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AN ANALYSIS OF HEAT TRANSFER AND POWER LOSSES IN MECHANICAL GEARED TRANSMISSIONS

Alexandru ILIEȘ, Radu F. MIRICĂ, Sorin GABROVEANU, Sorin CĂNĂNĂU, Andreea C. TOTU

Abstract: *This paper presents an analysis of heat transfer capability and power losses in involute gear mechanical transmissions using, for experimental testing, electrical resistances to heat oil in the lubrication bath. The main goal was to establish a precise correlation between the thermal power released in the transmission case and the temperature difference between the oil in the bath and the ambient environment. The results indicate a very good correlation between the two sets of results, numerical and experimental, thus showing that the calculation model generates credible results and match the experimental ones.*

1. INTRODUCTION

Involute gear mechanical transmissions are large applications in industry and are an essential component of many mechanical systems. Understanding the heat transfer and power losses in these transmissions is vital to optimizing their performance and efficiency.

In this context, this paper presents a detailed analysis of the thermal behavior of a gear mechanical transmission and the associated power losses, using a new and original method to evaluate the thermal behavior of an involute gear mechanical transmission.

There is a limited number of researches directly related to the subject of the article, but there are various researches that refer in general to power losses in mechanical transmissions with gears.In our research, we have considered some important researches in the field.

A literature review [1-5] indicates that the power loss sources are divided into load-dependent and load-independent components. But our interest is to have a global evaluation of the power loss.

One of important research is due to Changenet and P. Velex (2006) [6]; their paper provide a model to predict the power losses related to churning in gear transmissions and can be used to our model concerning the analysis of power loss. Another important research is due to Janakiraman [7].

The research is focus on modeling mechanical power losses in automatic transmissions with planetary gears and may provide insight into computational models for power losses in mechanical transmission with gears.

In addition, for a comprehensive approach, we also used the information of Teamah and Hamed [8]; they present the results of a numerical study on heat losses in an internal gear transmission, which may add context to our research on heat transfer in mechanical transmissions.

The main ideea of our paper is to evalute the heat transfer capacity and power losses in mechanical transmissions with involute cylindrical teeth. The main objectiv is to establish a precise correlation between the thermal power released in the transmission case (upper and lower case) and the temperature difference between the bath oil and the ambient environment, evaluation performed on a FZG gear testbench.

2. EXPERIMENTAL DEVICE

2.1. Gear geometry and test stand characteristic

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In order to evaluate the thermal power released in the casing and to understand the temperature difference between the oil in the bath and the ambient environment, we developed a complex experimental system. It included a closed-circuit test bench equipped with high-precision measuring instruments. We used a set of two 400W electric resistors to heat the oil in the bath and achieved a low agitation by turning the gear without load. The gear test stand is a closed circuit test device designed to provide a torque between 0 - 200 Nm and a speed between 0 - 3200 rpm. the oil temperature in the bath; Vibration measurement line on the test stand; as the active one.

. The main information about the geometry and test stand characteristics of the gear are presented in table Tab.1:

Tab.1

Gear geometry and test stand characteristics

Characteristic	Notation	Data	Characteristic	Notation	Data
Centre dist [mm]	a_w	125	Pinion hardness	HB	270-290
Pinion teeth [no]	z_1	15	Wheel hardness	HB	290-310
Wheel teeth [no]	z_2	46	Flank roughness [µm]	Ra	0.4
Helix angle [°]	β	10	Type of the spherical roller bearings	-	21310 E
Profile shift coeff at pinion	x_1	0.427			
Profile shift coeff at wheel	x_2	-0.138	Distance between bearings [mm]	-	200
Face width [mm]	b	72.37	Oil type	-	H46EP
Transv contact ratio	ε_α	1.4532	Oil volume [l]	V_{oil}	6
Overlap ratio	ε_β	0.871	Oil density [kg/m³]	ρ	877
Gear accuracy grade	-	5	Mean of thermal capacity of oil [kJ/kg K]	c_p	2.121
Gear material (case hardened)	-	41MoCr11			

Two transmission boxes, one for the test and one for the return accuracy class of 0.05; Electric motor vibration measurement line.; Voltage variator; Socket with digital energy meter that monitors instantaneous power, 2 electric resistances of 400 ;Fluke TiS60+ thermal camera; energy meter that monitors instantaneous power, 2 electric resistances of 400 W one of the gear case which is considered the test bench includes two cases.

Fig. 1. Mechanical Test bench type FZG with involute gear systems

This test bench is equipped with the following components:Optical transducers, (2 unit); type ROC 425, produced by Heidenhain from Germany; T10FS non-contact flange torque transducer from Hottinger Baldwin Messtechnik, having accuracy class of 0.05%; Lines for measuring with accuarate precision, after calibration,

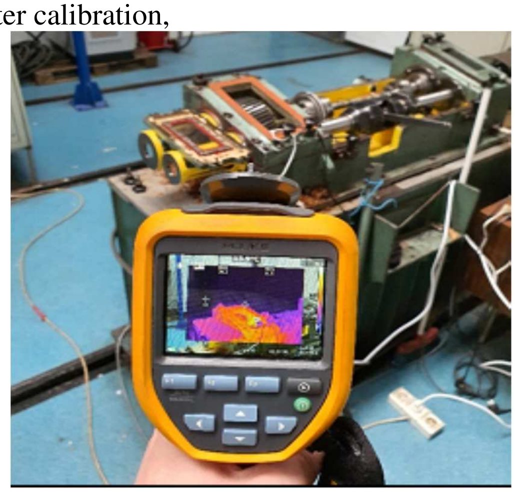

Fig.2. Camera Fluke TiS60+

In figure Fig.3 it is shown the gear mesh in the lower case of the transmission. Also, in the same figure, we can see the location and the position of the electrical resistances.

Fig.3. Test housing with electrical resistances in the oil bath

In figure Fig.4 its is shown the socket with digital energy meter. By this device we can control the energy.

Fig.4. The socket with digital energy meter

2.2 Heating process

In this section, we will explore the differential equation that describes the heating process of the stand used in our experiments. The differential equation is essential to understanding how heat energy is transferred and stored in the stand during heating. The equation is shown below:

$$m_{ech} \cdot c_{ech} \cdot dT = [\, P - A_{ech} \cdot k_{ech} \cdot (\, T - T_0 \,)] \cdot dt \quad (1)$$

where:

$m_{ech} \cdot c_{ech}$ -

represents the equivalent thermal energy storage capacity in the stand.

$m_{ech} \cdot c_{ech} \cdot dT$ -

is the variation of the thermal energy accumulated in the stand during dT

P - is the thermal power received by the system. If we use electric resistance, to simulate the heating of the stand, the power P is constant.

$A_{ech} \cdot k_{ech}$ -

is the stand's characteristic to dissipate heat. Due to the thermal gradient in the stand, the dissipation is uneven, as is the heat storage in the stand.

$A_{ech} \cdot k_{ech} \cdot (T - T_0)$ -

is the thermal energy dissipated in the ambient environment. At the beginning, $T=T_0$ and all the thermal power enters the stand heating it. When the equilibrium temperature is reached in the stand, temperature T_{max}, thermal energy no longer enters and practically all the thermal power is dissipated in the environment.

In the differential equation, it can be seen that if the temperature measured in the oil bath in the housing stabilizes, i.e. dT becomes equal to zero, only the right side of the equation remains that allows establishing a relationship between the thermal power inside the reducer and the temperature difference T-T_0 between the temperature measured in the bath of oil and ambient temperature.

This equation allowed establishing the correlation between the thermal power inside the mechanical transmission (the case) and the temperature difference between the temperature measured in the oil bath and the ambient temperature.

3. RESULTS

In Figure 3, we show the evolution of temperatures in our test stand at a power level of 750 watts, clearly illustrating the establishment of the equilibrium temperature.

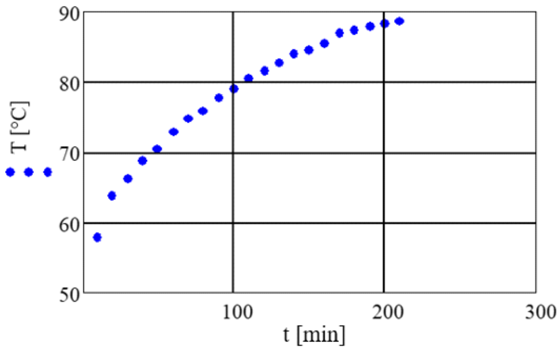

Fig. 5. Temperatures values for heat power P=750 W ($T_{ambient}$= 15.5° C, T_{max}=88.7° C)

In the graph in Figure 5, it can be seen that over time the value of the temperature in the oil bath stabilizes, thus obtaining an equilibrium temperature used to establish the correlation between the thermal power released by the electrical resistances and the temperature difference between the temperature T measured in the oil bath and temperature T_0 equal in this case to 15,5 °C and so, dT= 88,7-15,5=73,2 C^0.Seven tests were performed with seven different power levels and the steady state temperatures were obtained. The tests were performed on different days and had different ambient temperatures. To determine as accurately as possible the temperature of the oil in the casing, the churning was simulated and the oil was aerated manually using the driven wheel. The results of the tests, using electrical resistances, are centralized in the following table:

Tab.2

Test Results at Various Power Levels and Temperatures

No. Test	Ambient temperature [°C]	Power [W]	Equilibrium temperature [°C]	ΛT [°C]
T1R	14	85	27	13
T2R	14	185	39.5	25
T3R	15.5	310	54	38.5
T4R	14.5	390	59	44.5
T5R	16	430	65	49
T6R	16	570	77	61
T7R	15.5	750	88,7	73.2

Table 2 provides a detailed analysis of the results obtained in the tests performed at different power levels and average ambient temperatures. It includes the temperature data recorded in the heating stand at each power level, highlighting the average ambient temperature, the power applied and the equilibrium temperature reached in the stand. This table provides a detailed insight into the thermal behavior of our system under various operating conditions, representing an essential resource for understanding the heat transfer process and the performance of the heating stand.

Figure 6 shows the temperature variation in the different areas of the casing.

To quantify the correlation between the thermal power released in the transmission housing and the temperature difference between the bath oil and the ambient environment, we approximated this correlation by a third-degree polynomial. The process is not linear nor has a parabolic development. This is the reason for choosing as a prime approximation a third degree polynomial behavior.

To quantify the correlation between the thermal power released in the transmission housing and the temperature difference between the bath oil and the ambient environment, we approximated this correlation by a third-degree polynomial. We have searched by numerical methods to find the best approximation.

The approximation was performed using a commercial code MathSoft MathCad Application. [9]

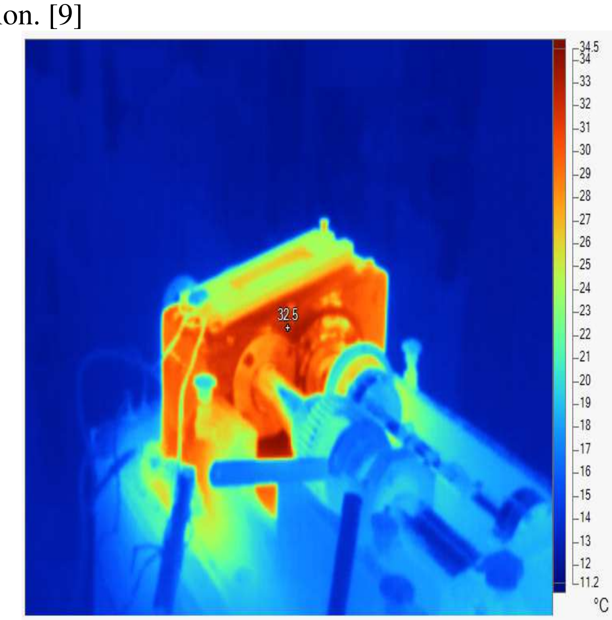

Fig. 6. Infrared image taken on the case

Equation (2) represents this approximation, where 'ΔT" represents the temperature difference between the oil in the bath and the ambient environment. Through this equation, we were able to accurately assess the impact of temperature variations on the thermal power in the transmission case, providing significant insight into the thermal phenomena within the system.

$$P(\Delta T) = 5.23497081\ \ 7136151 \cdot \Delta T + 0.09255890\ \ 83718236 \cdot \Delta T^2 - 0.00040284\ \ 1361301180\ \ 9 \cdot \Delta T^3 \quad (2)$$

The graph in Figure 7 is essential in evaluating the correctness of the computing model used to approximate the correlation between thermal power and temperature difference. P is the measured value of power and P_{calc} is the computed value.

It provides a direct comparison between the values calculated using the polynomial set and the experimentally measured values.

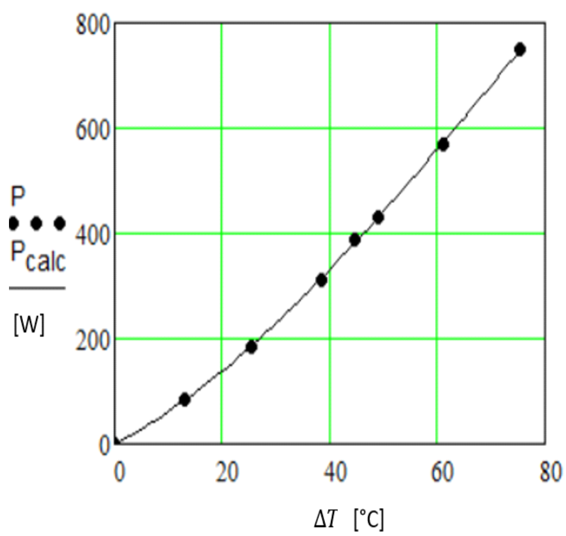

Fig. 7. Measured values, P, and computed values P_{calc}

We observe a remarkable agreement between these two data sets, indicating that our computational model provides accurate results and fits the experimental data well. This underlines the validity and robustness of our approach in the analysis of heat transfer and power losses in involute gear mechanical transmissions.

4. CONCLUSION

The conclusions of this particularly complex and rigorously conducted study successfully demonstrate a new innovative approach to the analysis of heat transfer capacity and power losses in mechanical transmissions with helical spur gears. The essential purpose of these tests was to establish a robust and accurate correlation between the thermal power dissipated through the mechanical transmission housing and the temperature difference between the oil in the sump and the ambient environment.

The study took a holistic and comprehensive approach, covering essential aspects related to the thermal behavior of the gearbox, including power losses in the gear system. The experimental method is an original one and is based on fundamentals of heating process.

The conclusions and results obtained will serve as a solid foundation for the subsequent optimization and design of similar systems, thus contributing to the improvement of their efficiency and performance. Future research could improve the method and also the experimental techniques.

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[9] PTC MathCad https://www.mathcad.com/en/education

O analiza a transferului termic şi a pierderilor de putere în transmisii mecanice cu angrenaje

Abstract: *Acest articol prezintă o analiză a capacității de transfer termic şi a pierderilor de putere în transmisii mecanice cu dantură cilindrică utilizand, pentru testare experimentală, rezistenţe electrice pentru încălzirea uleiului din baia de lubrifiere. Scopul principal a fost stabilirea unei corelații precise între puterea termică eliberată în cutia transmisiei şi diferența de temperatură dintre uleiul din baie şi mediul ambiant. Rezultatele indică o foarte bună corelatie intre cele doua seturi de rezulytate, numerice si experimentale, arătând astfel că modelul de calcul generează rezultate credibile şi se potrivesc cu cele experimentale.*

Alexandru ILIEŞ, PhD Student, Universitatea Nationala de Stiinta si Tehnologie POLITEHNICA Bucuresti, Dept.Machine Elements and Tribology, Spl.Independntei 060042, alexandru.ilies@comoti.ro , ilies_alrex86@yshoo.com

Radu F. MIRICA, Universitatea Nationala de Stiinta si Tehnologie POLITEHNICA Bucuresti, Dept.Machine Elements and Tribology, Spl.Independntei 060042, radu_mirica@yahoo.com

Sorin GABROVEANU, Dr.eng., COMOTI, Romanian Research and Development Institute for Gas Turbine, 220 Iuliu Maniu, Bucharest, S6,RO, Sorin.gabroveanu@gmail.com

Sorin CANANAU, Professor, Universitatea Nationala de Stiinta si Tehnologie POLITEHNICA Bucuresti, Dept.Machine Elements and Tribology, Spl.Independntei 060042, sorin.cananau@upb.ro,

Andreea C. TOTU, Dr.eng., COMOTI, Romanian Research and Development Institute for Gas Turbine, 220 Iuliu Maniu, Bucharest, S6,RO