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Power Parameters Automated Calculation for Transmission with Intermediate Rolling Bodies and Free Cage

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Abstract. In the article, techniques complex of the transmission with IRBFC power parameters determination are considered. Moreover, software of automated calculation of the power parameters is created based on the techniques. The software consists of two parts: program of the mechanical transmission creating as a computer object; program of the graphical user interface creating. In general, the software makes it possible to determine the distribution of forces and contact stresses in engagement along the cycloidal profile of gear, to determine the maximum force and contact stress in engagement and to generate a file in excel format with all calculated data.

1. Introduction

In modern industry, transmissions with intermediate rolling elements (IRE) are increasingly in demand. They are used in power plants, in pipelines valves of oil and gas systems, in transport drives, in aircraft mechanisms [1], in drives for mining industry [2]. These transmissions were studied by many authors [3-14]. Litvin and Feng [15] developed computer programs for generating the planar epicycloidal gearings. However, a transmission with intermediate rolling bodies and free cage (IRBFC) is the most promising for use in heavily loaded mechanisms. In connection with the growing need for the design of mechanisms based on transmission with IRBFC (figure 1), there is a need to accelerate the calculations and design of such transfers and mechanisms in general. For transmission with IRBFC operating in difficult conditions, the power parameters that this transmission is capable to provide are not unimportant. For cycloidal transmissions, contact stress is the main one. However, when performing calculations of efforts and contact stresses in the gear engagement “by hand”, the probability of an error and the receipt of an incorrect result are high. Therefore, the automation of the calculation of power parameters of transmission with IRBFC and the development of the calculation program is relevant.

The transmission with IRBFC design starts from initial parameters. For the transmission initial parameters are: R_{21} – the radius of the making circle, Z_2 - number of bodies of swing, χ – shift factor and R_{RB} –the radius of a rolling body [16].

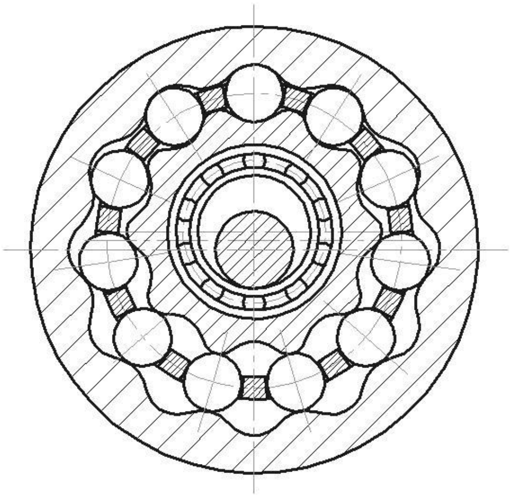

Figure 1. Cross section of transmission with intermediate rolling bodies.

2. Choosing equations

The determination of the forces in the transmission with IRBFC was carried out in [17], as:

$$F_i = \frac{T_c h_i}{\sum h_i^2}, \tag{1}$$

where T_c – torque of the cam, Hm;
h_i – the shortest distance from the center of the cam to the line of action of the *i*-th force.

The determination of contact stresses was described in [16]. And result expression we wright as

$$(\sigma_H)_i = \left(\frac{F_i(\rho_2 \pm \rho_{1i})}{\pi \cdot l \cdot \rho_{1i}\rho_{2i}\left(\frac{1-\mu_1^2}{E_1} + \frac{1-\mu_2^2}{E_2}\right)} \right)^{1/2}, \tag{2}$$

where ρ_1, ρ_2 – curvature radii of contacting bodies, mm;
l – contact length of roller and profile, mm;
E_1, E_2 – elasticity modulus of first and second contacting bodies respectively, MPa;
μ_1, μ_2 – Poisson's ratios for first and second contacting bodies respectively.

The sequence of calculating the radii of curvature of the profiles was decided to be taken from [18]. for cam wheel profile radius of curvature is

$$\rho_1 = l_{OP} - r_b - l_{MP}, \tag{3}$$

where l_{OP} – distance between of the rolling body center O and engagement pole P (figure 2), mm;
l_{MP} – distance between of the radius of curvature M and engagement pole P (figure 2), mm.

And for crown wheel profile radius of curvature is

$$\rho_3 = l_{MP} - r_b - l_{OP}, \tag{4}$$

Summarizing the methods presented in the sources we can obtain a program for automated calculation of loading parameters of the transmission with IRBFC. A program was developed for calculating the forces and contact stresses in the transmission engagement, the interface of which is shown in figure 1.

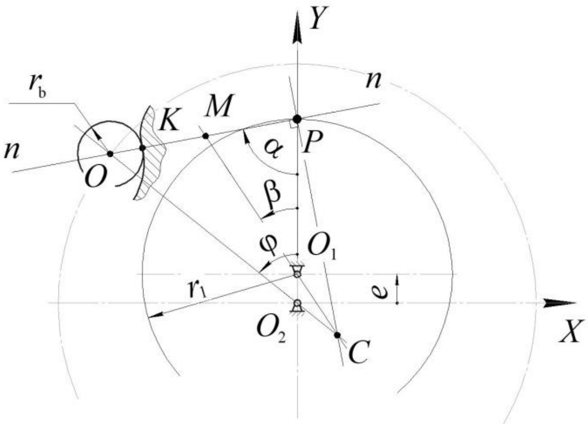

Figure 2. For cam profile to the determination of the radius of curvature.

3. Making an automated calculation program

The goal was to create a program that can be used on all types of computers with any operating system. This objective allowed choosing the computer language that would be used; in this case, the language was JAVA. On the other hand, this language requires the installation of java on the physical target (computer). This language is one of the most used in the computer world to create desktop applications because it is very powerful (belongs to object-oriented programming language). On Internet there are many resources and forums concerning this language such as "Stack overflow" or "Git Hub", which allows solving problems related to programming quickly.

To realize the computer object, the software used was "Eclipse" which is one of the best known to develop in JAVA. For the graphical interface, it was the software "NetBeans", which has a basic graphical interface designer.

The program allows performing calculation of contact strength of details loaded for transmission with IRBFC. The software allows us to change quickly the input parameters, if necessary. The program was developed by equations (1)-(4) for calculating the forces and contact stresses in the engagement of transmission with IRBFC, the interface of which is shown in figure 3.

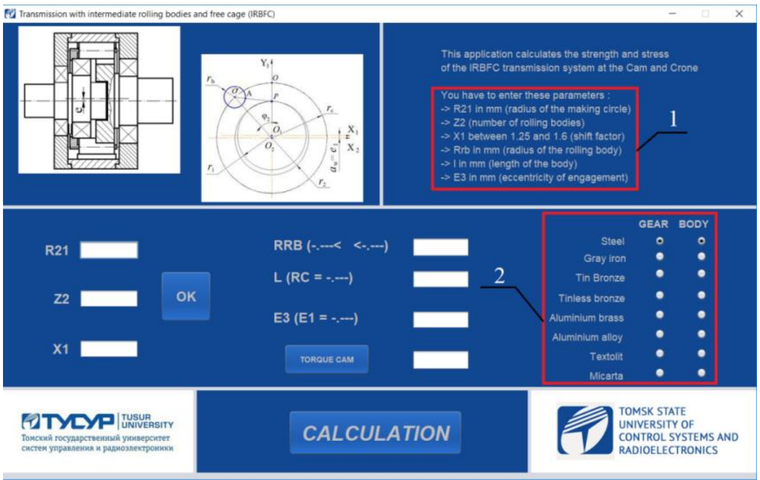

Figure 3. The interface of the program for the automated calculation of power transmission parameters with IRBFC.

The interface of the calculation program (figure 3) explains the meaning of the entered parameters and the dimension in which they should be entered into the program is indicated by frame 1. In addition, the program provides the ability to set the material of gear wheels and rolling elements of the gear, this is located in the lower right part of the interface (figure 3, frame 2).

In the process of working with the program, it is initially necessary to enter the values of three initial parameters: the radius of the generating circle R_{21}, the number of rolling bodies Z_2, and the shift factor χ. After "OK" button is pressed, intermediate parameters (radius of the rolling bodies' centers and eccentricity) and range of possible values of rolling body radius are calculated. Then we can enter the remaining data required to calculate forces and contact stresses (figure 4).

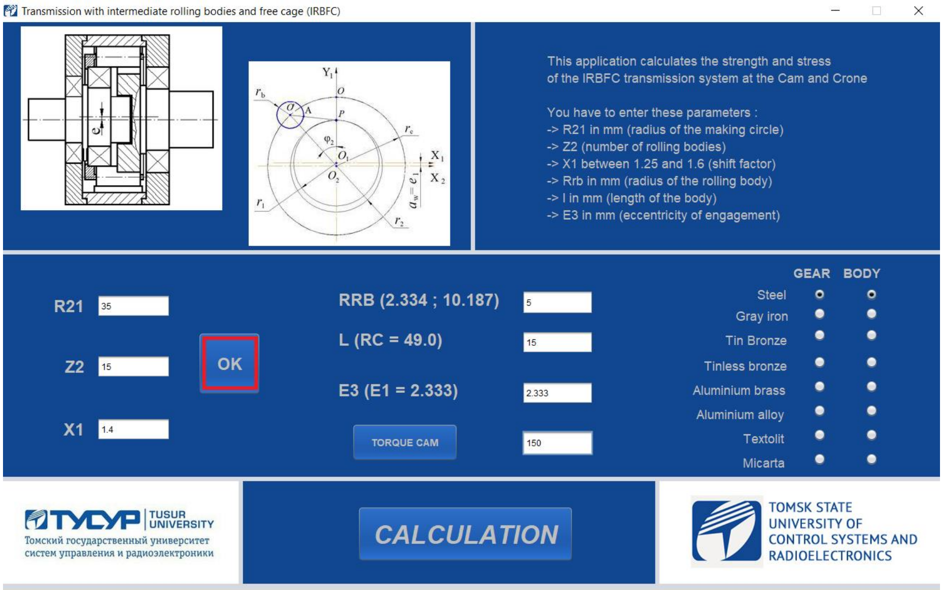

Figure 4. Introduction of initial and additional parameters for calculating forces and contact stresses.

When all the necessary data is entered and the material of the contacting transmission links is chose, the "CALCULATION" button is pressed, after which two windows are opened with graphs of the changes in the forces and contact stresses in the engagement of the transmission with IRBFC along the working length of the profile (figure 5).

One of the windows corresponds to the data by the cam wheel and the other window to the crown wheel. Moreover at the time of opening of these windows an excel file is created in parallel. This file contains all the values calculated and displayed by the windows. This file allows working directly with the exact values calculated by the program. The forces are expressed in Newtons and the contact stresses in Pascals. Since the accuracy of these data depends on the pitch of the angle φ (which varies from 0° to 180°), the chosen pitch is 0.5° which allows obtaining a good precision. Finally, we can see the data displayed in a drop-down table, as well as the maximum value of force and contact stress.

Figure 5. The results of the automated calculation program.

The creation of this computer program is unrolled in 2 parts:

-> the first part consisted of creating a simple program that performed all the calculations related to the mechanical system, and creating the mechanical transmission as a computer object (corresponds to a "class").

-> the second program was intended to create the graphical user interface (GUI), i.e. the link between the first part and the user of the computer program. Moreover, this part corresponds to the final program.

4. Example

Let us calculate of the transmission with rolling bodies from steel and gears from tinless bronze. We will make calculation for the transmission with the following initial parameters: R_{21}=35 mm; Z_2=15; χ=1.3.

After preliminary calculation we obtain: range of data for radius of rolling body – from 2.334 mm to 9.459 mm; eccentricity of cam and rolling body engagement – 2.333 mm.

We chose radius of rolling body R_{RB}=5 mm, and set torque on the cam like 200 Nm. Then calculation is continued. We obtain graphs of force and contact strength determination (figure 6).

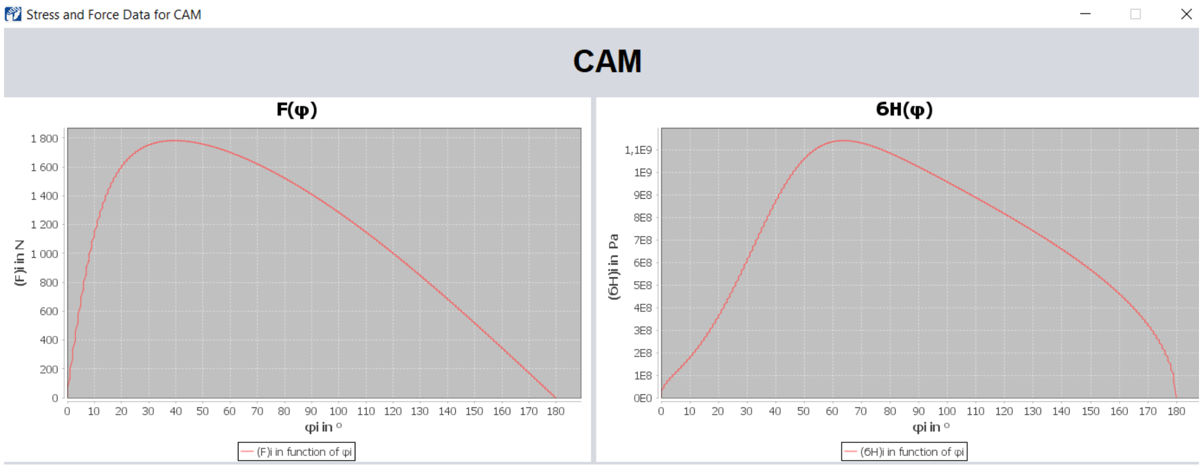

Figure 6. The result of the example calculation for cam wheel.

The maximum contact strength is calculated and equal 1 141.186 MPa, maximum force in the engagement is equal 1 782.519 N.

5. Conclusions

Thus, the developed computer-aided calculation program allows you to determine the maximum value of the force and contact stress arising in the transmission with IRBFC, gives the value of the same parameters for each rolling body in a tabular form and their change from the position of the rolling body in a graphical form. For the developed software, Certificate No. 2019660019 was received.

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