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Influence of Low Temperatures on No-Load Power Losses in Worm Gears

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Preliminary note

The paper gives research results on power losses in worm gears, i.e. no-load power losses for different initial temperatures. Two lubricants, intended exclusively for worm gears were used, one mineral oil and the other synthetic oil, both produced by the same manufacturer. Research results are shown in tables and diagram with the possibility of comparison for different temperatures. The expressions for no-load power loss at low temperatures for the constant slip velocity and different types of lubricating oils were also obtained.

Utjecaj niske temperature na gubitke snage praznog hoda pužnih prijenosnika

Prethodno priopćenje

Rad donosi rezultate istraživanja o gubitcima snage u pužnom prijenosu, odnosno gubitke snage praznog hoda za različite početne temperature. Rabljena su dva maziva, namijenjena isključivo za pužni prijenos, jedno mineralno ulje i drugo sintetsko ulje, oba proizvedena od istog proizvođača. Rezultati istraživanja prikazani su u tablicama i dijagramu s mogućnošću usporedbe za različite temperature. Također su dobiveni i izrazi za gubitak snage praznog hoda na niskim temperaturama za konstantnu brzinu klizanja i različite vrste ulja za podmazivanje.

1. Introduction

In spite of their good features, worm gears, in comparison with all other gears, have relatively high power loss during operation, and it is that fact that justifies this research. The above mentioned points to the research direction which should concentrate on improving durability, cheaper manufacturing and the reduction of power loss. Worm gear durability is to a great extent determined by a tribological system: worm material, worm wheel material and lubricant.

Materials in a tribological system are similar to materials in journal bearings; worm screw – journal, worm wheel – bearing lining, along with the third component, lubricant, represent the key elements of the system which defines the total no-load power loss of a worm gear. There have been efforts recently to change tin bronze for more suitable types of bronze, at least as far as the price is concerned. In relation to that, aluminium bronze is specially emphasized. Modern scientific researches show that it is possible to use the corresponding gray-cast alloys, as well as zinc and aluminium alloys. More

Symbols/Oznake

T_{2hg} - power losses of worm gears expressed through the output torsion moment according to the hydro-dynamic theory, N·m
- gubitci snage pužnog prijenosnika izraženi preko izlaznog torzijskog momenta prema hidrodinamičkoj teoriji

P_{pg}, P_{go} - no-load power losses, W
- gubitci praznog hoda

t - working temperature, °C
- radna temperatura

η_u - degree of utilization
- stupanj iskorištenosti

ρ_N - relative radius of curvature profile in the point of contact, mm
- relativni polumjer zakrivljenja profila u točki dodira

v_{red} - speed skating, m/s
- brzina klizanja

k_H - rolling pressure according to Striebeck, N/mm^2
- valjni tlak po Striebeck-u

v_s - speed rolling, m/s
- brzina valjanja

η - dynamic viscosity, Pa·s
- dinamička viskoznost

μ - friction factor
- faktor trenja

details on this topic are given in the papers by Neimann [1], Winter [2] and Huber [3].

The third factor in the tribological system is a lubricant, which has been developing both in the area of reduction of wear and increased resistance to contact pressure. When lubricants of synthetic origin appeared on the market, contact pressure limit was considered to have increased, but some authors proved the opposite in comparison with mineral lubricants. Huber [3] and Wilkesmann [4]. Lubricant's viscosity in real conditions cannot be unambiguously defined, and that is the basic problem. This feature requires a comprehensive approach with respect to working temperature and allowable pressure at the critical point of contact between the worm and the worm wheel.

Internal friction in ideal lubricating oil depends only on the temperature and pressure. Most of the authors researched worm gear power losses at temperatures between 60 °C and 80 °C, which represent worm gears' stationary state in the thermal sense. In this paper we would like to answer the question: "What happens to the no-load power losses of worm gears at low temperatures, which are also very often real working temperatures, and how individual factors influencing power losses behave in these real conditions." This also represents the key statement of this research. We should also bear in mind that ecological and ergonomic factors decide where particular mechanical transmission will be used, and it is these criteria which give a great advantage to worm gears.

2. Theoretical foundations

In order to find necessary values of power losses in a certain worm gear position, integration of all contacting lines which are at the same time present in interlocking must be carried out. Results for a certain worm position are obtained by summing integrated values of all contacting lines which are at the same time present in interlocking.

For calculation of worm gears according to power losses we used the expressions according to hydrodynamic theory of lubrication and the Hertz expression for curved surfaces contact [5-7].

Losses according to a hydro-dynamic classical theory of lubrication.

Hydro-dynamic power loss for one worm position (j):

$$(T_{2hg})_i = 2,3 \cdot \frac{\eta}{\omega_2} \cdot \sqrt{\frac{(\cos\tau_{max})_j}{s_{min}}} \cdot \sum_{i=1}^{n} \int_{(\text{D-line})_{ij}} \sqrt{\frac{\rho_N}{\cos\tau}} \cdot \left(v_s^2 + 1,23 \cdot v_{red}^2\right) dl. \cdot \tag{1}$$

Power losses obtained on the basis of friction factor for one worm position (j):

$$P_{pg} = 2\eta \cdot k_H \cdot \sum_{i=1}^{n} \int_{(\text{D-line})_{ij}} \rho_N \cdot v_{red} dl. \cdot \tag{2}$$

3. Laboratory model

3.1. Testing gear

Worm gear is a serial product of a Croatian factory with spacing between axes of 90 mm. The gearbox is ribbed and cooling is done by natural air circulation. All gear bearings are roller bearings. Measuring thermoprobes are placed on the housing and in the worm gear oil. Worm pairs are matched at the gear manufacturer. Profile: ZN, according to ISO –DIN 3975.

3.2. Worm screw material

Worm screw material is steel by ISO 683/11, 16MnCrS5 (cementing steel of chemical composition: 0,16 % C; 1,15 % Mn; 0,95 % Cr).

3.3. Worm wheel material

Worm wheel material is: alloy CuSn with 12 % Sn EN-designation C.CuSn12 of chemical composition: 88 % Cu; 12 % Sn (permissible impurities 0,1 % Sb; 0,2 % Fe; 0,01 % Al; 0,5 % Ni).

3.4. Lubricant

Selection of the applied lubricant was done upon the recommendation of the gear manufacturer. Two types of lubricants were used: mineral oil and synthetic oil. Basic characteristics of the applied lubricants are given in Table 1.

4. Experimental plan

The starting point of the experimental research represents the experiment plan or, to be more precise, the type and its structure. The plan of the experiment is defined by a set of all experimental or measuring points (in the experimental system or space) which may be expressed by means of a matrix.

Defined factors (F_i) and their levels (n_i) in the matrix are as follows in Table 2.

5. Research results

Research and no-load power losses measuring were carried out on a testing machine bed. Every value was measured six times, and the mean measured value is given in the Table 3.

In the series of experiments power loss was measured when the output torsional moment $T_2 = 0$, at various initial temperatures (from t_{01} to t_{04}). This research was carried out for mineral and synthetic oil. Values of the initial temperatures and measured no-load power losses are given in Table 3.

Table 3. Measured no-load power losses P_{g0} for different temperatures with synthetic and mineral oil in the gear, W

Tablica 3. Izmjereni gubici snge praznog hoda P_{g0} za različite temeperature sa sintetskim i mineralnim uljem u zupčanicima, W

Working temperature / Radna temeperatura, °C	Synthetic oil in the gear / Sintetsko ulje u prijenosniku	Mineral oil in the gear / Mineralno ulje u prijenosniku
	No-load power loss / Gubitak snage praznog hoda, W	
-15	287,2	380,1
-5	178,5	212,3
8	110,4	134,4
22	80,4	111,78

Table 1. Basic characteristics of the applied lubricants

Tablica 1. Temeljne karakteristike primijenjenog maziva

No. / Br.	Type of oil / Vrsta ulja	Viscosity / Viskozitet, cSt at 40 °C / cSt na 40 °C	Viscosity / Viskozitet, cSt at 100 °C / cSt na 100 °C	Density / Gustoća ρ, kg/m^3	Flash point / Plamište, °C	Pour point / Stinište, °C
1	Mineral oil / Mineralno ulje	220	19,4	899	238	-18
2	Synthetic oil / Sintetsko ulje	234	35	1026	321	-33

Table 2. Quantitative measuring points of the experimental plan

Tablica 2. Kvantitativne mjerne točke plana pokusa

F_i	n_i	Slip velocity / Brzina klizanja, m/s	Environment temperature / Temperatura okoliša, °C	Exit moment / Izlazni moment, N·m	Type of oil / Vrsta ulja	Worm wheel material / Materijal pužnog kola
1.		2,88	22	0	Mineral / Mineralno	CuSn12
2.		2,88	8	0	Synthetic / Sintetsko	
3.		2,88	-5			
4.		2,88	-15			

5.1. Power loss P_{g0} measurement results with synthetic and mineral oil in the gear

Of great practical importance conditions is the knowledge of the no-load power losses quantity dependence on temperature.

$$P_{g0} = f(t) \, . \tag{3}$$

By approximating curves (Figure 1) using the least squares method we obtained the no-load power losses equation dependence on temperature, which represents the exponential function.

$$y = y_0 + A_1 \cdot e^{\left[\frac{-(x+x_0)}{t_1}\right]} . \tag{4}$$

In the expression (4) variable x represents the initial working temperature, and variable y no-load power losses, where y_0, A_1, x_0, t_1, are coefficients of the exponential equation dependent on the type of lubricating oil and worm gear geometry. If these coefficients are inserted in the equation (4), we obtain the expression for the total no-load power loss dependent on the working temperature of the mineral oil:

$$P_{g0} = 102,5 + 227,67 \cdot e^{\left[\frac{-(t+15)}{10,7}\right]}, \text{ W} \tag{5}$$

and at synthetic oil, respectively:

$$P_{g0} = 59,9 + 227,32 \cdot e^{\left[\frac{-(t+15)}{15,33}\right]}, \text{ W.} \tag{6}$$

Expressions (5) and (6) are valid for the temperature interval from –15 °C to 22 °C, (which is the most frequent temperature interval when starting industrial worm gears) and for the slip velocity of 2,88 m/s.

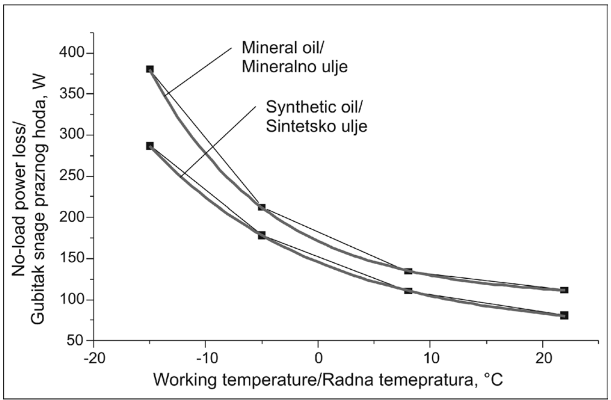

Figure 1. Joint diagram of power losses for synthetic and mineral oil in the worm gear

Slika 1. Zajednički dijagram snage gubitaka za sintetičko i mineralno ulje u pužnom prijenosniku

6. Conclusion

Through a comprehensive approach we reached the following concise set of ideas [8]:

1. Worm gear no-load power loss changes depending on temperature according to the expression representing an exponential function for both mineral and synthetic oils. Expressions (5) and (6) represent an original contribution to the determination of power losses at low temperatures.
2. No-load power loss is smaller with synthetic oils than with mineral oils.

Through a scientific procedure, this research established principles and laws which are a distillate of a long and exhausting process of experimenting. This paper gives tentative conclusions which quantify a natural phenomenon of worm gear power losses under real working conditions. Conclusions are testible, and through their values a vertical communication with former and future papers in this field is established.

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