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PRELIMINARY STUDIES OF PLANETARY GEAR DEMONSTRATOR MADE OF ABS POLYMER

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Abstract

The paper presents preliminary stand tests of a demonstrator of planetary gearing. The gearing used in the research has been made of ABS polymer with good strength parameters.

Parts of the gearing have been created by means of FDM (Fused Deposition Modeling). The input data come from 3D CAD solid model which geometry is determined by a file of any system equipped with the ability to save in STL format. This model is described by a grid of triangles and divided into levels (layers). Their thickness determines the accuracy of representation of a detail curvature. The thickness of the layers is also limited by the accuracy of the process and the equipment.

The research was conducted on a test stand designed in an open system powered by a three-phase electric motor. The control is provided by a single-phase inverter with three outputs, which ensures full speed control. The load of the stand is realized by an electromagnetic powder brake. The possibility to control working time lets you precisely define the time intervals of various stages of the research. Using timer makes it possible to observe the current consumption of the gearing and helps to establish the research process. The research at this stand allows for obtaining stable working parameters and thus for obtaining accurate, not distorted results of the demonstrator's operation.

The purpose of the research is verification of gear endurance calculations and verification of the design in conditions similar to real ones.

Keywords: *stand tests, gearing, planetary gear*

1. Introduction

Planetary gears are a distinct group of gears in which at least one gear is ball-bearing in an element rotating around the case [4]. In comparison to gearings with fixed axes they are characterized by small dimensions and weight, which is essential particularly in aerospace industry. Due to transmitting high loads these gearings must be made of metal. However, tests at such gearings are expensive and long-lasting, which increases the cost further. Therefore we have been trying to research planetary gears made of plastic in order to using modelling similarity carry out tests which are cheaper and faster.

This paper is a part of implementation of the research task number 4 „Development of a new, simpler and cheaper toothed gear in place of complicated and expensive planetary gears" of the project „Modern material technologies in aerospace industry" in which a fixed axe dual-power path gearing is considered [3, 8]. The planetary gearing has also been designed as dual-power path gearing (with two satellites) in order to compare them better.

2. Preparing the model for research

On the basis of design assumptions:

- total gear ratio: $u = 12$,
- maximum motor rating at input $N = 0.2$ [kW],
- rotational speed of shaft at input $n_1 = 1200$ [rpm]

and the adopted material - ABS polymer, calculations of the tested planetary gearing have been carried out and diagram of the gearing is presented in Fig. 1.

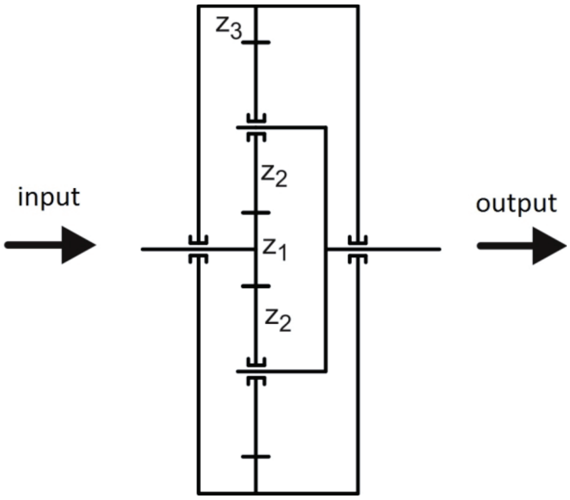

Fig. 1. A diagram of power transmission of the tested planetary gearing

As a result of geometric calculation the following parameters have been assumed:

- teeth number of sun gear z_1 = 19,
- teeth number of planet wheel z_2 = 95,
- teeth number of annulus gear z_3 = 209,
- module m = 1 [mm],
- active facewidth of gear b = 14 [mm] .

Strength calculation of the gears has been carried out in the same way as for gearings with fixed axis [4, 5, 7, 11]. Because the power is transmitted from a pinion to two satellite wheels there is no possibility to apply a solution that would allow automatic levelling of power coming from these cooperating wheels. That is why we have assumed a coefficient of unevenness of torque distribution for individual satellite wheels k_o = 1.3. It means that the cooperating gearing has been calculated for 30% greater load than in case of even power distribution.

Material data:

- $k_d = 16[\sqrt[3]{MPa}]$

and critical compressive stress:

- σ_{HP} = 25 [MPa],

assumed in accordance with guidelines for ABS polymer – the material used in FDM (Fused Deposition Modelling) technology.

ABS polymer has been chosen due to its good properties and because it is commonly used to make gears. Also it was possible to make parts of the gearing by means of uPrint system at the Department of Mechanical Engineering at Rzeszow University of Technology. Owning to the accuracy of this method, spur gear have been assumed (making helical gears can be subject to an additional surface error because of layered structure of model construction).

The ABS material obtained by FDM differs by strength properties from the one made by injection. It is caused by the technique of arranging filament of plasticized ABS polymer and applying software allowing to shape the structure of a model of different density (solid, sparse-low density, sparse-high density).

The CAD model of the gearing for stand tests has been made in Autodesk Inventor program. Teeth of gears have been shaped with rack-type tool by direct simulation of machining. After designing all parts, their models entered into uPrint software have been generated in STL format [2, 6, 10]. A ready model of gearing prepared for stand tests is shown in Fig. 2.

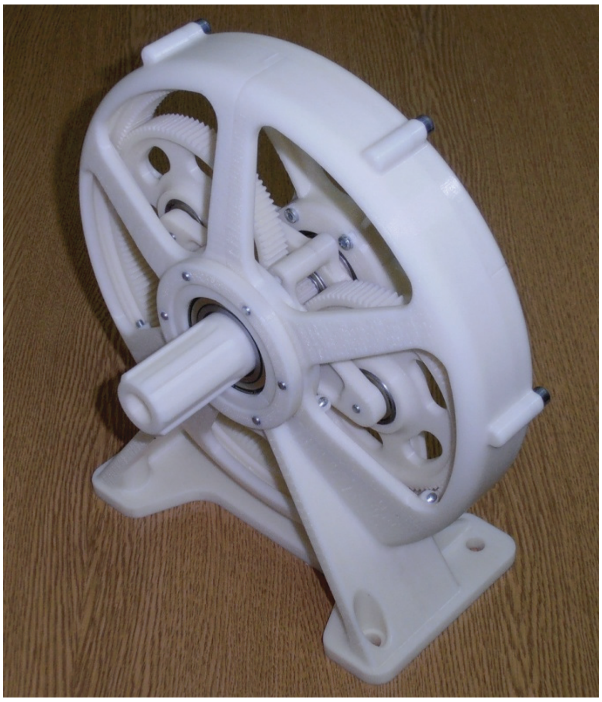

Fig. 2. A model of planetary gearing made by FDM method

3. The test stand

A diagram of connections and communication between units is shown in Fig. 3.

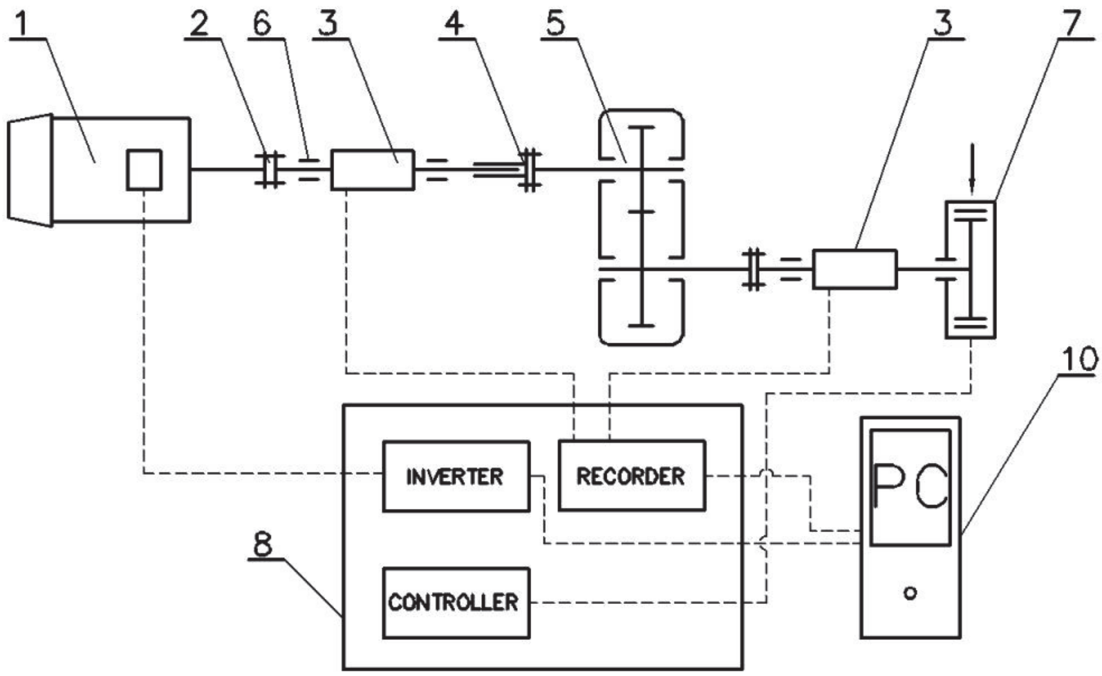

Fig. 3. A schematic diagram of the test stand [9]: 1 – electric engine, 2 – claw clutch, 3 – torque sensor, 4 – sliding clutch, 5 – tested gearing, 6 – support bearings, 7 – powder brake, 8 – control box, 10 – PC

The stand has been designed in an open system. It is powered by a three-phase 0.75 kW electric motor (1). The control is provided by a single-phase inverter with three outputs which is installed in a control box (8). The inverter is a frequency converter assuring full control of engine parameters, such as; speed (can be adjusted by changing the frequency at the output of the inverter in the range of 0 Hz to 650 Hz), “soft” start and stop. All components are installed on the table (9) with T-slots in order to determine the optimal position of the drive and the tested gear.

Load on the stand is provided by an electromagnetic powder brake (7). Torque incriminating the gearing depends on the supply current. Changes in settings such as speed or load torque can be changed during testing the gearing. Changing gear (5) is exceptionally simple thanks to the use of sliding clutch side splines. Pulling apart clutches (2) and (4) between which there is the gearing and unlocking the terminal makes it possible to change the gear. Torque sensors (3) installed at an input and output of the demonstrator allow to control the work of the entire gearing. The values measured by the torque sensor (torque and revolutions) are transmitted to an advanced recorder of power and torque. The measured values can be read directly on an LCD display. Moreover they are recorded on a computer in real time (according to PC RTC) and archived by specialized software.

4. Tests and results

Figure 4 shows a photograph of the tested planetary gearing made of ABS polymer during the research carried out on a stand [1, 9] at the Department of Mechanical Engineering at Rzeszow University of Technology.

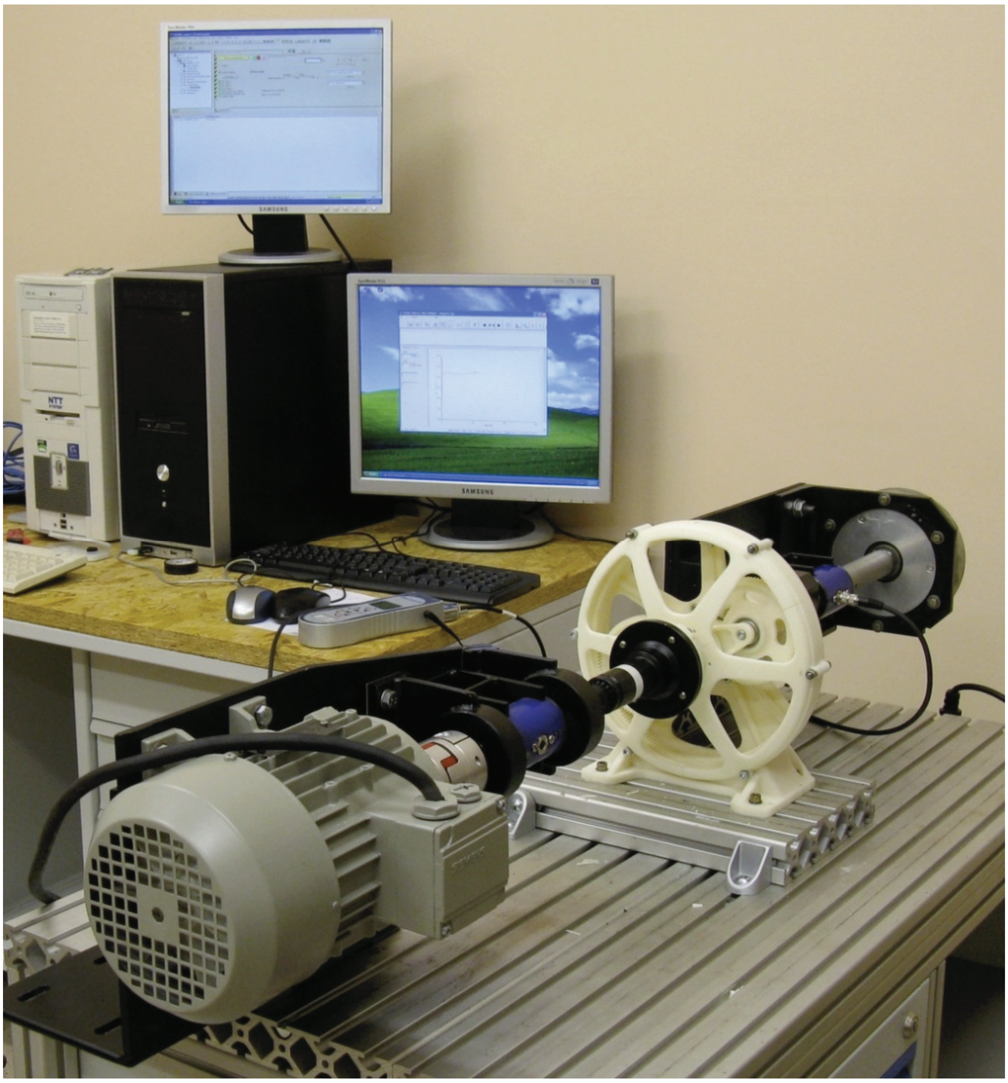

Fig. 4. The test stand with installed planetary gearing during the tests

Two independent computers are connected to the test stand. One of them controls parameters of work of an engine by means of Drive ES - Starter V4.1 program [12] which allows to change parameters directly on the test stand. The other computer is used for data acquisition from installed torque sensors by Emperor Lite program [13] which makes it possible to save and view the measurement results (Fig. 5). The results are displayed in binary and graphical mode, allowing to observe values of parameters and to determine the course of the testing process. Archived results can be edited at any time and subjected to further treatment. Thanks to recording the data it will be known exactly when the gearing is damaged. Additional hardware capabilities make it possible to control the working time and specify time intervals between various stages of the research.

Before the fundamental research, the gearing had been run in with a torque of 5 [Nm] for one hour. The research schedule presumed loading the gearing gradually with a braking torque in one-hour intervals. The initial value of 5 [Nm] was increased by 1 [Nm] until the gearing was destroyed which happened in 16th minute of work with the load of 12 [Nm]. The value of torque at which the teeth of the central gear got damaged was less than 30% lower than followed from the calculation. Having regard for the fact that in the calculation we assumed minimum values of coefficients (in order to shorten the test) the results of the tests carried out at this stage can be considered satisfactory. It also allows to draw a conclusion that increasing the coefficients from minimum to medium values will cause getting calculation parameters values similar to the ones obtained as a result of stand tests.

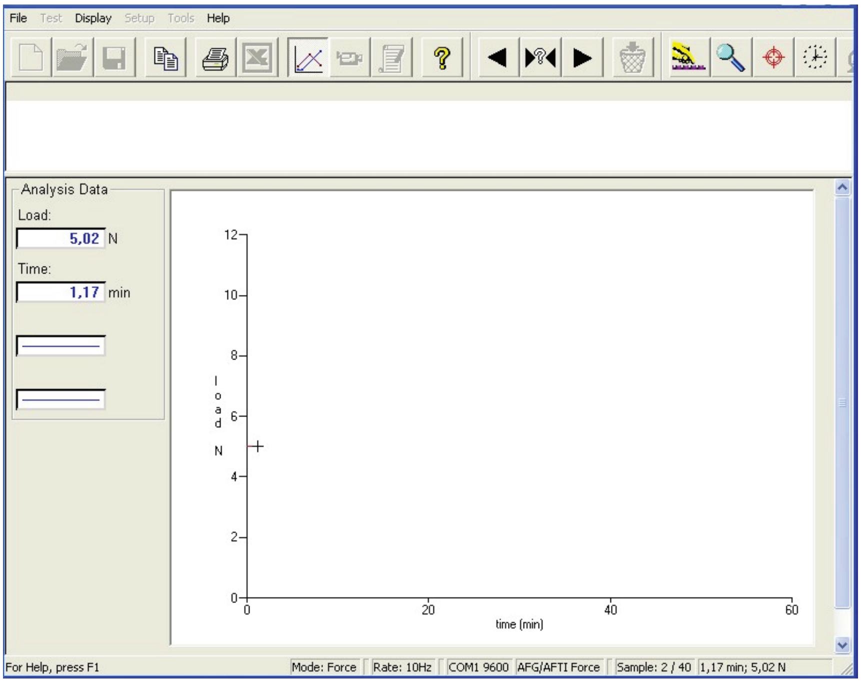

Fig. 5.The dialog box of Emperor Lite program (print screen after starting the test)

5. Summary

The paper presents a description of the test stand and the process of introductory stand tests of planetary gearing made of ABS polymer.

Tests at this stand allow to obtain a stable operating parameters and thus to obtain undistorted, accurate results of work of the demonstrator. Changing gears takes place in a short time and so does adapting to a different type of demonstrator.

Preliminary stand tests confirmed correctness of the calculation. However, it is necessary to change the values of coefficients from minimal to medium ones (especially the coefficient of uniformity of workload distribution) and adjust the accuracy of making and cooperation of gears.

It should be noted that in a planetary gearing with two satellites it is impossible to apply a solution allowing for automatic levelling of forces coming from cooperation with satellite wheels as it takes place in a gearing with three satellites [11].

The correctness of results depends on the accuracy of mathematical model representation of random load, so on adequacy of selecting a method of approximation and on assuming the right hypothesis of damage accumulation that will work in practice. It is also necessary to know the fatigue characteristics of the materials used [5].

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