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EXPERIMENTAL DETERMINATION OF THE EFFICIENCY OF A COMPOUND PLANETARY GEARBOX

Sanjin TROHA[1], Kristina MARKOVIĆ[2], Željko VRCAN[3], Filip ŠULJ[4], Miroslav MILUTINOVIĆ[5]

[1] 0000-0003-2086-372X, University of Rijeka, Faculty of Engineering, Vukovarska 58, Rijeka, Croatia, E-mail: sanjin.troha@riteh.uniri.hr

[2] 0000-0003-1569-7464, University of Rijeka, Faculty of Engineering, Vukovarska 58, Rijeka, Croatia, E-mail: kristina.markovic@riteh.uniri.hr

[3] 0000-0002-7005-4130, University of Rijeka, Faculty of Engineering, Vukovarska 58, Rijeka, Croatia, E-mail: zeljko.vrcan@riteh.uniri.hr

[4] 0009-0001-2077-0358, University of Rijeka, Faculty of Engineering, Vukovarska 58, Rijeka, Croatia, E-mail: filip.sulj18@gmail.com

[5] 0000-0002-1642-951X, University of East Sarajevo, Faculty of Mechanical Engineering, Vuka Karadzica 30, East Sarajevo, B&H Republic of Srpska, E-mail: miroslav.milutinovic@ues.rs.ba

1. Introduction

Planetary gear transmissions are essential components of industrial machinery due to their small size in relation to their rated power, high transmission ratios, and capability to transmit large torques within a compact design. They are widely applied in automotive, aerospace, and construction machinery industries owing to their reliable and efficient power transmission. The efficiency of planetary gearboxes directly influences energy consumption, operating costs, and environmental footprint. Power losses arise from gear and bearing friction as well as oil churning, and are determined by design parameters, manufacturing quality, lubrication properties, operating speed, and oil temperature. The accurate quantification of these losses is crucial for gearbox design, performance optimization, and durability, as well as for the development of energy-efficient control systems [1].

2. Design of the Experimental Gearbox

The experimental gearbox consists of two planetary stages connected in series (Fig. 1). The input shaft is the sun gear shaft of the first stage, while the output shaft is the planet carrier of the second stage. Both ring gears are stationary and fixed to the gearbox housing. The gears have a module of 1 mm in the first stage and 1.25 mm in the second stage, with an overall transmission ratio of approximately 19.6. The lubricating oil used is standard gear oil ER 90 BDS 14368-82.

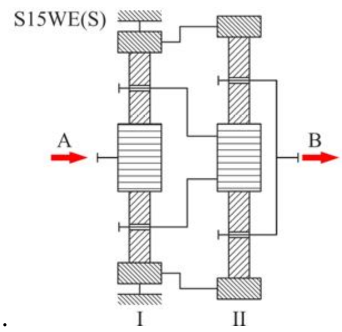

Fig. 1. Two-Carrier Gearbox

3. Test Rig and Measurement System

The test rig (Fig. 2) includes an asynchronous electric motor with VV/VF control for precise speed adjustment [2]. A torque meter positioned between the motor and the planetary gearbox measures the input torque, while a friction brake at the output simulates the load, with its torque precisely controlled by a screw mechanism and a digital force meter. Speed is monitored using a contactless tachometer, and all data (torque, speed, forces) are collected in real time and processed by a computer for system performance and efficiency analysis. The measurements were conducted at multiple input torque levels (up to the nominal value of 5 Nm), at different rotational speeds (750 and 1500 min^{-1}), and at oil temperatures of 35 °C and 75 °C. Multiple measurements were performed for each parameter set, with system cooldown between measurements to ensure repeatability. Efficiency was evaluated as the output torque to input torque ratio, while considering the kinematic transmission ratio.

Fig. 2. Dynamic testing rig for planetary gear trains; 1 electric motor; 2 torsion meter; 3 planetary gear train; 4 gear coupling; 5 brake drum; 6 bearing; 7 friction brake; 8 lever; 9 force meter; 10 data acquisition system

4. Results and Analysis

The results have shown that efficiency increases with higher input torque due to the reduced relative share of friction and oil churning losses. Viscosity drops at elevated oil temperature (75 °C), improving efficiency, while increased speed (1500 min^{-1}) results in increased churning losses and reduced efficiency when compared to lower speed (750 min^{-1}) (Fig. 3). The largest deviations between experimental and theoretical values occur at lower torque loads, coming in good agreement with theoretical results as the load is increased towards the design load. The theoretical model is based on relative component efficiencies and empirical coefficients for additional losses. Observed deviations at lower loads arise from gearbox design details, highlighting the importance of tailored models for different gearbox types and sizes.

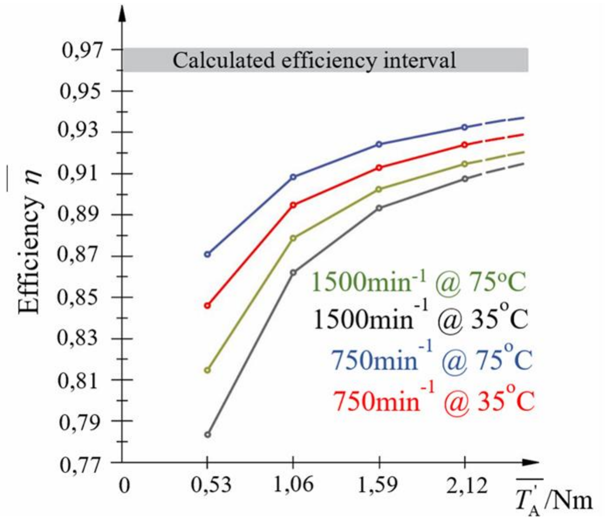

Fig. 3. The influence of input torque, oil temperature, and rotational speed on the mean efficiency of a planetary gearbox

5. Conclusions

The experimental investigation of the two-stage planetary gearbox demonstrated that increased load and oil temperature result in reduced losses, while higher speed increases churning losses. The calibrated theoretical model provides accurate efficiency estimation under nominal conditions, enabling the design of gearboxes optimized for operation with improved energy efficiency.

Acknowledgments

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