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Force Analysis of Permanent Magnet Bearing for Domestic Table Fan Applications.

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Abstract-This present work elaborates the modelling & mathematical analysis of permanent magnet bearings, as proposed replacement for conventional journal bearings of table fan rotor. Design consideration for table fan bearing arrangements are studied in details. Radially polarized permanent magnet rings for levitating fan rotor are modelled. The repulsive force of radially magnetized permanent magnet bearing is calculated by vector approach. Permanent magnet materials, polarization, levitation is studied and results were derived by FEA software for a real case. The result are studied and dimensions, shape for bearing is suggested. A FORTRON Code is used for evaluating the envisaged parameters value for three degrees of Freedom. Models of two ring bearing sets is developed using CATIA V5 and analysed for levitating force values for radial and axial directions.

Keywords- Table Fan, Journal Bearing, fan efficiency, Permanent Magnet, Levitation, Magnetic Force, Vector equations.

I. INTRODUCTION

A domestic table fan founds in every average house of the world, fans offer an economical alternative to provide air circulation and to cool down temperature. The machine is consisting of either a deep groove ball bearing or journal bearing mounted motor and the fan blades, in construction ,which needs to be overcome for friction and also generates lots of heat. A concept of use of permanent magnet ring type bearing as a replacement, can be a solution for overcoming the efficiency loss.

A 1ϕ induction motor having a rotor supported on two journal bearings at both ends of rotor and behaves like a simply supported beam. Operating power consumption of domestic table fan motor varies in the rage of 25- 110 Watts. Presenting a ring type magnetic bearing, as a replacement for conventional ball or sleeve bearing is to overcome all these losses and to save power in considerable amount. The weight of the rotor is entirely neutralized by the magnetic force and enables the shaft to turn without being affected by the gravity. Therefore, when the fan is operating, the highly balanced rotor assembly rotates in nearly a perfect circular motion in a consistent orbit. The centre of rotation of the rotor shaft is the true centreline of the shaft and the bearing assembly, the idea of an axial fan supported by a magnetic force is a sound principle.

II. LITERATURE REVIEW

There are two main types of bearings that are used in axial fans: ball and sleeve bearings. When choosing between a ball bearing and a sleeve bearing fan, the engineer must consider ball bearing fans on average outlasted sleeve bearing fans by 50 %. If an application generates high levels of heat, an engineer may want to use a ball bearing fan. If the equipment generates low heat intensities, or if the equipment has a short life span, the design engineer may want to use a sleeve bearing fan [1].As a household table fans are in second category, they are build with sleeve bearings.

A modern axial fan uses a sleeve or deep groove ball bearing design to provide the fast rotation needed to deliver large volumes of cooling airflow, usual rate of Minimum Air Delivery 4800 m^3/Hr. [2]

A] Types of Fan Bearings:-

1. Deep groove Ball Bearings:-

Ball bearings tend to have lower load capacity for their size than other kinds of rolling-element bearings due to the smaller contact area between the balls and races. In a deep-groove radial bearing, the race dimensions are close to the dimensions of the balls that run in it. Deep-groove bearings can support higher loads. As one of the bearing races rotates it causes the balls to rotate as well. Because the balls are rolling they have a much lower coefficient of friction than if two flat surfaces were sliding against each other. Widely used in transmission, instrumentation, electrical, household appliances, internal combustion engines, transport vehicles, agricultural machinery, construction machinery, engineering machinery, roller-skating shoes, etc

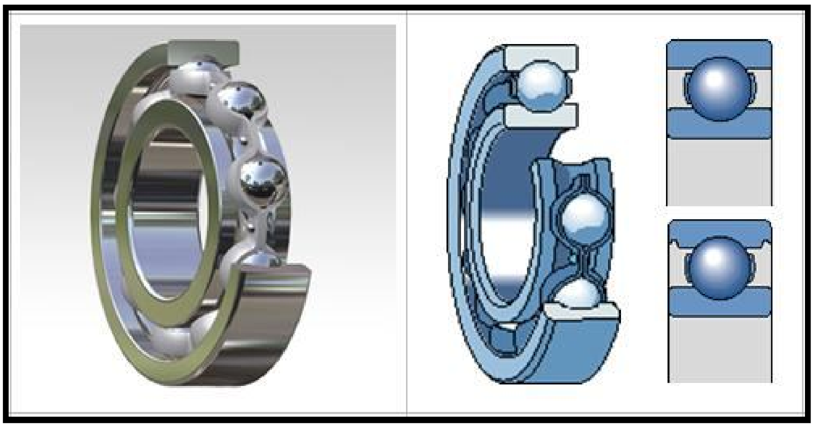


Fig. 1 Deep Groove Ball Bearing

2. Sleeve bearings:-

A sleeve bearing is a kind of cylindrical bearing. It got its name from having a single internal rotating cylinder inside it, Sleeve bearings are made of compressed powdered metal, such as bronze or copper. Because of the material from which they are made, the metal is microscopically porous. When they are oiled on the outside, the oil will be drawn up through the pores to lubricate the inner cylinder. Generally in many of the domestic table fan having cheap costing, are assembled for their rotor with these types of bearing Fig. 2 shows a 3D View of Domestic table fans Journal bearing.

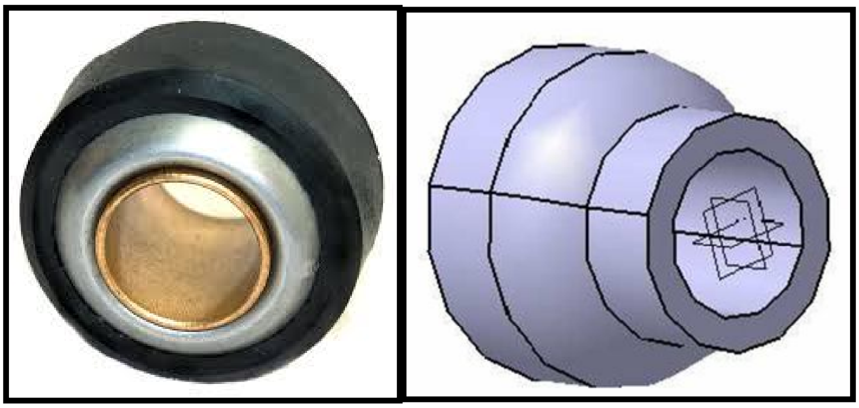


Fig. 2 Deep Groove Ball Bearing

B] Magnetic Levitation

The idea of letting a body hover without any contact by using magnetic forces is an old dream of mankind. There are many research and study going on levitation force of magnet, in world we can find many applications using magnetic levitation for carrying out work, Maglev train, PM Motors, Turbo machinery ,cranes and many has magnets as prime role players.The magnetically levitated vehicle, MAGLEV, which uses the electromagnetic principle, is suspended without any contact by several magnets from the iron track. [3]

A permanent magnet is an object made from a material that is magnetized and creates its own persistent magnetic field. Materials that can be magnetized,which are also the ones that are strongly attracted to a magnet, are called ferromagnetic (or ferrimagnetic). These include iron, nickel, cobalt, some alloys of rare earth metals, and some naturally occurring minerals such as lodestone. Permanent magnets are made from "hard" ferromagnetic materials such as alnico and ferrite that are subjected to special processing in a powerful magnetic field during manufacture, to align their internal microcrystalline structure, making them very hard to demagnetize. If the two same poles of two different magnets bring together their tendency is to repel each other while if two dissimilar poles bring together they attract with strong coercive force.

III. Research on Magnetic Bearing in Industrial Application

In a magnetic bearing system the rotor is levitated in the magnetic field. The magnetic field may be generated in two ways: either by employing electromagnets or by using permanent magnets. Utilizing the repulsive force between permanent magnets for levitating the rotor it is possible to reduce the number of electromagnets used in magnetic bearing system and the corresponding control circuit can be simplified, The configuration of permanent magnets depends on many factors such as type of machine in which it is used, the amount of weight to be levitated, the material characteristic of the magnet, and its availability etc. It is seen that the variation of the repulsive force with rotation of the rotor is negligible. The maximum variation of force is slightly more than 5 % of the average force [4].In the paper on Analytical calculation of the magnetic field created by permanent magnets, proposes a 3D analytical formulation of the field created by a radially magnetized ring. The magnet is modelled by a surface density of fictitious charges on the inner face of the ring. The effect of the outer face does not appear to simplify the expressions, but can be taken into account because the principle of linear superposition applies [5]. In the university of Texas in association with Cal Netix, Inc. Torrence., A permanent magnet bearing is tested and tried for dynamic analysis, during work they tested permanent magnet homopolar bearing at the place of conventional bearings for flywheel and obtained successful design speed of 42000 rpm.[6]

IV. CONVENTIONAL TABLE FAN PERFORMANCE

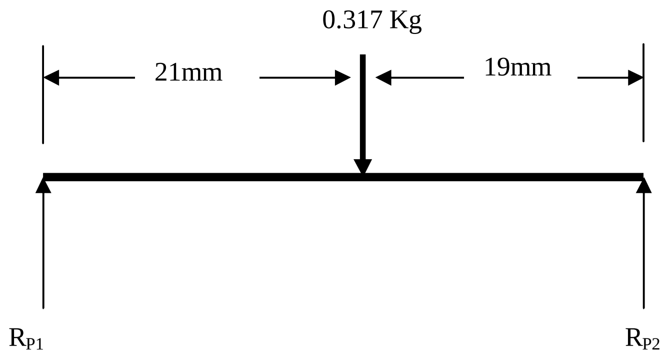
In the single phase induction motor which is used in table and ceiling fan, the only way to improve efficiency is to reduce motor losses .Various losses that occur inside the machine during the power flow from the power input at the motor terminal box to the power output measured at the shaft of the motor are evaluated in terms of the electrical equivalent parameters of the machine. By using the model developed in the MATLAB, appropriate efficiency is calculated. efficiency of the fan motor is 78.35 % [7] .The power required in axial fan is proportional to the cube of the fan speed.[8] Friction and windage losses results from bearing friction, windage and circulating air through the motor and account for 8 – 12 % of total losses. These losses are independent of load [9].

V. DESIGN AND MODELLING

Conventional table fan has rotor or armature mounted on its shaft with conventional journal bearing as shown in figure 3. Figure 2 earlier, shows its true dimensional model, developed in CATIA V5.

Fig. 3 Domestic Table Fan Rotor and Journal Bearings

The rotor of a table fan in combination with shaft for design and analysis, is obtained from real Indian made table fan assembly. The rotor weighs 317 grams. For design of support bearing and to calculate load supported by bearing considering rotor shaft as simply supported beam, with a point load of 317 grams at middle span of shaft, the resulting reactions at bearing support are calculated as follows;



Taking moments about Support R_{P1};

$$(0.317 \times 21) - (R_{P2} \times 40) = 0$$

Therefore, $R_{p2} = 0.1644\, Kg$ ………………….. (1)

$$= 1.612\, N.$$

Now,

$$R_{P1} + R_{P2} = 0.317\, kg$$

From (1),

$$R_{P1} = 0.317 - 0.1664$$

$$\text{Therefore,} \quad R_{P1} = 0.1506\ Kg \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

$$= 1.4768\ N.$$

From equation (1) & (2) minimum repulsive force required to lift the shaft at position P1 and P2 is 0.1506 Kg and 0.1664 kg respectively.

The modification proposed in arrangement of bearings for rotor is as shown in figure 4 below, conventional rotors journal bearings, are replaced with ring shaped permanent magnet bearings and radial polarization, such that the inner rings mounted on shaft face with outer circumferential face towards inner circumferential face of outer ring with air gap of 5mm in between and their same poles are facing each other for bearing at position P1 and P2 respectively.

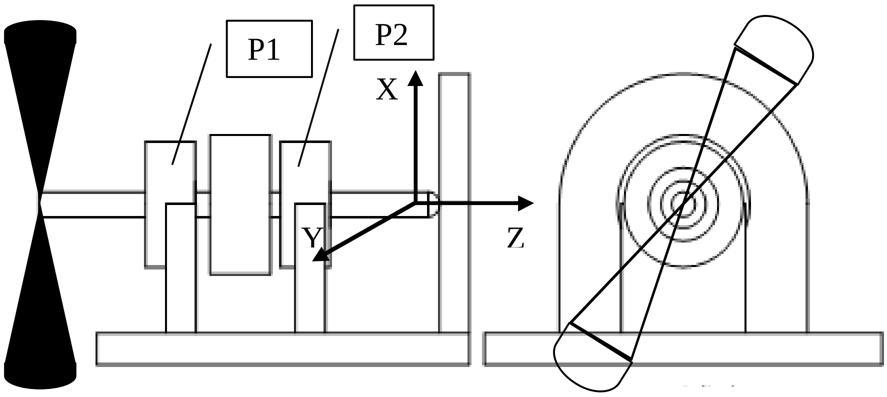
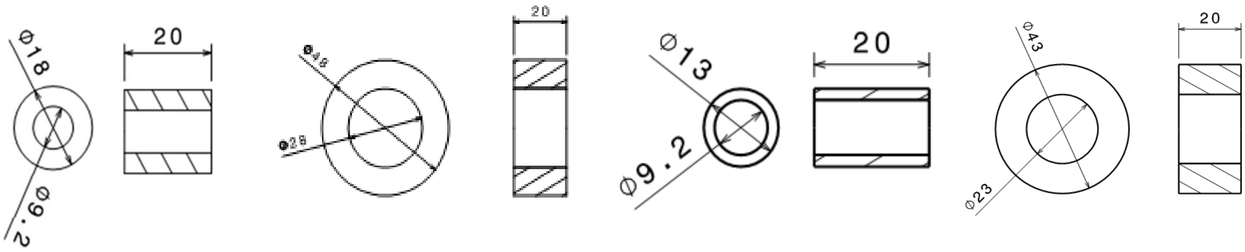


Fig 4 Arrangement of Bearing at Position P1 and P2

Magnet bearing dimensions are taken with respect to the size of journal bearing fitment in actual table fan. And two dimensioned sets are chosen for analysis. Case I for set A of bearing as shown in figure 5A, and Case II for set B of bearing as shown in Fig. 5B. The solid geometry to the real dimensions is constructed as ".igs" file in CATIA V5. And imported in an finite element analysis software "Altair's Hyperworks V11", fig 6 Shows screen shots for meshing of bearing set A & B respectively.



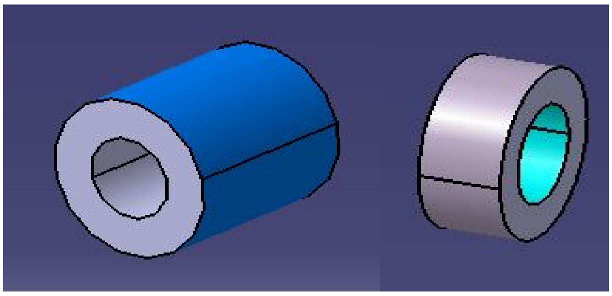


Fig. 5A Bearing Set 5A

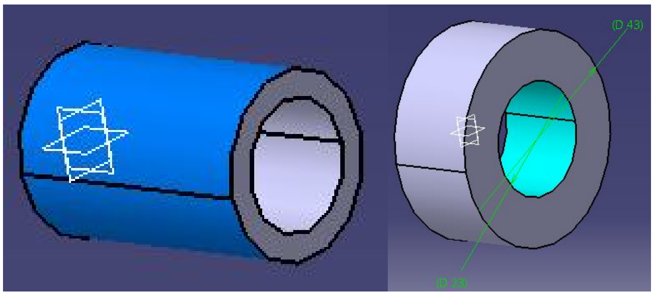


Fig 5B Bearing Set B

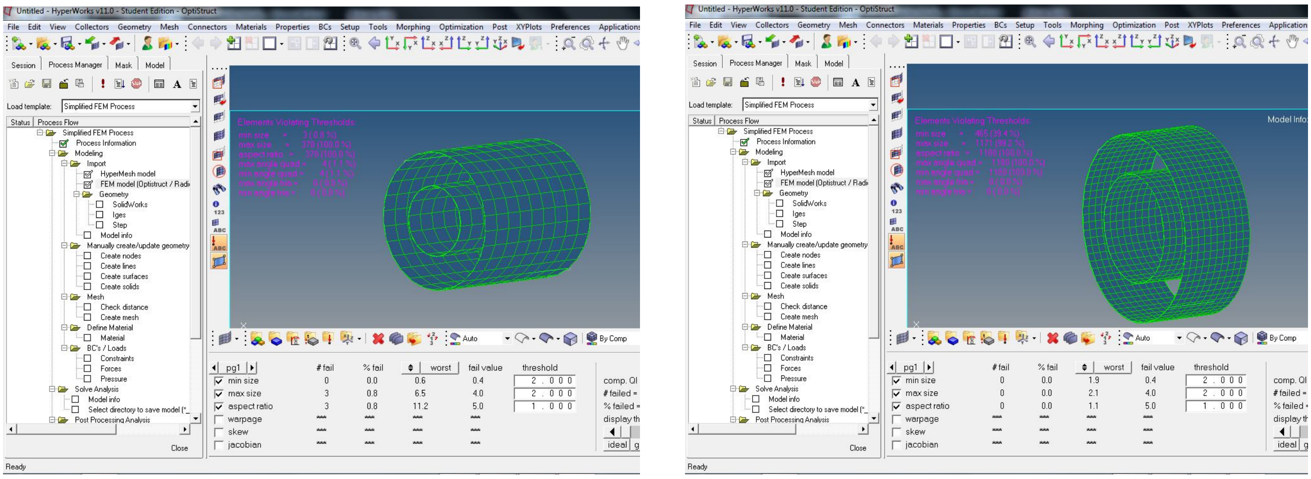


Figure 6A: Meshing of Bearing Set A

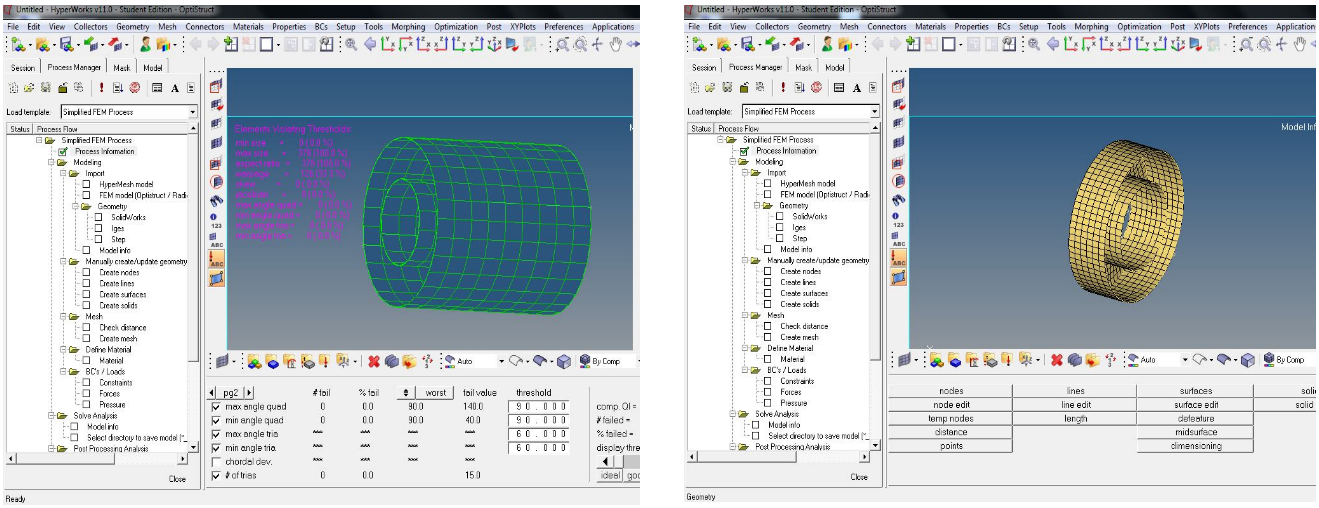


Figure 6B: Meshing of Bearing Set B

Results obtained for bearing set A & B after hexahedral meshing in "Altair's Hyperworks V11" are shown in Table I. Total number of elements obtained on various surfaces, responsible for repulsive force in bearing are counted and used in FORTRAN programming further.

Table I
COUNT OF MESHING ELEMENTS

	Bearing Set A		Bearing Set B	
	IM Ring	OM Ring	IM Ring	OM Ring
Number of Elements on Inner Surface	126	430	126	268
Number of Elements on Outer Surface	252	750	252	464

Radial force (Fx, Fy) and axial force (Fz), in two radial and one axial directions respectively are responsible for levitation of rotor. These forces for radially polarized ring magnets can be calculated with the equations (3),(4),(5) mentioned below [10]. Hexahedral meshing is carried out with the help of FEM software" Altairs Hyperworks V11" the output of meshing is mentioned for each set of bearing in Table I. Accordingly program is developed in FORTRAN to solve equation (3), (4), (5) for the output obtained in finite element meshing, A screenshot of a sample program is as shown in figure 6.

A. *Radial Force Developed By bearing:*

$$F_X = \sum_{p=1,q=1}^{p=n,q=m} F_{ApBqX} + \sum_{p=1,q=1}^{p=n,q=m} F_{ApDqX} + \sum_{p=1,q=1}^{p=n,q=m} F_{CpBqX} + \sum_{p=1,q=1}^{p=n,q=m} F_{CpDqX}$$

---------- (3)

$$F_Y = \sum_{p=1,q=1}^{p=n,q=m} F_{ApBqY} + \sum_{p=1,q=1}^{p=n,q=m} F_{ApDqY} + \sum_{p=1,q=1}^{p=n,q=m} F_{CpBqY} + \sum_{p=1,q=1}^{p=n,q=m} F_{CpDqY}$$

---------- (4)

B. *Axial Force developed by bearing in Z direction*:

$$F_Z = \sum_{p=1,q=1}^{p=n,q=m} F_{ApBqZ} + \sum_{p=1,q=1}^{p=n,q=m} F_{ApDqZ} + \sum_{p=1,q=1}^{p=n,q=m} F_{CpBqZ} + \sum_{p=1,q=1}^{p=n,q=m} F_{CpDqZ}.$$

---------- (5)

```
  PROGRAM Magnet_Bearing_Charecteristic
  IMPLICIT NONE

   INTEGER, PARAMETER:: m=430,n=252    !<---CHANGE the value of m =no. of discrete element on ou
>>ter magnet & n= no. of discrete element on innermagnet
   DOUBLE PRECISION :: Fx, Fy, Fz, a, b, Kxx, Kyy, Kzz
   DOUBLE PRECISION, PARAMETER:: x=5.0, y=5.0, z=5, dx=1.0, dy=1.0, dz=1.0  !<---------CHANGE th
>>e value of x,y,z,dx,dy,dz

   CALL Fofx(m,n,x,y,z,Fx)
   WRITE(*,*) "Fx is ",Fx

   CALL Fofy(m,n,x+dx,y,z,Fx)
   a=Fx
   CALL Fofz(m,n,x-dx,y,z,Fx)
   b=Fx

   Kxx=(a-b)/(2*dx)
   WRITE(*,*) "Kxx is ", Kxx


   CALL Fofy(m,n,x,y,z,Fy)
   WRITE(*,*) "Fy is ", Fy

   CALL Fofy(m,n,x,y+dy,z,Fy)
   a=Fy

   CALL Fofx(m,n,x,y-dy,z,Fy)
   b=Fy
   Kyy=(a-b)/(2*dy)

   WRITE(*,*) "Kyy is ",Kyy


   CALL Fofz(m,n,x,y,z,Fz)
   WRITE(*,*) "Fz is ",Fz

   CALL Fofz(m,n,x,y,z+dz,Fz)
   a=Fz

   CALL Fofx(m,n,x,y,z-dz,Fz)
   b=Fz
   Kzz=(a-b)/(2*dz)

   WRITE(*,*) "Kzz is ",Kzz

  END PROGRAM Magnet_Bearing_Charecteristic

  !--------------------------------------end of main program block----------------------------
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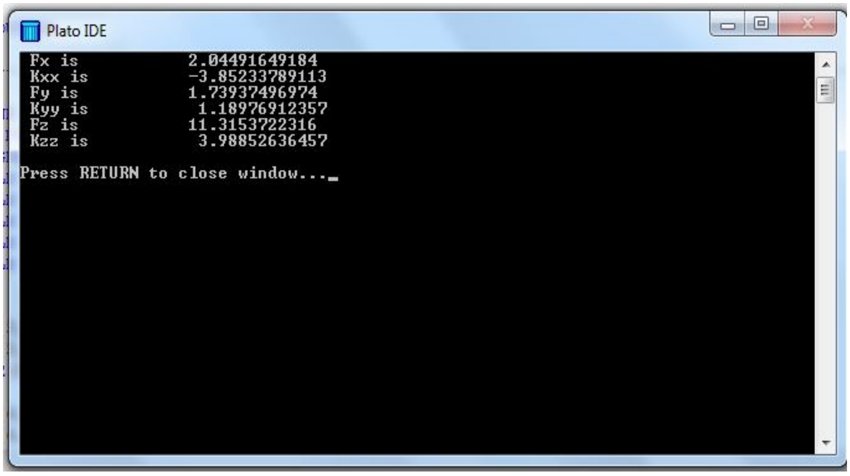

Fig. 6 FORTRAN Program to solve Force equation with Output's Screenshot

Table II shows the values of repulsive forces in three directions F_x, F_y, F_Z obtained by solving mathematical modelling equations in PLATO IDE, the values obtained are close to the values obtained by solving moments equation (1) & (2) for radial directions. The closest results are obtained in ring bearing set A, with consideration of values for various parameters in equations (3),(4),(5) as, surface flux density for magnet material (J)= 1.2 Gauss, Permeability(μ) = $1.00445 \times 10^{-6}\ H \cdot m^{-1}$, and 5mm air gap between both rings of set A.

Table II
VALUES OF FORCES

	Force Values in [N]		
Bearing Set	F_x	F_y	F_z
A	2.04	1.739	11.73
B	1.79	4.66	-5.39

VI. CONCLUSION

An innovative, economical and efficient solution is given to replace conventional journal bearing for table fan, which is a common mans asset for his comfort in life. Detailed study of conventional fan bearing used in domestic table fan is done. Use of radially polarized permanent magnets, is independent of any external energy input except small support for some axial direction, for instability in dynamics. By surface meshing using advanced softwares and using validated equations for force calculations the output obtained verifies the all three directional forces, closest to force values needed to levitate rotor shaft. While a small axial support for compensation will be needed. Reduction in power consumption can be achieved to positive extent, as friction in metal bearings is almost vanished with use of simple permanent magnetic radially polarized bearing.

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