DIFFERENT SELECTION PROCEDURES OF UNIVERSAL WORM GEAR DRIVES

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Abstract: The purpose of this paper is to point out the usual methods of determining the service factor, which is the most influential parameter. In order to provide the proper selection of the size of the worm gear reducer, manufacturers are trying to take detailed look at all the factors which influence the work gear and to provide customers with the best possible solution. The greatest impact on their defining has a safety factor which is used to calculate the gear unit and the effect of an ambient temperature i.e. cooling method.

Key words: worm gear units, selection procedures, safety factor.

1. INTRODUCTION

It is undisputed that the use of universal worm gears and worm gears in general is reduced to a minimum, because of relatively large losses that occur in them, in addition to a number of advantages they have. They are most commonly used only for short-term operations and in places which require large transmission ratios, within a relatively small body, quiet operation and self-locking (which occurs only at high ratios). In order to reduce this bad feature of the worm gears and the consequences arising from it (substantial warming and relatively short service life, due to the high wear) manufacturers are trying to take a detailed look at all the factors which influence the work gear, to provide customers with the best possible solution [1,2]. The purpose of this paper is to point out the usual methods of determining the service factor, which is the most influential parameter. The selection of the size of the worm gear is based on this parameter.

2. PROBLEM DESCRIPTION

The selection of universal worm gear units depends on many factors. In most cases, they are only selected in cases of short run, when it is required to reach large transmission ratios within a relatively small space. Also when it is required to ensure that the axis of the input and output shafts are passing each other; when it is required to ensure a peaceful and quiet operation, especially in cases where it is required to provide self-locking, although it should be noted that not all worm gears are self-locking [1,2].

While selecting worm gear unit, apart from the other conditions, (thermal capacity [3,4] and permissible radial and axial load [1,4]), the main condition has to be met. Nominal value of the torque (T_{2N}) should be higher than the value of the actual torque on the output shaft. Actual torque on the output shaft should be increased by all the imbalances which occur during the exploitation and it mostly depends on: driving machine type, working

machine type, daily operating period, starts per hour, indicated load during an hour, ambient temperature, type of lubricant, variability of the direction of a rotation, the type of the gear teeth and the desired service life of the gear unit. This condition is usually expressed by the equation:

$$T_{2N} \geq T_2 f_B \quad (1)$$

where is the following stand for:

T_{2N} – Nominal value of the torque which is the Maximum torque at the output. In a quiet load, it can load in a way that working in a single shift it can reach a work span of, typically, 5000 hours of maintenance at an acceptable price [1,4].

T_2 – Output torque at a certain power and at a certain number of rotations per minute

$$T_2 = 9550 \cdot \frac{P_2}{n_2} = 9550 \cdot \frac{P_1 \cdot \eta}{n_2} \quad (2)$$

where it is:

P_2 – output power,

n_2 – rotations per minute of output shaft,

P_1 – input power,

η – efficiency,

f_B – service factor,

$$f_B = \prod_{i=1}^n f_i \quad (3)$$

where is the following stand for:

n – The number of parameters to be taken into account, which differ significantly from manufacturer to manufacturer,

f_1 – factor which takes into account the type of driving machine, electric motor or hydro motor, multi-cylinder combustion engine and the single cylinder internal combustion engine,

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f_2 – factor which takes into account the type of working machine,

f_3 – factor which takes into account daily operating period in hours,

f_4 – factor which takes into account number of starts per hour,

f_5 – factor which takes into account real load of gearbox in an hour, ED factor,

f_6 – factor which takes into account ambient temperature, some of the producers consider that the value of normal temperature is 20°C, while others consider it to be 40°C. Some producers allows higher load if the temperature is equal or lower than 10°C,

f_7 – factor which takes into account the type of lubricant and size of the reducer (for synthetic oils, $f_7 = 1$ [3])

f_8 – factor which takes into account variability of the direction of a rotation (for reversible drive some producers calculate that $f_8 = 1,2$ [2]),

f_9 – factor which takes into account the type of gear teeth and thermal capacity,

f_{10} – factor which takes into account the desired service life of the gear unit.

For the proper selection a of gear motor with a specific power and number of revolutions, basic requirement must be fulfilled [1], which is:

$$f_B \leq f_{BD} = \frac{T_{2N}}{T_2} \quad (4)$$

where

f_{BD} – is permissible value of the service factor, which is calculated by the equation (4). Producers give it in their catalogues, for each gear unit, with each input power (power of electric motor) and rotations per minute of the output shaft - n_2 .

The service factor value, or the number of components of the service factor which are taken into consideration (n), varies from manufacturer to manufacturer.

Winsmith company has one of the simplest methods of selection. This company defines the value of the service factor in tables, according to the AGMA standard, depending on the type of driving and working machine and the duration of the drive working machine. It selects the gear unit according to the equation (1).

The ROSSI company has a more complex procedure of selection, because, in addition to these factors, it also takes into account the number of switching over an hour, ambient temperature and effective load during the day. The company takes into account the thermal capacity of the gear unit, ie. requires that the input power (P_1) has to be less than the thermal capacity (P_{tN}) increased by a factor that takes into account the ambient temperature and the effective load gear (f_t).

$$P_1 \leq P_t = P_{tN} \cdot f_t \quad (5)$$

In addition, it takes into consideration the maximum permissible load of gear unit in the short-term operation:

$$T_2 \leq T_{2\max} \quad (6)$$

This method of selecting a gear unit defines in detail the variation factor which occurs during the exploitation

Flender Cavex Company has the most complex selection method [3], which requires the fulfilment of several conditions:

1. As far as strength is concerned, the following requirement has to be fulfilled:

$$T_{2N} \geq T_2 \cdot f_1 \cdot f_2 \cdot f_3 \cdot f_4 \cdot f_7 \quad (7)$$

They see the first three factors as one factor and use different symbols to mark them.

2. As far as heating is concerned, the following requirement has to be fulfilled:

$$T_{2N} \geq T_2 \cdot f_5 \cdot f_6 \cdot f_7 \cdot f_9 \quad (8)$$

3. As far as Maximum load is concerned, while starting and stopping gearbox with brake, the following requirement has to be fulfilled:

$$T_{2N\max} \geq T_{2A} \cdot f_4 \cdot f_7 \quad (9)$$

4. As far as maximum permission load of gearing is concerned, the following requirement has to be fulfilled:

$$T_{2N\max^*} \geq T_{2A} \cdot f_4 \cdot f_8 \quad (10)$$

where :

$T_{2N\max^*}$ – stands for maximum peak permission load, at minimum RPM n_1 , presented in tables for $T_{2N\max^*}$.

A detailed analysis of those parameters and their values show us a different consideration of these factors.

3. PROBLEM ANALYSIS

Driving and working machine have a major impact on the appearance of shock loads as well as the duration of the driving [1], so all manufacturers devote great attention to these factors (table 1).

3.1. Winsmith

Table 1. Service factor value depending on the type of drive, working machine and the duration of the drive, in case of small number of starts

Electric motor drive			
Drive duration	uniform	moderate	heavy
to 0,5 h	0,80	0,90	1,00
to 2 h	0,90	1,00	1,25
to 10 h	1,00	1,25	1,50
to 24 h	1,25	1,50	1,75
Multi-cylinder combustion engine drive			
Drive duration	uniform	moderate	heavy
to 0,5 h	0,90	1,00	1,25
to 2 h	1,00	1,25	1,50
to 10 h	1,25	1,50	1,75
to 24 h	1,50	1,75	2,00
Single cylinder combustion engine drive			
Drive duration	uniform	moderate	heavy
to 0,5 h	1,00	1,25	1,50
to 2 h	1,25	1,50	1,75
to 10 h	1,50	1,75	2,00
to 24 h	1,75	2,00	2,25

Fig.1. Winsmith company worm gear unit [5]

Fig.2. Rossi company worm gear unit [6]

Table 2. In case of larger number of starts (from 10 to 20 starts)

Type of driving machine	Electric motor drive		
Drive duration	uniform	moderate	heavy
to 0,5 h	0,90	1,00	1,25
to 2 h	1,00	1,25	1,50
to 10 h	1,25	1,50	1,75
to 24 h	1,50	1,75	2,00

3.2. Rossi

Table 3. Service factor value

Type of driving machine		Electric motor drive		
Drive duration	Service life (h)	uniform	moderate	heavy
from 2 h	3150	0,67	0,85	1
from 2 to 4 h	6300	0,85	1,06	1,25
from 4 to 8 h	12500	1	1,25	1,5
from 8 to 16 h	25000	1,25	1,6	1,9
from 16 to 24 h	50000	1,6	2	2,36
Number of starts		uniform	moderate	heavy
4		1	1	1
8		1,06	1	1
16		1,12	1,06	1
32		1,18	1,12	1,06
63		1,25	1,18	1,12
125		1,32	1,25	1,18
250		1,4	1,32	1,25
500		1,5	1,4	1,32

3.3. Flender Cavex

Fig.3. Flender Cavex company worm gear unit [7]

The influence of working machine and drive duration with an electric motor drive (f_1, f_2, f_3).

Table 4. Service factor value

Type of driving machine	Electric motor drive		
Drive duration	uniform	moderate	heavy
to 0,5 h	0,8	0,9	1
to 2 h	0,9	1	1,2
from 2 to 10 h	1	1,2	1,4
from 10 to 24 h	1,2	1,4	1,6

Table 5. Number of starts (f_4)

Number of starts	to 10	from 10 to 60	from 60 to 240	from 240 to 600
f_4	1	1,1	1,2	1,3

Table 6. The influence of time of effective load, the so-called. ED factor

ED factor	100	80	60	40	20
f_5	1	0,94	0,86	0,74	56

Table 7. The influence of ambient temperature and number of revolutions of input shaft (fan speed) - f_6

Temperature (°C)	to 10	20	30	40	50
$n_1 \leq 300 \text{ min}^{-1}$	0,9	1	1,14	1,33	1,60
$300 < n_1 \leq 1500$	0,9	1	1,17	1,42	1,75
$n_1 > 1500$	0,9	1	1,20	1,50	1,90

Table 8. The influence of type of lubricant and the size of the reducer (for synthetic oils, $f_7 = 1$)

The axial height of the gear unit	from 63 to 100	from 120 to 250	from 280 to 450	from 500 to 630
f_6	1,2	1,25	1,3	1,36

Table 9. The influence of variability of the direction of rotation

Revolution in one direction	$f_8 = 1$
Revolution in both directions (reversible drive)	$f_8 = 1,2$

The influence of the type of gear profile and thermal capacity (f_9) is given in a manufacturer's catalogue for each gearbox.

Table 10. A summary of the analyzed service factors

Manufacturer	Moderate load, 8 hours, with 10 starts per hour
WINSMITH	$f_B = 1,25$
ROSSI	$f_B = 1,25 \cdot 1,06 = 1,325$
FLENDER CAVEX	$f_B = 1,2 \cdot 1 = 1,2$

Such a different approach to defining a service factor certainly has a great influence on gear selection. For example, if you are looking for a gear that will be driven by an electric motor, at moderate load, which will run for 8 hours, with 10 starts per hour, the analyzed manufacturers offer the following values of a service factor given in table 2. The differences between the service factors are small, ie. it can be seen that they respect working conditions the most because their influence on the safety factor is the greatest.

If we take into consideration the ambient temperature, for example, 40 °C at operation with a four-pole motor ($n_1 \leq 1500 \text{ min}^{-1}$), then the difference becomes even more significant (Table 3).

Table 11. A summary of the service factors that are included and the ambient temperature of the analyzed manufacturers

Manufacturer	Moderate load, 8 hours, with 10 starts per hour with ambient temperature 40°C
WINSMITH	$f_B = 1,25$ Does not take into account the temperature
ROSSI	$f_B = 1,25 \cdot 1,06 = 1,325$ The increased temperature limits the input power of the engine, and if this condition is met, the increase in temperature is not taken into account during the selection of the gear unit.
FLENDER CAVEX	$f_B = 1,2 \cdot 1 = 1,2$ In addition to this requirement, the condition $f_B = 1,25 \cdot 0,8 \cdot 1,42 \cdot 0,7 = 0,994$ has to be fulfilled as well; In addition to these two conditions, another two conditions must be met. However, as these conditions are related to the field of study of the first two manufacturers, they will not be mentioned here.

4. EXAMPLES OF SELECTION

For the torque at the output, for example, $T_{2N} = 300 \text{ Nm}$, revolutions per minute $n = 30 \text{ min}^{-1}$ and effective load of ED = 60 % manufacturers recommended the following gear units:

4.1. Winsmith

This manufacturer recommends the following procedure for gear unit selection for provided working conditions

$$T_{2N} \geq T_2 \cdot f_B = 300 \cdot 1,25 = 375 \text{ Nm}$$

This requirement corresponds to the gear unit marked 7FC, with the center distance of $a = 101,6 \text{ mm}$, input power $P_1 = 1,9 \text{ kW}$ and torque at the output $T_{2N} = 419 \text{ Nm}$. It should be particularly noted that the motor works with $n_{em} = 1200 \text{ min}^{-1}$.

4.2. Rossi

This manufacturer recommends the following procedure for gear unit selection

$$T_{2N} \geq T_2 \cdot f_B = 300 \cdot 1,325 = 397,5 \text{ Nm}$$

This requirement corresponds to the gear unit marked 80, the center distance of $a = 80 \text{ mm}$, input power $P_1 = 1,74 \text{ kW}$, output power $P_{2N} = 1,33 \text{ kW}$, torque at the output $T_{2N} = 407 \text{ Nm}$, maximum torque peak the gear reducer will withstand $T_{2\max} = 710 \text{ Nm}$. It should be particularly noted that the motor works with $n_{em} = 1200 \text{ min}^{-1}$ and that the number of revolutions of the output shaft is $n_{em} = 31,5 \text{ min}^{-1}$.

The company takes into account the thermal capacity of the gear unit, but at this size and the transmission ratio of the gear unit, permission load is not limited by thermal capacity.

In addition, this company takes into consideration maximum permissible load for short-run drive

$$T_2 \leq T_{2\max}$$

As the driving mode is not specified, it will be counted

$$T_2 = 1,2 \cdot T_2 = 1,2 \cdot 300 \leq T_{2\max} = 710 \text{ Nm}$$

So this size of the gear unit is acceptable.

4.3. Flender Cavex

This manufacturer has the most complex selection method and it requires the fulfilment of multiple requirements

1. As far as strength is concerned, the following requirement has to be fulfilled:

$$T_{2N} \geq T_2 \cdot f_1 \cdot f_2 \cdot f_3 \cdot f_4 \cdot f_7 = 300 \cdot 1,2 \cdot 1 \cdot 1,42 = 511,2 \text{ Nm}$$

They see the first three factors as a single factor and use different symbols to mark them.

This requirement corresponds to the gear unit marked 100, with input power $P_1 = 3,3 \text{ kW}$, torque at the output $T_{2N} = 813 \text{ Nm}$, with maximum torque peak the gear reducer will withstand $T_{2\max} = 1060 \text{ Nm}$ and service factor $f_9 = 0,58$. It should be particularly noted that the motor works with $n_{em} = 1500 \text{ min}^{-1}$ and that the number of revolutions of the output shaft is $n_{em} = 30 \text{ min}^{-1}$

2. As far as heating is concerned, the following requirement has to be fulfilled:

$$T_{2N} = 812 \text{ Nm} \geq T_2 \cdot f_5 \cdot f_6 \cdot f_7 \cdot f_9 = 300 \cdot 0,86 \cdot 1,2 \cdot 1,42 \cdot 0,58 = 255 \text{ Nm}$$

This is satisfactory.

3. As far as maximum load is concerned, while starting and stopping gear with braking, the following requirement has to be fulfilled:

$$T_{2N\max} = 1060 \text{ Nm} \geq T_{2A} \cdot f_4 \cdot f_7 = 300 \cdot 1,2 \cdot 1 \cdot 1,42 = 511 \text{ Nm}$$

This is satisfactory.

It was calculated that the minimum value of the starting torque or braking torque is higher than $T_{2A} \geq 1,2 \cdot T_2$.

4. As far as maximum permission load of gearing is concerned, the following requirement has to be fulfilled:

$$T_{2N\max}^* = 1680 \text{ Nm} \geq T_{2A} \cdot f_4 \cdot f_8 = 300 \cdot 1,2 \cdot 1 \cdot 1,2 = 432 \text{ Nm}$$

Where $T_{2N\max}^* = 1680 \text{ Nm}$ - stands for maximum torque peak, at minimum revolutions per minute n_1 , which is given in tables for $T_{2N\max}$. In addition, it was calculated that it was the most unfavourable alternating drive. Selected gear unit satisfies.

5. CONCLUSION

Based on the analysis, it is evident that some manufacturers take into account different load mode, which significantly influences the selection of the size and thus the price of a gear unit. Of course, in addition to the standards that strongly defines the parameters of the service factor manufacturers have a different experience and approach to their own defining. The greatest impact on their defining has a safety factor which is used to calculate the gear unit and the effect of an ambient temperature ie. cooling method. If the safety factor is lower than the external conditions, it has to be more significantly respected and vice versa. In this particular case it can be noted that one of the manufacturers recommended a slightly smaller gear unit ($a = 80 \text{ mm}$) for the given conditions of the drive, while the other two recommended a gear unit with the same axial distance of $a \approx 100 \text{ mm}$. It is particularly interesting that one of the manufacturers, which has a greater axial distance, has twice as big capacity as the other manufacturers with the same axial distance.

It is undisputed that great attention should be devoted to this extremely important factor.

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