The Study of the Dynamic Properties of Some Structural Components of Harmonic Drive

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Abstract. Under the studies performed, geometrical models of flexsplines being manufactured for the CSD, CSG, HFUC and HFUS flexsplines type harmonic drivers were developed based on their actual structures and geometrical dimensions. In order to enhance the data preparation process, the model geometry was recorded in a parametrical form. By altering the individual properties of the models, it is possible to automatically generate finite element grids for flexsplines of various geometrical and structural properties. The calculations prepared for the sake of the study by application of the finite element method (FEM) were conducted using the Femap/NX Nastran software. A preliminary numerical modal analysis of the structural solutions for the harmonic driver flexsplines assumed to be applied was conducted.

1. Introduction

Recent technical developments have caused the emergence of new and improvement of old torque transformation methods. For large ratios, the classical multi-gear transmissions are being replaced by planetary gears, and those by a more efficient harmonic drives [1-3]. Gear, which was first to use elastic deformation of the toothed ring gear in order to transform the torque, was patented in 1959 by W. Musser. Since then, especially during the last twenty years, various types of harmonic drive were developed and patented. Compared to classical toothed gears, harmonic drives have numerous advantages, but there are some disadvantages as well. Their main advantages include: high torque capacity, excellent positioning accuracy and repeatability, compact design, zero backlash, high single-stage reduction ratios and high torsional stiffness. On the other hand, their drawbacks are: high elasticity and nonlinear stiffness and damping. The application of toothed harmonic drives in various fields of life is more and more wide. They are currently used by the automotive and space industry, in aviation, medicine, automatics and robotics, while most of them are two-wave harmonic drives with mechanical wave generators. When considering transmissions used in automatic control systems, issues connected with their high kinematic precision, smoothness of torque transmission and dynamic characteristics (stiffness, damping, moments of inertia and natural frequencies) gain utmost importance. The working principle of a harmonic drive is that the relative motion of the wheels is in fact the result of co-deformation of one of them. Deformable wheel is called the flexspline and the wheel prone to it – rigid circular spline. Generator produces the elastic deformation waves of the flexspline. Depending on the number of waves distortion we distinguish one-wave and two-wave harmonic drives. Two-wave harmonic drive diagram is shown in figure 1 [4]. This gear consists of a flexspline connected to the output shaft, rigid circular spline with an internal toothed ring and an elliptical wave generator connected to the input shaft of the harmonic drive. While choosing the flexspline material [3, 5-8], one must consider the deformations and stresses occurring in the flexspline operating in the driver, both unloaded and loaded by the torsional moment. The heat treatment method to be applied to a spline must be determined entailing the criterion of ensuring its elastic properties as well as the service life assumed. As a material flexspline adopted steel with the characteristics given in table 1.

On the basis of the actual construction and geometric dimensions of mass-produced harmonic

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drives (type CSD, CSG, HFUS and HFUC [4]) the geometric models were developed. Figure 2 shows the actual HFUC type gear and the CAD-developed geometric model.

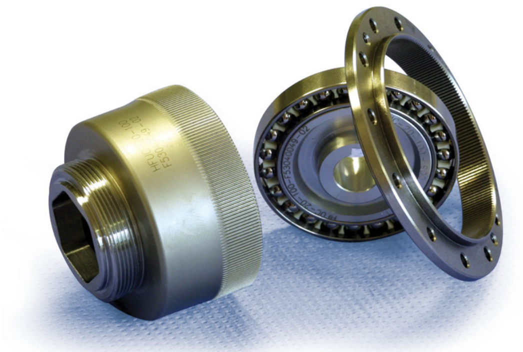

Figure 1. The main components of a harmonic drive: flexspline, rigid circular spline and wave generator [4].

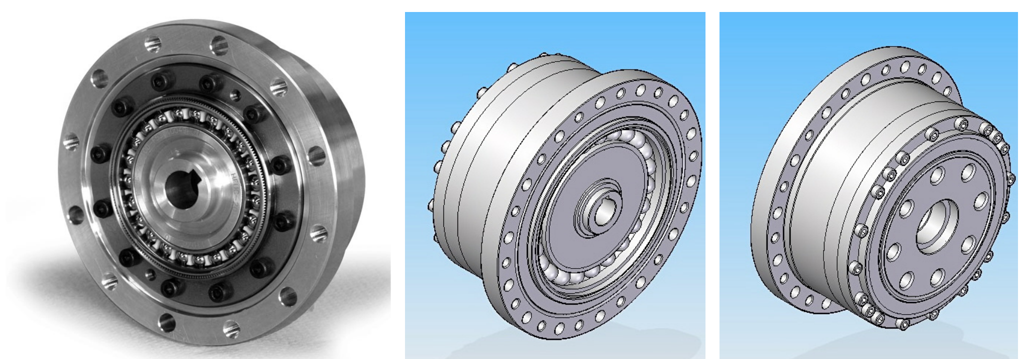

Figure 2. Harmonic drive and her geometric model.

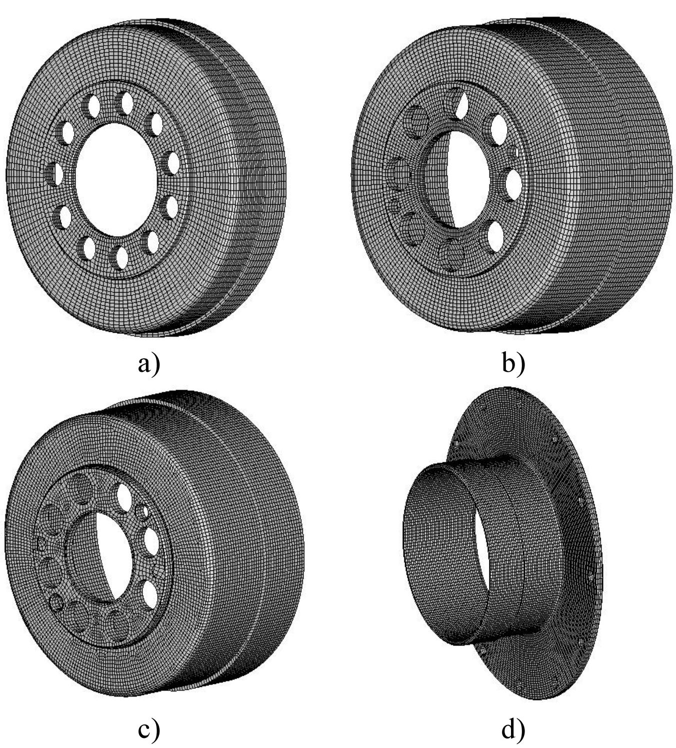

Figure 3. The three-dimensional FEM models of flexsplines:
a) short cup-type CSD,
b) a cup-type CSG,
c) a cup-type HFUC,
d) with an outer flange HFUS.

Table 1. Properties of the steel 42CrMo4

Tensile modulus (GPa)	210
Shear modulus (GPa)	80
Poisson's ratio	0.3
Density (kg/m3)	7850

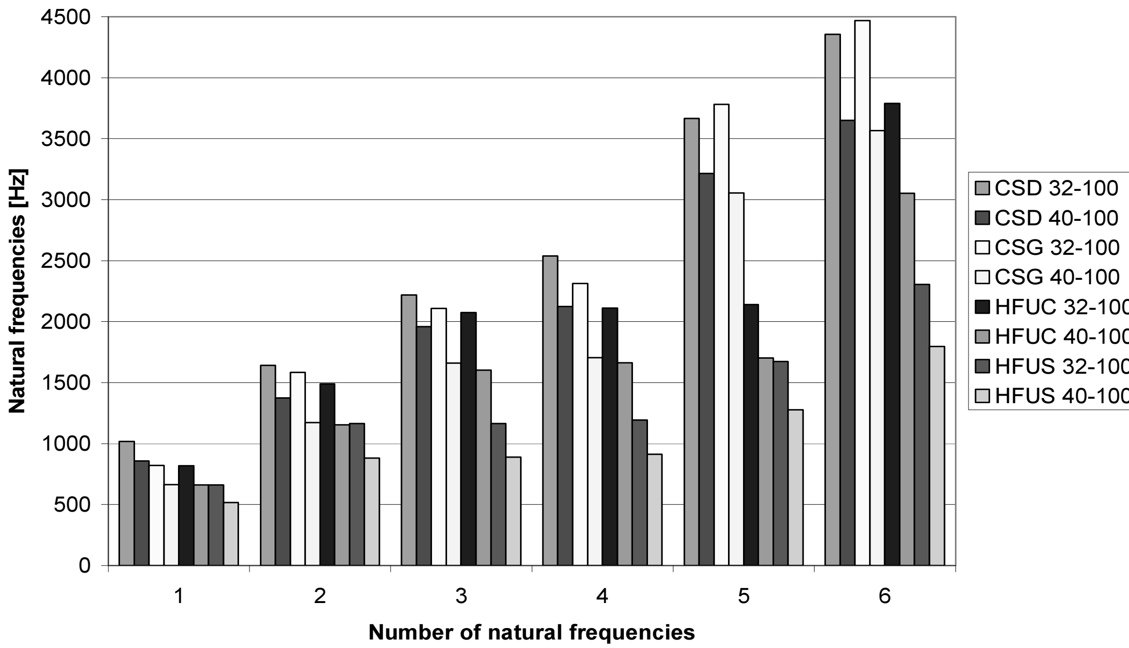

Figure 4. Chart summary of the analysed flexsplines natural frequencies.

2. Numerical modal analysis of flexsplines

Modal analysis is the study of the dynamic character of a system which is defined independently from the loads applied to the system and the response of the system. Analytical models are developed to describe the system mass and stiffness characteristics of a component. The model is decomposed to express the part in terms of its modal characteristics (frequency, damping and shapes). The dynamic characteristics help better understand how the structure will behave and how to adjust or improve the component design. The study developed eight three-dimensional models that represent the four flexspline design solutions adopted for the analysis. For each design solution two models with different dimension sets were assumed. During the conducted calculations the first forms of natural frequencies for the developed flexspline models were determined using the FEM. Sample three-dimensional numerical models of the flexsplines with the finite element mesh are shown in figure 3. Figure 4 summarizes the natural frequencies values for all of the analysed flexspline design solutions and figure 5 shows vibration form examples for CSD, HFUC and HFUS type.

3. Conclusions

The calculations performed using the FEM determined characters and natural frequencies for the developed flexspline models. We analysed the CSD CSG, HFUC and HFUS flexsplines with varying features. The influence of the flexspline size on the results is important. Increasing the geometric dimensions for the same circular shape flexspline leads to a reduction in the vibration frequency (fig. 4). The natural frequencies values are affected by the adopted flexspline design solution. The highest frequency values are observed for the CSD flexspline, and the lowest for the HFUS flexspline.

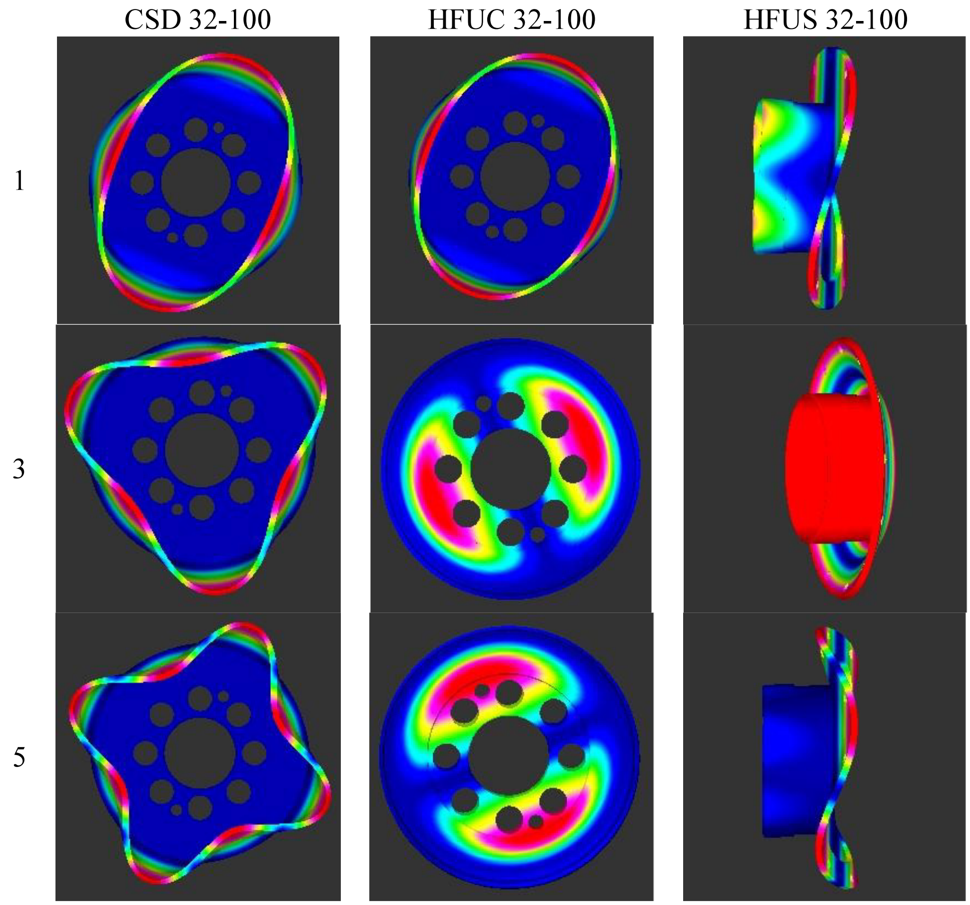

Figure 5. Analysed flexspline vibration shape.

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