Extended Abstract

Experimental Testing and Dynamic Modelling of a Planetary Magnetic Gearbox Prototype

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1. Introduction

Magnetic gears are an innovative solution for power transmission systems that relies on the interaction of magnetic fields instead of mechanical contact to transfer torque and motion. This contactless operation leads to reduced wear and tear, reduced noise and vibrations, and elimination of lubrication, as well as providing an inherent overload protection in case of excessive torque inputs.

A particularly effective model of this technology is the coaxial Planetary Magnetic Gearbox (PMG), which adapts the traditional robustness and reliability of the epicyclic gear design with the advantages deriving from the magnetic torque transmissions, while retaining high enough transmissible torque density values. A coaxial PMG prototype was developed at Politecnico di Torino, consisting of two pairs of magnetic wheels acting as the sun and the ring of an epicyclic gear, and a set of ferromagnetic poles, acting as the planets, that can axially shift between the two wheels passing through a neutral position.

2. Objective and Methodology

This study had two main objectives: first, to conduct a detailed experimental testing of the PMG prototype, and second, to develop and validate a dynamic model built in Simulink environment that is capable of accurately replicating the configuration of the test bench and its working conditions.

The experimental tests have been performed using two different scenarios: Neutral tests, used to isolate and quantify the mechanical losses due to bearing friction, and Engaged tests, used to evaluate the total system losses and transmission efficiency, as well as its mechanical and magnetic contributions. While both sets of tests were already previously performed, a revised procedure was implemented to ensure thermal stabilisation of the system before the data acquisition process, enhancing the repeatability, accuracy and consistency of the measurements. Additionally, the adoption of a correction factor was introduced to adjust the neutral losses, compensating for any residual magnetic effect that was not fully eliminated when the PMG was in disengaged configuration.

The results of the experimental tests served as the reference base for the development of a Simulink dynamic model of the test bench: while the corrected neutral losses have been inserted into the system to simulate the bearings losses, the engaged tests results have been used to fit the damping coefficients of the PMG prototype and to compare the final losses and performance values. The digital model fully resemble the prototype's architecture, including the model of its motors, inertia and transmission elements, bearings, and the coaxial Planetary Magnetic Gears, which interaction has been simulated via the adoption of previously computed Finite Element Method (FEM) torque maps.

While the prototype allows for the study of two different sets of gears, namely first gear and second gear, the engaged tests and the dynamic model simulations focused exclusively on its first gear configuration.

3. Results

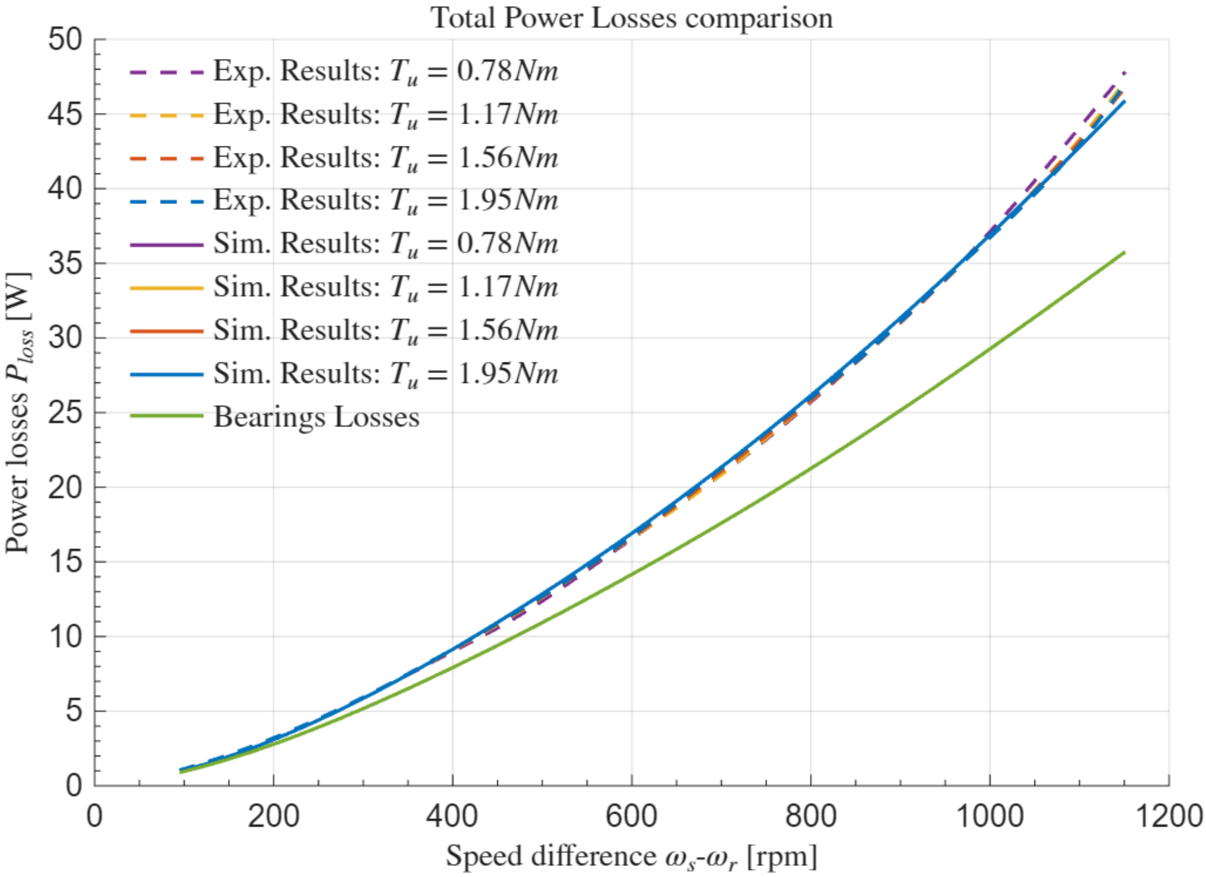
One of the main contributions relates to the experimental testing of the test bench, where the newer methodology applied to the data acquisition showed significant improvements in either sets of tests. While in the neutral tests the mechanical losses follow trends that are much more physically consistent, in the engaged tests there was an improvement towards the repeatability of the results, with performance results that are much less dependent on the applied loads configurations. Additionally, the definition of a correction coefficient applied to the neutral tests results led to an accurate depiction of the magnetic losses in the prototype, which has been essential for the estimation of its magnetic damping coefficients.

Other important results come from the creation of a consistent and accurate dynamic model of the system under study, which has demonstrated great capabilities of replicating the performances of the prototype, with an average prediction error of the total efficiency below 0.5% across all load scenarios. Furthermore, the simulation results confirmed that the main source of power losses inside the system is due to the mechanical friction of the bearings in the PMG assembly, accounting for $60\% - 80\%$ of the total losses. Overall, the model demonstrated strong predictive capabilities of the dynamic behaviour of the test bench, validating its use as a simulation tool that can be adopted for further evaluation and analysis.

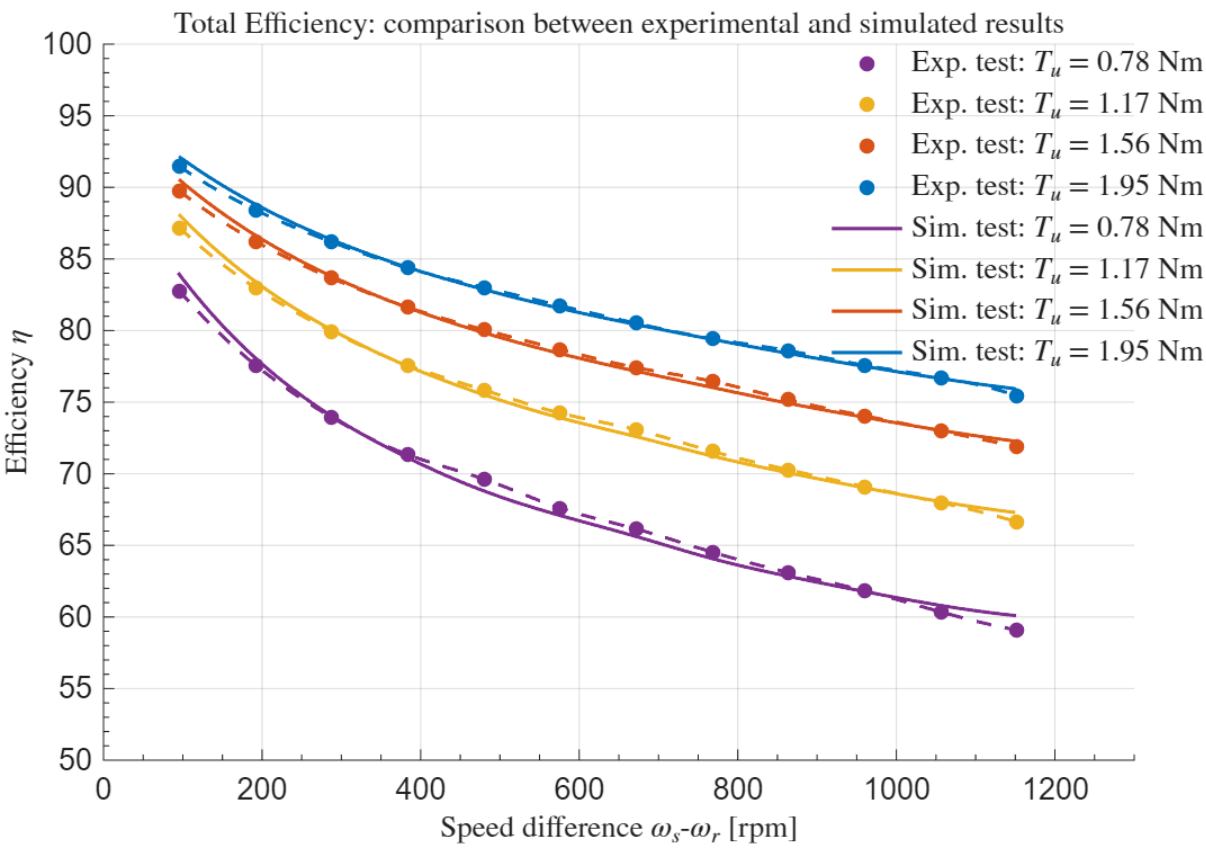
4. Conclusions and Future Work

This work has shown significant results regarding the effectiveness of using a combined experimental and simulation approach to study a planetary magnetic gears system dynamic response. The renewed testing methodology applied to the experimental testing provided a more accurate characterisation of the prototype's losses and performances. These results were significant for the development and validation of the dynamic model of the test bench in Simulink environment, which successfully managed to replicate the behaviour of the prototype with high level of accuracy.

While this study obtained significant results, several aspects can be analysed in future studies. For starters, the study of the second gear configuration of the prototype can be further analysed, together with the simulation on the dynamic model of this condition, to further validate the proper design of the simulation environment. Another important aspect that can be discussed is the frequency response of the system. Finally, it could be useful to implement a degradation model into the simulation environment that can study how a degradation of the system and of the permanent magnets or iron poles could affect the torque transmission capability of the system.



Total Power Losses comparison
Exp. Results: $T_u = 0.78 Nm$
Exp. Results: $T_u = 1.17 Nm$
Exp. Results: $T_u = 1.56 Nm$
Exp. Results: $T_u = 1.95 Nm$
Sim. Results: $T_u = 0.78 Nm$
Sim. Results: $T_u = 1.17 Nm$
Sim. Results: $T_u = 1.56 Nm$
Sim. Results: $T_u = 1.95 Nm$
Bearings Losses
Power losses P_{loss} [W]
Speed difference ω_s-ω_r [rpm]
0
5
10
15
20
25
30
35
40
45
50
0
200
400
600
800
1000
1200



Total Efficiency: comparison between experimental and simulated results
Exp. test: $T_u = 0.78$ Nm
Exp. test: $T_u = 1.17$ Nm
Exp. test: $T_u = 1.56$ Nm
Exp. test: $T_u = 1.95$ Nm
Sim. test: $T_u = 0.78$ Nm
Sim. test: $T_u = 1.17$ Nm
Sim. test: $T_u = 1.56$ Nm
Sim. test: $T_u = 1.95$ Nm
Efficiency η
Speed difference ω_s-ω_r [rpm]
50
55
60
65
70
75
80
85
90
95
100
0
200
400
600
800
1000
1200