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MODELING A HCR GEAR WITH VARIABLE THICKNESS OF THE THIN HARD COATING ON THE TOOTH SURFACE FOR FEM ANALYSIS

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Abstract: This work presents a computer model of HCR gear wheels with thin hard coatings of variable thickness. The coating thickness fluctuates along tooth depth due to limited technological space, particularly at the dedendum. Experimental studies revealed coating destruction occurs mainly at the tooth dedendum when thickness falls below 2 μm, leading to peeling. The varying stiffness between tooth addendum and dedendum affects coating strength and load-bearing capacity. The model, developed in SolidWorks CAD, accounts for HCR gearing kinematics, contact path geometry, and simultaneous multi-pair tooth engagement.

KEYWORDS: HCR gearing, thin hard coating, stress-strain state, path of contact

1 Introduction

Modern technologies for applying thin hard coatings used in mechanical engineering, for example PVD, have such a feature as the uneven thickness of the resulting hard layer on parts with a complex surface shape [1, 2]. Such parts include power trans-mission gears, especially gears with HCR gearing, which have an increased tooth height [3-6]. In this case, the contact surface in the area of the cavity between the teeth (dedendum tooth area) has a small thickness of a thin hard coating, which can lead to its premature destruction [7]. At the same time, increasing the time of the technological process of coating, in order to increase its thickness in a hard-to-reach area of the gear, can lead to an unjustified increase in the cost of the product.

In order to determine the critical value of the thickness in the area of the tooth stem, an HCR engagement model was created to study the stress-strain state, taking into account the change in the thickness of the thin hard coating on the surface of the side of the tooth. Also, the proposed model will make it possible to simulate a two-pair contact when transmitting a load by a gear train, taking into account the contact of several bodies with different tooth profile geometries (curvature at the point of contact) and different thicknesses of the hard coating.

Today's gear transmissions must simultaneously meet the conditions of small dimensions and high load capacity with a certain service life and low price. Low noise is also a common requirement for gearings. In the technologically simplest involute gears with straight teeth, it is possible to achieve a low noise level either by using gears with high precision or by modifying the profile of the teeth. HCR gearing can also be considered as one of such modifications [8].

An increase in the bearing capacity of gear transmissions can also be realized by chemical-thermal treatment of the contact surfaces of the teeth or by applying thin hard coatings. The latter method makes it possible to reduce to a certain extent the requirements for the quality and

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hardness of steel for gears. At the same time, one of the most common coating technologies – PVD is performed at a temperature of about 400-450 degrees, which can lead to an undesirable decrease in the hardness of the tooth material, therefore it is necessary to use steels with a high tempering temperature [1, 9].

The design peculiarity of PVD hard coating technology is also the location of the cathode at a certain distance relative to the surface of the component, and its position should be at an angle close to 90 degrees to the surface [9]. In the case of gears, the space between the teeth does not allow the cathode to be positioned perpendicularly and at a given distance from the side surface of the tooth, as a result of which the thickness of the coating will be less in the dedendum of the tooth than at the addendum of the tooth.

2 Materials and Methodology

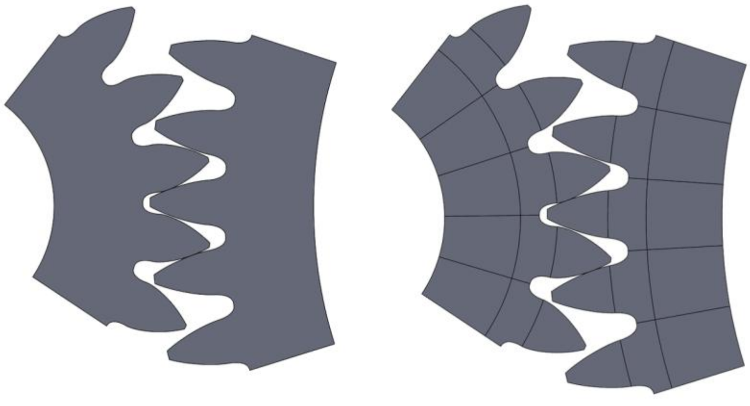
Modelling of thin hard coatings using the finite element method in CAE-system ANSYS Workbench can be solved by entering the surface on the 3D body of a special mesh element of the "surface coating" type, in the parameters of which it is possible to specify its thickness and material, which are different from the material of the rest of the part [10]. However, in the case of studying the volumetric stress-strain state of a region consisting of a thin hard coating, a subsurface layer, and the rest of the tooth, it is necessary to create a finite element model that would contain at least 4 layers of elements per thickness of the hard coating and as many or more elements per thickness of the subsurface layer.

Considering that the minimum thickness of the hard coating is usually 1.5 – 2 μm, the finite element size should be 0.5 μm. In the examined gearing, the dedendum tooth thickness is more than 7 mm [3]. It is necessary to consider this fact when creating a computer model. The proposed computational model enables the realization of a gear identical to the experimental gear, the parameters of which were as follows: tooth module 4 mm, number of pinion teeth 21, number of gear teeth 51, face width 14 mm [11]. Based on experimental data and computer simulations of similar trans-missions carried out in the past, the sufficient thickness of the layer under the surface of the hard coating in terms of the size of the final element is 0.5 μm, in which stresses of 0.1 – 0.2 mm will be investigated. Therefore, the calculation model should contain three groups of layers: a layer with the characteristics of a hard coating and a layer with the characteristics of steel below with a thickness similar to or greater than the thickness of the hard coating layer, transition layers with gradually increasing size of finite elements and the residual gear. If we take into account such parameters as the tooth depth and tooth thickness, as well as the dimensions of the smallest finite elements, the use of a three-dimensional model is demanding in terms of hardware and time [7, 12, 13]. It is also not the task of this study to evaluate the behavior of the coating on the edges of the teeth or to model the meshing inaccuracy of these gears. Thus, the computational model will be implemented as two-dimensional – 2D.

3 Design of a graphical calculation model of HCR gearing

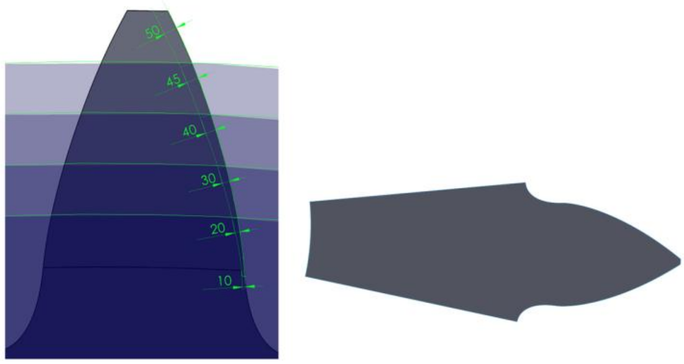
When a gear wheel with HCR gearing is loaded, there will be a certain elastic deformation of the teeth, which will increase the contact gear ratio. Therefore, it was found suitable to model this thin hard coated gear to model three pairs of teeth that will be in contact during torque transmission, and near the first and third teeth on each gear, it is necessary to design one more tooth to eliminate the stiffness deviation under load. The remaining teeth and the hub will not be taken into account in the calculation, as they will not have a significant effect on the result in the contact zone [8, 13]. Therefore, a gear ring consisting of 5 teeth is used to model the pinion and the wheel, Fig. 1a. This simplification saves computer performance and calculation time. In addition, each tooth and the gear ring below it will be represented by a separate sur-face from the neighboring elements and teeth, Fig. 1b. This will allow the dimensions of the finite elements to be set separately for each tooth. The thickness of the ring gear under the teeth was determined as 2.5 modules based on empirical formulas. [8, 14]. A Fig. 2a shows the distribution of the thickness of the hard layer along the HCR tooth depth with a module of 4 mm. It can be seen from the figure that the range of thicknesses is from 1 µm at the addendum to 5 µm at the dedendum tooth. The stated facts result from the actually measured wheel [7]. Since the PVD technology of applying a hard coating allows a thickness of up to 10 µm to be realized, the computational geometric model must have the possibility of entering a thickness from 1 µm to 10 µm.

A Fig. 2b shows the primary tooth that will form the examined model. Contact and other necessary surfaces will be created on this model.



a) b)

Fig. 1 a) The original 2D model of the HCR gears, b) 2D model of a gear with HCR gearing with each tooth divided into separate elements.



a) b)

Fig. 2 a) Distribution of the thickness of the hard layer along the height on the lateral surface of the tooth, b) Primary 2D model of HCR gears

The subsequent step of creating the model is the creation of individual layers as shown in Fig. 3. Thus, on the tooth flank of the pinion, which will be in contact with the tooth flank of the gear, a sketch was created consisting of curves that are equidistant to the profile of tooth flank [15]. These curves will later be used to create individual surfaces. Some surfaces will be set to hard coating properties, while others will be set to gear material (steel). In Fig. 3, position 1 represents a set of 10 surfaces that simulate a surface layer thickness of 5 µm, that is, it is possible to set the thickness of the hard coating in the range from 0.5 µm to 5 µm in increments of 0.5 µm. Position 2 represents 5 surfaces with a total thickness of 5 µm, which allows the additional thickness of the hard coating to be set from 6 to 10 µm in increments of 1 µm. So, for example, in the case of entering a hard coating thickness of 3.5 µm, the first 7 sur-faces will have the properties of the hard coating, but the remaining 8 surfaces will have the properties of steel. In Fig 3 position 3 represents a 10 µm subsurface steel layer for which the same finite element size will be used as for the hard coated areas.

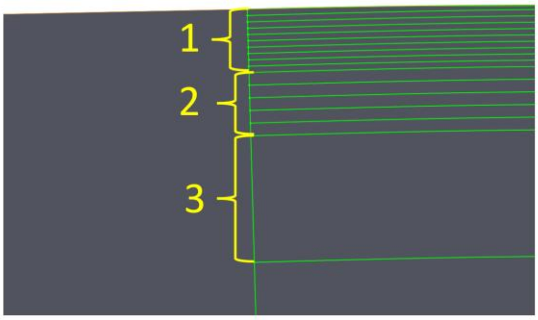


Fig. 3 Modeling surfaces for hard coating and subsurface applications.

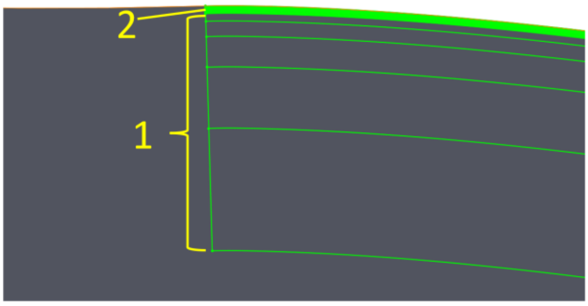


Fig. 4 Transition zone in the substrate of the tooth.

In Fig. 4, position 1 represents a transition zone in the tooth substrate, which serves for a continuous and gradual increase in the size of the finite elements from the smallest in the area of the hard coating to the largest in the corresponding area of the tooth. The Fug 4. position 2 – areas of hard coatings and subsurface layers with a total thickness of 10 µm.

In Fig. 5, position 1 represents the area of the part of the tooth without coating, 2 – the transition area from the tooth to the crown, position 3 represents the crown, position 4 the surface of the hard, subsurface and transitional layers. For areas 2 and 3, the dimensions of the finite elements will be even larger than for the tooth – pos. 1.

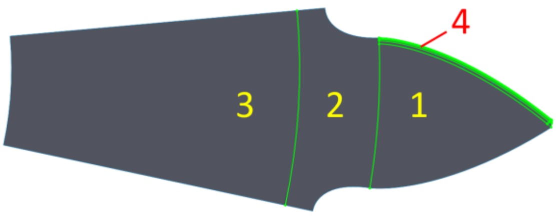


Fig. 5 Splitting certain areas of a single-tooth gear sector.

The contact surface along the tooth flank is divided into 6 parts, Fig. 6. This allows to leave a detailed model of the hard ceramic and subsurface steel layer with a small size of finite elements that are in contact with the wheel tooth, position 1. All other parts of the tooth flank – position 2, which do not participate in contact, can there-fore be replaced by a simplified model (surfaces) of the tooth flank, in which there will be no hard coating layer. A similar localization of the contact researched area, in which the stress-deformation state of the teeth in their mutual contact will be monitored, will simplify and speed up the simulation process.

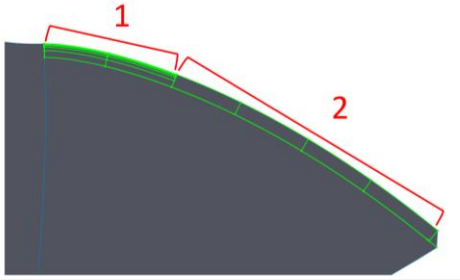


Fig. 6 Modeling the contact and non-contact areas of the side of the tooth.

The size of the detailed model will make it possible to perform a quasi-static simulation of the contact task, that is to obtain calculation results at several points of the tooth flank without changing the finite element model. The last step in the creation of a graphical calculation model is the creation of a circular segment, which will consist of 5 teeth. Creating a computational model of a gear is similar to creating a pinion model. In Fig. 7 the calculated model, position 1 – pinion, position 2 – gear.

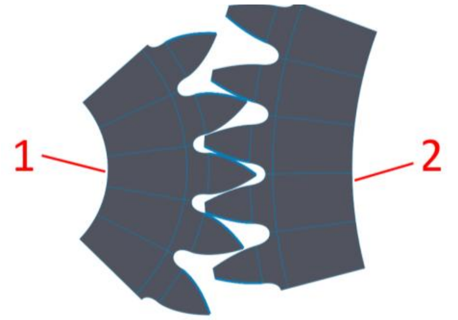


Fig. 7 Calculation model of HCR gearing.

In Fig. 8a shows the finite element model in the contact area and the transition area of the finite elements. In Fig. 8b shows the finite element grid at the point of con-tact. In Fig. 9 shows the von Mises stress in the contact area. It is easy to see the difference in the stress state of the hard coating and the steel substrate.

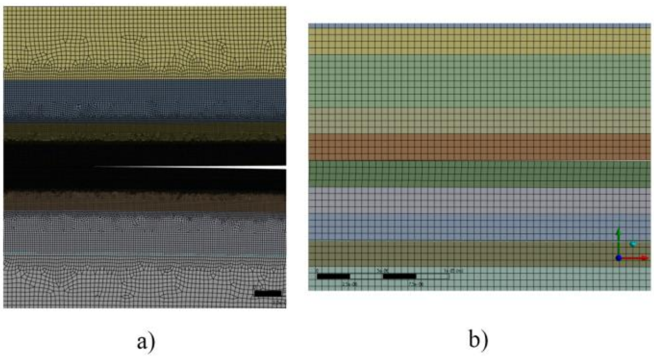


Fig. 8 a) Finite element model of HCR gearing in the contact area, b) Finite element mesh at the point of contact

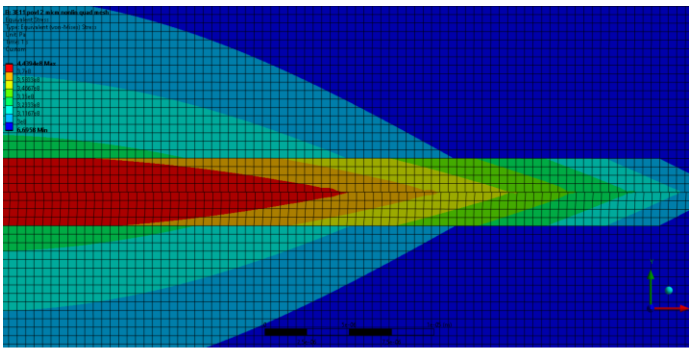


Fig. 9 Results of a test calculation of a contact problem with hard coating, showing von Mises stresses.

CONCLUSION

The proposed model of HCR gearing with a thin hard coating in the test calculations of the contact task showed the possibility of further investigation of the influence of the hard coating layer applied to the sides of the teeth on the transfer of stress to the steel substrate when specifying different thicknesses and mechanical properties of the materials. The goal of further research will be to determine the relationship between the thickness of the hard layer and the geometric parameters of the toothing, such as the curvature of the tooth side and the edge contact of the head of the wheel tooth with the heel of the pinion tooth.

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