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BADANIE PRZYCZYN USZKODZEŃ ZĘBÓW PRZEKŁADNI

Streszczenie: Ważną rolę podczas określania awarii urządzenia oraz zapewnienia dalszej bezawaryjnej pracy ma charakter uszkodzenia przekładni, który zależ od wielu parametrów. Częstym defektem jest uszkodzenie występujące na powierzchni bocznej zęba przekładni. W artykule przedstawiono analizę uszkodzenia, które wystąpiło w przekładni zębatej stożkowej małego hydrogeneratora hydroenergetycznego. Awaria spowodowała wzrost hałasu podczas pracy urządzenia. Celem pracy było określenie przyczyn uszkodzenia zęba na podstawie analizy jego stanu. Identyfikując przyczyny uszkodzeń zaproponowano działania, które doprowadziłyby do niezawodnej pracy urządzenia podczas dalszego użytkowania.

Słowa kluczowe: koła zębate, stożkowe koła zębate, awaria, uszkodzenie

INVESTIGATION OF CAUSES CONCERNING TOOTH DAMAGE IN THE GEARBOXES

Summary: The important role in determining and secure the safe operating conditions is character of gearing failures, divided according to broad variety of their causes. Wear of gear flanks is an observed and always present phenomenon in gearboxes. This paper deals with defect of bevel gear of small hydropower hydro-generator. The discussed failure caused an increased noise during operation. The aim of the paper is to determine the causes of the tooth damage based on the analysis of tooth damage. By identifying the causes of the damage, measures have been proposed that would lead to a fail-safe operation of the device during its further service life.

Keywords: gearing, bevel gear, failures, damage

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1. Introduction

The fluency and safety of the operation of the equipment depends on the fail-safe operation of the individual technological equipment. The interruption of all the technologic device is causes mainly the failures of power transmissions. The important role in determining and secure the safe operating conditions is character of gearing failures. Complex teeth surface failure is not possible to be defined in a deterministic way. Interaction of separate damage processes is not the same for different stress levels, for different materials, thermal and mechanical treatment, lubrication, etc. [1].
Defects of gears are very diverse. Gears for the design are important those defects which are fatigue nature and seizing at higher speeds, respectively at high slip speeds. This paper deals about devoted to the issue tooth damage specific gears, defining the extent of damage and determine the possible causes tooth damage.

2. Types of tooth damage

Classification of gear faults by cause of the utmost importance, as it allows defining operating conditions, which led to the damage. American Standard provides up to 22 different kinds of tooth damage gears, but in our environment while there is no uniform classification [2].
Gear teeth damage is very diverse. Damage to gears is divided into two groups according to the result: damage of tooth surfaces and damage of gears by tooth fracture. Damage to the tooth surface can be divided into wear, seizure, plastic deformations caused by rolling, knocking or foreign bodies, pitting, hole corrosion (run-in, progressive, micropitting). In addition to the above mentioned defects, there are technological failures (grinding cracks, hardening cracks, forging cracks or castings) [3-5]. Fracture is caused by external or internal stresses that have exceeded the strength limit or fatigue limit in a section of the cross-section. If the gearing is overloaded, the static strength limit of the tooth may be exceeded, in which case an overload fracture occurs. The most common cause of fracture is fatigue damage due to repeated bending of the tooth [6, 7].
The gear load capacity is limited by different kinds of teeth flanks wear: pitting, abrasive and adhesive wear (scoring and scuffing), squeezing, etc. [8,9]. These flank damages are parallel or complementary. For pitting development, it is necessary to start the crack and grow it up along high stress cycles number. In the meantime, by sliding or squeezing it is possible to eliminate cracks in the very initial period and slow down the pitting process (especially micro pitting). Each of the mentioned damages can be disturbed or supported by some of the others [10-13].
Pitting is the damage which corresponds to the gears with surface hardened teeth, with surface stress close to surface endurance limit [14]. Sliding wear (scoring) is characteristic for the gears with non-hardened teeth and with high surface stress. The process of sliding wear is not limited by surface endurance limit. There is no stress level which cannot make surface damage along unlimited stress cycles number (teeth mesh revolution) [15-16]. Scuffing is damage characteristic for highly loaded gears with a very high speed of rotation. Squeezing of gear teeth flanks can arise with not

hardened materials caused by a very high flank stress level, especially at a low speed of rotation [17].

3. Damage of bevel gear of small hydropower hydrogenerator

This chapter is devoted to damage teeth in small hydro generator of small hydroelectric (power) plant (Fig.1). After 10 years of activity is reflected increased noise. By measuring the vibration frequency analysis and subsequent hydro-generator which evaluated the mechanical vibration of rolling bearings and bevel gear has been found to be an error teeth of gear. After removing the gearbox is determining the extent of damage.

Figure 1. The small hydroelectric (power) plant

It is a one-speed bevel gear unit with curved teeth and gear ratio of i = 3.083. Number of teeth on pinion is z_1 = 12, on wheel z_2 = 37, power is P = 600kW and input speed is n_1 = 750 min^{-1}. The manufacturer specifies oil change after 10 000 hours of gearbox operation.

There are several methods for strength calculation of gearing both national and international standards. Their purpose is to formulate the conditions which must be fulfilled so that the limit state does not occur in the gearing during the required service life. The oldest calculation methods include the calculation ac-cording to Bach, which has become the basis of the strength calculation according to STN 01 4686. According to this standard calculation is based on the control of bending strength and contact stress.

In bending strength calculation, the fatigue fracture of the teeth, starting from the root transition area on the active side of the teeth, is monitored as a limit state. According to this standard, the bending capacity can be proved by calculation the safety factor for bending failure in the root, for which applies:

$$S_F = \frac{\sigma_{Flimb} \cdot Y_N \cdot Y_{N\delta} \cdot Y_X}{\sigma_F} \geq S_{Fmin} \tag{1}$$

where S_F - safety factor for bending failure in the root, σ_{Flimb} - bending fatique life for the intended way of load (MPa), Y_N - coefficient of durability, Y_δ - coefficient of nick

sensitivity, Y_X - coefficient of dimension, σ_F - bending stress in the critical cross section of root (MPa), S_{Fmin} - the minimum value of the factor: S_{Fmin} = 1.4.
In contact stress calculation, the progressive surfaces fatigue damage (pitting) of the teeth is monitored as a limit state. According to this standard, the contact capacity can be proved by calculation the, for which applies:

$$S_H = \frac{\sigma_{Hlim} \cdot Z_N}{\sigma_H} \cdot (Z_L \cdot Z_R \cdot Z_V) \geq S_{Hmin} \tag{2}$$

where S_H - safety factor against fatigue damage of tooth side, σ_{Hlim} - fatigue limit in contact (MPa), 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 - Hertz stress in pitch point (MPa), S_{Hmin} - the minimum value of the factor: S_{Hmin} = 1.1.
Intensive research in the area of the gear damage resistance is resulted by standard.

A bevel gearing with curved teeth, it is also the bevel pinion and bevel gear has been widespread damage to teeth.

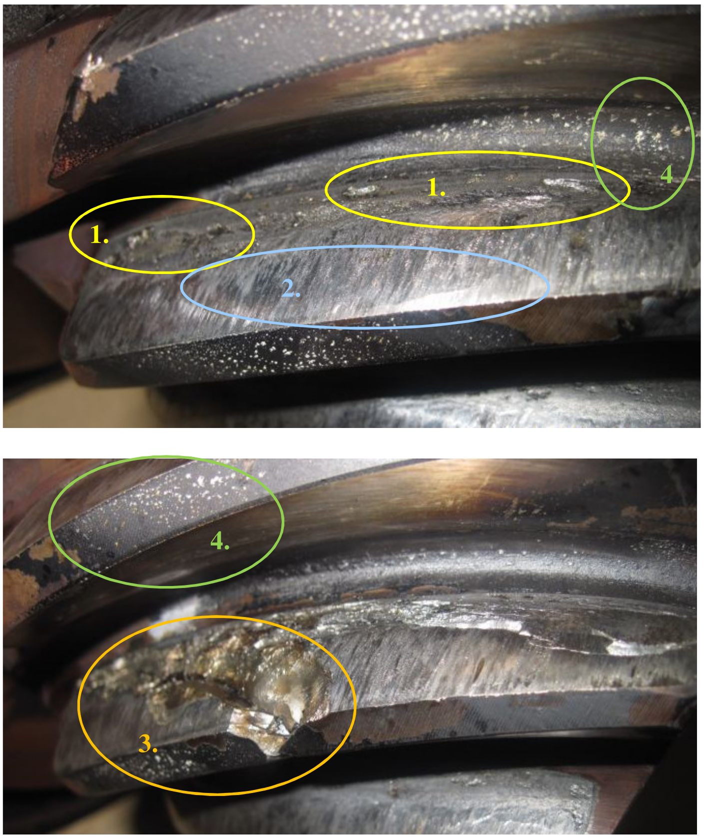

Figure 2. Damage of bevel pinion

Damage to the bevel pinion gear (Fig. 2) can be divided into four categories:

1. Near the foot of the tooth to a height of ⅓ to ½ tooth there are distinct, very large and distinct wells along the entire tooth length at each pinion tooth. This is called pitting.
2. Damage to the tooth flanks of the pitch to the head of the tooth vertical grooves that go over the heads of the tooth towards the tooth root belongs to damage teeth sticking.
3. Damage to one bevel pinion tooth fracture.
4. Damage to the tooth tip and tooth root has elements of abrasive wear.

Each tooth of bevel pinion is damaged by the pitting (Fig. 2 - type 1), aamage to the tooth flanks of the pitch to the head of the tooth vertical grooves (Fig. 2 - type 2) and abrasive wear (Fig. 2 - type 4). Only one tooth is damaged by fracture.

Pitting is a manifestation of superficial fatigue. The damage is manifested by the removal of metal particles and the formation of cavities (wells). Pitting aren't due to wear, but due to surface and under surface tension due to the repeated effects of forces. The load level has effects at the surface pressure value. High flank pressure can succeed pitting cracks but, at the same time, it can eliminate lubricant and succeed sliding wear, which eliminates initial cracks. For this reason, better conditions for pitting development exist if the contact stress is not much higher than the endurance limit.

A bevel gear (rim) there was extensive damage to tooth fracture. All teeth are damaged, or not to leave one is intact, and we can distinguish two types of fractures (Fig. 3). Corner tooth fracture (A), this fracture is damaged every tooth cone wreath. Fold in the middle of the tooth face width (B), so only a few were damaged teeth.

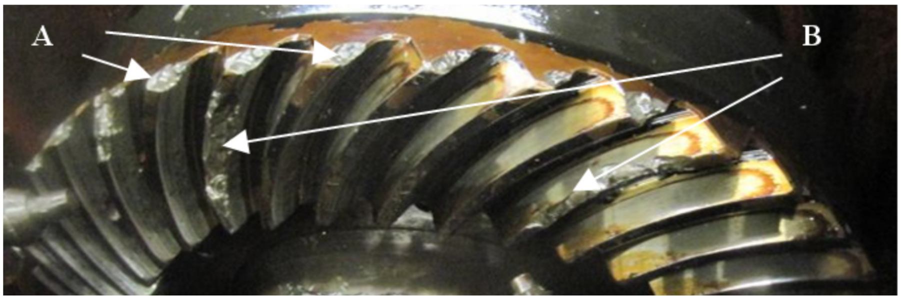

Figure 3. Tooth fracture on the bevel gear wheel

Fatigue failure starts at the tooth surface and tensile stress fracture has two distinctive parts - fatigue (fine-grained) and power (crystalline, rough). Fatigue failure may also start working on the side of the tooth, causing the cracks after sanding.

Fracture surface static fracture is approximately equal and perpendicular to the direction of tension. Its surface is grainy, rough, coarse or subtle, depending on the grain size of the material. Because it was breaking open only part of the tooth can be an unbalanced tooth. This may be caused by improper tooth meshing, which could be caused by assembly (wheel bearings) gearbox, improper storage shafts and thereby excite vibrations, etc.

For flawless operation must be fulfilled to ensure lubrication has been fluid friction, if these conditions are not met leads to tooth wear and time to seizure. In this case the seizure was caused by impurities in the lubricant. In case of insufficient lubrication, respectively due to impurities in the oil occurs to metal contact between the tooth flanks, which leads to micro weld and then splintering due to the relative motion tangential to the surface. This is explained in the holes of the head towards the tooth spacing. Impurities in the oil are due to peeling paint surface inside the gearbox and coat gears (Fig.4).

Figure 4. Error primer coating gearbox

The damage was due to a combination of several causes. The first is application of inappropriate coating (prescription or non-compliance with protective coating applications) inside the gearbox. He caused the contamination in lubricants and defective lubrication of the gearing. Insufficient lubrication resulted in damage to the tooth flanks contact pitting. Effect of external or internal stresses which exceed the ultimate strength or fatigue strength of the material led to fracture teeth. If the material is brittle, explodes and arise cracks or break of tooth.

Influences that lead to it are varied, may be an inappropriate design (not suitable shape or size), inappropriate material (solid poorly or insufficiently tough), the error in the manufacture or assembly (indentations caused by stress due to improper technology) or the influence of temporal changes material properties (fatigue). So extensive damage to the gears could be prevented shutdown of the machine when the first increase in noise transfer and subsequent correction of errors that can be detected by checking the status gear already at this stage.

4. Conclusion

If it were possible to calculate the wear distribution already in the design phase, much would be gained since indications as to the performance and service life of the designed product will be obtained. Wear is normally treated rather casually using blunt proximations and without reflecting on the effects of wear on the working behaviour of the gears. Wear analysis of tested gears is generally carried out using a scale to indicate the degree of wear. In service conditions, a failure process is combined of a number of damage processes. Which of them will be dominant depends on design parameters, technological and exploitation conditions. Periodically, for some of gears, extremely difficult service conditions exist, which creates a possibility for progressive teeth wear. Characteristics of faults in the gears according of the emergence causes has important role in determining safe operating conditions.

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