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DESIGN DEVELOPMENT, PROTOTYPE MANUFACTURING USING FDM TECHNIQUES AND ACCURACY ANALYSIS OF AERONAUTICAL DUAL-POWER PATH GEAR UNIT

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ABSTRACT: The paper presents a complex process calculations and design development, FDM model manufacturing and accuracy analysis of a demonstrative prototype of a dual-power path gear unit to be applied in aeronautical systems of drive transmission. The process of making a demonstrator of a dual-power path gear unit by means of 3D-CAD modeling and Rapid Prototyping has been described here. The first stage of the designing process of a gear unit is always defining basic parameters of gear work (among others; power, rotational speed, transmission ratio) depending on the unit's predestination. On the basis of the above, the calculation of main constructional parameters is carried out. Subsequently, it is possible to make 3D-CAD models of toothed wheels and the remaining parts of the gear unit. In case of designing demonstrative prototypes, it is important to take into consideration the assumptions of modeling similarity to a real gear unit. 3D-CAD systems are often equipped with modules for analyzing geometrical parameters and cooperation of individual parts of the unit for example the area of contact. A detailed analysis of cooperation of gear parts of the unit allows for detecting models' faults early and for deleting them. After making 3D-CAD models one can approach to creating a prototype by means of Rapid Prototyping methods. It is necessary to prepare the numerical data essential as a subsequent stage of the process of making the demonstrator. On that basis the individual parts of the gear unit are made in an incremental process. The accuracy of creating a physical prototype depends mainly on the accuracy of a 3D-CAD/3D-RP model prepared in a process of processing numerical data. A demonstrator described in the paper has been made by means of FDM method. The prototype allowed for analyzing constructional solutions of gear units on a physical model and for preparing assumptions for introductory stand tests. In case of measurement of gear wheels using modern technologies based on numerical machines, measurement process is based on processing of numerical data obtained by measurement using coordinate measuring machines. In this paper is present the opportunity to automate the measurement process of gears, using coordinated optical CMM Baty Venture machine.
KEYWORDS: coordinate measurements, rapid prototyping, aeronautical gears, toothed wheels, aeronautical power drives

INTRODUCTION

Analysis of the accuracy of air items gears at different stages of technological process requires control of geometrical parameters with the use of coordinate measuring methods [1-4].

The development of coordinate measuring technique is closely linked with the development of computer-aided design methods. The measurement process is based on computer processing of measurement data to a discrete form, thus it is possible to determine the dimensions of the measured object in a virtual three-dimensional space.

The measurement procedures are based on determining the value of the measured coordinates of points. In the initial phase of development of these basic methods of measuring device was a tactile coordinate measuring machine. At the moment, are booming photonics - using non-contact measurement methods coordinate data processing.

A dual-power path gear is one of many multi-power solutions of transmitting power where two paths are used in order to split the transmitted power. In a classic multi-phase toothed gear, one gearing transmits the whole power on every phase. In an analogous dual-power path gear, two gearings are found on every phase and they transmit the required power. That is why modules of these wheels are smaller and the gear size is comparable to a traditional one. In case of a dual-power path gear it is also possible to obtain lower weight in comparison to a traditional gear which is especially important in aeronautical gear units [1-3, 7, 9]. A prototype of the described in the paper dual-power path gear (the

assumed ratio of 12) has been made according to a diagram presented in figure 1.

In order to diminish size of the dual-power path gear it was assumed that axis of its shafts are not placed at one plane. As a result of analyzing introductory solutions of kinematic structure of dual-power path gears, a layout of individual elements of the gear has been determined in accordance with a diagram (fig. 2). As can be seen, an input shaft I and an output shaft III are not coaxial.
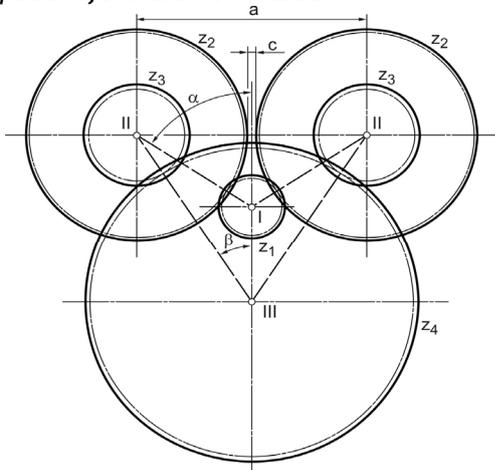

Figure 1. A diagram of wheel arrangement in a dual-power path gear – front view

CALCULATION PROCESS FOR A DUAL-POWER PATH GEAR

Kinematic assumption data for cooperating wheels is extremely vital in case of a dual-power path gear. To ensure steady operation of wheels, gearings working at a given phase should simultaneously be at the same phase (at an identical arrangement of pinion teeth and wheel teeth in respect to one another). To assure this, the value of α angle should equal:

$$\alpha = i \cdot \frac{180}{z_1} \quad (1)$$

where i – an integer, z_1 – a number of teeth in wheel nr 1.

β angle should analogically equal:

$$\beta = j \cdot \frac{180}{z_4} \quad (2)$$

where j – an integer, z_4 – a number of teeth in wheel nr 4.

Assuming minimal anti-collision backlash between wheels c one can determine minimal values of angles α and β:

$$\alpha_{min} = \arcsin\left(\frac{m_I(z_2 + 2) + c}{m_I(z_1 + z_2)}\right) \quad (3)$$

$$\beta_{min} = \arcsin\left(\frac{m_{II}(z_3 + 2) + c}{m_{II}(z_3 + z_4)}\right) \quad (4)$$

where m_I – module of wheels of gearing I, m_{II} – module of wheels of gearing II, z_2 – a number of teeth in wheel nr 3, z_3 – a number of teeth in wheel nr 4.
Preliminarily, while calculating one assumes α angle on the basis of (1) and (3) and then assuming that:

$$\frac{m_I(z_1 + z_2)}{2}\sin\alpha = \frac{a}{2} \quad (5)$$

$$\frac{m_{II}(z_3 + z_4)}{2}\sin\beta = \frac{a}{2} \quad (6)$$

and comparing sides:

$$\frac{m_I(z_1 + z_2)}{2}\sin\alpha = \frac{m_{II}(z_3 + z_4)}{2}\sin\beta \quad (7)$$

one can determine β angle:

$$\beta = \arcsin\left(\frac{m_I(z_1 + z_2)}{m_{II}(z_3 + z_4)}\sin\alpha\right) \quad (8)$$

However β angle must comply with condition (2), therefore it is necessary to assume an angle closest to the determined one and complying with conditions (2) and (4). That is why a correction of toothing is necessary in most cases.

Wheels z_2 and z_3 should be situated in respect to each other so that between wheels there is an angle which is a result of subtraction $\alpha - \beta$. One should not make a correction of angle of mutual settlement of wheels instead of correction of toothing because it leads to uneven transmission of load by the two paths.

Resistance calculations of wheels of the designed gear have been carried out on the basis of guidelines for gears assuming that each gearing transmits maximum 65% of load [6].

DEVELOPMENT AND IMPLEMENTATION OF A DEMONSTRATIVE-RESEARCH PROTOTYPE OF A DUAL-POWER PATH GEAR

The carried out calculations of dual-power path gear make it possible to design it in 3D-CAD environment. Contemporary CAD/CAM/CAE/RP systems assist the process efficiently. INVENTOR system has been used for the research. It allows to make geometrical prototypes and to carry out many introductory tests and analysis confirming the designing assumptions or influencing their modification [1, 8].

Models of toothed wheels have been made on the basis of tooth profiles generated by means of copyright computer programs developed in accordance with INVENTOR environment (fig. 2a).
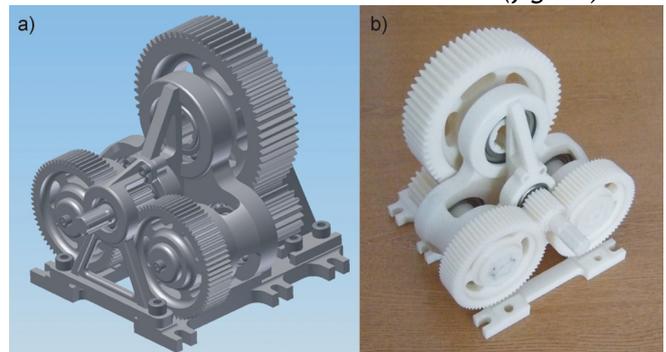

Figure 2. The gear model:
a) 3D-CAD model, b) RP – FDM model

As a result of modeling individual parts of the gear and selection of normalized parts taken from a program library, a three-dimensional numerical prototype of a dual-power path gear has been made.
An additional task of the 3D-CAD model is checking correctness of construction and operation of the gear in defined conditions. In case of the discussed gear it is also checking the division of power into two paths.

CAE programming modules, which are helpful on the stage of analysis, can be applied here. The basis for making a research prototype was 3D-CAD models recorded in STL format. STL models subjected to program processing – division into layers 0,254mm thick applying CatalystEX program attending FDM machines – Staratasys U-Print machine. In this program the models were placed on a plane of working platform of the device (fig. 2b).

COORDINATE MEASURING SYSTEM - BATY VENTURE

Coordinate measuring system BATY VENTURE it's a optical CMM machine allows you to perform measurements of the curve or points of objects with complex shapes including gears. A view of optical measuring station is shown in figure 3. Acceleration measurement process BATY scanner can be obtained using automation hardware and software.

Figure 3. The coordinate measuring system – BATY VENTURE

Application program BATY inspection module allows the subsequent analysis of the accuracy of the measured performance of the element with respect to the nominal model in DXF format data. The possibility of analyzing the whole item - described many points - it gives a complete picture of the accuracy of its execution in x,y plane section (fig. 4).
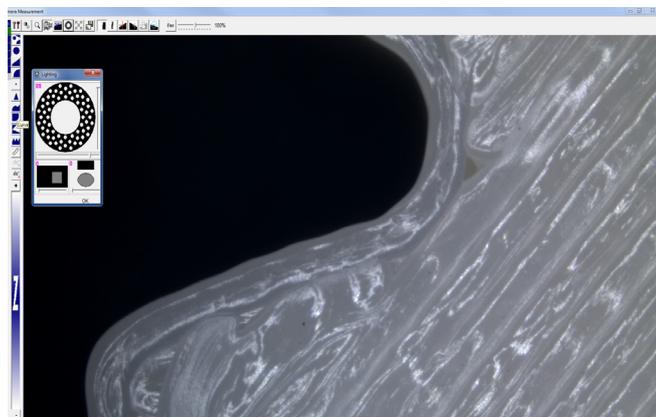

Figure 4. A camera view of gear section during the measurements process

In addition, optical measurement coordinate system gives the possibility to use different systems of measurement to match the CAD model: the geometric elements or best-fit (fig. 5). Since the density of collected points is a big deviations are visualized as a color map (fig. 6).
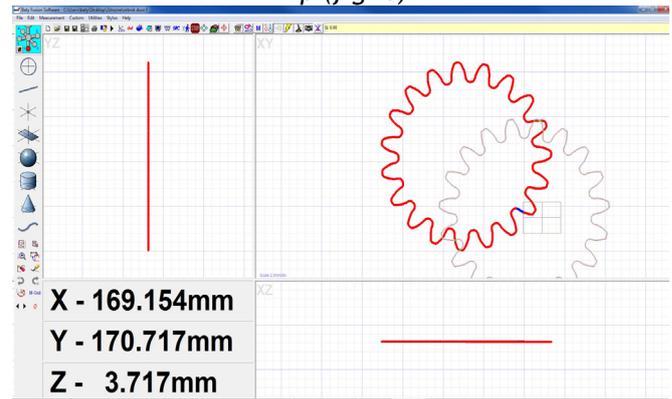

X - 169.154mm
Y - 170.717mm
Z -   3.717mm

Figure 6. Import DXF data of gear and best-fit operation in machine software
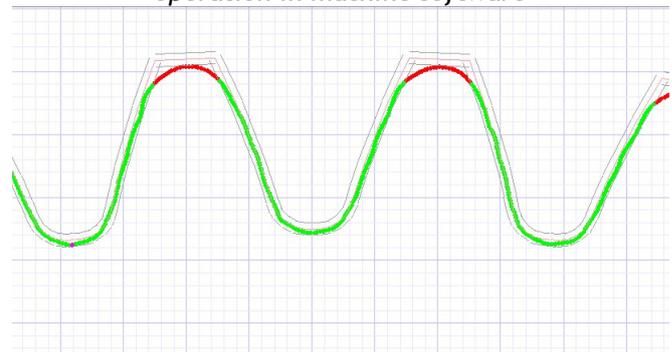

Figure 7. A deviations visualized as a color of FDM model of gear

CONCLUSIONS

The test gears have higher accuracy than the estimate for FDM method. One way to increase the accuracy of the prototype, may be a change in the way of modeling the outline of gear rim and the wheel hub. This is especially true if the wheel second grade, which is sensitive to the contraction of material due to its size and shape of the hub. The test gears have a higher accuracy than the estimate for FDM method (± 0.1 mm).The research prototype studied in this paper was made by means of FDM method and the material used was ABSplus.

Additionally introductory tests on models of this kind made it possible to carry out an analysis determining correctness of the applied designing methodology and constructional solutions of aeronautical dual-power path gear. The prototype is meant for tests determining power division.

The tests will be carried out on a test stand. They will allow for verifying an assumption that division of power is equable in case of geometrical synchronization of gearing cooperation on a given phase of gear.

The following stage of the research will be making a gear prototype of a material having qualities similar to target ones and subsequently carrying out tests in conditions of real loading.

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