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Design and Analysis of Concentric Magnetic Gear for Speed Enhancer

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Abstract: Magnetic gears have gotten a lot of attention and become rivals to mechanical gear in recent years. Among many types of Magnetic gear (MG), the Concentric Magnetic Gear (CMG) has been more focused on research studies and development. With benefits delivered from MG such as high efficiency in the case of the magnetic gear, harmonics are used to advantage by making use of specific characteristics of these harmonics to realize a gear action between input and output rotors. The MG has been designed and published with the new structures that have been studied by the researcher in the past year. There are many types of structures of CMG that function as the speed reducer in which the inner rotor moves at a high speed which resulted in the outer rotor moving slowly between the air gap and the modulator. In this project, several types of methods had been proposed to design and analyse the performance of Concentric Magnetic Gear for speed enhancers. To analyse the performance of the Concentric Magnetic Gear Speed reducer. To propose the concept of a Concentric Magnetic Gear speed reducer arranging magnet to apply in speed enhancer. The method used to design a CMG speed enhancer is variable the reverse the amount of PM of inner and outer CMG speed reducer. The amount of inner PM/outer PM of design for speed reducer is 12/28 while speed enhancer has been proposed as D1, D2 and D3. The result of this project focused on output torque, the gear ratio and gear efficiency. The torque output produced more than torque input for the CMG speed enhancer. In a conclusion, the torque analysis has been analyzed and has been compared with the other 3 designs. The 28/12 CMG speed enhancer has the best performance of torque analysis at a different speed that has been simulated by observing the graph and the mean of the torque.

Keywords: Concentric Magnetic Gear, Speed Reducer, Speed Enhancer.

1. Introduction

Magnetic gears have gotten a lot of attention and become rivals to mechanical gear in recent years. Among many types of Magnetic gear (MG), the Concentric Magnetic Gear (CMG) has been more focused on research studies and development. With benefits delivered from MG such as high efficiency, low noise, low maintenance and overload protection comparable to mechanical gears. The potential applications for this novel gear technology include industrial drives, material handling, electric vehicles,

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and wind turbine applications [1]-[2]. The research has been made since in 19th century as an alternative to mechanical gear with the use of the permanent magnet force. The main concept of CMG was using the North (N)-poles and South (S)-poles of permanent magnets (PMs) to replace the teeth and slots of mechanical gear in spur and worm structures [3]-[6]. High-order magnetic flux harmonics are normally unwanted because they cause torque ripple or loss, as well as overheating and reduced efficiency in electrical devices. In the case of the magnetic gear, harmonics are used to advantage by making use of specific characteristics of these harmonics to realize a gear action between input and output rotors [7]. The Discovery of MG by K.Atallah in 2001 proposed CMG that yields 100kN.m/m3 of torque density [8]. The inner rotor and outer rotor share a common axis and various structures had been researched that adopt the Flux modulation Technique used in CMG. The result of the flux modulation techniques enables good modulation of magnetic field and thus, produces high torque transmission between two rotors.

2. Methodology

In this project, the concentric magnetic gear (CMG) speed reducer was designed with the structure and implementation of the material with the specification to achieve the best result. The specific design in part of the gear, inner rotor, outer rotor, permanent magnet, and pole pieces has been approached in used for design and analysis data. For a better understanding of the process of developing a structure of CMG speed reducer and speed enhancer, the flow of this project will cover the structure of CMG Speed reducer and its concept to implement into CMG speed enhancer.

2.1 Specification

A 2D modelling of structure CMG speed reducer and speed enhancer is designed by using Geometry Editor with the specification to analyse. The part that needs to design is Inner Rotor, Outer Rotor, Permanent Magnet, and pole piece. The Specification of the Geometry Structure of CMG is shown in Table 1.

Table 1: The Specification of Geometry Structure of CMG speed reducer and speed enhancer.

Item	Value
Number of Inner magnet pole pairs (Speed Reducer)	12
Number of Outer magnet pole pair (Speed Reducer)	28
Number of Inner magnet pole pairs (Speed Enhancer)	28, 56, 112
Number of Outer magnet pole pair (Speed Enhancer)	12, 24, 36
Number of pole piece pole pairs	25
Inner rotor diameter, mm	68.5
Outer rotor diameter, mm	90
Gap Between inner rotor – pole piece	2
Gap Between pole piece - inner rotor	1
Stack length	30

2.2 Material

Neodymium iron boron (NdFeb) with a 1.2T remanence is the material used for the PM, whereas the inner rotor, outer rotor, and pole piece. The pole is made of NSSMC 35H210. Eddy's current loss is not considered.

2.3 Conditions

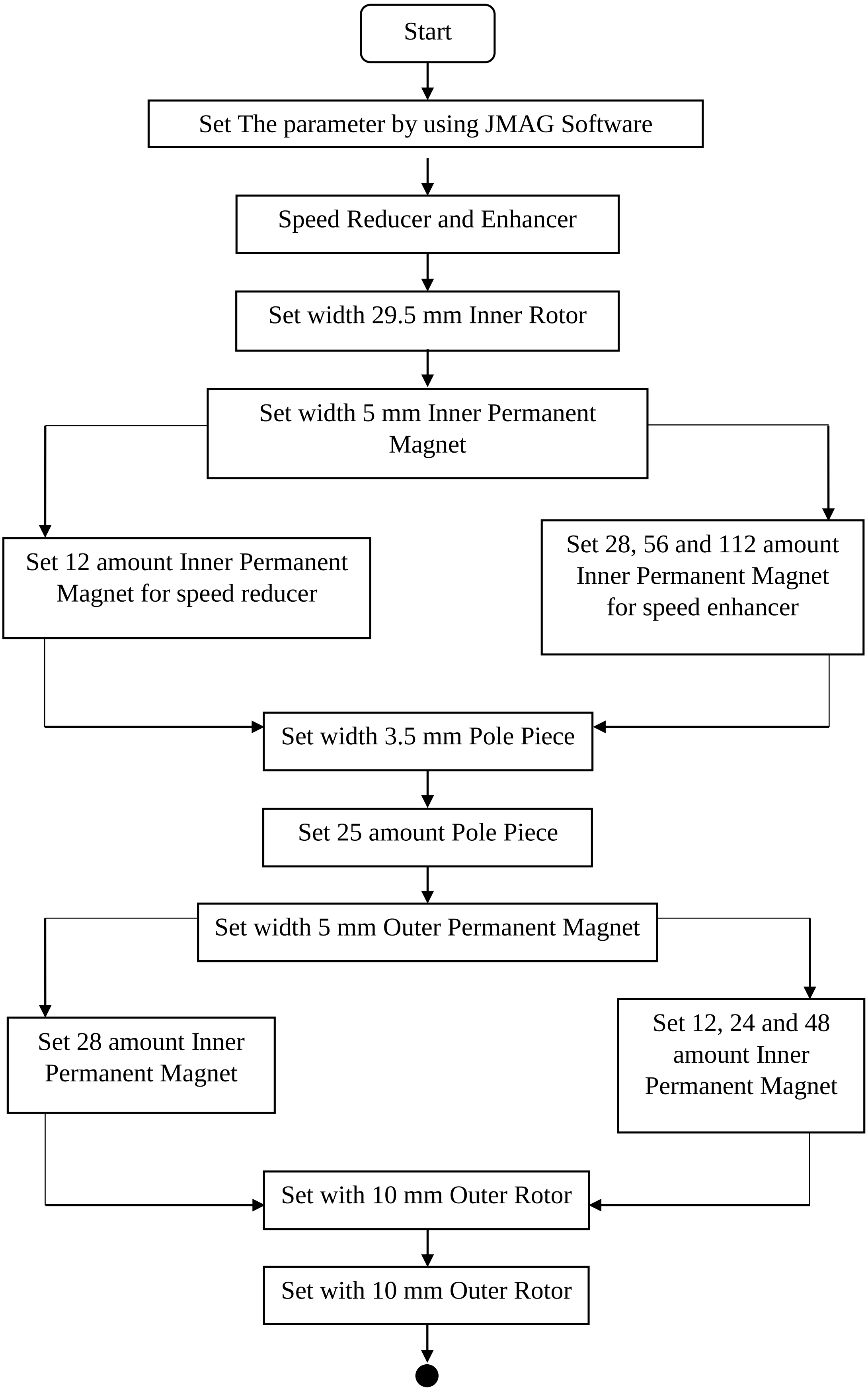
The condition will cover the speed of the inner rotor, outer rotor and magnetization pattern that will use in this simulation. Table 2 for the condition of the CMG speed reducer and speed enhancer.

Table 2: Drive condition specification CMG speed reducer and speed enhancer.

Item	Value
Inner rotor revolution speed reducer, rpm	700
Outer rotor revolution speed reducer, rpm	300
Inner rotor revolution speed enhancer, rpm	300, 600, 900, 1200, 1500
Outer rotor revolution speed enhancer, rpm	700, 1400, 2100, 2800, 3500
Inner rotor rotation	Clockwise
Inner rotor rotation	Anti-Clockwise
Magnetization pattern	Radial Anisotropic pattern

2.4 Flow Chart

This project focused on two part of modelling which is geometry editor and JMAG Designer. The Geometry Editor was used to draw for Inner Rotor, Outer rotor, Permanent Magnet and Pole Pieces while the JMAG Designer was used to implement for the material, and condition of the simulation. The flow chart of the project in Figure 1 illustrates a deep understanding of the modelling structure for both CMG.


Start
Set The parameter by using JMAG Software
Speed Reducer and Enhancer
Set width 29.5 mm Inner Rotor
Set width 5 mm Inner Permanent Magnet
Set 12 amount Inner Permanent Magnet for speed reducer
Set 28, 56 and 112 amount Inner Permanent Magnet for speed enhancer
Set width 3.5 mm Pole Piece
Set 25 amount Pole Piece
Set width 5 mm Outer Permanent Magnet
Set 28 amount Inner Permanent Magnet
Set 12, 24 and 48 amount Inner Permanent Magnet
Set with 10 mm Outer Rotor
Set with 10 mm Outer Rotor

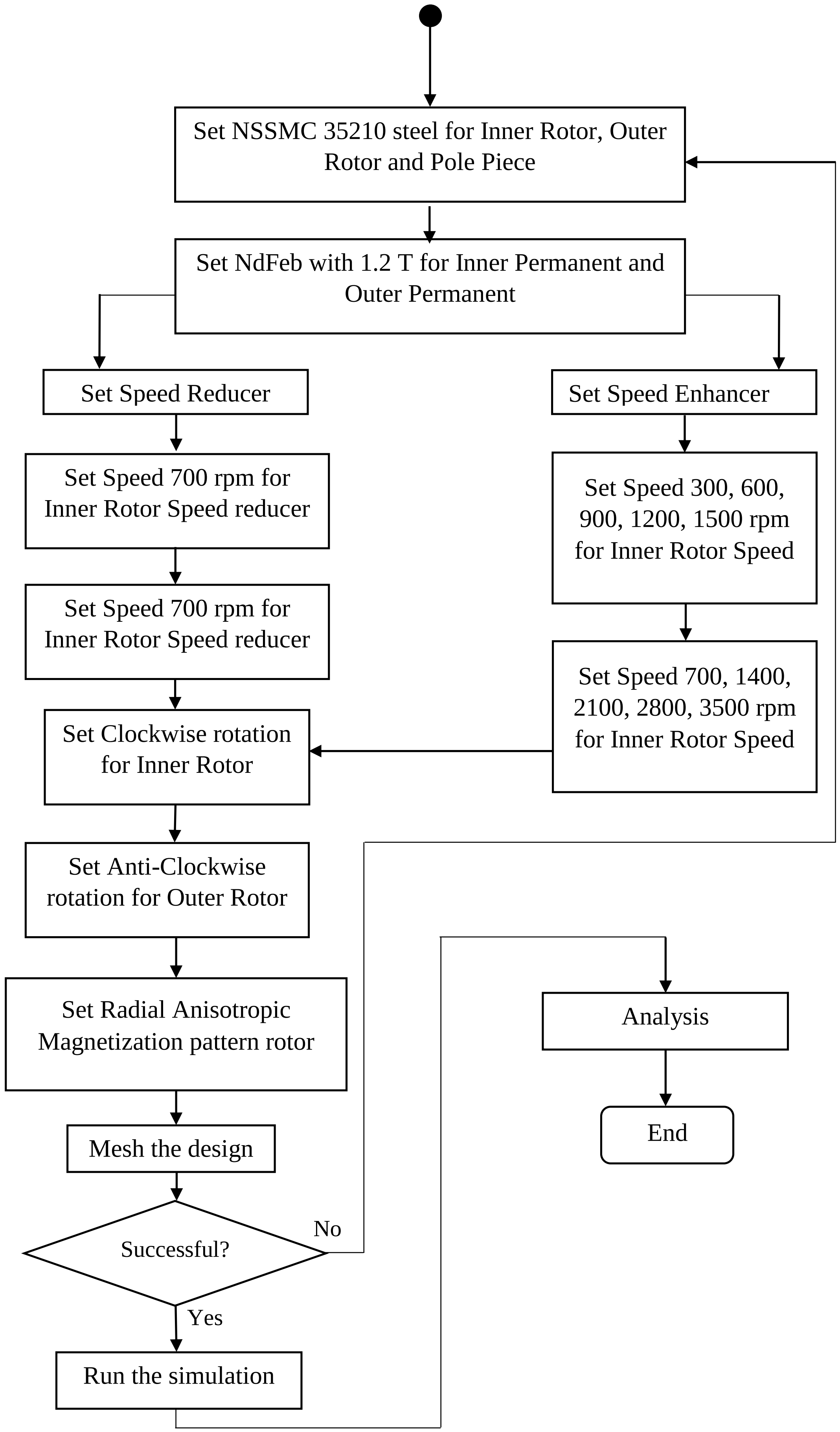


Figure 1: Flow chart of the process all design CMG speed reducer and speed enhancer.

2.5 Model of design Concentric Magnetic Gear for speed reducer and speed enhancer.

The design of the structure CMG Speed reducer and enhancer has been proposed by using JMAG software. There are 1 type of design CMG speed reducer and 3 different types of design speed enhancers with consist different numbers of PMs. Figure 2 is the CMG speed reducer while Figure 3, 4, and 5 is speed enhancer. The structure CMG speed enhancer is labelled as D1, D2 and D3 with the set amount of PM.

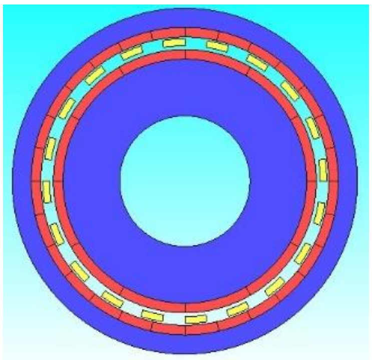


Figure 2: The structure of model CMG speed reducer where inner PM is 12 and outer PM is 28.

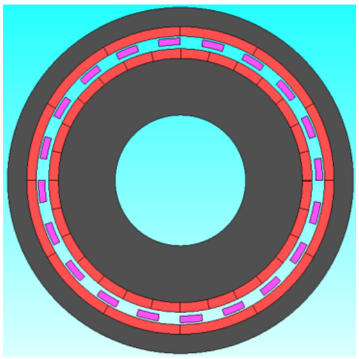


Figure 3: The structure of model CMG speed enhancer as D1 where inner PM is 28 and outer PM is 12.

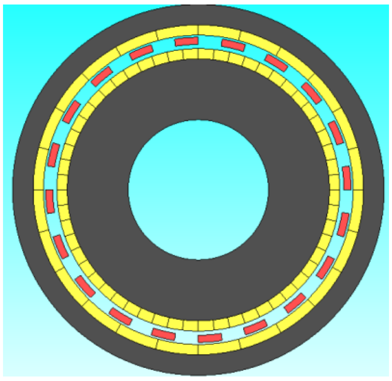


Figure 4: The structure of model CMG speed enhancer as D2 where inner PM is 56 and outer PM is 24.

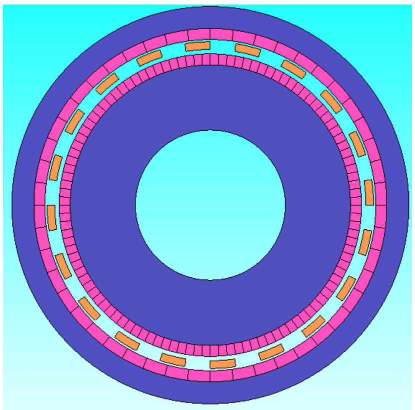


Figure 5: The structure of model CMG speed enhancer as D3 where inner PM is 2112 and outer PM is 48.

3. Results and Discussion

In this section, the performance of the CMG speed reducer and speed enhancer is analyzed mainly for the torque, gear ratio and gear efficiency. The performance is analyzed as torque, degree of rotation gear, the gear ratio and gear efficiency.

3.1 Speed reducer.

Based on Figure 6, shows the simulation response of the CMG speed reducer when the parameter. Based on the graph, torque from the outer rotor have almost linear than the inner rotor which it is show the constant ripple. It can study that the inner rotor graph almost synchronizes with the outer rotor. The mean torque of the inner rotor is 1.5757 Nm while the mean for the outer rotor is 0.5966 Nm. The gear ratio is 2.877 while the gear efficiency is 16.23%.

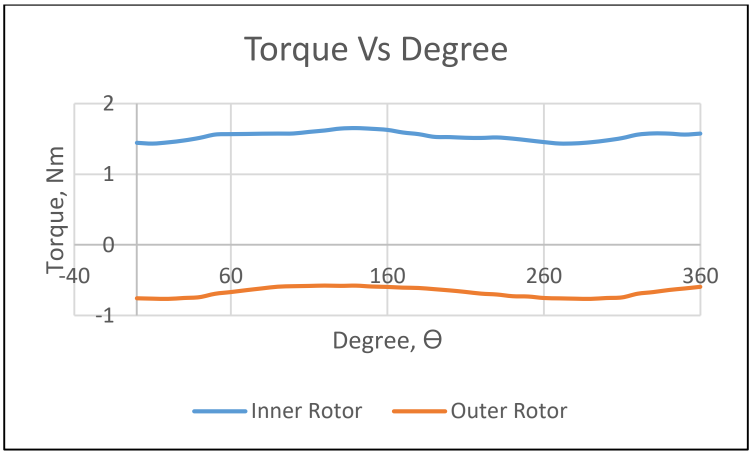


Figure 6: Graph Torque against the degree of rotation for Concentric Magnetic Gear (CMG) speed reducer.

3.2 Speed enhancer.

The performance of the CMG speed Enhancer is analyzed mainly to the outer torque, gear ratio and gear efficiency. There 3 different types of designs of CMG speed enhancers and each of them has different pole pair. The 3 designs of the CMG speed enhancer it observed with 5 different speeds of the rotor to analyze the performance of the torque. It shows the output torque among different speeds.

(i) Speed enhancer 300/700.

Based on Figure 7, it can conclude that D1 CMG produces the highest mean output torque which is 0.5123 Nm followed by D2 CMG produce 0.024 Nm. The lowest produce means output torque is D3 CMG which is 0.0009 Nm. Based on the graph, D2 CMG has the best performance of 3 CMG because the gear efficiency of D2 CMG is the highest and the waveform is close to a sinusoidal wave showing that the rotation is well performed.

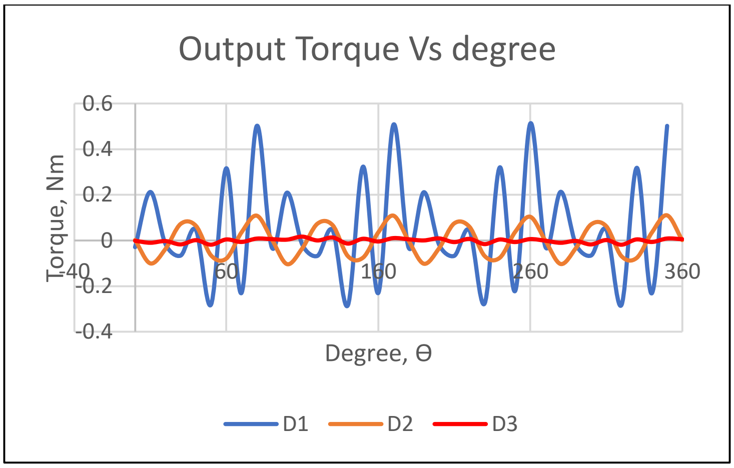


Figure 7: Graph Torque against degree for 3 type design Concentric Magnetic Gear (CMG) speed enhancer.

(ii) Speed enhancer 600/1400.

Based on Figure 8, it can conclude that D1 CMG produces the highest mean output torque which is 0.0012 Nm followed by D2 CMG produce 9.576e-05 Nm. The lowest produce means output torque is D3 CMG which is 4.3345e-05 Nm. Based on the graph, D1 CMG has the best performance of 3 CMG because the gear efficiency of D1 CMG is the highest which is 82.14% and the waveform is close to a sinusoidal wave showing that the rotation is well performed.

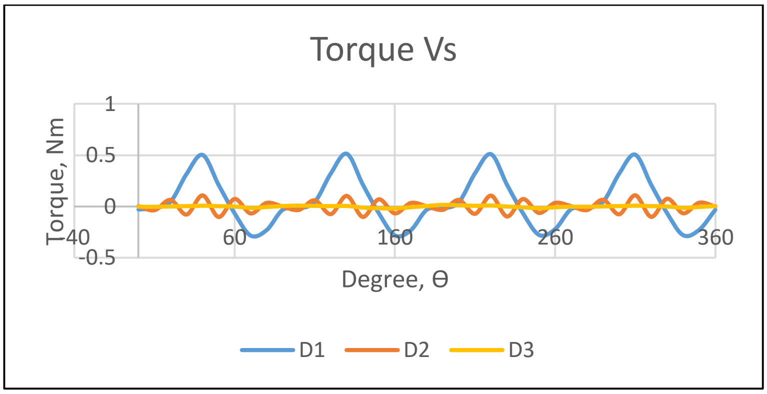


Figure 8: Graph Torque against degree for 3 type design Concentric Magnetic Gear (CMG) speed enhancer.

(iii) Speed enhancer 900/2100.

Based on Figure 9, it can conclude that D1 CMG produces the highest mean output torque which is 0.0742 Nm followed by D3 CMG produce 0.0005 Nm. The lowest produce means output torque is D2 CMG which is 0.0002 Nm. Based on the graph, D1 CMG has the best performance of 3 CMG because the gear efficiency of D1 CMG is the highest which is 62.32% and the waveform is close to a sinusoidal wave showing that the rotation is well performed.

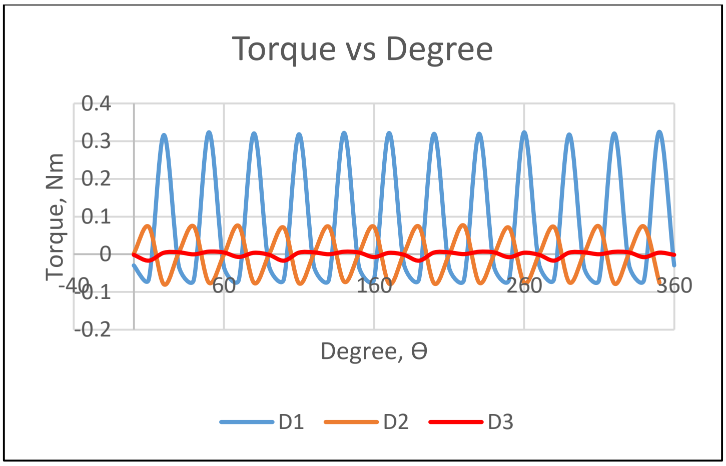


Figure 9: Graph Torque against degree for 3 type design Concentric Magnetic Gear (CMG) speed enhancer.

(iv) Speed enhancer 1200/2800.

Based on Figure 10, it can conclude that D1 CMG produces the highest mean output torque which is 0.0510 Nm followed by D3 CMG produce -0.00021 Nm. The lowest produce means output torque is D2 CMG which is 0.0001 Nm. Based on the graph, D3 CMG has the best performance of 3 CMG because the gear efficiency of D3 CMG is the highest which is 85.71% and the waveform is close to a sinusoidal wave showing that the rotation is well performed.

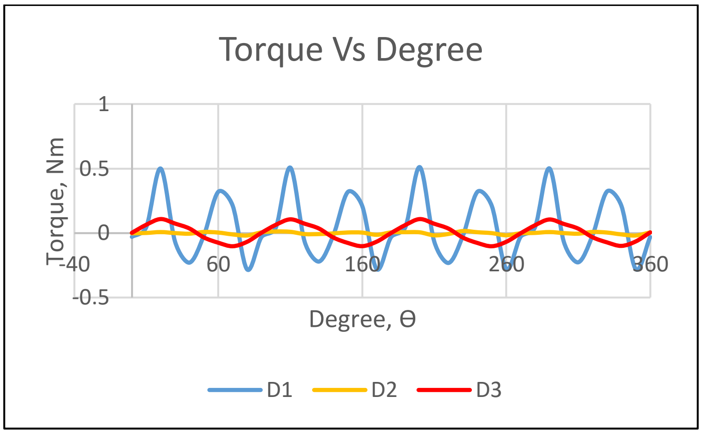


Figure 10: Graph Torque against degree for 3 type design Concentric Magnetic Gear (CMG) speed enhancer.

(v) Speed enhancer 1500/3500.

Based on Figure 11, it can conclude that D1 CMG produces the highest mean output torque which is 0.0510 Nm followed by D2 CMG produce -6.0258e-05 Nm. The lowest produce means output torque is D3 CMG which is 0.0004 Nm. Based on the graph, D1 CMG has the best performance of 3 CMG because the gear efficiency of D1 CMG is the highest which is 95.8% and the waveform is close to a sinusoidal wave showing that the rotation is well performed.

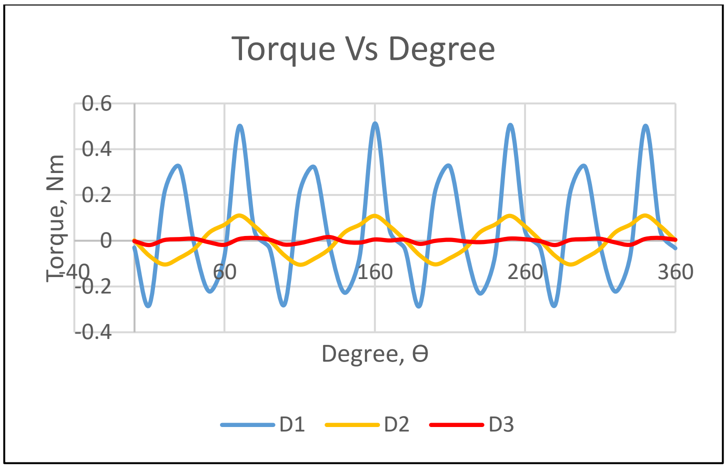


Figure 11: Graph Torque against degree for 3 type design Concentric Magnetic Gear (CMG) speed enhancer.

3.3 Comparison performance CMG speed enhancer

Based on Figure 12 is the performance gear efficiency for 5 speeds with different types of design CMG. The analysis of the CMG Speed Reducer has been studied to produce a method for CMG Speed Enhancer. The D1 has the best performance of torque analysis at 600/1400 rpm, 900/1200 rpm and 1500/3500 rpm which has been simulated by observing the graph and the mean of the torque. The D2 has the best performance of torque analysis for 300/700 rpm and the highest mean torque. The D3 has the best performance of torque analysis for 1200/2800 rpm and the highest mean torque.

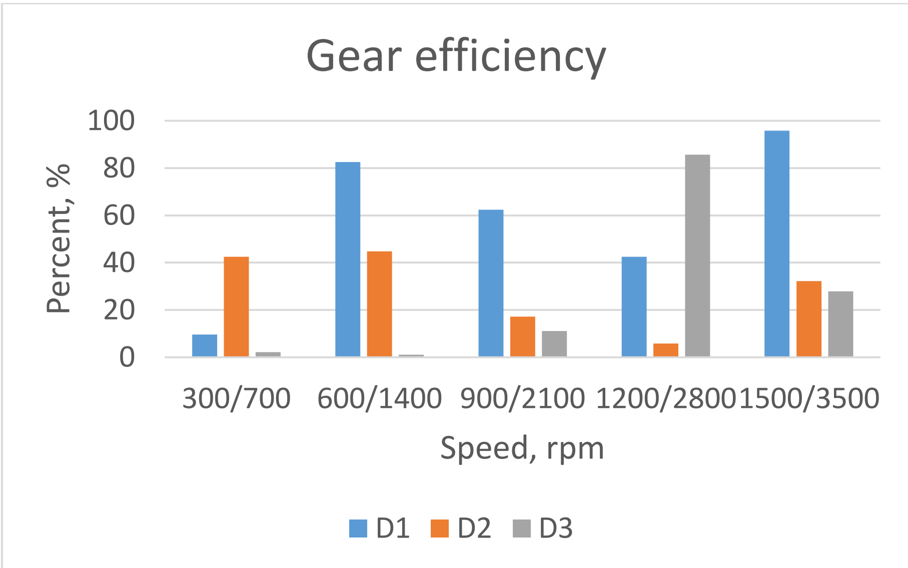


Figure 12: Performance gear efficiency for 5 speeds with a different type of design CMG.

4. Conclusion

In this chapter, the simulation that is performed will be concluded from the observation taken and discussed the result of torque analysis of the speed reducer and speed enhancer of CMG. The observation of this project is focusing on the torque produced by both CMG by manipulating the amount of the pole pair. The simulation has been done with coming out the proposed design and analysis using JMAG Software in JMAG Geometry and JMAG Designer. It can allow designing all components Magnetic and desired conditions to make it easier to analyze the torque at different speeds. The objective of this project is to analyze torque performance at a different speed for CMG Speed Enhancer. The gear ratio that uses is in every CMG is 2.33, while the speed is 300/700, 600/1400, 900/2100, 1200/2800, and 1500/3500 rpm. There 3 types of designs which use different types of amounts of PM. These 3 types of design are represented as D1, D2 and D3. The D1 use 28 inner PM and outer 12 PM, D2 use 56 inner PM and outer 24 PM and finally D3 use inner 112 PM and outer 48 PM. The D1 has the best performance of torque analysis at a different speed that has been simulated by observing the graph and the mean of the torque.

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References

[1] R-J Wang, S. Gerber, "Magnetically geared wind generator technologies: Opportunities and challenges", Applied Energy, 136:817-826, Elsevier, 2014.

[2] N. Niguchi, K. Hirata, M. Muramatsu, and Y. Hayakawa," Transmission Torque Characteristics in a Magnetic Gear", XIX International Conference on Electrical Machines (ICEM), 6p, Rome, Sept. 2010.

[3] Neves, C.G.C., Figueiredo, D.L., Nunes, A.S.: Magnetic Gear: A Review. 2014 11th IEEE/IAS Int. Conf. Ind. Appl. 1–6 (2014). https://doi.org/10.1109/INDUSCON.2014.70594 17.

[4] Rasmussen, P.O., Andersen, T.O., Joergensen, F.T.: Development of a HighPerformance Magnetic Gear. In: Industry Applications Society Annual Meeting (IAS). pp. 1696–1702 (2003).

[5] Furlani, E.P.: A Two-Dimensional Analysis for the Coupling of Magnetic Gears. IEEE Trans. Magn. 33, 2317–2321 (1997).

[6] Kikuchi, S., Tsurumoto, K.: Design and characteristics of a new magnetic worm gear using permanent magnet. IEEE Trans. Magn. 29, 2923–2925 (1993).

[7] A. Matthee, S. Gerber and R-J Wang, "A High Performance Concentric Magnetic Gear", Conference Paper, January 2015.