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INFLUENCE OF OPERATING AND AMBIENT TEMPERATURE ON LOAD CAPACITY OF UNIVERSAL WORM GEAR REDUCER

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Abstract: The problem of worm gear heating is analysed in this paper. In most of cases, this heating has great impact on load capacity of worm gears, but in a great measure defines efficiency of worm gear transmission. Heating of worm gear is restricted by thermal power capacity of the gearbox. Thermal power capacity of the gearbox is defined as the biggest input power of the gearbox which could be transmitted by the gear unit, with the condition that power losses can be given to the surrounding without overheating of the gearbox, in the case of normal air temperature. Determination of the operating temperature represents the main problem for defining thermal power capacity of the gearbox. The highest operating temperature represents a limit until the gearbox (the oil in the gearbox) can be heated, but also in dependence of surrounding temperature (the ambient temperature where the gearbox operates). Influence of these temperatures is analysed in this paper.
Keywords: operating temperature, ambient temperature, thermal power capacity, worm gear

INTRODUCTION

Efficiency (η) is one of the most important characteristics of modern mechanical drives. Efficiency indicates the drive's effectiveness; so it is necessary to specify its values in catalogues and on the label plates which are mounted on the drive casing. It should have in mind that the value of mechanical drives is variable during a time.

Energy losses occurred during operating of mechanical drive are mostly transformed to the thermal energy, but smaller part is converted to energy of vibration and noise [1, 2]. This paper will consider only the losses transformed to the thermal energy to surrounding air by convection, while the small energy losses transformed by radiation and conduction are neglected. Since load capacity of worm gears depends on losses, i.e. its efficiency, during its calculation thermal flux of worm drive have to be defined. This thermal flux is necessary condition for convecting the energy to surrounding air without overheating the gearbox [1, 3]. This data is usually defined by thermal capacity of mechanical drive. Thermal capacity of universal gear reducer (P_Q) represents the greatest input power that can be transmitted through the gear unit, under a continuous duty and an ambient temperature of 20°C, without resulting in the damage of the inner parts or the degradation of the lubricant properties [2, 4]. Here the main problem represents determination of maximal operating temperature of mechanical drive, i.e. maximal permitted temperature of the oil in gear unit and the temperature of the ambient.

THE PROBLEM INTERPRETATIONS

During operating of mechanical drives, the loss of energy is converted into thermal energy which is given to the surrounding air mostly by convection.

Thermal capacity is calculated from the following equation [2, 4]:

$$P_L = P_1(1-\eta) \approx q \leq q_o \tag{1}$$

where: P_L – loss of energy, P_1 – input power, η – efficiency of gear drive, q – thermal flux obtained due to losses in the gear unit, q_o – thermal flux that can be transferred to the environment, calculated from

$$q_o = k\,A\left(\vartheta_{1\max} - \vartheta_o\right) \tag{2}$$

where: k – coefficient of the heat transmission from the gear reducer oil to the environment, A – surface area of the housing of the gear reducer that can exchange heat, $\vartheta_{1\,max}$ – temperature of oil in the gear reducer (usually $\vartheta_{1\,max}$ = 80 - 100 °C), ϑ_o – temperature of the ambient where the gearbox operates (usually ϑ_o = 20 °C).

From the equations (1) and (2), it follows that the value of the thermal power capacity (P_q) is:

$$P_Q \leq \frac{q_o}{1-\eta} = \frac{k\,A\left(\vartheta_{1\max} - \vartheta_o\right)}{1-\eta} \tag{3}$$

It is necessary to emphasize that the value of thermal power capacity changes with the changing of ambient temperature where the drive operates.

If a gear unit transmits larger power than thermal power capacity (P_Q), it starts to overheat and lubricant properties are changing. There is unwanted increase of components dimensions, incorrect operating of bearings and thus incorrect operation of whole mechanical drive, and also changing properties of materials which are a part of gear unit. If that problem ($q > q_o$) is noticed during design, it is tried to be eliminated by increasing the surface of the gear box in order to speed up heat convection from the housing (usually making the ribs on the housing).

If it is not enough, additional cooling is installed (installation of the fan on the high-speed shaft for forced air circulation around the gearbox, and/or installation the heat exchanger and the oil pump and cooling the oil of the gear drive).

If it is noticed that input power is larger than thermal power capacity during the selection of gear reducer, then the problem is usually eliminated by selecting larger size of mechanical drive (with higher thermal power capacity), or by cooling the oil which is always more expensive solution. This case usually occurs when transmitting high powers, or if mechanical drive operates in ambient with high temperature, or when power losses are significant (which is the usual case for worm gear drive).

The greatest influence in defining thermal power capacity has adopted operating temperature of the gearbox and adopted temperature of the ambient, so these two factors will be given special attention in the paper.

OPERATING TEMPERATURE

Permitted operating temperature of mechanical drive in large amount depends on applied type of lubricants, but also depends on permitted dilatation of mashed gear elements, material sensitivity on temperature dilatation, permitted heating of bearings, etc. Mineral lubricant was used for lubrication of gear units, but in recent time synthetic lubricant based on polyglycols is more often used. Lubricants are used for lubrication of gearing elements in order to reduce friction and teeth wearing, for lubrication of bearings, for heat dissipation and for corrosion protection.

Selection of lubricant depends on expected operating temperature, loads and number of revolutions of geared elements. Operating temperatures until 60°C are considered as normal operating condition, temperatures until 90°C are considered as higher and temperatures until 100°C or higher are considered as very high thermal conditions.

Operating temperatures of universal gear units usually covers normal and higher temperature conditions, so their lubricants can be heated until 80°C, or even 90°C. For specific thermal condition, driving units use lubricants intended for high temperatures [6].

AMBIENT TEMPERATURE

In calculation of thermal capacity of gearbox temperature of 20°C is assumed as normal ambient temperature, but some manufacturers adopt 40°C as a normal temperature of ambient [7]. According to instructions of most manufacturers, ambient temperature can be found in the range between 10 and 50°C.

Ambient temperatures depends on the conditions where the gearbox operates (outdoors subject to direct weathering, outdoors under roof, indoors with no room heating, indoors with room heating, indoors with room air conditioning), but it also depends on operating mode, specific operating conditions and year season. Also, the operating mode (continuous duty, intermittent duty with incomplete or complete cooling the gearbox) can affect the heat capacity since in the case of short time duty or intermittent duty with complete cooling, the gearbox can be higher loaded if it depends on load capacity.

Since these modes are specific and the load capacity of gear drives depends on other factors, but not only of thermal capacity, most of manufacturers of universal worm gear drives do not pay attention on these specific factors during defining thermal power capacity [6].

SELECTION OF GEAR DRIVE

Manufacturers of universal worm gearboxes propose the selection of gear unit size in three ways.

— The first way: Gear drives manufacturers who always take into account the ambient temperature have the simplest procedure of gearbox selection, no matter whether the load capacity is limited by thermal capacity or not. In this way, gearbox selection is significantly simplified, but certain mistake is consciously made since all possibilities of gear drives, whose load capacity is not limited by thermal factor, are not exploited. For example, company SEW recommends selection [7] of its worm drives by checking permitted load capacity of free output and input shafts, but in addition also by checking condition

$$T_{2N} \geq T_2 \; f_B \qquad (4)$$

where: T_{2N} – nominal output torque, i.e. the highest torque that can be transmitted continuously through the output shaft with the gear unit operating under a service factor $f_s = 1$ and with the economically acceptable maintenance costs; T_2 – output torque for defined power and rotations number:

$$T_2 = 9550\frac{P_2}{n_2} = 9550\frac{P_1\eta}{n_2} \qquad (5)$$

Service factor (f_B) takes into account all imbalances that occur during exploitation and it's calculated according equation:

$$f_B = f_1 \; f_2 \; f_3 \qquad (6)$$

≡ f_1 – factor which takes into account the type of driving machine (in this case electric motor), the type of operating machine, i.e. load classification (light, moderate, hard, very hard loads [6]), daily operating duration and number of starts per hour;

≡ f_2 – factor which takes into account the actual loading of the gear drive during the hour;

≡ f_3 – factor which takes into account the ambient temperature of surroundings where the gear drive operates (Table 1).

Table 1: Values of factor f_3 (SEW) [7]

ϑ, °C	light loads	moderate loads	hard loads
20	1	1	1
30	1.11	1.14	1.18
40	1.28	1.37	1.5
50	1.5	1.7	1.9

For proper selection of gear drives within the given power and rotations number it must be satisfied following condition:

$$f_B \leq f_{BD} = \frac{T_{2N}}{T_2} \qquad (7)$$

where: f_{BD} – permissible value of the service factor calculated according to Eq.(7) and it defines how heavy the gear drive can be loaded, given in catalogues of gearboxes.

— The second way: The company Rossi gives a more complex procedure of selection since heat capacity is observed

$$P_1 \leq P_q \; f_t \qquad (8)$$

where: P_1 – input power, P_q – thermal capacity of gearbox, given in catalogues of gear units limited by thermal capacity, f_t – factor which takes into account the ambient temperature and effective loads of gearbox, i.e. operating mode (Table 2).

Table 2: Values of factor f_t [6]

ϑ, °C	Continuous operation S1	Operating mode Continuous operations S3 … S6 with ED factor 60	40	25	15
40	1	1.18	1.32	1.5	1.7
30	1.18	1.4	1.6	1.8	2
20	1.32	1.6	1.8	2	2.24
10	1.5	1.8	2	2.24	2.5

Additionally, company Rossi considerate permitted load capacity from the point of strength, wear and stiffness:

$$T_{2N} \geq T_2\, f_B \qquad (9)$$

Service factor (f_B) takes into account all imbalances that occur during exploitation and it's calculated according equation:

$$f_B = f_1\, f_2 \qquad (10)$$

≡ f_1 – factor which takes into account the type of driving machine (in this case electric motor), the type of operating machine, i.e. load classification (light, moderate, heavy) and daily operating duration;

≡ f_2 – factor which takes into account number of starts of the gear drive during the hour.

Condition given in Eq.(7) must be satisfied for proper selection of gear drives within the given power and rotations number. Operation and all imbalances are certainly defined in more detail by this way of calculation. This means the temperature is not considered if load capability is not limited by thermal capacity.

— The third way: The company Flender Cavex has the most complex procedure of selection since it requires more conditions to be satisfied:

1. From the point of strength, it must be satisfied following condition:

$$T_{2N} \geq T_2\, f_1\, f_2\, f_3 \qquad (11)$$

2. From the point of heating, it must be satisfied following condition:

$$T_{2N} \geq T_2\, f_3\, f_4\, f_5\, f_7 \qquad (12)$$

3. From the point of the highest load capability, it must be satisfied following condition:

$$T_{2N\max} \geq T_{2A}\, f_2\, f_3 \qquad (13)$$

The minimum torque value of starting or breaking is at least $T_{2A} \geq 1.2\, T_2$, while $T_{2N\max}$ is the highest permitted value of short-time duty and it is given in catalogues.

4. From the point of the highest permitted load capability, it must be satisfied following condition:

$$T_{2N\max^*} \geq T_{2A}\, f_2\, f_6 \qquad (14)$$

where the highest permitted value of short-time duty $T_{2N\max^*}$ is given in tables in producer's catalogue for the smallest rotation number n_1.

≡ f_1 – factor which takes into account the type of driving machine (in this case electric motor), the type of operating machine, i.e. load classification (light, moderate, heavy) and daily operating duration;

≡ f_2 – factor which takes into account number of starts of the gear drive during the hour;

≡ f_3 – factor which takes into account the lubricant type and the size of gearbox (for synthetic lubricant $f_3 = 1$);

≡ f_4 – factor which takes into account the operating cycle per hour (ED factor);

≡ f_5 – factor which takes into account the ambient temperature of surroundings where the gear drive operates and input revolutions number (fan speed);

≡ f_6 – factor which takes into account direction of load (for alternating direction of load $f_6 = 1.2$);

≡ f_7 – factor which takes into account the type of gearing and thermal capacity and it is specially defined for each gear drive and gear ratio value.

PROBLEM SOLUTION

It is evident that thermal capacity of gear drive decreases with increasing of ambient temperature (Figure 1). So, if load capability is limited by thermal capacity that means the gear drive has lower load capability. If load capability is limited by strength of particular components, thermal capacity is not important factor for loadability until the moment it becomes limiting.

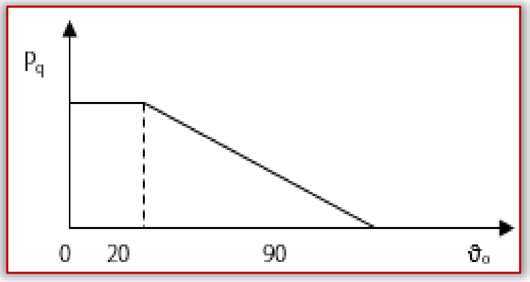

Figure 1. Diagram of thermal capacity decreasing with increasing ambient temperature

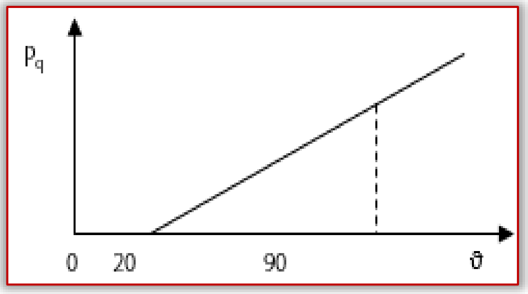

Figure 2. Diagram of changing thermal capacity with increasing permitted ambient temperature

If the changing of operating temperature of lubricant is permitted, it comes to similar change of thermal capacity (Figure 2). But, if load capability is limited by thermal capacity, the loadability will be also changed.

CONCLUSION

Analysing the influence of operating temperature, it can be concluded that it is very important feature since it is often limited factor for the thermal power capacity and thus for the load capability of gear drive. Some manufacturers do not show its value in their catalogues, since it is not important for the gearbox user.

The ambient temperature depends on the place of gearbox installation and it is taken into consideration by all manufacturers, but not with the same significance. If thermal power capacity, i.e. load capability, is limited by thermal capacity of gearbox, its value can be changed for 10-25 % with the changing of ambient temperature for only 10°C.

Heat capacity of gear drive cannot be crucially changed by changing limiting temperature, but only by increasing the efficiency of system (primarily the efficiency factor), by increasing the active surface of the housing, as well as by the method of lubricant cooling. Only in that way load capability of gear drive can be increased, and thus the gear drive will be competitive on the market.

Note

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