[1.] Blaža STOJANOVIĆ, [1.] Lozica IVANOVIĆ

THE INFLUENCE OF LUBRICANT VISCOSITY ON THE EFFICIENCY AND POWER LOSS OF THE WORM GEAR

[1.] University of Kragujevac, Faculty Engineering, Sestre Janjic 6, 34000 Kragujevac, SERBIA

Abstract: This paper presents an experimental analysis of the influence of lubricant viscosity on the efficiency and power loss of a worm gear transmission. The tests were performed on the open circuit power specialized testing device AT200 at the Center for testing power transmissions at the Faculty of Engineering, University of Kragujevac. In the experiment, three oils of different viscosities were used: 220 mm²/s, 460 mm²/s and 680 mm²/s. The efficiency was measured for three different values of input number of rotations: 1500 min^{-1}, 2000 min^{-1} and 2500 min^{-1}. Output torque values range from 2.2 Nm to 6 Nm. The test results showed that the efficiency of worm gear increases with increasing input shaft speed. It was also observed that the efficiency increases with increasing oil viscosity in all test regimes. The results of the work are a reference for researching the efficiency of worm gears and engineering optimization, which is of great importance for the development of gears.
Keywords: efficiency, power loss, worm gear, oil, viscosity

1. INTRODUCTION

Mechanical transmissions are used to transfer mechanical energy from the drive machine, most often the electric motor, to the driven machine. The power transmission can also change the direction of rotation if necessary, [1].

Today, the following types of mechanical transmissions are most often used: gear drives, chain drives, friction drives, belt drives, toothed belt drives, cardan shaft, etc.

Gear transmissions have the largest application of all power transmissions. They transmit power and torque from one shaft to another when coupling gear teeth. The gear pair is the simplest form of gear transmission consisting of two gears. One gear is drive gear, while the other is driven. Torque and power are transmitted from the drive gear to the driven one, [1].

Worm gears have a wide range of applications due to numerous advantages over other types of gears. A worm gear transmission is a worm gear pair, which consists of a worm and a worm wheel. This type of transmission is a type of hyperboloid gear pair, that is, a gear pair whose axes pass each other. The angle at which the axes pass is usually 90°, but in some cases it may be smaller or larger, although this range is limited. Worm gears are rarely used as multipliers, and the reason is their relatively low value of the efficiency, which is η<0.5. The worm is smaller in diameter than the worm gear and can have one or more thread, so that it resembles a screw or a threaded spindle, which is why it is usually the drive part of the gear pair. Depending on the number of thread, the following types of worms are distinguished [1, 2, 3]: single-start, double-start, triple-start and multi-start worms.

In general, the efficiency represents the ratio of input and output power, ie. power used for work. When it comes to worm gears, the most common problem when using them is to achieve the optimal degree of efficiency. The efficiency of the worm gear depends in part on the gear ratio and can, in certain cases, range from 0.49 for the gear ratio i = 300 to 0.9 for gear ratio i = 5. Accordingly, it is recommended that worm gears be used for lower gear ratios, [4].

As the relatively low efficiency is one of the main disadvantages of the worm gear, many researchers have worked on solving the problem, conducting experiments and analyzing the results. B.Magyar and B.Sauer [5] performed the calculation of the efficiency of the worm gear transmission ZK type, lubricated with lubricant viscosity 150 mm²/s at the output torque of 430 Nm. Their experiment resulted in a value of the efficiency in the range of 0.65÷0.74. M. Turci et.al. [6] examined the influence of axial distance, transmission ratio and type of lubricant on the degree of efficiency. They found that at an axial distance of 50 mm, gear ratio i=49 and various lubricants (polyethylene glycol (PEG), a combination of PEG + WS2 (tungsten disulfide) and synthetic oil) can achieve an efficiency in the range of 0.572 for PEG, up to 0.637 for synthetic oil.

In his work, S. H. Kim [7] examined the influence of the axial mismatch of the steering system due to vibrations when moving the vehicle, on the degree of efficiency. The results showed that in a certain short time interval, the efficiency can reach values up to 0.93. H. Sieber [8] determined the degree of utilization

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depending on different types of lubricants at an axial distance of 63 mm, transmission ratio i = 39 and input number of rotation 350 min^{-1}. The investigation showed a wide range of efficiency from 0.62 for PEG oil with a viscosity of 220 mm²/s, to 0.74 for PEG oil with a viscosity of 460 mm²/s.

This paper analyzes the influence of lubricant viscosity on the efficiency and power loss of the worm gearbox. The obtained results showed that the efficiency increases with the increase in the number of revolutions of the input shaft of the reducer and the increase in the viscosity of the used oils.

2. EFFICIENCY AND POWER LOSS

In practice, the efficiency of a worm gear is calculated as the ratio of output power to input power, [2,3]:

$$\eta = P_{out}/P_{in} \tag{1}$$

where:

P_{out} – output power, W, and

P_{in} – input power, W.

Output power can be calculated as:

$$P_{out} = P_{in} - P_G \tag{2}$$

where P_G – power loss, W.

Power loss of is also one of the challenges that arise in solving the problem of the degree of efficiency. H.E. Merritt [9] listed the following as one of the most common types of power loss that occur in worm gears:

- power losses, proportional to the input power, due to the friction that occurs between the worm teeth and the worm gear during their contact and
- power losses in bearings, as well as due to resistance to fluid movement, ie lubricating oil.
- In the case where the worm gear is mounted on a shaft with ball bearing, then the resistance to the movement of the lubricating oil is the main influence on power loss which is a function of speed and temperature, but independent of load, [9].

The basic equation used in the calculation of power losses that occur in the worm gear, implies power losses due to resistance to sliding of the worm gear during movement (P_{Gz}), power losses that occur in bearings (P_{GB}) and power losses at idle (P_{G0}).

Mathematically, total power losses represent the sum of all these individual values, by expression [3]:

$$P_G = P_{Gz} + P_{GB} + P_{G0} \tag{3}$$

2. TESTING THE EFFICIENCY OF THE WORM GEAR TRANSMISSION

Test rig

Testing of the efficiency and power losses in the worm gear was performed on the device AT 200, which works on the principle of open power circuit, in the Center for testing power transmissions at the Faculty of Engineering, University of Kragujevac (Figure 1). Measurement of the degree of efficiency, oil temperature as well as the volume of noise that occurs in the operation of the worm gear transmission was performed on this rig. [10-12].

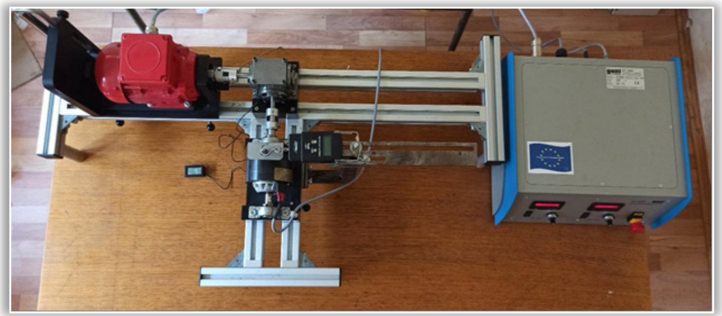

Figure 1. AT 200 device

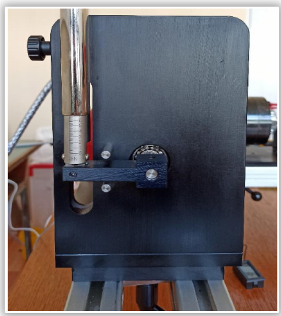

Figure 2. Dynamometer on an electric motor

The open power circuit consists of an electric motor that rests on the main frame over 2 bearings, so that it has no contact with the stand that is below it and can rotate around its axis. When the engine produces torque, it is subjected to a reaction moment of the same intensity but in the opposite direction. When the lever is placed in a horizontal position, and the value of the force on the dynamometer is read, the dynamometer remains locked at the given value with the help of the screw (Figure 2).

In addition to the electric motor, the device also has an electromagnetic brake with a dynamometer. On the input and output shaft there are appropriate sensors that are connected to the amplifier bridge on which the appropriate operating conditions are set.

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Test conditions

The testing of efficiency on the AT 200 device was performed on a worm gear with a gear ratio i = 18, with a worm made of 42CrMo4 alloy steel and a CuSn14 tin bronze worm gear wheel. During the test, the values of the input number of rotations, the electric current on the brake (ie the corresponding output torque) were varied, and oils of different viscosities were used.

The values of the input number of rotations are 1500 min^{-1}, 2000 min^{-1} and 2500 min^{-1}, the interval of change of electric current is 0.025 A, in the range from 0.1 A to 0.2 A (corresponding to a torque of 2.2 Nm to 6 Nm depending on the test mode). The viscosities of the lubricants used in the test are 220 mm²/s, 460 mm²/s and 680 mm²/s. The basic characteristics of the lubricants used are given in Table 1

Table 1. Characteristics of lubricants used in the tests

Oil	Characteristics	Value	Unit
ISO VG 220	Viscosity on 40°C	220	mm²/s
	Viscosity on 100°C	18	mm²/s
	Pour point	-15	°C
	Flash point	260	°C
	Density on 15°C	896.1	kg/m³
ISO VG 460	Viscosity on 40°C	460	mm²/s
	Viscosity on 100°C	28	mm²/s
	Pour point	-12	°C
	Flash point	260	°C
	Density on 15°C	896.1	kg/m³
ISO VG 680	Viscosity on 40°C	680	mm²/s
	Viscosity on 100°C	40	mm²/s
	Pour point	-8	°C
	Flash point	300	°C
	Density on 15°C	905	kg/m³

Test plan

The test was performed in three cycles, with three series of five repetitions. Three cycles involve three different oil viscosities, three series involve three different values of the input number of rotations and five repetitions involve different values of electric current. The value of the electric current changed every hour, except for the first repetition of 0.1 A, which lasted an hour and a half, because the worm gear takes about half an hour to reach operating temperature, and the same amount is needed for the lubricant to form a hydrodynamic layer [13]. All values were measured in an interval of five minutes. After every third repetition, more precisely changes in the strength of the electric current, a break of half an hour was made in order for the device and the oil to cool down to room temperature.

3. TEST RESULTS & DISCUSSION

Based on the measured experimental results, a program for calculating the efficiency and power loss was developed at Microsoft Excel. Figures 3-5 show the dependences of the efficiency of worm gears and torque. At the same time, three values of input number of rotations and three values of lubricant viscosity were varied.

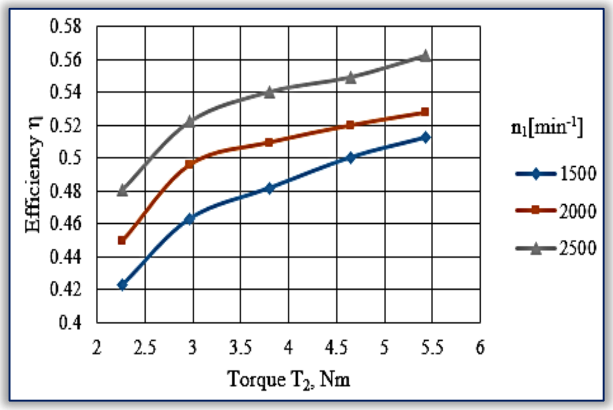

Figure 3. Influence of number of rotations on the efficiency for oil with viscosity 220 mm²/s

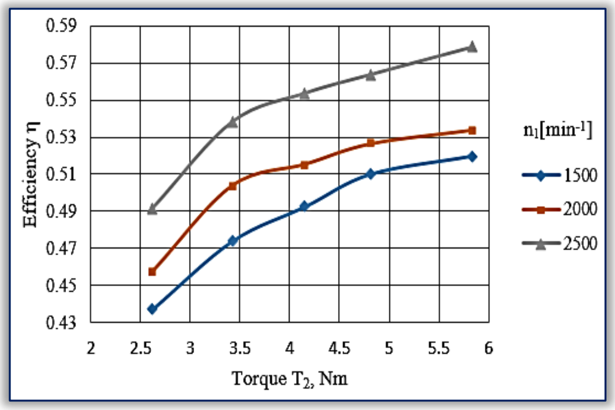

Figure 4. Influence of number of rotations on the efficiency for oil with viscosity 460 mm²/s

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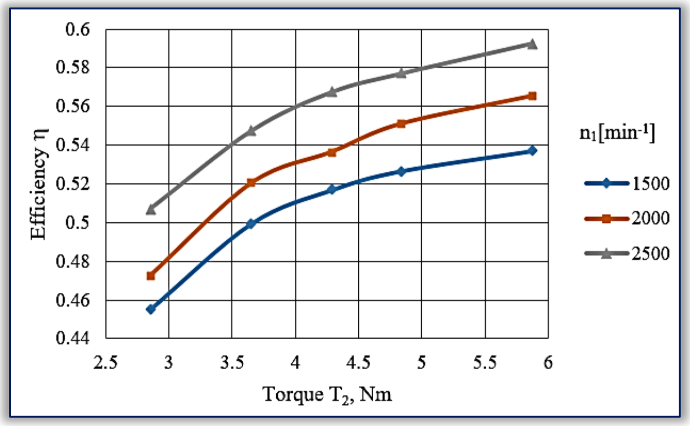

Figure 5. Influence of number of rotations on the efficiency for oil with viscosity 680 mm^2/s

In the given diagrams, it can be observed that the increases with increasing output torque and with increasing input number of rotations, for all three values of lubricant viscosity.

Figures 6-8 show the dependences of the efficiency on the number of rotations of the input shaft for all three values of the viscosity of the lubricant.

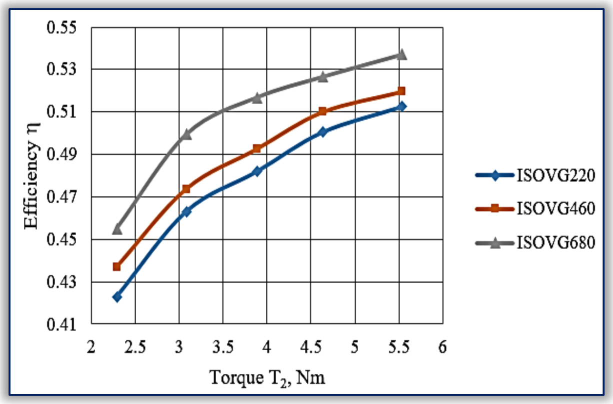

Figure 6. Influence of lubricant viscosity on the efficiency for number of rotations 1500 min^{-1}

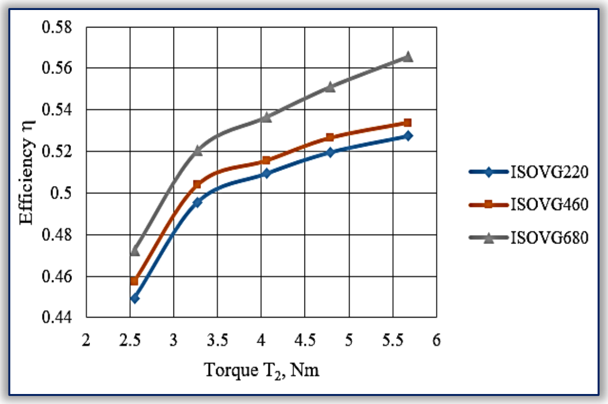

Figure 7. Influence of lubricant viscosity on the efficiency for number of rotations 2000 min^{-1}

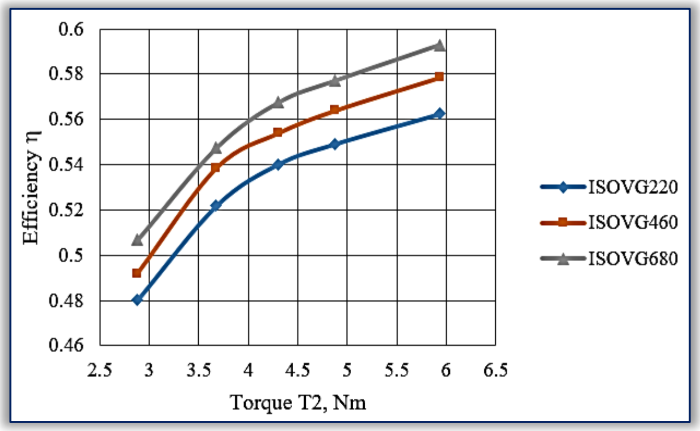

Figure 8. Influence of lubricant viscosity on the efficiency for number of rotations 2500 min^{-1}

The diagrams show that the efficiency increases with increasing lubricant viscosity in all test modes, ie for different input shaft number of rotations. The maximum values of the efficiency are obtained by using oil with a viscosity of 680 mm^2/s and are 0.53 ÷ 0.59.

The influence of lubricant viscosity on the degree of power loss P_G/P_1 is shown in Figures 9-11. The diagrams show that the lowest losses occur when using oils of the highest viscosity and at the highest output torques.

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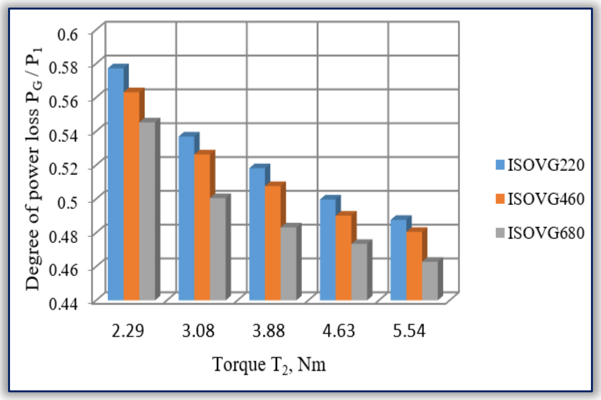

Figure 9. Influence of lubricant viscosity on the degree of power loss for number of rotations 1500 min^{-1}

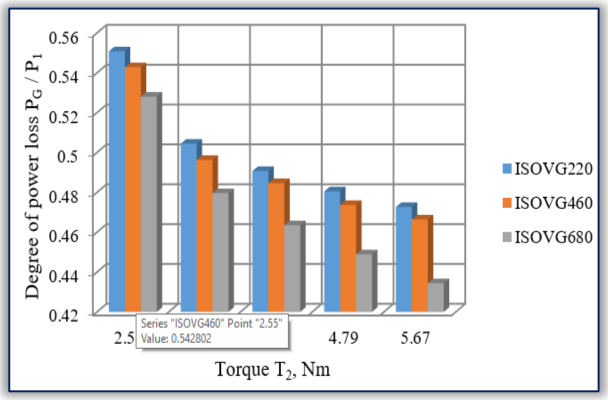

Figure 10. Influence of lubricant viscosity on the degree of power loss for number of rotations 2000 min^{-1}

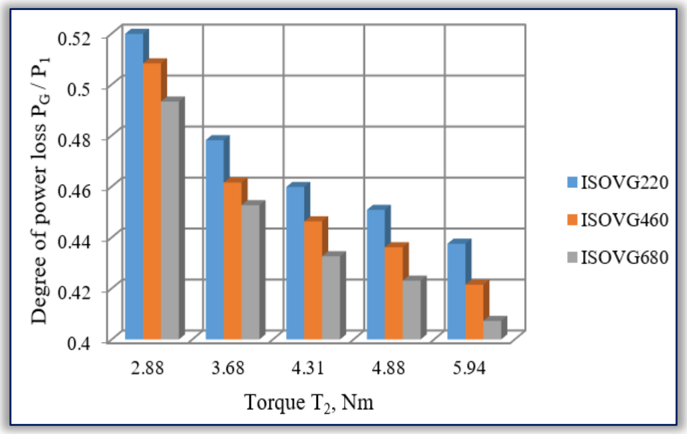

Figure 11. Influence of lubricant viscosity on the degree of power loss for number of rotations 2500 min^{-1}

4. CONCLUSIONS

At a time when the value of electricity is growing enormously and when there is a lack of all forms of energy, the analysis of the efficiency and power loss of the worm gear has become even more important. Based on the theoretical analysis and realized experimental tests, the following conclusions can be drawn.

- The value of the efficiency is influenced by the viscosity of the oils used, the input shaft number of rotations as well as the value of the output torque.
- As the number of revolutions of the input shaft increases, the efficiency of the worm gear increases.
- With the increase of the output torque, the efficiency of the worm gear also increases.
- From all the considered parameters, the viscosity of the lubricant has the greatest influence on the efficiency of worm gears. As the viscosity of the lubricant increases, the efficiency increases.
- The highest values of the efficiency occur when using oils with a viscosity of 680 mm2/s and range from 0.53 to 0.59.
- The lowest power losses occur at the highest number of rotations and with the use of the highest viscosity oil.

The results of the research provide guidelines for increasing the efficiency of worm gears, which is of great importance for the field of mechanical transmissions.

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