The manufacturing method of the composite worm gear housing using the cold injection

A Baier, K Herbus and P Ociepka
Silesian University of Technology, The Faculty of Mechanical Engineering, The Institute of Engineering Processes Automation and Integrated Manufacturing Systems, Konarskiego 18A, 44-100 Gliwice, Poland

E-mail: krzysztof.herbus@polsl.pl

Abstract. In the work the innovation manufacturing method of the composite worm gear housing of the electric power steering system was presented. Modification of the worm gear housing of the electric power steering system consisted in changing the material from which it will be manufactured. Until now, gear housings were made of aluminum by hot injection method. The present works aim at using the pDCPD material and the cold injection method into manufacturing the new generation of the worm gear housing. The planned change was aimed at eliminating the machining process of the cast aluminum body and reducing its mass. In the work was assumed, that the assembled worm gear housing, with all cooperating elements, will be manufactured using the cold injection method. As a result of the manufacturing process the finished product in the worm gear form of the electric power steering system will be obtained. In addition, the geometrical form and the dimensions system of the support elements were determined in relation to the assembled worm and the worm wheel together with the bearing system. The presented method allows eliminating the expensive and time-consuming process of machining of the molding gear housing.

1. Introduction

The dynamic development of engineering materials allows modeling the characteristics of a material in relation to its application. Therefore, basic engineering materials such as steel and aluminum are being increasingly replaced, in many industrial solutions, by new their types. One of materials the more and more often used for manufacturing different machine components is the pDCPD material. PDCPD is a thermosetting polymer plastic that is made from two liquid monomers in a 1:1 ratio. Therefore, there is no need to melt the plastic components during the casting process. The obtained material does not plasticize in the conditions of high temperature of its operation, which is an important feature when it is used to manufacture machine and equipment components.

At the Institute of Engineering Processes Automation and Integrated Manufacturing Systems, there are conducted numerous works in the field of the use of composite materials for manufacturing different machine elements [1-10]. The paper deals with the issue related to the production of the worm-and-sector steering gear casing with electric-assisted system from the pDCPD material, which is implemented as part of the research project PBS3/B6/37/2015 (PST-41/RMT2/2015) jointly by Nexteer and the Silesian University of Technology. One of the main goals of the mentioned project is developing a body characterized by a lower mass in relation to the body being currently manufactured of aluminum. The equally important goal is also to eliminate the process of machining the casting
casing. The pDCPD material is characterized by a lower density in comparison to aluminum (table 1). Therefore, its application, with appropriate modification of the body construction, enables to achieve the first objective of the project.

| Parameter       | Value          |
|-----------------|----------------|
| Density         | 1.03 g/cm³     |
| Young module    | 1337 MPa       |
| Tensile strength| 45 MPa         |
| Poisson's ratio | 0.26           |
| Curing time     | 6 min          |

The work presents the method of manufacturing the gear casing in the context of the assembly, which allows eliminating the expensive and time-consuming machining process of casting casings. The presented field of the problem is also the subject of the patent application “Steering column power assist assembly housing”, United States Patent and Trademark Office, Application Number - 15/684,338. The first stage of the work was related to the modification of the geometrical form of the worm gear casing of the steering system with electric assisting. Its purpose was to create a geometric constructional form of the body that would provide the same stress state in the modified casing. Based on the numerical analyzes carried out using the FEM method, the geometrical form of the gear casing was created which is shown in figure 1.

![geometrical form of the aluminum worm housing]

![geometrical form of the pDCPD worm housing]

**Figure 1.** The modified virtual model of the worm gear housing.

Virtual tests were carried out based on boundary conditions resulting from the operating conditions of the designed system. All the critical dimensions, from the point of view of the correct cooperation of the gear transmission elements, such as dimensions for the bearing or spacing and the angular position of axis of the worm and worm-wheel were preserved.
2. Concept of the assembly of components of the worm gear before its manufacturing

In the classic manufacturing method of the worm-and-sector steering gear with electric-assisted system, the casing forms the basis for assembled bearings, compensators, the worm and the worm-wheel. The geometrical form of the casing after machining also determines, in an unambiguous manner, the arrangement of the worm and worm-wheel axis. Due to the need to ensure the correct angular position between the cooperating axes of the worm gear and to ensure the correct distance between them, the surfaces of the casing intended for cooperation with other elements of the gear unit are made in a narrow range of the tolerance field width.

The concept of manufacturing of the worm gear casing, presented in this work, consists in the assumption that the ready assembled mechanical system of the transmission is subject to the casting process. Therefore, it was necessary to distinguish a number of elements that should take over the support functions of the casing and protect the assembled components against inundating with the plastic during cold injection. In connection with the development of the concept of manufacturing of the worm gear casing, the following steps were carried out:

- setting apart from the geometrical form of the future gear casing the base elements with reference to the axis of the worm and the axis of the worm-wheel,
- setting apart from the geometrical form of the future gear casing the elements protecting the installed system against inundating during the cold injection process,
- elaboration of the concept of the assembly process of worm gear components,
- elaboration of the concept of the stand for assembling of the worm gear components,
- elaboration of the model of a geometrical form of the casing, which maps its external shape and at the same time takes into account all the components being previously distinguished.

![Concept of the assembly process of the worm gear components.](image)

In the work it was assumed that the system of the worm-wheel (figure 2) includes such elements as: the worm-wheel, the worm-wheel sleeve, the bearing system and the worm-wheel shield. The worm system, on the other hand, consists of: the worm, the worm sleeve, the bearing and compression system, and the worm shield. The worm-wheel sleeve and the worm one are fixing and supporting elements in relation to the worm-wheel and worm itself. The assembly process can be represented in the following steps (figure 2):
• assembly of the shield of the worm-wheel axis on the worm-wheel sleeve,
• assembly of the worm-wheel in the sleeve using the bearing system,
• assembly of the worm along with the bearings system and compensators in the worm sleeve,
• assembly of the shield of the worm axis on the worm sleeve,
• adjustment of the position of the worm axis and worm-wheel axis in order to obtain the correct meshing between the cooperating gear components.

![Image](https://example.com/image1)

**Figure 3.** Concept of manufacturing of the casing based on the assembled transmission system.

The components with the names the shield of the worm-wheel axis and the shield of the worm axis along with the appropriately shaped geometrical form of the mold (figure 3) protect the assembled system against its inundating with the material during cold injection. The design process of the presented components of the system was based on the method based on knowledge and experience and the features method [11-19].

3. **Manufacturing of the worm gear casing on the test stand using cold injection**

In order to implement the concept of the assembly process presented in the paper, the laboratory stand was created as shown in figure 4. The stand is equipped with three supports that uniquely position the assembled axes of the worm and the worm-wheel. The proposed system maps the way in which the subassemblies are located in the casing of the worm gear. In the work it was assumed that the axis of the worm does not change its position, while the adjustment of the degree of meshing between the worm and the scroll wheel is accomplished through the vertical movement of the axis of the worm-wheel. Therefore, it is not the geometrical form of the gear casing that determines the degree of meshing of the worm and worm-wheel instead the distance between their axes is regulated at the assembly stand. As a result, the width of the tolerance fields of individual dimensions may be widened. During the adjustment of the meshing rate, the resistance moment that occurs in the assembled system is checked. The adjustment process ends when the desired torque value is reached. After the adjustment the position of supports do not change until the end of the injection process, so as
not to change the positioning of the transmission axis. In the next step, the assembled and properly located system is “built-over” with a form consisting of 6 elements. The number of components results mainly from the need to adjust the form to the designed station and to the assembled subsystems. All joints of components are sealed in such a way that the material would not inundate the cooperating elements of the gear.

Figure 4. Course of the process of preparation of the worm gear system for cold injection.

The first phase of production tests consisted in the application of a mold in the form of a 3D printout. Whereas the next tests were carried out using an aluminum mold (figure 5). The use of quick 3D printing to create the mold allowed for initial verification of the method of assembly of the mold at the assembly stand in the context of the positioned axes of the transmission system. Conducted tests of assembling of the mold on the test stand allowed reducing the number of mold elements from 6 to 3. As a result of the conducted researches of the complete system of the worm gear was manufactured with assembled mechanical components. Manufactured gear casing with the use of the presented technique of the cold injection was mounted to the electric power steering system (figure 4).
Testing of the behavior of the manufactured casing is carried out in the context of the entire assembly of the worm-and-sector steering gear with electric-assisted system at diagnostic stands designed for testing systems with aluminum casings.

4. Conclusion
The use of the pDCPD material enables the utilization of cold injection in relation to the manufacturing of the casings in the context of its assembly. The temperature occurring during the injection and hardening of the material does not cause damage to the gearbox assembly components.

The manufacturing of first components basing the worm and worm-wheel axes, setting apart from a large volume of the casted casing, characterized by a small volume in relation to the whole casing, makes it possible to obtain a smaller absolute value of shrinkage of the material. In this way elements are obtained whose dimensions are characterized by greater repeatability in a narrower range of tolerance fields.

The elimination of the machining process of the casted casing is possible thanks to the application of adjustment of the meshing ratio. One should consider that it is not the previously unambiguously shaped body is the basic base element instead the assembled axes are matched without any hindrances.

In order to protect the interior of the gear casing against plastic material inundating, it is necessary to use protective elements in the form of the shields of the worm-wheel and worm axes.

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