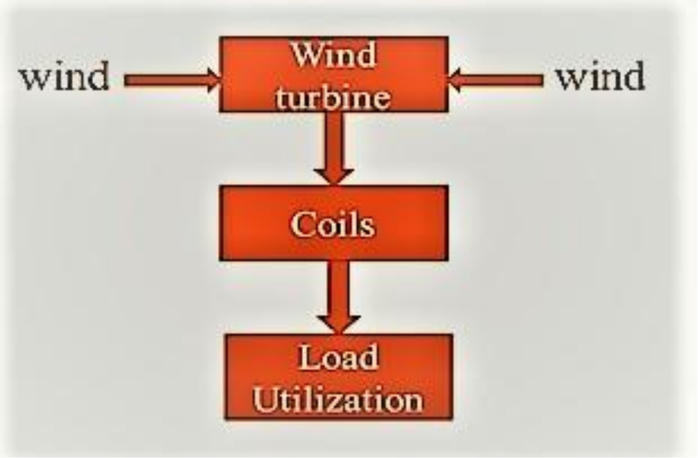



Fig.1. Block diagram of maglev wind turbine

**Use a conventional axial flow generator:**

Generator is used for various applications and the most part have similarities that exist between these applications. However the few different presents what is really distinguishes a system operating on motor. With the axial flux generator design, its operability is based on permanents magnets alternator where the concepts of magnets and magnetic field are the dominants factors in this form of generator functioning these generators have air gap surface perpendicular to the air gap generates magnetic fluxes parallel to the axis.

**Axial flux hybrid excitation generator for vertical axis wind turbine:**

An axial flux permanent magnet generator with asymmetric double-stator interior-rotor is used in APAFHG. The topology of the studied wind turbine system is shown in Fig. 2. Both the upper and lower stators attract the interior rotor. The dimension of the lower stator is slightly smaller than the upper stator, resulting in the imbalance of the attraction, so that the rotor and bearing are subjected to the upward levitation force. A fixed air gap is adopted to avoid the fluctuation of levitation force and generator power caused by the change of air gap length. The relative position of the rotor and the bearing in the generator is fixed, and the force of the bearing is reflected by the pressure sensor.

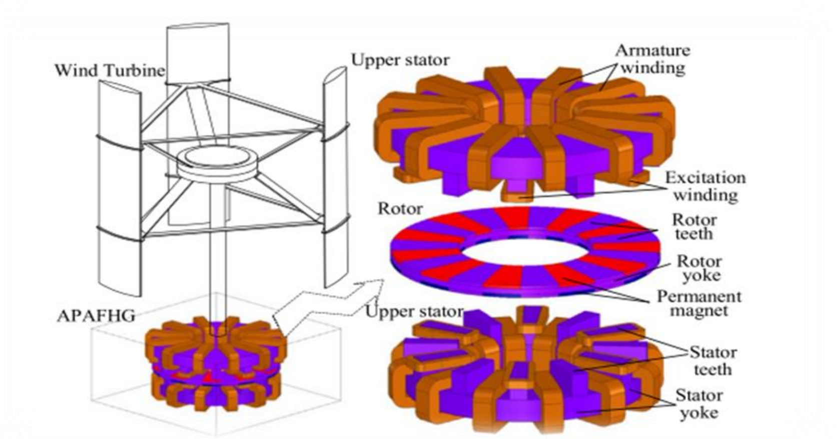



Fig. 2. The topology of the studied wind turbine.

The armature windings are placed in the stator slots and wound around the stator yoke. The armature current in the windings under the control of the converter not only affects the power, but also affects the levitation force on the rotor. The DC excitation windings wound around the stator teeth can affect the magnetic flux density of the stator teeth by applying DC current in the windings to improve the rotor levitation force. The disk-shaped rotor is composed of permanent magnets, rotor teeth and rotor yoke. The permanent magnets can provide stable basic levitation force as a constant magnetomotive force source during the operation of the generator.

The upper stator and lower stator have the same operation principle and topology. In addition, the two stators are independent parts, applying only different levitation forces on the rotor. Therefore, a single stator can be used as the research object to simplify the model. Circumferential cross section and winding distribution of Simplified APAFHG model are shown in Fig. 3

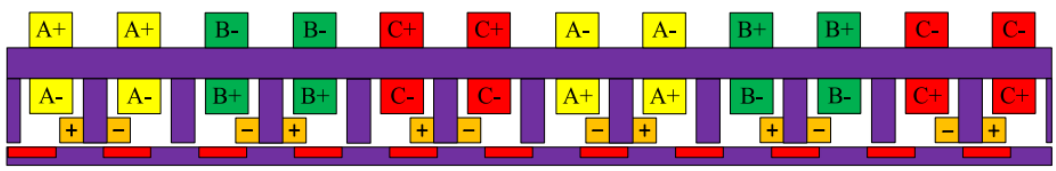



Fig. 3. Circumferential cross section of APAFHG and winding distribution.

The researcher conducted a simulation with and without the compensation technique, and the result of the simulation was as in Fig. 4

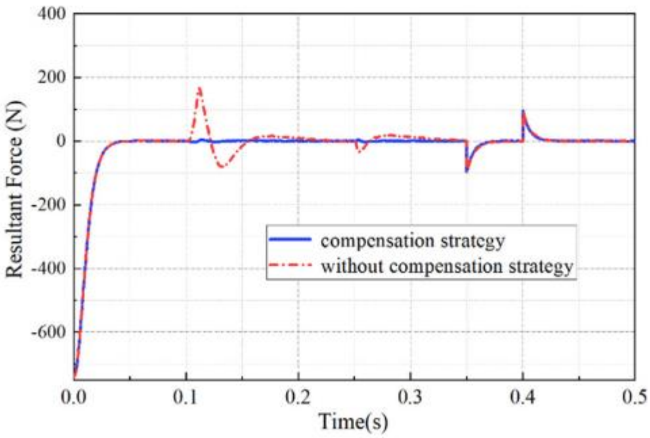
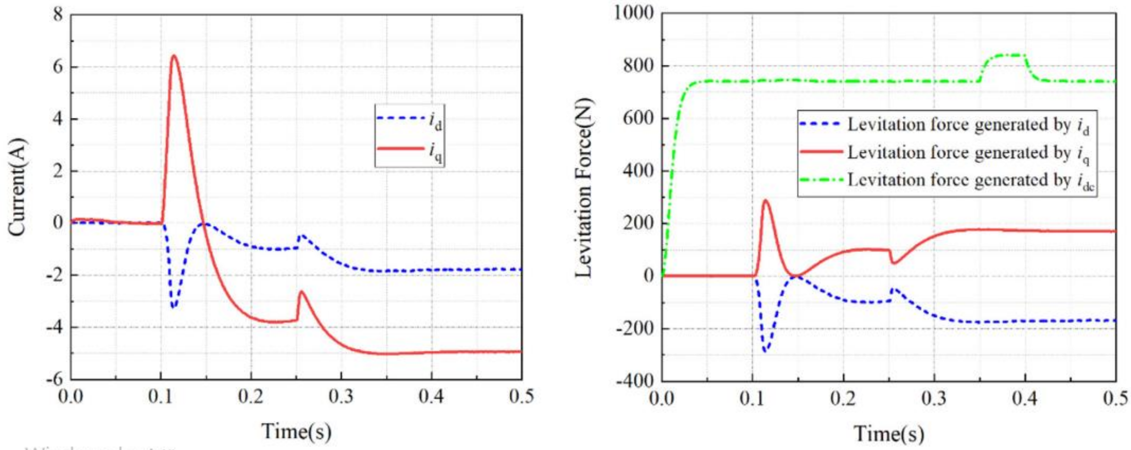



Fig. 4. The resultant force on the bearing.

The system is started at 0 s, and the DC excitation provides the levitation force to stabilize the resultant force on the bearing at the set value 0 N, so as to improve the starting capacity of the wind turbine. The wind turbine starts at 0.1 s and the wind speed changes abruptly at 0.25 s. Without the compensation strategy, the q-axis current change has a great impact on the bearing.but the disturbance caused by the power change after the compensation strategy is adopted is effectively offset, which ensures the stability of resultant force on the bearing and realizes the decoupled control of levitation force and generator power. The bearing suffers external disturbance at 0.35 s and 0.4 s. Under the regulation of DC excitation current, the resultant force on the bearing can quickly reach a stable state without affecting the output power of the generator. The current and levitation force of d-axis component and q-axis component under the compensation strategy are shown in Fig. 5. The compensation strategy makes the d-axis current adjust quickly with the change of q-axis current. The d-axis current can achieve bidirectional adjustment and strong adjustment ability to the levitation force, so the small negative d-axis current can offset the levitation force disturbance caused by q-axis current. According to Fig. 5(b), the levitation forces generated by d-axis and q-axis current are equal in size, opposite in direction and have the same phase. The resultant force of the two acting on the rotor and bearing is zero, which effectively offsets the disturbance caused by the q-axis current variation.






(a) $i_d$ and $i_q$ curve (b) Levitating forces generated by $i_d$, $i_q$ and $i_{dc}$

Fig. 5. The current and levitation force of d-axis component and q-axis component under the compensation strategy.

**Using magnetic levitation technology in fans:**

The maglev fan provides superior performance, low noise, and long life. By using magnetic levitation forces, these fans feature zero friction with no contact between shaft and bearing. With excellent rotational stability, the maglev fan eliminates vibration and typical wobble and shaking typically experienced in fan motors. The maglev fan also provides excellent high temperature endurance that results in long life, and the maglev fan models also feature all-plastic manufacture of major items for optimal insulation resistance and electrostatic discharge (ESD) performance. The maglev fan offers a true solution to equipment and systems cooling, with the promise of lower cost of ownership and long service life. The maglev fan overcomes the problems of noise, abrasion, and short service life that beset traditional fan motors. The maglev motor fan features zero friction and no contact between the shaft and bearing during operation. The maglev fan design is based on magnetic principles and forces that not only propel the fan but also ensure stable rotation over its entire 360 degrees of movement. Utilizing the attraction of the magnetic levitation force, maglev eliminates the wobbling and shaking problems of traditional motor fans. With this new technology, the maglev fan propeller is suspended in air during rotation so that the shaft and bearing do not come into direct contact with each other to create friction. The result is a new and improved fan with a low noise level, high temperature endurance, and long life. Maglev fans can be used in various industries and products that require highlevel heat transfer, such as notebook computers, servers, projectors, and stereo systems. Traditional fans apply the principle of like-pole repulsion to rotate. But with no control exerted over blade trajectory, the fan blades tend to produce irregular shuddering and vibrations. After long-term use, the shaft will cause severe abrasion on the bearings, distorting them into a horn shape. The worn-out fan then starts to produce mechanical noises and its life-time is shortened. The unique feature of the maglev fan is that the path of the fan blades during operation is magnetically controlled .The result is that the shaft and bearing have no direct contact during operation and so experience no friction no matter how the fan is oriented. This means that the characteristic abrasion noises of worn-out components are not produced and also allow a service life of 50,000 hours or even longer at room temperature (see Figure 6). In a traditional fan, the embedded magnets of the rotor and the stator exert repulsive forces, and it is this continuous force of repulsion that makes the fan spin.

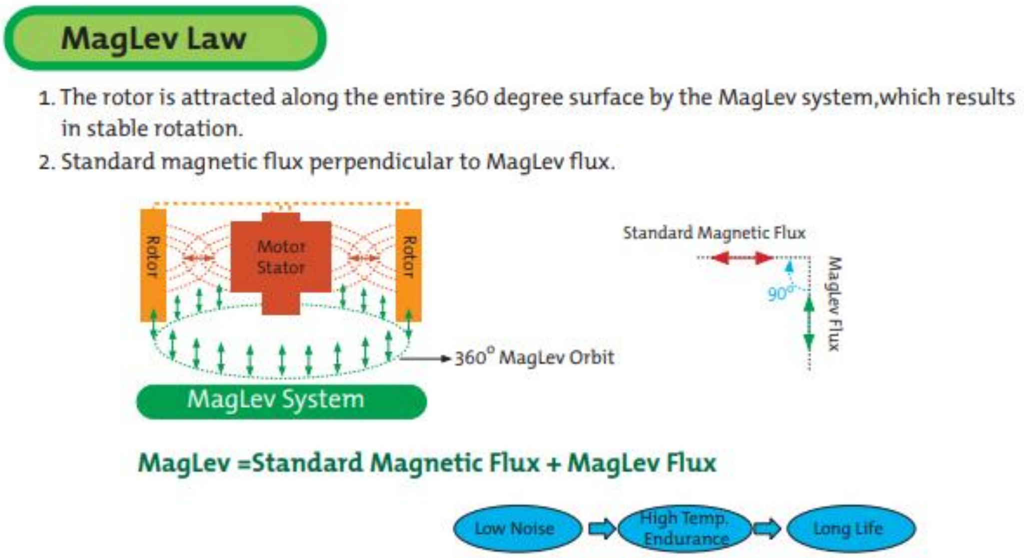



Figure 6: Maglev fan.

This is the basic principle behind all cooling fans. If we visualize the magnetic forces between the stator and the rotor, we see only dense lines of standard magnetic flux running without any control mechanism to stabilize vibration of the blade rotor during the repulsion-driven operation. The maglev fan includes just such a control mechanism in its design. This requires that each fan, in addition to standard magnetic flux, contains maglev flux required to sustain for the unique maglev orbit in its design. A maglev cross-section view reveals a uniquely designed set of conductive elements on the main board—the maglev plate. This maglev plate and the embedded magnets in the fan blades together generate comprehensive vertical magnetic forces, which is the maglev flux. From the crosssection, the standard magnetic flux and maglev flux form a 90-degree vertical angle, in others words, the maglev flux acts perpendicular to the standard magnetic flux. This is the first key trait to use to identify a maglev fan. The design of vertically intersected standard magnetic flux and maglev flux ensures that the rotator is affixed to the maglev orbit. Therefore, regardless of the mounting angle of the fan, the shaft will always rotate around a fixed point and at a constant distance from the bearing without coming in contact with it to produce friction or mechanical noise. The problem of bearings being worn down into an oval shape or horn aperture after long use is effectively resolved. The greatest benefit with maglev flux is in fact the 360-degree complete force of attraction between the conductive element (maglev plate) and the rotor above it. This ensures an evenly distributed force of attraction to help keep the optimal balance of the rotor during operation and to avoid shuddering or instability. Fans with well-balanced blades not only last longer but produce a steady air flow. In short, the second easy trait for identification of the maglev fan is that the maglev system creates 360∘ attraction on the rotor, which results in stable rotation (see Figure 7). In the traditional DC brush-less fan motor design, the impeller rotor (simply called Rotor) by means of a shaft which extended through the bore of oil-impregnated bearing,

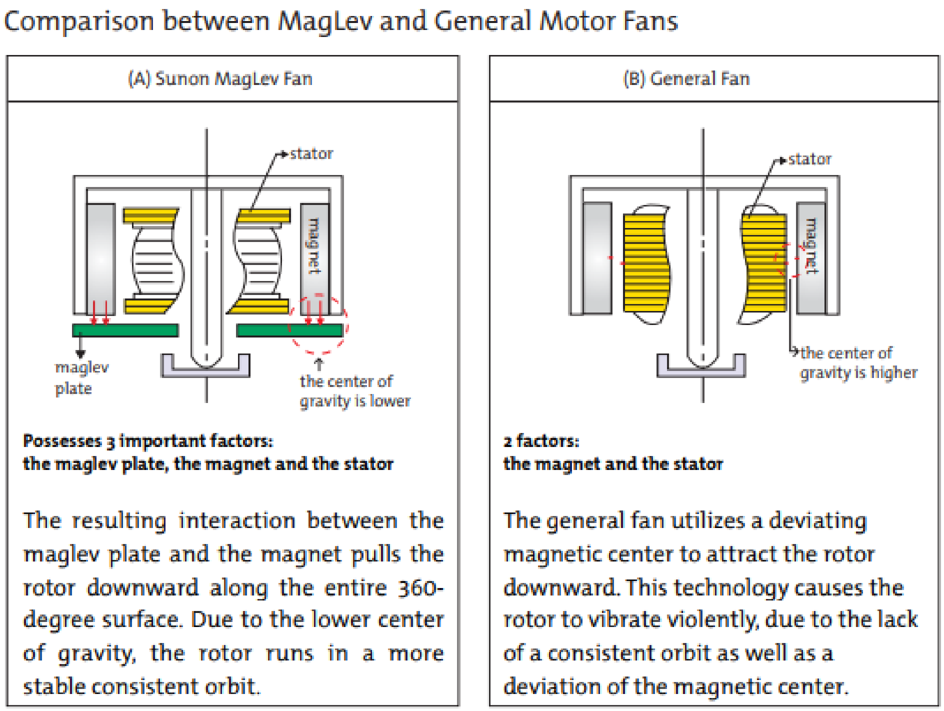



Figure 7 Comparison between maglev fan and traditional fan

(a) Maglev fan possesses 3 important factors: the magnet plate, the magnet, and the stator. The resulting interaction between the magnet plate and the magnet pulls the rotor downward in a full 360 degrees. Through the lower center of gravity, the rotor runs stably in a consistent orbit. (b) Traditional fan possesses 2 factors: the magnet and the stator. The conventional fan utilizes a deviating magnetic center to attract the rotor downwards. This kind of technology causes the rotor to vibrate violently due to both the lack of a consistent orbit and a deviation of the magnetic center.

Sleeve bearing, pivotally held in the center position of motor stator. A suitable air gap was maintained between the rotor and the stator. Of course, there must be gap between shaft and bearing bore, otherwise, the shaft would be tightlocked and unable to rotate. The stator assembly (simply called stator) after connection to power supply will generate induced magnet flux between rotor and stator. With the control of driving circuitry the fan motor will start to rotate. In a traditional fan motor structure, there is an impeller rotor, a motor stator, and a driving circuitry. The rotor is pivotally joined to the stator by the rotor shaft and bearing system. The rotor is driven to rotate by the induced magnetic field between stator and rotor as shown in Figure 8. Advantages of sleeve bearing are the following.

(i) More impact-resistant, less damage resulted during delivery.

(ii) Sleeve bearings cost much lower in comparison with ball bearings.

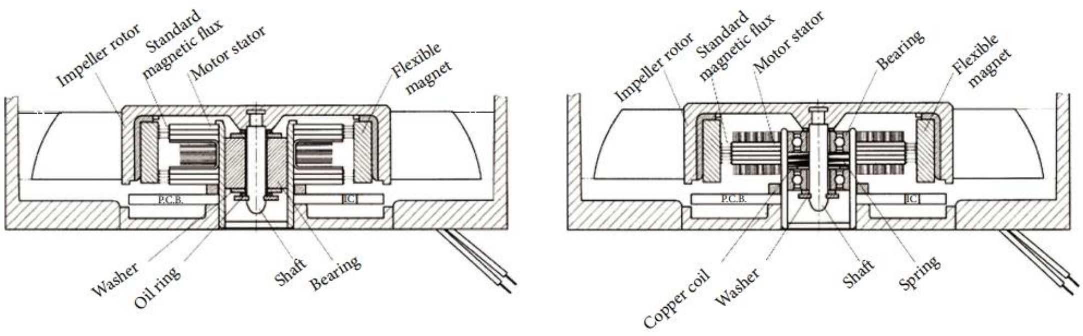



Figure 8: Sleeve bearing and Ball bearing

Imperfections of sleeve bearing are the following. (i) Dust from outside may penetrate into bearing and mix with nitride particles to clog the motor, which may result in noise and much slower operation of the motor. The inner surface of bearing bore easily gets worn and influences the performance. The space between the shaft and sleeve-bearing bore is small this results in rough uneven start-ups. Ball bearing workings utilize small metal balls for rotation. Since they have only point-contacts, rotation can be started easily. With the use of springs to hold the outer metal ring of the ball bearing above, the weight of the entire rotor can sit on the ball bearing, indirectly supported by the springs. Therefore, ball bearings are ideal for use in portable devices with various mounting angles. However, caution should be used to prevent the product from falling and impact damaging the ball bearing, which could lead to noise and shortened product life-time (see Figure 8). Advantages of ball bearing are the following.

(i) Steel ball bearings have an operating life much longer than that of sleeve bearings.

(ii) However, the product must avoid rough handling or being dropped on the ground. Imperfections of ball bearing are the following.

(i) Ball bearings are quite weak. It cannot bear any external impact.

(ii) When the fan motor is operating, the steel balls inside will generate a higher rotational noise than that of a sleeve bearing. (iii) High price makes it uneasy to compete with sleeve bearings.

(iv) Limitation on both supply sources and supply quantities makes it unacceptable for mass production needs.

(v) The use of tiny assemblies, such as springs, results in inefficiencies for mass production. When a spinning top (a kind of toy) is thrown, the top continues to accelerate even as it hits the ground. During this acceleration the top tilts and sways until a consistent speed is obtained. At this point, the top will balance itself, for example, the swaying and tilting have faded and have become fixed perpendicular to the ground. This is the simple concept that maglev fan system roots form (see Figure 9).

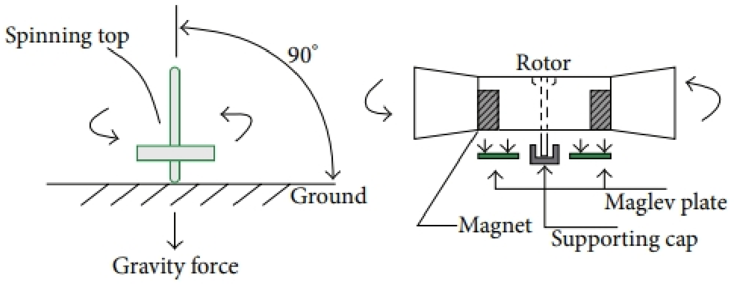



Figure 9: Performance of maglev fan system roots.

From the illustration above, we know that no matter how the motor fan is mounted, the force induced by the existing magnet inside the hub and the magnetic plate that is added to the PCB of the fan attracts the rotor continually. This results in the rotor rotating perpendicular to the ground with a constant distance between bearing and shaft without any contact. Therefore, no rubs or noise can occur. The operating life of the motor fan is extremely long (see Figure 10).

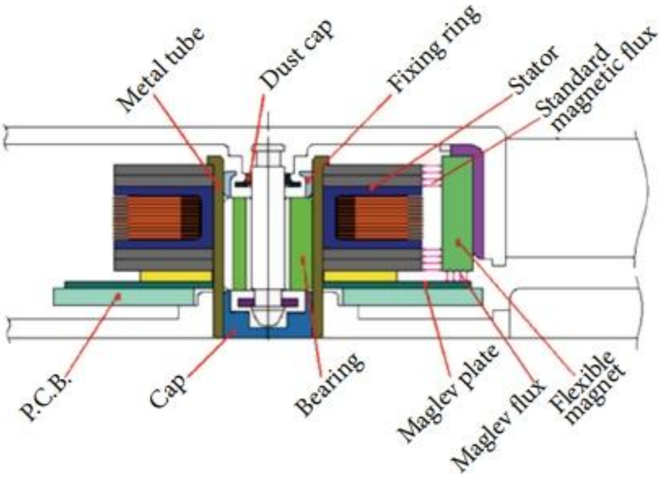



Figure 10: Vapo bearing

(1) Maglev system helps the impeller to rotate evenly in a fixed orbit within the orbit center. Consequently, the shaft inside the Vapo bearing bore turns without creating friction. The bearing bore is hardly ever abraded into irregular or oval shapes such as seen in conventional fans. Hence the operating life of the bearing becomes very long.

(2) The shaft inside the bearing bore is in friction with nothing except air, and the fan motor starts up easily.

(3) This new system removes the use of oil rings and washers, thus leaving space for the release of gas occurred during normal operation. There are no more clogging problems. Hence, the fan motor may operate smoothly for quite a long time.

(4) The use of magnet flux and supporting cap creates the same function as ball bearing; therefore, no matter how the fan is placed, no slanting and wobbling occurred, which means it is suitable for design in portable applications.

(5) Vapo bearings are made of a material specially treated for wear-resistance and impact-resistance. When used in conjunction with the maglev, it creates a spring function, which helps the fan motor to bear impact.

(6) Vapo bearing with maglev is capable of an operating temperature of more than 70∘ C. It also performs very well in a low temperature environment.

(7) The elimination of washer and oil ring may also allow the automatic production thus brings manufacturing efficiency.

(8) The dust cap prevents dust penetrating into bearing and mixing with nitride particles to clog the motor, which may result in noise and slower motor operation. With the combination of maglev design and Vapo bearing, all the advantages of ball and sleeve bearings are maintained, while eradicating all the imperfections. Vapo Bearing can be explained as follows.

(i) Vapo bearings are made of a material specially treated for wear-resistance and impact-resistance. When used in conjunction with the maglev, it creates a spring function, which helps the fan motor to bear impact.

(ii) Maglev design helps the rotor to rotate evenly in a fixed orbit within the orbit center without any friction with the bearing bore. No vibration occurred.

(iii) This new system eliminates the use of oil rings and washers, thus leaving space for the release of gas occurring during normal operation. There are no more clogging problems. Vapo bearing is named after this character.

There is no friction and contact between the shaft and the bearing during operation. They have become favorite due to its superior features such as low noise, high temperature endurance, and super long life. The axial-flow radial-flux permanent magnet motor along with an iron strip segment, as shown in Figure 25, has been used for small-power cooling fan applications. This motor is equipped with only one set of axial stator winding that can supply the desired radial flux through adequate stator pole design, and such structure design is quite promising for applications with limited spaces. With the undesired vibration forces mainly generated in the motor radial direction, the concept is to provide adequate flux path such that a passive magnetic suspension can be established. As can be observed from Figure 10(b), the magnetic fluxes generated from the motor stator winding will first flowing through its stator center shaft, getting out of the stator pole pairs at its top/bottom part, and then coming back to the bottom/top part stator pole pairs after passing through the corresponding rotor magnets. With the pole pairs on the stator top and bottom parts being perpendicular to one another, undesired vibration forces mainly generated in the motor radial direction will be exhibited. The resultant frictions applied onto motor bearing system will certainly generate extra heat and energy losses and thus reduce the reliability and lifetime of this motor. The major concerns on cooling fan motor manufactures are low construction/maintenance cost and high operational reliability. In addition, to satisfy these construction prerequisites, it is also desired that the overall performance of such motors can preserve their market competitions without implementing complicate sensor and driver control devices. A magnetic suspension will be established through the extra flux path being provided. Though it is anticipated that the attraction force between the rotor permanent magnet and the passive magnetic suspension segment will be induced to stabilize the rotor vibrations, intuitively it is also suspected that this segment with high permeability might yield the motor rotational performance.

**Pumps that depend on levitation magnetic force:**

According to Earnshaw's Theorem （1839）, the permanent maglev cannot achieve stable equilibrium[1] and thus an extra coil is needed to make the rotor electrically levitated in a maglev pump. Therefore, most current maglev pumps are electro-magnetically levitated pumps which need at least one electrical magnetic bearing. The advantages of no mechanical bearing wear and less thrombosis along the bearing will be unavoidably accompanied by many major disadvantages, such as, additional electromagnet, extra power consumption, complicated rotor position detection and feed-back control, and subsequently bulky and heavy pump with complexity of the system.

To simplify the electric maglev rotary pumps, the author tried to use merely PM bearings in centrifugal pumps. Successively, an available PM bearing (Bearing A) and a novel PM bearing developed by the author(Bearing B) were applied in three prototypes: an axially driven centrifugal pump, a radially driven biventricular assist pump and a radially driven centrifugal pump. Experiments demonstrated that the rotors in all these centrifugal pumps could be levitated stably, if the rotating speed would be high enough; and the Bearing B had better stability than the Bearing A.

**PM bearings:**

Two PM bearings were used (Fig.11): one was Bearing A, an available bearing in common use applied by others too; and the other was Bearing B, the author’s novel bearing. The Bearing A consisted of two passive magnetic cylinders with same length but different outer and inner diameters; the smaller cylinder was located within the bigger one and both were magnetized same in axial direction.

The Bearing B had two passive magnetic rings with different outer and inner diameters but same thickness; the smaller ring was located beside the bigger ring concentrically and both were magnetized same in axial direction. Compared with the Bearing A, the Bearing B needed smaller axial occupation and had bigger axial magnetic bearing force; besides, as mentioned below, the Bearing B had better stability than Bearing A

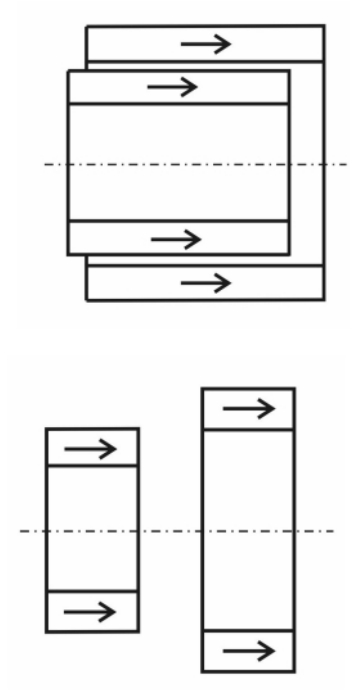


Fig.11: The available PM Bearing A (above) and the novel PM bearing B (below). Comparatively, the bearing B needs smaller axial occupation but has bigger axial bearing force; more importantly, the bearing B has better stability than bearing A as mentioned below

**Axially driven centrifugal pump:**

The axially driven centrifugal pump was developed based on a DC motor driven centrifugal pump with magnetic coupling and passive magnetic bearings. The main improvement was changing magnetic coupling driven system by DC motor with a motor coil (Fig.12).

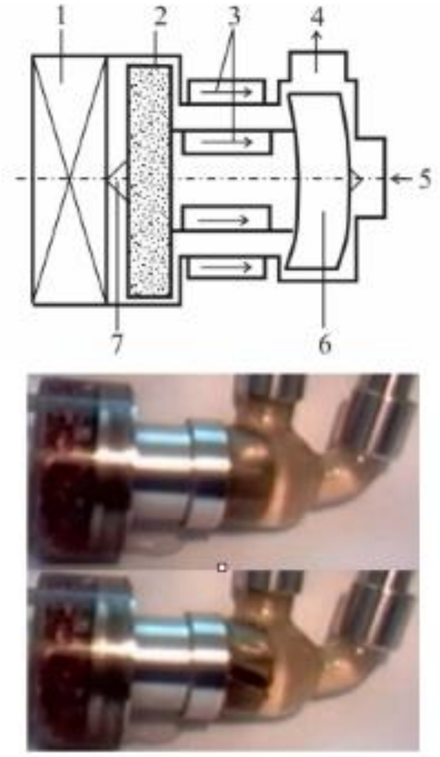



Fig.12: Schematic drawing(above) and prototype(below) of axially driven permanent maglev centrifugal pump. 1-motor coil; 2-driven magnets; 3-Bearing A; 4-outlet; 5-inlet; 6-impeller; 7-one point contact

The rotor with impeller was born by Bearing A radially as well as axially; the rotor had one contacting point with the stator axially. The press in this contacting point equaled the attractive force between motor coil iron core and the driven magnets, minus the forces of both magnetic bearing and hemodynamic reacting force on impeller.

If the rotating speed increased to a certain value, the hemo-dynamic reacting force would be large enough to pull the rotor disaffiliated from the stator. Then the rotor became full suspended. This axial movement of the rotor could be seen by pumping water.

**Radially driven biventricular assist pump:**

This is a device with one motor driving two pumps. The rotor together with two impellers was bore by Bearing A and changed its rotating speed periodically to produce a pulsatile flow. By experiments with water it can be seen that the rotor moved back and forth axially except rotating, demonstrating that the rotor was suspended freely without bearing friction.

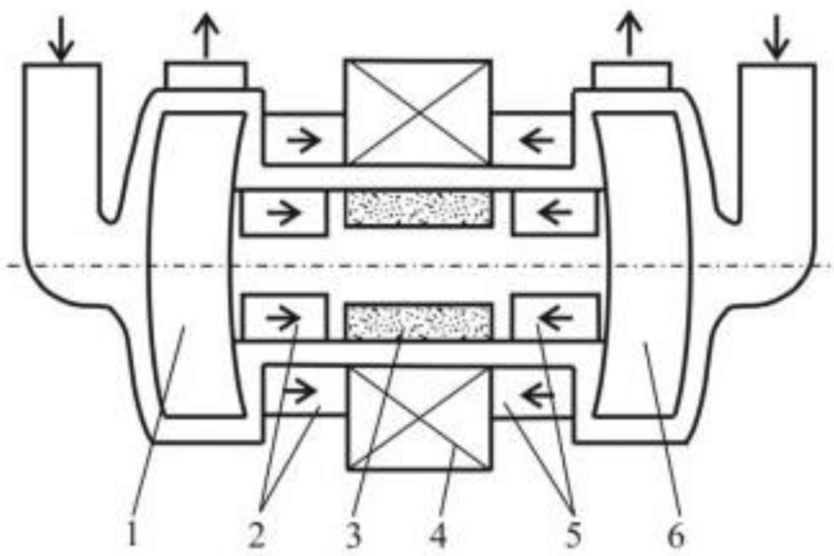
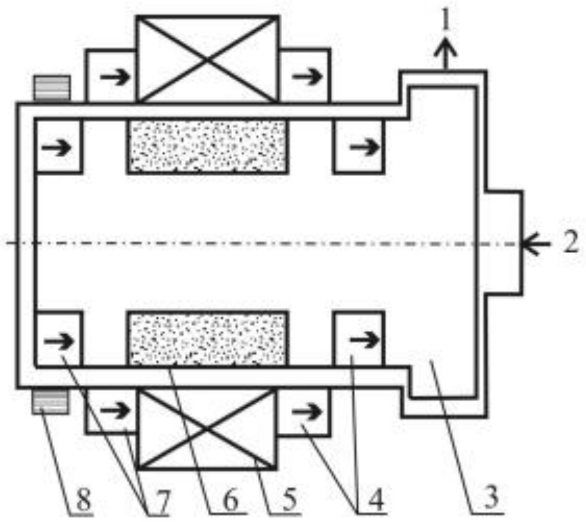



Fig.13: Schematic drawing of a radially driven permanent maglev centrifugal pump. 1-impeller; 2-Bearing A; 3-rotor magnets; 4-motor coil; 5-Bearing A; 6-impeller

**Radially driven centrifugal pump:**

The radially driven centrifugal pump had similar structure as figr biventricular assist pump, but with two differences: 1. both Bearing A and Bearing B were used for comparison; 2. one motor droved one pump. To verify whether the rotor was levitated in the stator, 4 Hall-sensors were devised onto the stator evenly in periphery. The distances between the rotor and the sensors were detected by voltage differences in the sensors. Then the eccentric distance and vibration amplitude of the rotor were calculated. The results indicated that these eccentric distances and vibration amplitudes of the rotor by use of Bearing B would be under 0,07mm and 0,05mm respectively, smaller than the gap between the rotor and the stator (0,20mm), if the rotating speed increased to over 3250RPM. That means the rotor had no contact with the stator, namely, was suspended in the stator. By use of Bearing A, the minimal speed for stable maglev should be ca. 50rpm higher than by use of Bearing B, that is, round 3300rpm. This pump was used together with an American artificial lung in animal experiments for both cardiac and pulmonary bypass. The survival lasted over 1 month.



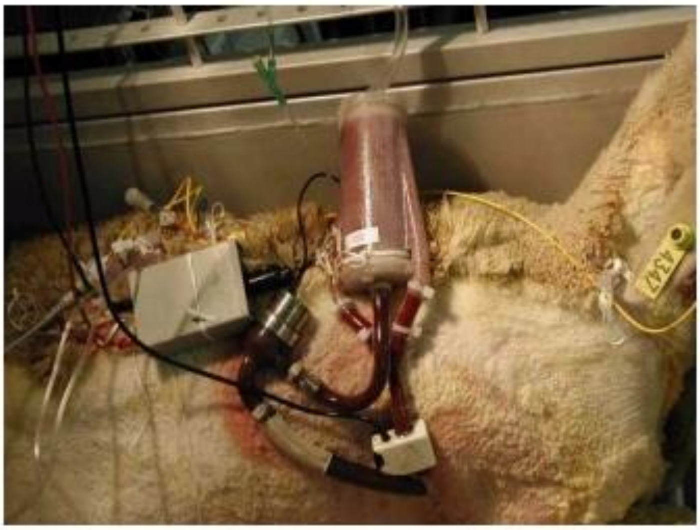



Fig.14: Schematic drawing (above) and prototype(below) of radially driven centrifugal pump. 1-Outlet; 2-Inlet; 3-Impeller; 4-Bearing B; 5-Motor coil; 6-Rotor magnets; 7-Bearing B; 8-Hall sensors.

**Maglev Heart Pump:**

Heat failure is one of the main causes of death. Treatments of heart failure generally have heart transplantation, ventricular mechanical assistance, artificial organs substitution, and so on. Although heart transplantation is a relatively nature technology, there is a serious shortage of donated hearts and will result in transplant rejection reaction. The support of traditional artificial heart pumps often uses rolling or sliding bearings. Because of the contact between bearing and blood, the blood will be polluted and will easily produce thrombosis. With the development of maglev, motor and control technology, artificial heart pump overcome the problems such as friction, sealing, and lubrication, which reduced the damage of blood cells and improved the heart pump life and safety. Artificial heart pump requires small structure, low energy consumption, certain stiffness and damping for transplanting, and long time using. A hybrid-type axial maglev blood pump not only has small size, almost no energy, and poor dynamic characteristics of permanent magnet bearing but also has low power consumption, long life, and good dynamic characteristics of magnetic bearing. Artificial heart pump (also known as blood pump) can be divided into displacement, pulsating, and continuous-flow heart pump. The bionic performance of pulsating pump is good but its disadvantages are relatively large volume and will be prone to hemolysis because it has big blood contact area. These shortcomings seriously restricted its application. Continuous-flow artificial heart pump can be divided into axial flow pump, centrifugal pump, and mixed flow pump. Maglev centrifugal heart pump has a greater pressure in a small flow rate and has fewer destruction to blood in low speed, while its disadvantage is not suitable for implantation; the axial maglev heart pump has a big flow rate, low pressure, which need to increase speed for obtaining much greater pressure. Axial flow pump has a tight structure, smaller drive components, low power consumption, light weight, high efficiency, and so forth, so it is easier to implant and can save the cost of the surgery and the possibility of infection, but its impeller has a high speed and its hemolytic is also high. Either axial or centrifugal, the traditional supports are contacted bearings such as ceramic bearing, and there are some problems about friction, lubrication, and sealing which is easy to damage the blood, leading to hemolysis and blood clots. The magnetic bearing avoid, contact of rotor and stator by the magnetic force which does not need lubrication and overcome the traditional shortcomings such as direct friction, big loss, and short life, and it is one of the ideal support for a new generation of artificial heart pump. It has been widely acknowledged that permanent maglev is unstable according to Earnshaw's theory (1839). This the orem is applicable only to a levitator in static state. A passive magnetic (PM) bearings could achieve stable maglev in all centrifugal pumps, if the rotor had high enough speed and thus obtained a so-called gyroeffect, namely, a rotating body with high enough speed could maintain its rotation stably.

To simplify the electrically maglev rotary pumps, a shaftless full-permanent maglev impeller pump without actively controlled coil for rotor suspension has been developed. The left side of the impeller is a magnet's disc for rotation and the right side of the impeller is a magnet's disc for suspension. The pump weighing 150 g has a maximal diameter of 42 mm, and its length in largest point is 35 mm. The device consists of a stator and a rotor. The stator has a hard polyurethane housing with cylindrical inner surface; on its left side an axially driven DC motor coil winded on an iron core is connected and on its right side a balancing iron ring is screwed. The rotor is compacted by a magnet disc for rotation (in the left), an impeller (in the middle), and a magnet disc for suspension (in the right). The attractive force between the motor coil iron core and the rotor magnet disc for rotation is balanced by the attractive force between the magnet disk for suspension and the balancing iron ring. Furthermore, two novel patented permanent magnetic bearings are devised on both sides of the rotor, eliminating the remaining attractive forces and preventing the rotor being affiliated axially to the stator either in the left or in the right. Each bearing is composed of a small and a big permanent magnetic ring; the small ring is inlaid into the rotor and the big ring is buried in the stator. Two rings magnetized in the same axial direction reject each other, providing an axial bearing force. The attractive force between the rotor and the stator resists the radial eccentric movement of the rotor and thus serves as a radial bearing. The inlet and outlet of the pump are located respectively in the center of the balancing iron ring and onto the periphery of the PU housing. By the bench testing with water the pump produces a flow as large as 10 L/min with 100 mmHg pressure head. The pump weighing 150 g has a maximal diameter of 42 mm and a length of 35 mm (excluding inlet and outlet tubes). Implantable rotary pumps have been developed and used to assist the impaired heart ventricle because of lack of heart donors for transplant. Pulsatile flow rate measurement is important for controlling the flow rate of these rotary pumps. Conventional flow meters are not particularly compact, while the reliability and durability of small flow meters made using microelectromechanical system technology is still uncertain. Several groups have proposed estimating flow rate using the motor power of the centrifugal blood pump (CBP).

Figure 15(a) shows a schematic of an implantable ventricular assist system using a rotary pump. The fourth design iteration (PF4) of the PediaFlow Pediatric Ventricular Assist Device (VAD) was developed for infants and toddlers with congential and acquired heart disease. Key attributes of the PediaFlow Pediatric VAD include the following:

(i) unparalleled biocompatibility due to the maglev technology, streamlined single-flow-path design, and computer-optimized design process;

(ii) exceptionally small due to the supercritical (above resonance frequency) rotordynamic technology;

(iii) valveless turbodynamic design with one moving part to minimize size;

(iv) computationally optimized using first principles of bioengineering and physics.

The current VAD design arose from the comprehensive evaluation of three pump topologies incorporating a variety of magnetic suspension, motor, and fluid path arrangements. Each of the selected topologies utilized permanent magnet radial and moment bearings, an active axial thrust bearing, and a brushless DC motor.

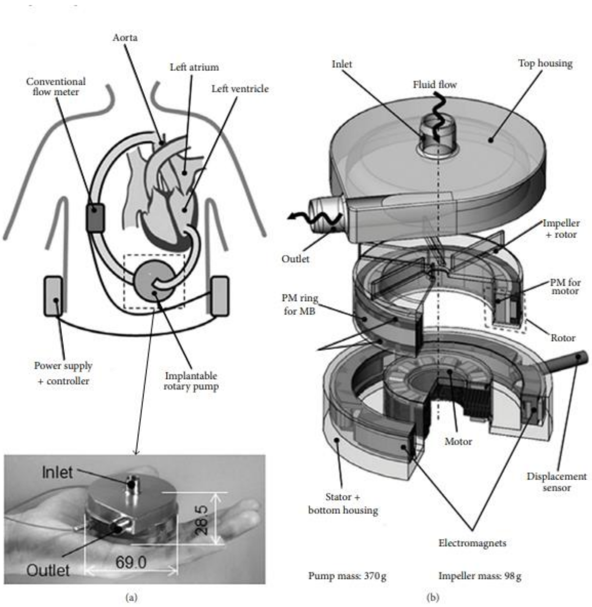



Figure 15: (a) Ventricular assist system and photograph of an implantable maglev CBP, and (b) configuration of the implantable maglev CBP

**Conclusion:**

Through our review of previous studies, we can say that the use of magnetic levitation and the maglev system has provided many positive points in rotating machines, whether as generators or as energy-consuming tools.

As it increased the efficiency of generation by dispersing losses and increased the efficiency of energy-consuming devices by reducing the force of friction and compensating for part of the energy with the energy latent in the permanent magnets.

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