MAGNETIC FORCE ANALYSIS FOR MAGNETIC GEAR APPLICATION

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Abstract

Magnetic gears (MG) are one of the latest and most eccentric innovation in mechanical gear technology due to this reason a lot of consideration is shown in magnetic gear research in the recent period. This paper represents magnetic force analysis for the magnet which is to be used in the magnetic gear. The analysis is done with the help of software to find the Magnetic force field for the selected NdFeB rare earth metal magnet and at the same time analyse its magnetic force at different airgap with several condition like between magnet to magnet & magnet to ferrous metals. The data obtained is further analysed to find magnetic field strength at varying airgap.

Key word *— Magnetic gear, Magnetic force analysis, experiment, NdFeB, pole slip, airgap, rare earth permanent magnets, Magnetic flux density*

I. INTRODUCTION

The history magnetic gear (MG) is started when Armstrong in 1901 proposed a design of an electro-magnetic spur type gear. The MGs work on a basic working principle which is very similar to that of the usual or we can say conventional mechanical gears except the fact that here the power transmission which is exerted using by tooth meshing is replaced with the contactless magnet force. Initial MGs improvement mostly engrossed on spur type and worm type topologies. Essentially, a MGs can be designed according to respective obtainable topology of its similar mechanical gear system [1].

MGs stands as an appealing alternative technology indicating possibility of substantial benefits above conventional mechanical gear such as bi-directional and zero contact power transfer, lubrication free operation, inherent overload safety, high torque density, feasible for high efficiency and insignificant or no maintenance [2].

A MG seem like in part with the customary mechanical gear aside from the cogwheels of each gear section of magnetic gears are arranged in an alternate periodic manner of opposite magnetic poles on mating surfaces. A MG is constituted of different type of magnets like permanent (includes both ferrous & rare earth type), electromagnetic and/or any different type which can magnetically induced fields. A minimum of two or more components that are typically revolving but can be linear or curve linear in characteristic. When it comes to working it is fairly simple with the magnetic poles “pulling” & “pushing” the poles present in the other rotor. Each rotor is made up of permanent magnets with a radial field. The shaft which has to rotate slower and provide higher torque has a greater number of poles. The fundamental of working of the MG can also be explained as the consequence of attraction & repulsion occurring among the magnetic field created by the magnet pole pair of the magnetic gear [3].

MG technology can be said to be at its start point compared to the development in the field of the conventional mechanical gears. The somewhat intricate building and design process of MGs & associated with the cost of manufacturing, magnets, etc. put it at back foot in comparison to the conventional gears. The rewards that this machinery could bring are hefty and encourages for further development. [1]

In this work the magnetic force are analysed for the magnet which is to be used in the magnetic gear for further experiment work. The permanent magnets can be simply divided into two types: Simple ferrous magnets & Rare earth magnets.

For the purpose of magnetic gear most of the time rare earth metal permanent magnet are used & among this category the most used are Neodymium based, it can also perform well under the limit of certain temperature limits.

II. LITERATURE SURVEY

P.O. Rasmussen and the team developed an early design of the recommended MG which was designed, analysed and optimized using an analytical model concerning torque density. The tentative test model was able to reach up to 33 Nm. Optimizations for cycloid gears revealed that there was a possibility to reach high torque densities. A cycloid MG may well be able to possibly a choice for future applications where a motor/ generator is incorporated together with the cycloid-gear design, power-split devices for hybrid cars, wind turbines with a fixed-speed synchronous generator, etc. [2]

The principle of function of a novel form of magnetic gear is shown which is predominantly suitable to the usages in which a high gear ratio is required. The change in airgap length and magnetic force due to the permanent magnets instilled in the MG, are modified such that a synchronous space harmonics are generated by one set of magnets consisting of same number of poles as the other set of permanent magnets, and vice-versa. A practical dual-stage execution of the magnetic harmonic gear, which exhibits a gear ratio that is greater than the outcome of the product of ratios of the different stages [5].

Uppalapati et al performed experiments whose outcomes are presented in terms of low-speed flux-focusing in three several types for the magnetic gearboxes. Utilizing ferrite and NdFeB and also a hybrid design which consists of ferrite magnets are used in the internal rotor and NdFeB magnets are used in the outside rotor and the running of the magnetic gearbox is compared. Experimental results for this three cases shows Remarkable disagreements among the calculated and measured torque values for the ferrite and hybrid came into picture and this was because the ferrite magnets not having the expected magnetic properties. To be precise the hybrid MG functioned superior than the ferrite system MG [6].

The airgap between the magnetic gears plays a vital role in torque density & essence of magnetic field in the performance of the Magnetic Gear and by making suitable air gap a high power ripple free transmission can be achieved. The type of magnet have vast effect on the performance as we are working with permanent MG this research work. It is a significant parameter which is needed to be taken in consideration. (NdFeB are one of the best permanent magnets available).Low speed gear box may suffer more ripple but it depends on design features.

It can be said that with increasing the magnetic field area for example using more no. of gear will result in higher torque transfer. By using stronger permanent magnet &/or hybridising them with ferrous magnet results in increase in efficiency. By modulating the magnetic gear with the help of steel pole pieces results in better performance as well as reduce in rippling. An anatomy between the mechanical gear & a magnetic gear can be seen but the working is a lot different [1], [2].

III. MAGNETIC FORCE ANALYSIS

For the purpose of magnetic gear most of the time rare earth metal permanent magnet are used & among this category the most used are Neodymium based, it can also perform well under the limit of certain temperature limits. In MG the no of pole pieces & there capability to transfer the required torque is important by varying the size of the magnet or the distance between them a no. of combination of gear ratio can be obtained for the same diameter rotor. Even though the magnet size & pole distribution is different for each MG of the transmission pair they will still transfer the torque as there is no meshing requirement like mechanical gear where similar profile is required.

Neodymium magnets are considered in the category of Rare Earth magnet family and are the most powerful permanent magnets in the world.

They are also mentioned to as NdFeB or NIB magnets, for the reason that they are comprised mainly of Neodymium (Nd), Iron (Fe) and Boron (B). Neodymium magnets are more than ten times powerfull than the strongest ceramic magnets.

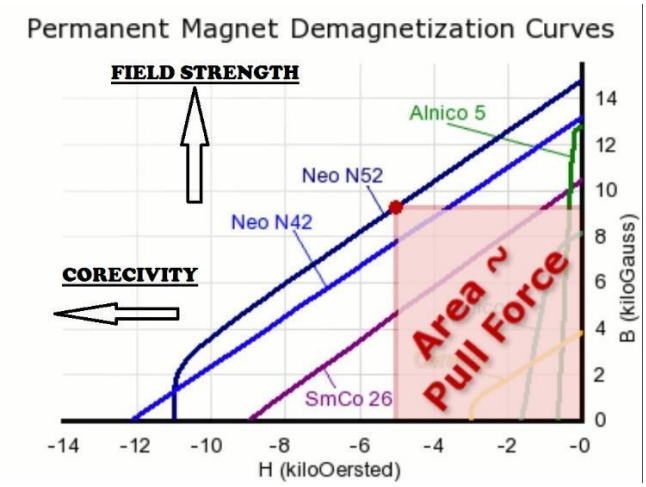

Fig. 1: Demagnetization curve

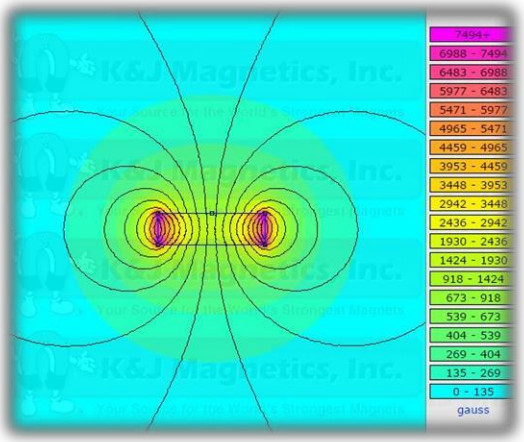

Fig. 2: Magnetic Flux Density

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The Fig 1. Represents the Demagnetization curve for the magnet. It is also indicating the corecivity, field strength according to the grade. And for understanding things better demagnetization curve explains the magnetic potentials of a permanent magnet further wholly than a single values of Pull Force or Surface Field. It presents knowledge about the strength of the magnet, how tough it is to demagnetize, and how a magnet's shape (or use in a magnetic circuit) influences matters.

The Fig 2 shows the magnetic field force distribution for our case as it can be interpreted from the distribution near the pole the magnetic field line concentration is higher which in return enhances the magnetic force in that specific region. The magnetic force is represented in terms of gauss (G) which is the CGS unit for it. The SI unit is Tesla (T) where 1T = 10000G.

Before going for magnetic force the concept of air gap is very important as it will be an important role player in the working of the Mg's. Airgap (g), it is important to have the most suitable air gap between the two gears.

By using rare-earth magnets, a high torque density can be achieved, with efficiencies in excess of 97% for transmitted torque values higher than 75% of the pull-out torque [12].

In our calculation we have taken 5 set of calculation where each set is for specific air gap corresponding to two conditions which are further divided as shown below:

1. Pulling force (due to attraction)
    a. Against steel plate (SP)
    b. Between steel plates (BSP)
    c. Magnet to magnet (MTM)
2. Repelling force (due to repulsion / similar pole property)

The air gap considered are 2, 4, 6, 8 & 10 mm are analysed with respect to the selected magnet using software. With the use of analysis important data has been obtained which can be further utilized to have data analysis as well. The table 1 represents the results:

Where; SP: STEEL PLATE, BSP: BETWEEN STEEL PLATES, MTM: MAGNET TO MAGNET

A graph is shown in Fig 3 above which is representing magnetic force with respect to the air gap and as it can be seen magnetic force whether it was pulling or repelling is best between magnet to magnet conditions. Also the magnetic force keeps decreasing with the increase of air gap & it will reach to zero at a certain high enough air gap.

Table 1: Magnetic force analysis

SR. NO.	AIR GAP		MAGNETIC FORCE			
			PULLING FORCE (lb : pound)			REPELL FORCE (lb)
	in : inch	mm	AGAINST SP	BSP	MTM	MTM
1	0.394	10	0.39	0.62	1.32	1.32
2	0.315	8	0.67	1.1	1.94	1.94
3	0.236	6	1.23	2.05	2.92	2.92
4	0.157	4	2.4	4.08	4.6	4.6
5	0.079	2	5.25	9.11	7.83	7.83

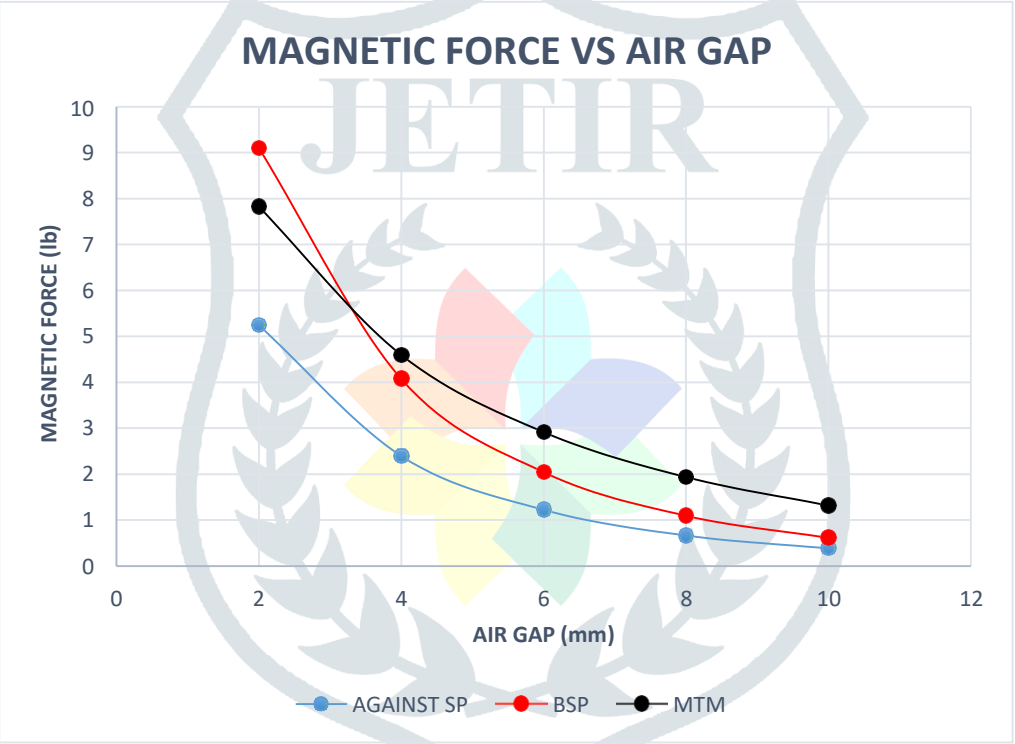

Fig. 3: Magnetic force vs Airgap

From the graph we can see three cases of magnetic forces. Among them in the case of this work magnet to magnet (MTM) situation occurs between the Magnetic Gears. The graph shows how the force is increasing with decrease in air gap. Also the steep rising of magnetic force can be seen when air gap decreases from 4mm to 2mm. The highest value is found at 2 mm air gap 7.83 lb (32.87 N)

IV. RESULTS AND DISCUSSION

From the literature survey & data gathering it has been found that in permanent magnets the rare earth metal magnets are the most powerful & by narrowing down according to functional requirement we came to understand the application requirement and thus selected the required magnet type & size.

The magnetic Field force is measured for different airgap & it is observed that increase in airgap results in decrease in magnetic force. The lowest value is obtained at the airgap of 10 mm which is 0.39 lb at a condition force field between magnet & a steel plate.

From comparing all the values from analysis the condition where the interaction is between the two magnets shows the best results among all the other cases.

From the results of magnetic force which is shown in Figure 2 maximum magnetic force for the chosen size of the magnet is around 7500 Gauss (G).

V. CONCLUSION

With the help of software the magnetic field strength analysis which is done for different air gap & also the data regarding the magnetic flux density are generated which shows that the strength of magnet is higher in a particular zone compared other field area. It has been found that as we move closure to the magnet the magnetic force field increases but at a very close range it may decrease as well.

By doing the Magnetic force analysis we understand that the magnetic force produce is inversely proportional to Air gap that is if air gap increases the magnetic force decreases. Also the highest pulling & repulsion magnetic force is to be found 32.87 N is obtained when there is interaction between the two magnets at the airgap of 2 mm.

So theoretically it can be said that when this magnets are used for Magnetic gear & at the time of perpendicular contact at the airgap of 2 mm it can have the power to transmit the maximum of the 32.87 N.

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