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PRINCIPLE OF THE ROLLING CONTACT FATIGUE FORMATION

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Abstract: *There is a lot of theoretical methods how to proceed at the service life assessment of the machine components like gears, bearings, cam mechanisms. This paper deals with principle of the rolling contact fatigue, which is necessary to take into account at the service life estimation. On the basis of these knowledge we can make experimental testing of the samples and from results we can determine relatively exactly the value of the service life of the chosen machine part.*

Keywords: Rolling contact fatigue, Pitting, Fracture mechanics.

1. Introduction

VÚTS, a.s. deals with the design of cam mechanisms and cams production more than thirty years. This provides us a lot of experience in design and calculation of both axial and radial cams. With designing is connected the methodology of the life prediction of the cam surface. On this basis, we can determine the life of the cam mechanism respectively time when damage occurs.

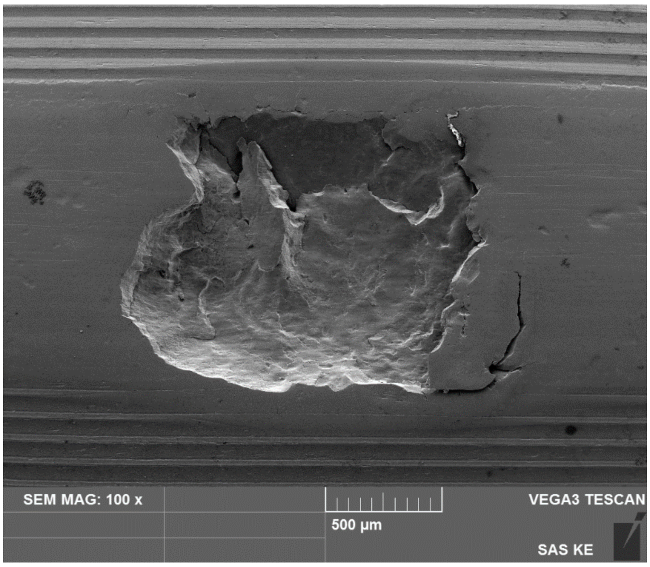

Fig. 1: Damaged surface (pitting) (acquired in own research).

The rolling contact fatigue (RCF) occurs in functional surfaces that are exposed to repeated loading (high local pressure) during movement of the functional surfaces of the machine components (see Fig. 4). It may be a relative rolling movement or a combination of sliding and rolling, what is more common in practice. Characteristic for RCF is gradual accumulation of the cracks in the surface layer at the repeated contact stress. The best known cases of the RCF are at the roller bearings, gears, cam mechanisms, railway wheels etc. Formation, progress and intensity of damage caused by fatigue wear are very dependent on the working conditions (e.g. lubrication, temperature).

There is more types of RCF. The most common (at cam mechanisms) is pitting (Fig. 1). We can observe micro- and macropitting by size of the pits on the damaged surface. Other types of RCF are e.g. spalling, galling, scuffing and scoring.

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2. Mechanical (mathematical) analysis of RCF

The commonly used theoretical models are based on the Hertz's contact theory. On its basic is given the value of the Hertzian pressure, which is decisive at the determining of the save load. At this load it will not occur damage of the functional surfaces of the cam and roller.

Assumptions of Hertz's theory are available in the literature Koloc (1988). There is a schematic view of the contact of the two cylinders in Fig. 2. There is a contact of cam and roller at the cam mechanism. The length of the contact area is denoted l, the radii of curvature at point of contact are ${}^{1}\rho_y$, ${}^{2}\rho_y$ and F defines normal reaction between the particular elements of the pair (Koloc, 1988).

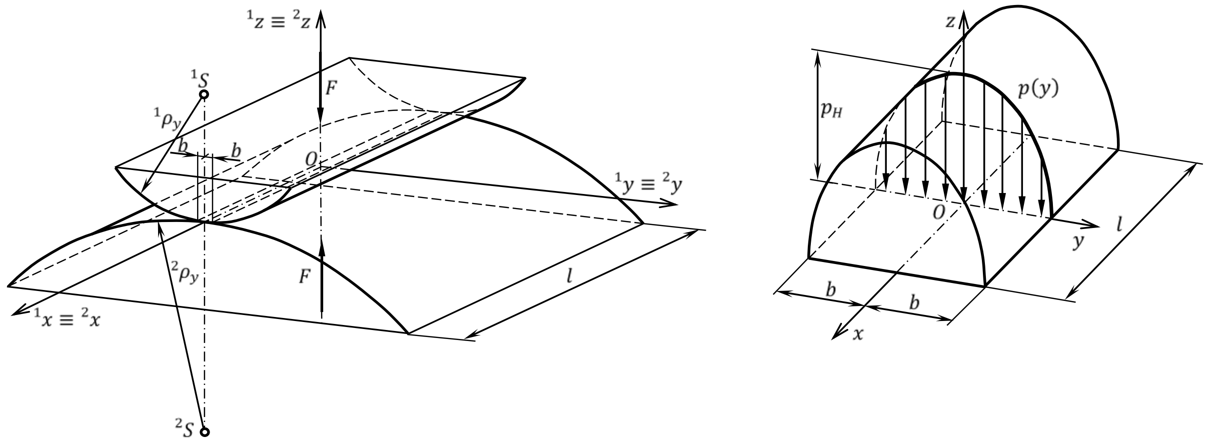

Fig. 2: Contact of cylindrical bodies with parallel axes and pressure distribution in contact.

Hertzian pressure is a maximum compressive stress p_H defined as (1), where f is the load in proportion to the length unit.

$$p_H = \frac{2f}{\pi b} = \sqrt{\frac{f\left(\left|{}^{2}\rho_y\right| \pm {}^{1}\rho_y\right)}{\pi(\delta_1+\delta_2)\,{}^{1}\rho_y\left|{}^{2}\rho_y\right|}} \tag{1}$$

Unlike the positive radius of curvature of the roller follower ${}^{1}\rho_y$, the radius of curvature of the cam surface in contact ${}^{2}\rho_y$ may attain both, positive or negative values. Actually this fact is defined in relation (1) by quantity $|{}^{2}\rho_y|$.

$$\delta_{1,2} = \frac{1-\mu_{1,2}{}^{2}}{E_{1,2}} \tag{2}$$

The quantities δ_1, δ_2 are the characteristics of elasticity of the elements in the pair (2), where the Poisson's ratio and the modulus of tension elasticity are denoted as $\mu_{1,2}$ and $E_{1,2}$ respectively. Rearranging relation (1) we get the bisected contact area (3).

$$b = 2\sqrt{\frac{f(\delta_1+\delta_2)\,{}^{1}\rho_y\left|{}^{2}\rho_y\right|}{\pi\left(\left|{}^{2}\rho_y\right| \pm {}^{1}\rho_y\right)}} \tag{3}$$

The next step is to calculate a reduces stress (Koloc, 1988).The reduced stresses $\sigma_{red}\,(\psi,\varsigma)$ are limited by the actual strength condition, written in the form (4), where ψ is an angular cam displacement and $\psi \in \langle 0.\,2\pi)$ and $\varsigma = |z|/b \geq 0$.

$$\max \sigma_{red}(\psi, \varsigma) < \sigma_h \tag{4}$$

For steel are the usual values $\sigma_c \approx 0.33\,R_m$ and $R_e \approx (0.55\ to\ 0.8)\,R_m$. However, since the transitory stress limit is $\sigma_h \approx 2\sigma_c \approx 0.66\,R_m$, the relation (4) may be replaced by the inequality (5), where $\psi \in \langle 0.2\pi)$ and $\varsigma = z/b \geq 0$. This equation states that no destructive action of elastic deformation is produced in the general pair under operation.

$$\max \sigma_{red}(\psi, \varsigma) < R_e \tag{5}$$

The other view at the mathematical modelling is shown in the Fig. 3. We can see the course of the stress in dependence of the depth below surface. The most important information is, that the maximum of the stress is in the certain depth under the surface. This place is the most loaded and here may form cracks.

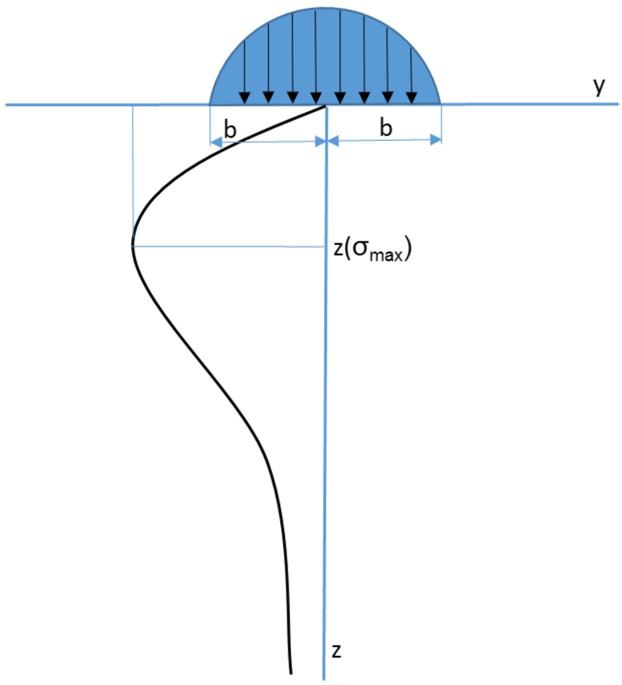

Fig. 3: Dependence between depth below the surface layer and stress.

3. Material analysis of RCF

As it has been written above, pitting is the often type of the RCF. From the material point of view we can RCF describe by 3 stages (Pekař, 2015):

1. Stage of the material mechanical properties changes
2. Stage of the cracks nucleation
3. Stage of the cracks propagation to fracture

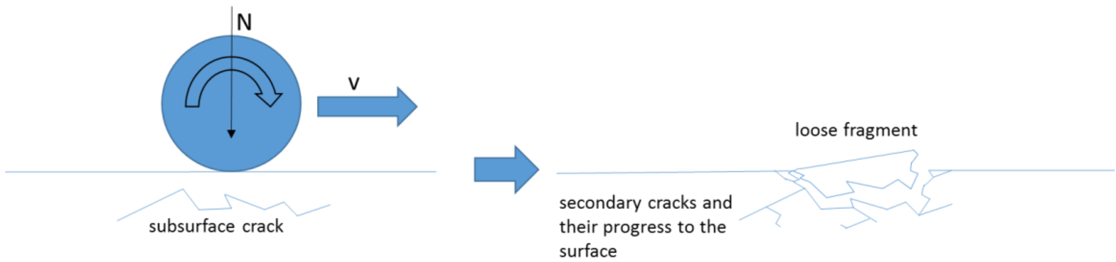

Fig. 4: Pitting formation.

The pitting formation is shown in the Fig. 4. Below the surface can be formed cracks. These cracks can join together with cracks on the surface and it leads to loosening of the small part of the surface (see also Fig. 6). The cracks formation below the surface is connected with the dependence shown in the Fig. 3. If the stress below the surface is high, there can occur the small plastic deformations in the material and repeated loading may lead to crack formation.

RCF is hard depend on the surface hardness, impurities and roughness of the surface (see Fig. 5) (Pošta, 2010)

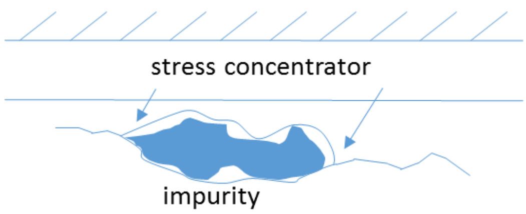

Fig. 5: Material imperfections.

It is important to mention influence of the lubrication on the RCF. At the motion of the contact surfaces penetrates oil to surface cracks. At the next movement of the contact surfaces is the oil closed in the cracks and his pressure increases. This leads to further distribution of cracks. (Pošta, 2010)

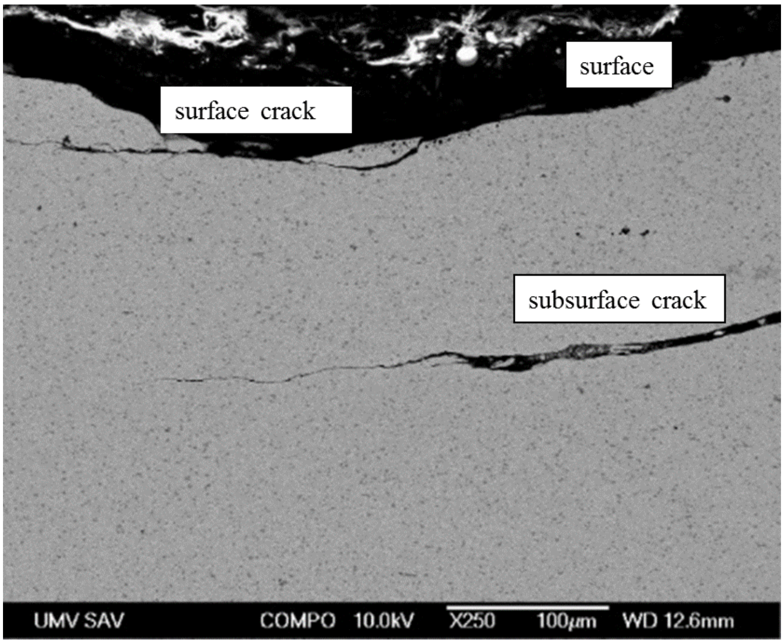

Fig. 6: Detail of the damaged part (acquired in own research).

We can say, that process of the service life estimation is not only theoretical, but we have to do a lot of tests before we obtain the concrete value. We need detailed information especially about material quality and these information we can obtain from macroscopic and microscopic analyses.

4. Conclusions

We need to have knowledge not only about fracture mechanics but also about calculation of the pressure distribution under the surface. Then we may determine the service life of the examined machine component. RCF is close connected to properties of the concrete material. These properties specify range in which are calculations valid and service life estimation is correct.

The service life may be determined on the basis of the equations including empirically obtained coefficients. Accuracy of this estimation is given by more factors. These are mechanical properties of examined material, surface treatment quality, purity of the material. Of course, the role play working conditions, too.

Acknowledgement

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