# Cost-Effectiveness Comparison of Coaxial Magnetic Gears with Different Magnet Materials

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***Abstract*—This paper presents a comparative study between the non-rare-earth permanent magnet (PM) and rare-earth PM based coaxial magnetic gears. Firstly, by using finite element analysis, the electromagnetic performances of four coaxial magnetic gears which are installed with non-rare-earth PMs or rare-earth PMs are analyzed and quantitatively compared based on the same structure. Then the cost-effectiveness of coaxial magnetic gears adopting different types of PMs is assessed. The results support that the non-rare-earth PM, especially the aluminum-nickel-cobalt (Alnico), is preferred for application to coaxial magnetic gears.**

***Index Terms*—Magnetic gear, finite element analysis, non-rare-earth, rare-earth, permanent magnets, cost-effectiveness comparison.**

## I. Introduction

Magnetic gears offer the advantages of free of contact, inherent overload, silent operation and improved reliability over the traditional magnetic gears [1]-[3]. They can be integrated into electric machines to further improve the torque density [4]-[5]. These attractive characteristics are mainly attributed to the permanent magnet (PM) materials. Nowadays the neodymium-iron-born (NdFeB) and samarium-cobalt (SmCo) are two common types of rare-earth PMs whereas the aluminum-nickel-cobalt (Alnico) and ferrite are two common types of non-rare-earth PMs for application of magnetic gears. Recently there are ever-increasing concerns on the price and supply of rare-earth PMs although the rare-earth PMs have better performance.

The purpose of this paper is to present a comparative study between non-rare-earth PM and rare-earth PM based coaxial magnetic gear. By using finite element method (FEM), the electromagnetic performances of magnetic gears which are installed with non-rare-earth or rare-earth PM materials are analyzed and compared. Then the cost-effectiveness comparison among different types of PMs is assessed.

## II. Performance Comparison

In order to conduct a fair comparison, the four coaxial magnetic gears, which are installed with Alnico, ferrite, NdFeB and SmCo respectively, adopt the same topology. The corresponding configuration is shown in Fig. 1[2]. By using finite element analysis, the electromagnetic performances of these four magnetic gears are evaluated and quantitatively compared. Firstly, the torque performance waveforms of the Alnico based magnetic gear are simulated as depicted in Fig. 2. Secondly, similar waveforms of the ferrite based magnetic gear are obtained as shown in Fig. 3. Thirdly, similar waveforms of the NdFeB based magnetic gear are shown in Fig. 4. Fourthly, similar waveforms of the SmCo based magnetic gear exhibit in Fig. 5.

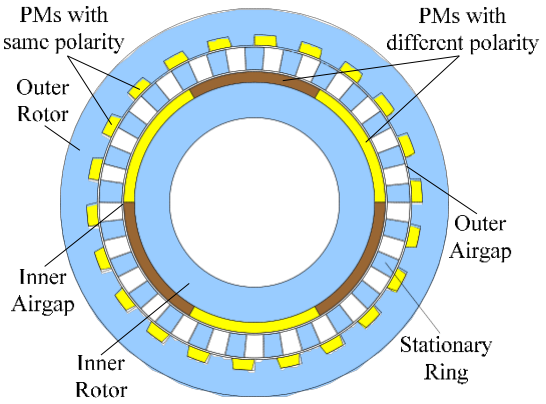


Fig. 1. Configuration of interior-magnet outer-rotor magnetic coaxial gear

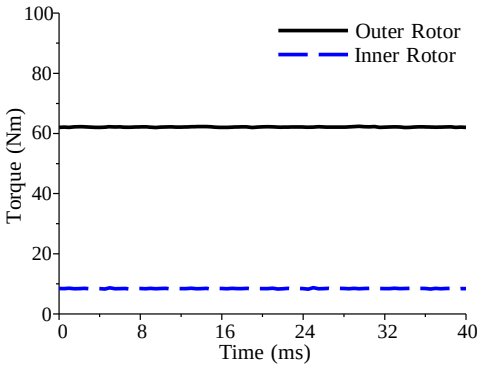


Fig. 2. Steady torque waveform of the Alnico based magnetic gear

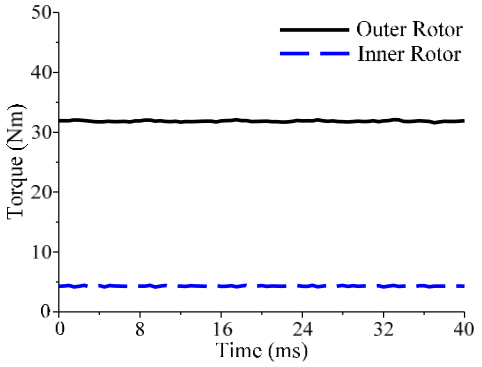


Fig. 3. Steady torque waveform of the Ferrite based magnetic gear

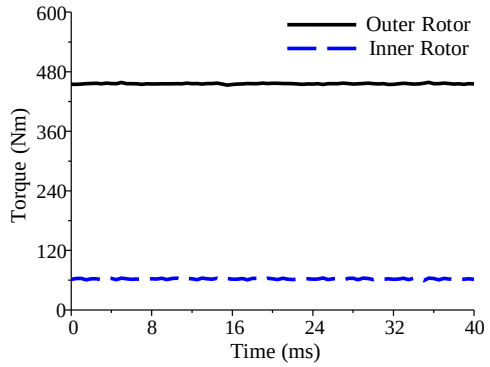


Fig. 4. Steady torque waveform of the NdFeB based magnetic gear

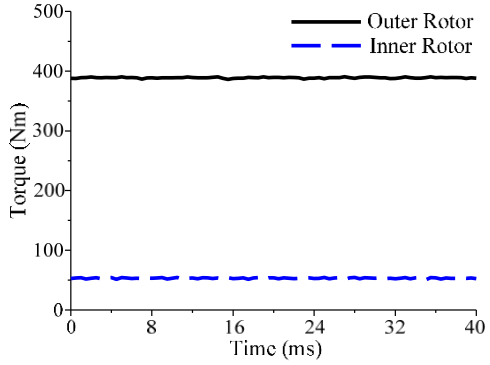


Fig. 5. Steady torque waveform of the SmCo based magnetic gear

TABLE I
ELECTROMAGNETIC PERFORMANCE COMPARISON

| | Outer rotor torque [Nm] | Inner rotor torque [Nm] |
|---|---|---|
| Alnico | 62.15 | 8.45 |
| Ferrite | 31.85 | 4.35 |
| NdFeB | 456 | 62 |
| SmCo | 389 | 53 |

As expected, it is obvious that the rare-earth PMs based magnetic have better performance than the non-rare-earth PMs based magnetic gears. The steady torques developed at the outer rotor and inner rotor of the Alnico based magnetic gear are about 62.15 Nm and 8.45 Nm respectively, which are almost 7 times lower than the torques transmitted by the NdFeB based magnetic gear which exhibits about 456 Nm and 62 Nm. Meanwhile, the steady torques developed at the outer rotor and inner rotor of the ferrite based magnetic gear are about 31.85 Nm and 4.35 Nm respectively, which are almost 12 times lower than the torques transmitted by the SmCo based magnetic gear which shows about 389 Nm and 53 Nm. Table I gives the data of the performance comparison.

## III. Cost-effectiveness Comparison

In order to conduct a fair comparison, the raw material prices of these four types of PM materials are considered, while neglecting the product prices which are significantly influenced by many factors such as supply and demand as well as government policy. Their raw material prices can readily be calculated according to the current market prices of individual elements and the chemical compositions of these four PMs.

Consequently, the steady torque of outer rotor is taken as the key indicator to reflect the cost-effectiveness. Table II gives the detailed data of the cost-effectiveness comparison. The key is that all the three linear magnetic gears adopt the same volume of PMs (978 $cm^3$). It is obviously that the non-rare-earth PM based magnetic gears are more cost-effective than the rare-earth PM based magnetic gears. Although the Alnico based magnetic gear possess low torque output (62.15Nm), it is most cost-effective. Namely, its cos-effectiveness is only 1.197 USD/N which is only 18.2%, 25.3% and 74.6% lower than that of the ferrite one (1.4153 USD/N), NdFeB one (1.5 USD/N) and SmCo one (2.09 USD/N). Considering the abundant reserves of all required elements and high Curie temperature for Alnico, it is preferred to other types of PM based magnetic gears.

TABLE II
COST-EFFECTIVENESS COMPARISON

| | Alnico | Ferrite | SmCo | NdFeB |
|---|---|---|---|---|
| Volume [$cm^3$] | 978 | 978 | 978 | 978 |
| Density [$g/cm^3$] | 6.7 | 5 | 8.4 | 7.5 |
| Composition | 8%-12%Al; 15%-26%Ni; 5%-24%Co; Up to 6%Cu; Fe (balance) | $BaO{\cdot}6Fe_2O_3$ or $SrO{\cdot}6Fe_2O_3$ | 35%Sm; 60%Co; 2.5%Fe; 2.5%Cu | 29%-32.5%Nd; 63.9%-68.6%Fe; 1.1%-1.2%B; 0.6%-1.2%Re |
| Br [T] | 1.05 | 0.3 | 1.0 | 1.1 |
| Outer rotor steady torque [Nm] | 62.15 | 31.85 | 389 | 456 |
| Cost-Effectiveness Price [USD/N] | 1.197 | 1.4153 | 2.09 | 1.5 |

## IV. Acknowledgments

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