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COMPARATIVE STUDY AND PARAMATRIC ANALYSIS OF CONVENTIONAL GEAR BOX BEARINGLESS GEAR BOX FOR THE MACHINE TOOL

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ABSTRACT

The inefficiency of gear box of a machine tool is a serious problem as it increases maintenance cost and also affects the reputation of a firm. Hence its life has to be increased and should be made more reliable. The work to be done here is to find, rectify the causes of failure of present gear box for Double disc surface grinding machine thereby improving the life of it. Also bearing failure which is also seen a prime cause of failure in present gear box needs to be reduced. The alternative for such problem is bearingless gearbox; which is achieved by either active or passive magnetic bearings. The benefits of a bearingless gear box are reduced maintenance and improved reliability, less lubrication requirements, precise peak torque transmission, inherent overload protection, physically isolated input and output shafts, misalignment tolerance, and low acoustic noise and vibration etc. So to reduce the problem of noise, backlash and bearing failure of present gear box, bearingless gear box will be effective. Analysis of the current gear box is done and modification is proposed. There will be two benefits out of it; the present errors will be solved and a modified design/arrangement will be available for the same gear box. This paper illustrates the approach for solving the problem of noise and backlash which led to the direction of using magnetic bearings.

Keywords: *Bearingless gear box, magnetic bearing and machine tools.*

1. Introduction

The efficiency of any machine tool depends upon the working of its different components and mechanisms. The functioning of the comprising components of a machine should be smooth for the continuous working of it and high output. But if one component starts to be deficient, it affects the reliability of the whole system. Gear box is the heart of a machine tool and if ever it doesn't function properly, it leads to a breakdown in near future. Here the gear box of double disc surface grinding machine was not giving its 100% and there were problems of backlash which resulted in noise.

In the double disc grinding process the workpiece is fed through to the two grinding wheels which are, up to the required specification, fixed or movable. Various working modes include rotary, through-feed, reciprocating, continuous and plunge grinding mode, which are selected according to process requirements. In such type of surface grinding machine tools, gear box is used to provide feed to the slide, to which grinding wheel is attached. Hence gear box is used to provide feed for surface grinding of workpieces. There were complaints regarding low efficiency of gear box of Double Disc Surface Grinding Machine. There were problems like noise, backlash, and with gradual time lapse, bearing failure was also observed. So instead of manufacturing gear box in-house, readymade gear box was imported. By doing so, the earlier design was altered and had to mount gear box externally, also the cost being high. Hence it was necessary to rectify the errors of gears, if any, and give a long time profitable solution for the bearing failure also. The present work is intended to rectify the error of the gear box and suggest a modification in the gear box for this machine tool.

There is also failure of bearing in case of gear box, and noise too, which shows that there may be metal contact that leads to failure. Hence the new or modification will be based on reducing that contact. The present work will be in the direction of designing bearingless gear box.

2. Analysis of the Present Gear Box

Based on reliability, causes of failures of engineering components and systems are as under.

- Poor Design
- Incorrect manufacturing
- Improper testing
- Complexity
- Improper maintenance
- Poor raw material
- Inadequate Quality Assurance
- Inappropriate packaging & transportation

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- Improper installation
- Lack of knowledge for operation
- Human error

Amongst the above listed causes, the important ones relevant or most effective for present work are design, manufacturing, maintenance. The design is made by keeping in my mind all the parameters and it is also compared with the same type of standardized gear boxes available for the same condition & application. Next comes the manufacturing, which is even more important because a good design can result in a failure/disaster if the manufacturing is not in a controlled way. And the last but not the least is maintenance, which if not done properly or timely, will surely lead to failure.

For the present work, data from the designer of the gear box and their manufacturers were taken in order to compare them and verify. Firstly, the drawings for the gear box were taken from the designer which shows the shaft diameter, pitch of the worm, bearings used etc.

It was clear from the comparison that dimensions were not maintained as per the design. Even the designer was consulted and the deviation in the dimensions of gear box was highlighted. The following points were observed at the gear manufacturing firm.

- Usage of old machines
- Lack of control over the process (milling)
- Lack of calibrated instruments
- Less skilled workers
- Improper and inefficient fixtures
- No quality assurance

Hence the quality and reliability should be improved by improving the working standards, controlling the environment, improving process control, and reducing human error.Keeping aside design and manufacturing, the other important factor is regular and proper maintenance in order to keep the machine tool in good working conditions. If the maintenance is not done periodically, chances of failure are strong. Also the lubricant's properties are to be monitored as it plays a crucial role in reducing friction and thereby reducing vibration.

But bearingless gear box, which works on the principle of magnetic levitation, frees one from the hectic maintenance schedules.

3. Bearingless Gear box

Bearingless gear box is a type of gear box in which the phenomenon of metal to metal contact of shaft and conventional bearing is eliminated. Hence the friction loss is reduced and also torque transmission achieved is more[4].

3.1 Replacement of conventional gear box

The defects in the bearing due to design or manufacturing may result in the failure of whole system. The vibration problems are generated due to defects in the rolling elements and hence solution is to be done to remove it. Hence any defect in the bearing may reduce the reliability of the whole system [1,2,3]. Some of the causes of premature bearing failure are as under.

- Dirt in the lubrication system
- Oil starvation
- Misassemble
- Improper machining of components
- Overloading
- Corrosion
- Cavitations

All these being the failures in shaft bearings, thrust bearings too have their own drawbacks. Thrust bearings run on a thin film of oil, just like radial journal (connecting rod and main) bearings, they cannot support nearly as much load, thrust bearings can only support loads of a few hundred psi. The vast majority of the bearing surfaces and the entire shaft surface are flat making it much harder to create and maintain an oil film. If you have ever taken two gauge blocks and wiped them perfectly clean and pressed them together with a twisting action you know that they will stick together. This is very much like what happens as a thrust load applied to the end of a crankshaft squeezes the oil out from between the shaft and bearing surfaces. If the load is too great, the oil film collapses and the surfaces want to stick together, resulting in a wiping failure. Magnetic bearings offer a myriad of operational advantages and efficiency improvement over traditional oil lubricated bearings[5].

3.2 Proposed Technology

3.2.1 Bearingless gear box

Bearingless Gear box actually is a gear box which does not consist of conventional ball/roller bearings. Instead it uses magnetic bearings.Magnetic bearings are contactless suspension devices, which are mainly used for rotating applications but also exist for translational ones. Their major interest lies of course in the fact that there is no contact and therefore no friction at all between the rotating part and its support. As a consequence, these bearings allow very high rotational speeds.

A magnetic bearing is a bearing which supports a load using magnetic levitation. Magnetic bearings support moving machinery without physical contact.

Permanent magnet bearings for rotating shafts are constituted of ring permanent magnets. The simplest structure consists either of two concentric rings separated by a cylindrical air gap or of two rings of same dimensions separated by a plane air gap. Depending on the magnet magnetization directions, the devices work as axial or radial bearings and thus control the position along an axis or the centering of an axis. The point is that in each case the basic part is a ring magnet. Therefore, the values of importance are the magnetic field created by such a ring magnet, the force exerted between two ring magnets and the stiffness associated. Some advantages of magnetic bearing are as under.

- No contacts.
- No Abrasion
- Close to Zero friction
- No Noise or Vibration
- Extreme Life time expectancy
- No lubricants
- No Maintenance
- Cost effective
- Ultra High Performance
- Enabling Extreme high speed operation [5]

3.2.2 Types of magnetic bearings

There are basically two types of magnetic bearings existing at normal temperature.

- Active Magnetic Bearings
- Passive Magnetic Bearings

3.2.2.1 Passive magnetic bearings

The passive magnetic bearings do not need any sensors and electronic equipments for control and extra input energy, so they are compact and suitable to use. The possible ways to achieve passive magnetic bearings are by using superconductors, diamagnetic, eddy current effect and permanent magnets.

The simplest type of passive magnetic bearing is the structure consisting of only permanent magnets. PM bearings are magneto-mechanical elements and they offer relative motion between the moving parts without any physical contact by utilizing the attractive or repulsive forces generated between the magnets. The suitable characteristics (no lubrication, no maintenance, no power and no input energy etc.) of PM bearings made of ring magnets are utilized in many applications such as energy storage flywheels, turbo molecular pumps, hard disk drive spindle motors, moment gyro applications and conveyor systems [6].

3.2.2.2 Active magnetic bearings

Active magnetic bearings are replacing oil-lubricated bearings in many applications. The benefits of using magnetic bearings in rotating machinery include higher reliability with little or no maintenance, reduced frictional losses, no contaminating or flammable lubricants, reduced machine vibration, and improved health monitoring and diagnostics.

An active magnetic bearing consists of a stator, which contains the electromagnets and the position sensors, and the rotor, which rotates with the shaft. When the magnetic bearing is operating, each magnetic bearing rotor is ideally centered in the corresponding stator so that contact does not occur. The position of the shaft is controlled using a closed-loop feedback system. The position sensors detect the local displacements from the shaft, and these signals are sent to a digital controller. The controller processes these signals, and calculates how to re-distribute the currents in the electromagnets to restore the shaft to its centered position. Power amplifiers in the controller then readjust the currents in the electromagnets according to the calculations.

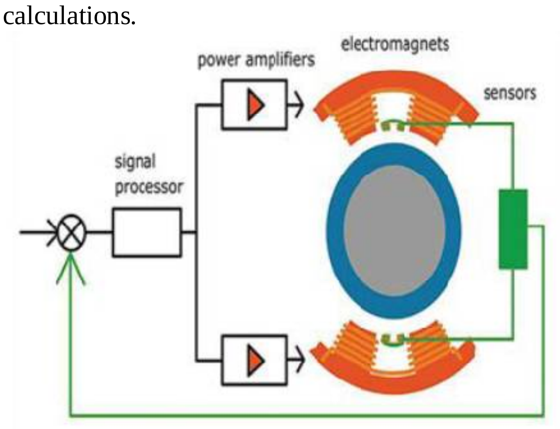

Fig.1 Control system of active magnetic bearings [5]

In the present work, we are using permanent magnetic bearings, which work on the principle of magnetic levitation due to magnetic repulsion. The magnets used for permanent magnetic bearings are either ferromagnets or Neodymium-Iron-Boron magnets which are more powerful, and compact in size than the conventional ferromagnets, electrodynamic magnets, superconducting materials, diamagnetic materials, ferrofluids. Some of the permanent magnetic bearings available in the foreign market for specific applications are shown below comprising of ring magnets [5].

(a) (b) (c)

Fig.2 Different types of permanent magnetic bearings (a) Single row intermediate bearing for hollow shafts (b) Double row intermediate bearing for hollow shafts (c) Quad row external magnet bearing for solid shafts[7]

The advantages and disadvantages of bearingless gear box over conventional gear box is mentioned below.

3.2.2.3 Advantages

- Reduced maintenance
- Improved reliability
- Less lubrication requirements
- Precise peak torque transmission
- Inherent overload protection
- Physically isolated input and output shafts
- Misalignment tolerance
- Low acoustic noise and vibration[4]

3.2.2.4 Disadvantages

- More initial cost
- Lack of damping(Passive Magnetic bearing)

Though it has some disadvantages, but it certainly has more number of advantages. Also the load variation can be compensated and its break-even point can be achieved very early as it reduces the metal to metal contact.

3.2.3 Experimental set up & data collection

In order to show the possibility and feasibility of the permanent magnetic bearings for the present work, i.e. gear box, a prototype is made consisting of four bar magnets, two ring magnets, a small cylindrical wooden log which will represent the shaft of the gear box. The repulsive forces are utilized for the magnetic levitation. Using the same concept, further development can be done to make permanent magnetic bearings for the same application and others too. The specifications of the magnets used for the prototype are listed below.
The dimensions of the bar magnets are mentioned below:

Length, L= 25 mm
Width, W= 10 mm
Height, H= 40 mm

The two ring magnets are used for making the prototype. The picture and dimensions of the same are mentioned below.
Internal Diameter, I.D.= 24 mm
Outer Diameter, O.D.= 52 mm
Width, W= 10 mm

Fig.3 Photograph of bar magnets used for the prototype

The prototype is made using a wooden base plank, making slots for the bar magnets, making a wooden shaft that will replicate the original shaft, and which will pass through or will carry the ring magnets. The main concept is to levitate the shaft carrying the ring magnets on it. Hence the concept of “repulsion” is to be incorporated, which is the dominant force while using the permanent magnet bearings. So now it is required to place the ring magnets above the bar magnets in such a way that we get the maximum of repulsive force, which won’t allow the ring and the bar magnets to come in contact.

Fig. 4 Photograph of wooden prototype

The 3D model of the above prototype is made using the 3D modeling software Creo Parametric 2.0. The model is made as per the original scale of the prototype. The different commands that are used in generation of the model are extrude, revolve, mirror etc. The assembly of the individual part is done and is presented below.

The prototype was allowed to rotate freely and the speed was noted with respect to time. The free rotation was allowed and the data of speed v/s time was noted and is plotted on the graph as below.

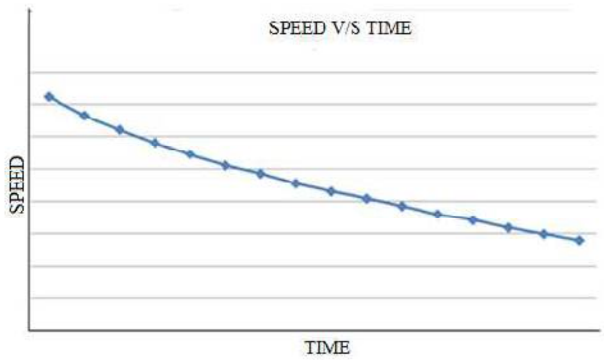

Fig.5 Speed v/s time graph

During the experiment of the prototype, when the vibrations start, a support is provided at its free end, and the vibrations are totally damped. Hence in the real practice, if we provide a simple support of a glass or a plate perpendicular to the axis of shaft, the vibrations can be damped, thereby making it sable and steady for low speed operations too. The proposed model modification for damping the vibrations is shown by the help of 3D model below.

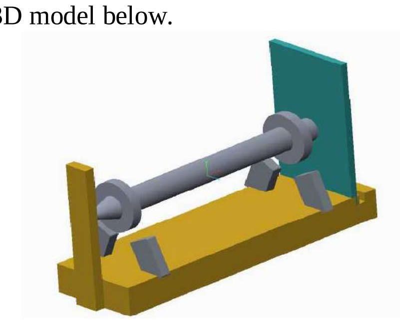

Fig. 6 Proposed model for vibration damping

3.2.3.1 Calculations

Some of the equations and calculation of torque, required for the design of permanent magnetic bearings are mentioned below.

Motor used for the input:- 0.5 hp
= 0.5 *745.69 watt
=372.845 watt
No. of Rotations(rpm) =1440 rpm
Now Power, P =(2π NT)/60
Hence Torque, T =2.473 N m

The formula related to radial load calculation in x-direction is given by Backer and is mentioned below.

$$F = \frac{LRM_0^2}{4\mu_0}(1-e^{-2\pi d/\lambda})^2 e^{-2\pi g_0/\lambda}\int_{-\pi}^{\pi} e^{-2\pi x/\lambda\cos\phi}\cos\phi d\phi$$

Where L=Length of magnet stacks
R=Radius of magnetic rings
M_0=Magnetization co-efficient
μ_0 =Magnetic permeability
λ=Distance between extreme ends of two consecutive ends [8].

The integral in the above equation is a series and hence the exact solution of that integration cannot be found. So it has been calculated keeping it as a function of x, which is the displacement due to loading. Recognizing that this integral can be expressed in terms of an *n*th order modified Bessel function of the first kind commonly denoted as I_n and normalizing by the area $2LR$, we have the force equation for the sinusoidal magnetized radial bearing,

$$\frac{F}{2LR} = \frac{\pi M_0^2}{4\mu_0}(1-e^{-2\pi d/\lambda})^2 e^{-2\pi g_0/\lambda} I_1(2\pi x/\lambda)$$

Note that all length parameters appear normalized by λ. As a consequence, all the design parameters are conveniently expressed as dimensionless quantities [8]. Some values are assumed based on the dimensions and working parameters of present gear box and are substituted in the above equation. Based on that a formula is obtained, using which different trials can be done and results can be obtained. The formula obtained is shown below.

M_0 I_1(392.5 x)=2273.2

The assumptions of the values for above formulation were made based on the present gear box data. The values for the same are as under.

- F= 50*9.81 N
- L=60 mm=0.06 m(6 magnets of width 10 mm assumed)
- R= 55mm= 0.55 m (As the outer radius of rotor is 50 mm)
- M_0 = 0.12 T
- d=15 mm=0.015 m
- λ=16 mm=0.016 m
- g_0= 45 mm=0.045 m
- μ_0 = 12.56*10^{-7} H/m

4. Summary

Bearingless gear box, comprising permanent magnets remove the use of conventional bearings for the support of the shaft, thereby removing the metal to metal contact and reducing friction. Further use of active magnetic bearings can be done which work by the use of electromagnets, controller and sensors which are more accurate but costlier than passive magnetic bearings. Also magnetic gears can be developed for co-axial speed reduction, which is costly, but very efficient as it removes the friction loss of gear meshing.

5. Future Scope

Other than magnetic bearings, magnetic gears are also on their way to replace the conventional gears. In magnetic gears, bipolar or multi-polar magnets are mounted on the stator and rotor. A cage, comprising of steel bars, separates the stator and rotor maintaining the air gap. These steel bars cut the magnetic flux induced by the magnets of stator and rotor and hence it starts to rotate. This rotating cage is connected to the output shaft and hence we obtain direct reduction of speed [4]. If we use a ball bearing for the support in magnetic gear, then it is called Pseudo Direct Drive (PDD).

Acknowledgement

We acknowledge the manufacturers of the machine tool for providing us an opportunity to deal with the existing problem with novel approach. Although the approach is not new the application is a novelty in the field of bearingless gearbox in machine tool.

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