S. MEDVECKÁ - BEŇOVÁ, I. VIRGALA, M. KELEMEN, Ľ. MIKOVÁ

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INFLUENCE OF MATERIAL AND GEAR PARAMETERS ON THE SAFETY OF GEARING IN METALLURGICAL INDUSTRY

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This paper deals with the appropriate choice of parameters to obtain the desired level of safety of gears in a gearbox to drive the conveyor in the metallurgical industry under increased load. Steel with surface hardness up to 350 HBW, or heat treated steel with hardness of 500 - 650 HBW are used. As a final heat treatment are used surface hardening, cementation and hardening, nitridation. Good properties of heat-treated steels are at the correct thickness of the heat-treated layer of the tooth. Results are presented for dual-ratio gearbox with spur gears from operation of an integrated steel company.

Key words: steel, material, heat treatment, gearing, safety factor

INTRODUCTION

Basic material for gearing is steel. Suitable heat or chemical - heat treatment may improve the mechanical properties of the core and the surface hardness of the teeth of gears. The high hardness of the teeth is a prerequisite for high contact strength and good resistance of tooth flanks against wear and seizing. While maintaining the toughness of the core the teeth of the steel gears are resistant to brittle break, which occurs beside the load of the gear with shocks.

The aim of strength calculation of gearing is to formulate the conditions that must be met to avoid creating limit states in the gearing during the required durability of the gearing. Sufficient safety of gearing is a concept that must be understood in the context of the very different requirements that are imposed on gears in different application areas.

PARAMETERS OF GEARING IN METALLURGICAL INDUSTRY

It is a dual-ratio gearbox with spur gears from operation of an integrated steel company, whose production program consists of a wide assortment of hot rolled and cold rolled products. It is necessary to carry out strength calculation of gearing when changing (magnification) the thickness of steel coils, for the change of input parameters. It is necessary to propose the necessary adjustments, if strength calculation is inconvenient. Transmitted power is changed from 600 kW to 800 kW. Speed of winding sheet metal is changing depending on the amount of coil sheet metal. The rotation speed at the start winding is greatest n_{max} = 1 250 min^{-1}. Gradually the speed is decreasing to a minimum n_{min} = 330 min^{-1}, with increasing winding diameter of wound coil. The rotation speed is changed so that the peripheral speed of the sheet metal is line constant. Transmission ratio of gearbox is i = 9,48. The first driving position is characterized by the number of teeth meshing gears z_1 = 30 and z_2 = 79, value of the teeth module m_{n1} = 8 mm, angle of bevel teeth β_1 = 10 °. The second driving position is characterized by values z_3 = 30 a z_4 = 108, m_{n2} = 10 mm, β_2 = 10 °. Rotation speed of the input shaft is alternate, accordingly in strength calculation of gearbox is considered value of the input speed n_{min} = 330 min^{-1}. The torque on the input shaft is M_{k1} = 23 149,81 Nm, on the countershaft is M_{k2} = 60 961,67 Nm and on the output shaft is M_{k3} = 219 460,2 Nm.

THE STRENGTH CALCULATION OF GEARS

There are some methods of strength calculation of gears. Their common feature is to formulate conditions. These conditions must be met to avoid creating limit state in the gearing during gear durability.

To the oldest calculation methods belongs the calculation according to Bach, which became the basis for strength calculations according to standard STN 01 4686. This calculation consists of checking of the gear teeth on bend and contact.

When calculating, the fatigue failure of teeth is monitored. The safety factor against fatigue fracture in the heel of the tooth can be expressed in form by [1]:

$$S_F = \frac{\sigma_{F\,lim\,b} \cdot Y_N \cdot Y_\delta \cdot Y_X}{\sigma_F} \geq S_{F\,min} \qquad (1)$$

where S_F - safety factor against fatigue fracture in the heel of the tooth, $\sigma_{F\,min}$ - flexing fatigue life, Y_N - co-

S. Medvecká-Beňová, I. Virgala, M. Kelemen, Ľ. Miková, Faculty of Mechanical Engineering, Technical University of Košice, Košice, Slovakia

efficient of durability, Y_δ - coefficient of nick sensitivity, Y_X - coefficient of dimension, σ_F - bending stress in the dangerous cross section of heel tooth, S_{Fmim} - minimum value of the coefficient, $S_{Fmin} = 1,4$.

The safety factor against fatigue damage of tooth side is calculated as:

$$S_H = \frac{\sigma_{H\,lim} \cdot Z_N}{\sigma_H} \cdot (Z_L \cdot Z_R \cdot Z_V) \geq S_{H\,min} \qquad (1)$$

where S_H - safety factor against fatigue damage of tooth side, $\sigma_{H\,lim}$ - fatigue limit in contact, Z_N - coefficient of durability, Z_L - coefficient of lubricants, Z_R - roughness coefficient of tooth side before meshing, Z_V – coefficient of peripheral speed, σ_H- stress of contact (Hertz pressure) in pitch point, S_{Hmin} - minimum value of the coefficient, $S_{Hmin} = 1,1$.

MATERIALS AND HEAT TREATMENT

The most common materials for gear wheels are steels. They are divided into so-called "soft" and "hard". The boundary between them is considered a hardness of 350 HBW (tensile failure strength of about 1 200 MPa). The desired mechanical properties of gears with hardness up to 350 HBW are achieved by normalizing annealing or heat-treating. Since the load gear is great, it is necessary to use gears with higher hardness.

For gears „hard" with hardness greater than 350 HBW, high bearing capacity is achieved by selection of appropriate steel in combination with heat treatment as hardening, cementation and nitriding. Practically achieved surface hardness values are 350 - 650 HBW in the strength of the core 700 to 1 500 MPa. The „hard" teeth are badly run-in and such gears are extremely exacting for precision manufacturing. For technologic argument the thermal treatment of gears is carried out after manufacture (cutting operation), what is the cause of deformation of the gear rim. It is therefore necessary to include gear teeth grinding, lapping or shaving.

By surface hardening is achieved a hard and wear resistance tooth surface while maintaining a relatively soft and resilient core of the tooth (Figure 1). For surface hardened gears are used steels and carbon content of 0,3 to 0,5 % C. Heating is done inductively or by flame. Gears of small size are hardening by a single application or gradually tooth after tooth [2]. For large module (module greater than 6 mm) is used hardening in the blank space. Achieved hardness of teeth is 45 to 55 HRC.

For cementation are used alloy steel containing 0,1 to 0,25 % C and alloy of Cr, Mn, Ni, or Mo. Toughness of the core is increased by the addition of Mn and Ni [3].

Nitrided gears achieve a hardness of HRC 60 to 65. Load bearing capacity of the surface layer is smaller. Nitridation does not cause deformation of the gear rim, so there is no need for finishing operations.

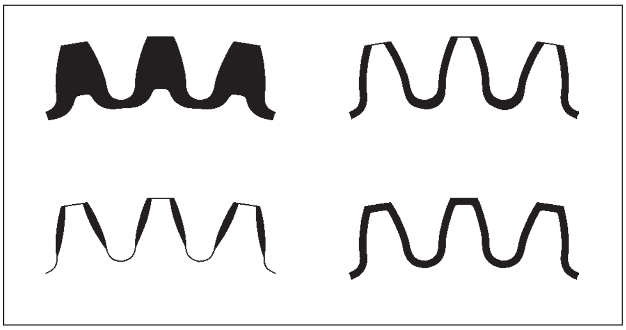

Figure 1 Shapes of hardened layer of gearing. (a - deep hardening, b - hardening tooth after tooth, c - hardening in the blank space, d - contour hardening)

RESULTS OF STRENGTH CALCULATION

For the geometric parameters of gear, such as power P = 800 kW and working life 25 000 h strength calculation of gears was made according to standard by the teeth bend and touch. 16 % of its working life the gear is working with minimal transmission input speed $n_{min} = 330$ min^{-1}. Material at input pinion is steel – W. Nr. 1.1221 and input gear – W. Nr. 1.7034. Material at output pinion and gear are steel W. Nr. 1.7034. The values of safety factors in bending and contact of the original gearing did not qualify according to standard. For the first speed gear are the values of the safety factor in bending $S_{F1} = 0,823$ for pinion and $S_{F2} = 0,785$ for gear. For contact is $S_{H1} = 1,030$ for pinion and $S_{H2} = 1,135$ for gear. For the second speed gear are the values of the safety factor in bending $S_{F3} = 0,589$, $S_{F4} = 0,559$. For contact are $S_{H3} = 0,912$ a $S_{H4} = 1,008$.

Gearing does not meet the strength calculation. When changing the geometrical parameters (number of teeth, module and angle of inclination of the teeth) the values of gear ratio and the axial distance must be observed. The condition was to maintain the gear box and to change own gear mechanism.

By changing only the geometric parameters of gear (such as resizing module - Figure 2) it is not possible to meet the conditions of strength calculation. Therefore it was necessary to change the gearing material and the heat treatment. Table 1 shows the effect of heat treat-

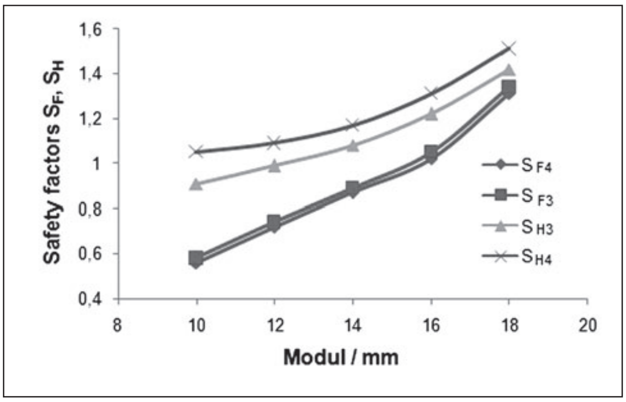

Figure 2 Influence of module on safety factors

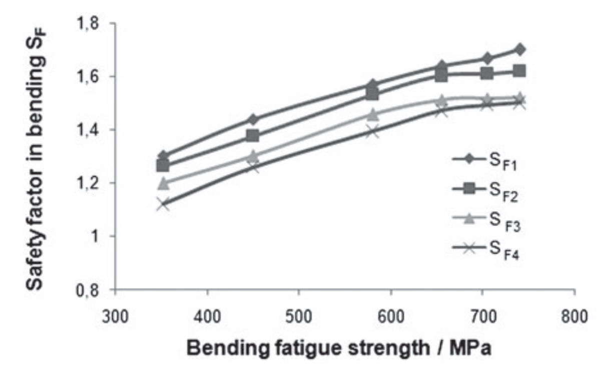

Figure 3 Influence of material on safety factors

ment on the safety factor for the pinion of the original parameters and material (W. Nr. 1.1221).

Table 1 **Influence of heat treatment on the safety factors**

Heat treatment	SF	SH
Normalizing annealing	0,589	0,901
Refining	0,796	0,980
Surface hardening	0,823	1,030
Nitridation	0,921	1,176

Influence of materials (characterized by a bending fatigue strength) of the safety factor for the bending transmission is shown in Figure 3.

The final draft of the new parameters of the transmission is in Table 2.

CONCLUSION

The original gearbox with spur gears is not unfit for the new drive parameters, thus for new parameter load. Based on strength calculations the change of own gear mechanism was proposed. A change in geometric parameters of gears (module, number of teeth, etc.) was proposed. Suitable material and type of heat treatment were selected.

Table 2 **The final parameters of gears**

Parameters	IS	first speed gear	
		input	output
Material of gears W.Nr.	-	1.5752	1.5752
Accuracy to size	-	8	
Working life	h	4 000	
Rotation speed	min^{-1}	330	125,31
Torque	Nm	23 149,8	60 961,6
Safety factor S_F	-	1,699	1,618
Safety factor S_H	-	1,179	1,231
Parameter	IS	second speed gear	
		input	output
Material of gears W.Nr.	-	1.5752	1.6582
Accuracy to size	-	8	
Working life	h	4 000	
Rotation speed	min^{-1}	125,31	34,81
Torque	Nm	60 961,6	21 9460
Safety factor S_F	-	1,521	1,481
Safety factor S_H	-	1,135	1,225

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REFERENCES

[1] Standard STN 014686: Strength calculation of spur and bevel gears.
[2] M. Vereš, M. Bošanský, M. Rackov, Theoretical and experimental research of the HCR gear´s contact strength. In. Machine Design, 2 (2011) 3, 105-108.
[3] P. Tököly, M. Bošanský, A. Vanya, The effect of gear geometry on the thickness of tooth face hardenen layer. In. Vistnik Nacionaľnogo Techničnogo Universiteta, 27 (2010), 10-19.
[4] B. Mateša, I. Samardžič, M. Dunder, The influence of the heat treatment on delta ferite transformation in austenitic stainless steel welds. Metalurgija, 51 (2012) 2, 229-232.

Note: English language: PhDr. Marianna Dombrovská, Translation agency Zita Panková - A.Z.P., Košice, Slovakia