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B. KOPILÁKOVÁ, M. BOŠANSKÝ, L. PETRÁK

COMPARISON HRC AND C-C GEARING FOR DAMAGE TO PITTING

Розглянуті зубчасті зачеплення евольвентного типу (HCR) та неевольвентного – опукло-увігнутого (C-C), з позиції пітінгу. Описана фундаментальна різниця між HCR та C-C зубчастим зачепленням та вплив залежності коефіцієнту ковзання к пошкодженню зубчастої передачі. Наведено результати експерименту для обох типів зубчастих зачеплень на стенді Ньюмана для визначення пітінгу.

Ключові слова: пітінг, вершина зуба, втомне вищерблення, опукло-увігнуте зачеплення, евольвентне зачеплення

Рассмотрены зубчатые зацепления эвольвентого типа (HCR) и неэвольвентного – выпукло-вогнутого (C-C), с позиции питтинга. Описано фундаментальное различие между HCR и C-C зубчатым зацеплением и влияние зависимости коэффициента скольжения к повреждению зубчатой передачи. Приведены результаты эксперимента, для обоих типов зубчатого зацепления на стенде Ньюмана для определения питтинга.

Ключевые слова: питтинг, вершина зуба, усталостное выкрашивание, выпукло-вогнутое зацепление, эвольвентное зацепление

In this article are comparison HCR and Convex-Concave (C-C) gearing from the point of view to pitting. The introduction of the article describes a fundamental difference between the involute HCR and noninvolute (C-C) gearing and the influence of some parameters, especially of the slip ratio to damage of gearing. The paper also shows the basic results of the experiment, which was executed on two types of gearing (involute HCR gearing and noninvolute C-C gearing) on the Niemann´s stand from the point of view damage flank of tooth to pitting.

Keywords: pitting, tooth flank, fatigue wear, C-C gearing, HCR gearing.

Introduction. The influence of time-variable load in transfers commute to the mechanical fatigue abuse. As is well known, during the engagement of the tooth under the influence of surface and subsurface tension is formed stress, which results to the pitting. Touching of the surface of the working portion of the tooth leads to removing of the metal, to splintering of the particles of surface and to the formation of the holes, i.e. to the formation of pitting. The emergence of pitting are also influential the factors such as: the geometrical parameters of gearing, the ratio of traction determining the loading tooth by the external forces, the resolved shear ratios on the tooth faces, the frictional forces, the finish of tooth faces, selected material and hardness of the working tooth faces of the pinion and the gearing, the properties of the lubricating oil and operating conditions [2].

Characteristic types of the gearing based on mating line. Touching of two tooth is the point of touch during the rotation moved. The geometric point of all the items image that progressively come to the gear is the trajectory – mating line. According to the shape of the mating curve and its position in term of the rotating centre of the profile, is also defined the type of the gearing. The gearing is clearly defined by the shape of the mating line, however the shape can be generally arbitrary.

General planar gearing can be understood as the gearing with the axis of rotation O_1, O_2 of the both together engaging wheels. It is defined by the mating line "*S*", composed by two circular curves that centres lies on the any straight line crossing the point *C*. The centres of the circular curves can be in the headquarter or out of it and the ratio of the circular curves could be arbitrarily sized [2]. In general the gearing can be divided on the bases of the process of the mating line, whereupon the gearing is distinguished by the following tooth face:

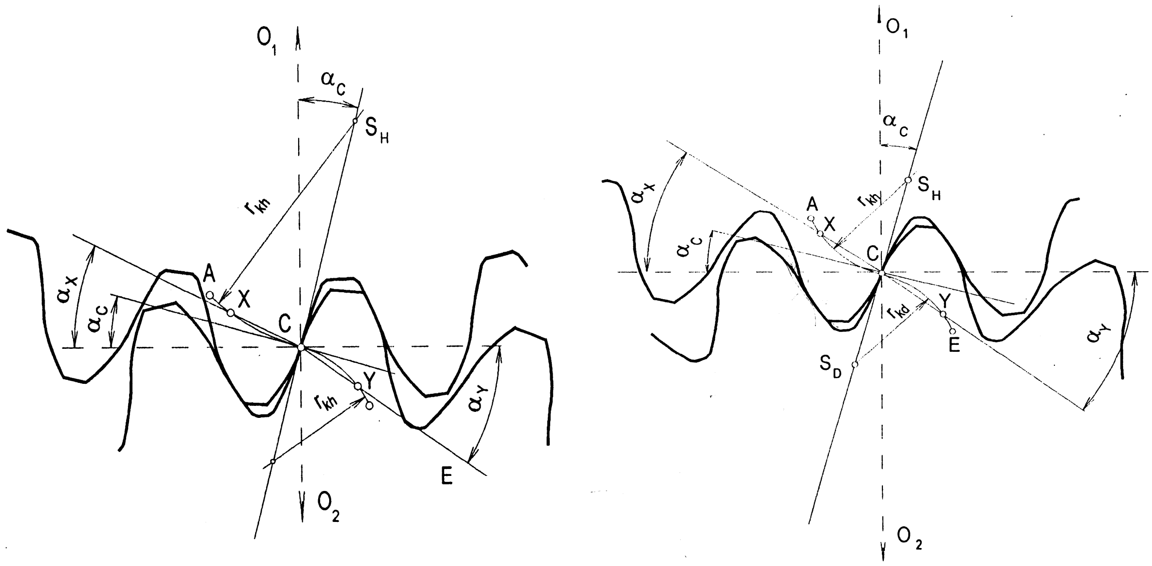
1. In case that the curvatures of the mating line "*S*" are not identical with the curvatures of the rolling circle, both together engaging wheels and the centres of the arc *Skh* and *Skd* that form the line of engagement and lie on the centre joins of the rotating of the wheels, that is the case of cycloid gearing.

2. In case that the angle of the mating line and the radius of the both parts of curvatures, which are representing the mating line and having infinitely large radius. The curvatures of the circle are degenerating to the line, what defines the involute gearing.

3. In case that the mating line "*S*" is composed of two circular curvatures, which centres are not on the headquarter of both wheels then it is the special case of general planar gearing – convex-concave (C-C) gearing. Its properties are depended on the geometrical parameters of the mating line: the angle of the slope of the mating line, radius of the circular curves of the mating line defined by the angle shot and by the endpoints of arcs of the mating lines defined by the angle or by the coordinates of relevant points, resp. [2].

C-C gearing could be generally understood as any gearing, which the tooth face forms a curve with the convex-concave portion, where in the mating line may be composed of two non-symmetrical or symmetrical arcs (fig. 1) [3]. If the mating line is defined by one or more of general curve, it is a case of the virtually identical case to the case of the fig. 3. In practice, we can meet with a combined mating line, for example when in the vicinity of pole *C* the gearing is defined by the linear mating line and in the other points by circular curves [3]. From this it is clear that the curve of the tooth face and may take the form of a general curve (involute, cycloid, epicycloid, hypocycloid, etc.).

Evaluation of the pitting in the drives gearing. Geometric and qualitative parameters of gearing can strongly influence their failures. In case of pitting, the failures are mainly measuring deviations. Since the goal of this presentation is to compare involute HCR gearing and non-involute C-C gearing, there are developments of deviation rates for a sprocket and a wheel shown in the fig. 2. In the fig. 3, the development of distribution of strain of teeth along mating line is described.



a *b*

Fig. 1 – C-C Gearing: *a* – non-symmetrical; *b* – symmetrical

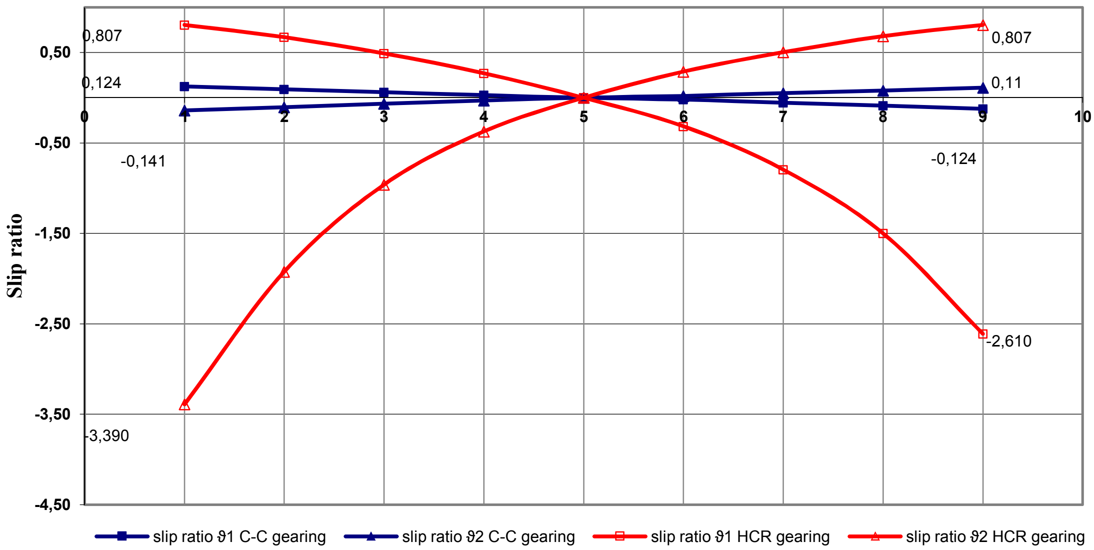


Fig. 2 – Slip ratio of involute HCR and non-involute C-C gearing

In the fig. 4, *a*, pitting on involute HCR gearing is shown and in the fig. 4, *b*, it's the pitting on non-involute C-C gearing. It is obvious that in case of involute HCR gearing, the pitting developed under rolling circle and in case of non-involute C-C gearing it developed around or above the circle. The origin of pitting in non-involute C-C gearing strongly influences its geometric parameters and the size of contact pressure. If we change some of the parameters or the combination of them, we can get a change of the curve of the tooth face [3].

Conditions of stroke in C-C gearing and in involute gearing are different. That is why we have to verify the theoretical thinking about contact solidity of C-C gearing which we gained through MKP method through an experiment and find out if the usual procedures of involute geari ng are applicable on C-C gearing too. One of these parameters is fatigue ratio during straining in touching. Niemann stend, standard testing machine with enclosed output in accordance with norm DIN 51354 according to methods FZG, was used for experimental finding out of values of fatigue ratio for C-C gearing as well as for the standard involute gearing in accordance with norm DIN 3990 T5.

During the experiment C-C gear was tested under given strain based on analysis of suitable geometrical parameters at ÚDTaK SjF STU in Bratislava and made of non-hardened carbon steel classed C60. Conditions of stroke in C-C gearing and in involute gearing are different. That is why we have to verify the theoretical thinking about contact solidity of C-C gearing which we gained through MKP method through an experiment and find out if the usual procedures of involute gearing are applicable on C-C gearing too. One of these parameters is fatigue ratio during straining in touching. Niemann stend, standard testing machine with enclosed output in accordance with norm DIN 51354 according to methods FZG, was used for experimental finding out of values of fatigue ratio for C-C gearing as well as for the standard involute gearing in accordance with norm DIN 3990 T5.

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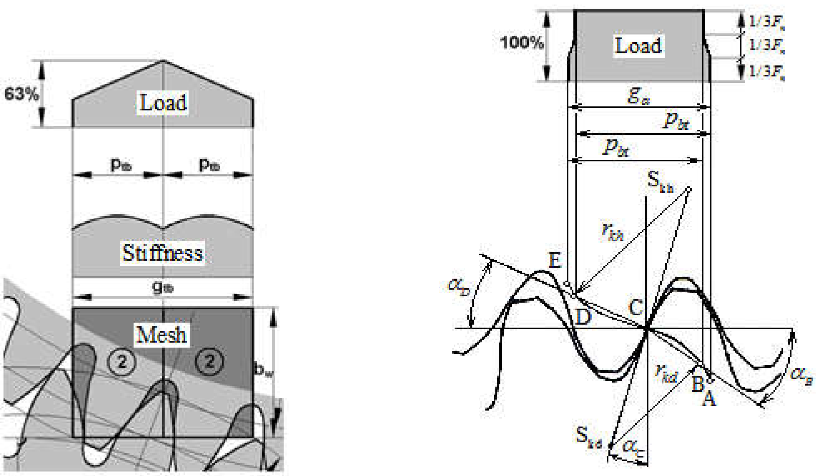
The basic principal of testing gearwheels on load machines DIN 51354 consists of gradual loading of gear and finding out the number of finished cycles until damaging the testing sample. 8 different tests were made at 3 different load levels A÷C with gradual decline of load (table 1). Three experiments were made at first two levels. 2 experi-



a *b*

Fig. 3 – Allocation F_n along mesh in: *a* – HCR gearing; *b* – C-C gearing

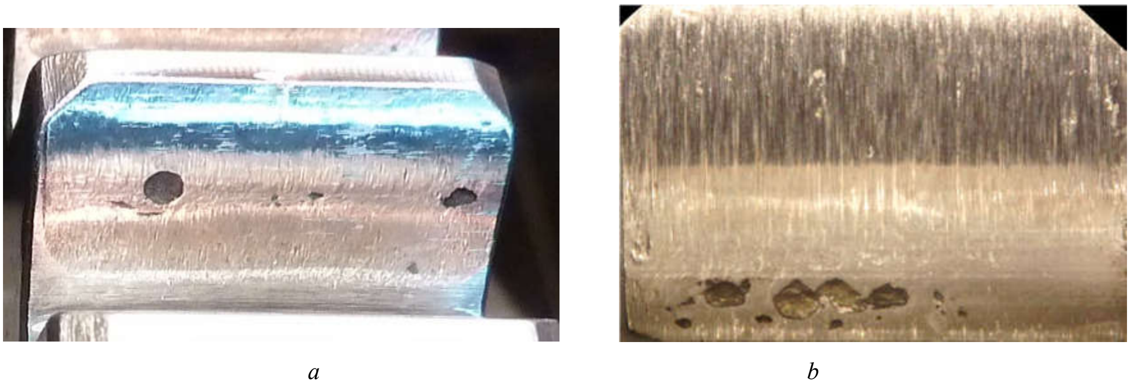


Fig. 4 – Pitting: *a* – non-standard gearing HCR[10], $\varepsilon_\alpha = 2{,}003$; *b* – C-C gearing, $\varepsilon_\alpha = 1{,}116$

ments were made at the third level near to high-cycle fatigue. The load at each level was set by lever mechanism [2]. The experiment was interrupted after given number of cycles so the area damaged by pitting could be evaluated.

Table 1 – Burden surfaces

Surface *i*	Load torque $M_{k(i)}$
A	$M_{k(A)} = 265\ \text{N}\cdot\text{m}$
B	$M_{k(B)} = 185\ \text{N}\cdot\text{m}$
C	$M_{k(C)} = 125\ \text{N}\cdot\text{m}$

There are many ways of evaluating in which the condition of damaged tooth faces by pitting. In the past the damaged area have been deducted through the squared network of the graph paper, what was too laborious and time-consuming. Later, the situation was simplified by using digital cameras and their interface with PC. The disadvantage of this method is the necessity of a lot of configuration and compliance of lighting conditions during the taking the photography for the best possible quality of the image.

In consideration of the weaknesses of the used methods so far, we have proposed and used a new method macrophotography [7], the principle of which is shown in fig. 5. The digital microscope connected via USB to a personal computer was obtained a digital image of each tooth faces of the testing gearing. The image was recorded directly to a PC. To evaluate the percentage of damage of each tooth faces was used the Pitting – check software that allows to process digital images. The program includes utilities that enable simple system of check sampling areas affected by pitting. Also, the beveled edges are considered etc. Then the content of the damaged surface is percentually shown and compared with the value limit state. This new method streamlines the procedure of evaluating of the damaged state during the experiment. On the base of the extent of damage was determined following step of the experiment or its termination.

Conclusion. The experiment was done at the STU in Bratislava on Niemann´s stend and the same conditions and load for HCR and C-C gearing. The results that have been obtained are the following: in the tests of the C -C gearings the samples were tested in the range (265÷125) N·m, what corresponding to the period of the marked examination to failure (437÷1483) hours and to the range of probable number of cycles to failure, approximately $(18÷65)\cdot10^6$ cycles. The description of the pitting formation shows that in C-C gearing, this type of fatigue wear much less aggressive than in HCR profiles, where the initialization of the crack occurs at greater depth. At the first load rate on the surface of A (Table 1) in the C-C gearing, where Mk = 265 N·m and the marginal state of the contact stress occurred at 19 106 cycles. The percentage of damage to tooth flank was evaluated by software Pitting – check and showed 4,04 %. On the reduced load rate on the surface of B, where Mk = 185 N·m, this state occurs at 50 106 cycles with damage of 3,83 % on one

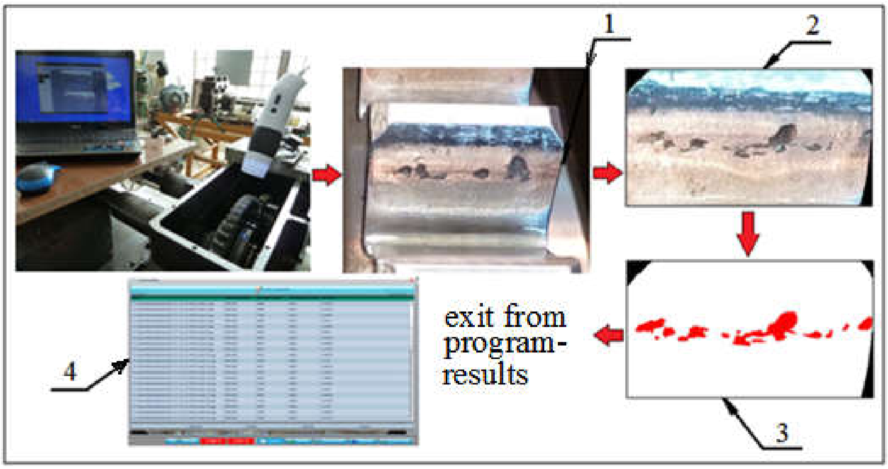


Fig. 5 – The principle of evaluation pitting makrofoto graphical method:
1 – created a digital image; 2 – processed a digital image;
3 – with program marked damage area; 4 – evaluation of damage (%)

of the tooth flank. In the third stage the lowest load for Mk = 125 N·m, the damage was 0,4 % at 64 106 cycles when the experiment was terminated. From this it is clear that the extreme case (4 %) the damage by the pitting to such surface would be created only after extremely large number of cycles burdensome. The result is that in the case of C-C gearing was achieved a higher carrying capacity touch.

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