MARCIN MIGUS*, KAROL OSOWSKI**, ARTUR OLSZAK***,
ANDRZEJ KĘSY**, ZBIGNIEW KĘSY**

COMPUTER-AIDED MACHINE DESIGN WITH REGARD TO NEW TECHNOLOGIES AND MATERIALS

KOMPUTEROWE WSPOMAGANIE W BUDOWIE MASZYN Z UWZGLĘDNIENIEM NOWYCH TECHNOLOGII I MATERIAŁÓW

Abstract

The aim of the paper is to present the issue of using computer-aided methods as well as 3D printing technologies and not typical materials connected with it. Selected problems that can occur while applying computer-aided methods and their solutions have also been described.

Keywords: *computer-aided methods, design, high-speed machining, 3D printing, design problems*

Streszczenie

W artykule przedstawiono zagadnienie wykorzystania metod komputerowego wspomagania konstruowania oraz wytwarzania z użyciem technologii drukowania 3D oraz związanych z tą technologią nietypowych materiałów. Opisano wybrane problemy, jakie występują podczas stosowania metod komputerowego wspomagania w praktyce inżynierskiej. Przedstawiono sposoby rozwiązania tych problemów.

Słowa kluczowe: *metody komputerowego wspomagania, konstruowanie, obróbka szybkościowa, drukowanie 3D, problemy konstrukcyjne*

*   Ph.D. Eng. Marcin Migus, The State School of Higher Education in Sandomierz.
**   M.Sc. Karol Osowski, Prof. Ph.D. Eng. Andrzej Kęsy, Prof. Ph.D. Eng. Zbigniew Kęsy, Institute of Applied Mechanics and Energetics, Faculty of Mechanical Engineering, Kazimierz Pulaski University of Technology and Humanities in Radom.
*** Ph.D. Eng. Artur Olszak, New Chemical Syntheses Institute in Puławy.

1. Introduction

Currently, computer-aided engineering work plays an important role in machine design. The design process as well as the production process may be supported with new methods and technologies.

Computer-aided design can be used in the preliminary stage of the machine design process [1]. The result is the increase in the accuracy and the calculation design time reduction as well as the possibility of construction optimization [2].

Due to the development of computer-aided design, new design technologies appeared. They are: high-speed machining carried out using CNC machine tools and an additive manufacturing method using 3D printers. New technologies for the machine part design caused the application of materials that have not been widely used yet [3].

However, despite a considerable progress in the development of new technologies, including the software for computer-aided design of machine parts in practical applications, there is a number of new problems requiring unusual approach from the constructor.

The article presents selected examples of problems that occur when using computer-aided engineering works concerning calculations, virtual model design and 3D printing technology, including the use of not typical materials. In addition, ways to solve these problems have been suggested.

2. Calculation of non-Newtonian fluid flows

In order to meet requirements to design a machine part, as soon as materials with new properties have been produced the constructor looks forward to using them as soon as possible.

The main obstacle in practical applications is the lack of theoretical basis regarding behaviors of these new materials while influenced by different factors. This is due to the fact that basic research is costly and time-consuming. One of the ways to solve this problem is modifying traditional calculation methods, in order to find a way to carry out calculations with sufficient accuracy for the construction process.

In machine design, two kinds of smart fluids are used: magnetorheological fluids, responding to the magnetic field presence and electrorheological fluids, activated when using the electric field [4, 5]. An important feature of these fluids is that their rheological properties can be described by the Newtonian model, but only in the absence of the physical field (magnetic or electric), according to the equation:

$$\tau = \mu \cdot \dot{\gamma} \qquad (1)$$

where:

τ – shear stress,
μ – viscosity,
$\dot{\gamma}$ – shear rate.

To simulate the behavior of smart fluids in the presence of a suitable physical field, non-Newtonian rheological models have been used (e.g. Herschel-Bukley, Ostwald-de Waele), but the Bingham's model is the most commonly used:

$$\tau = \mu_p \dot{\gamma} + \tau_0 \qquad (2)$$

where:

    μ_p – plastic viscosity,
    τ_0 – yield stress.

During the process of machine design using magnetorheological or electrorheological fluids, it is often necessary to carry out calculations for the right fluid flow, e.g.: calculations of fluid flow rate through the work channels based on the dimensions of these channels and pressure decrease along the channels. In case of channels with the simple structure (rectangular or cylindrical), such calculations can be carried out on the basis of analytical equations [6].

For channels with more complicated shapes, it is necessary to carry out numerical calculations. The Navier-Stokes equation for describing the motion of the Newtonian fluid with constant viscosity μ [7] is commonly used for flow calculations. However, this equation cannot be used directly for the magnetorheological or electrorheological fluid flow because these fluids are non-Newtonian.

To enable calculations of non-Newtonian fluid flow, the concept of apparent viscosity μ_a, which is treated as viscosity μ has been introduced. Small changes in shear rate $\dot{\gamma}$ have been taken into consideration [8]. A method for determining the apparent viscosity μ_a for a selected A point located on the straight Bingham fluid model is shown in Fig. 1.
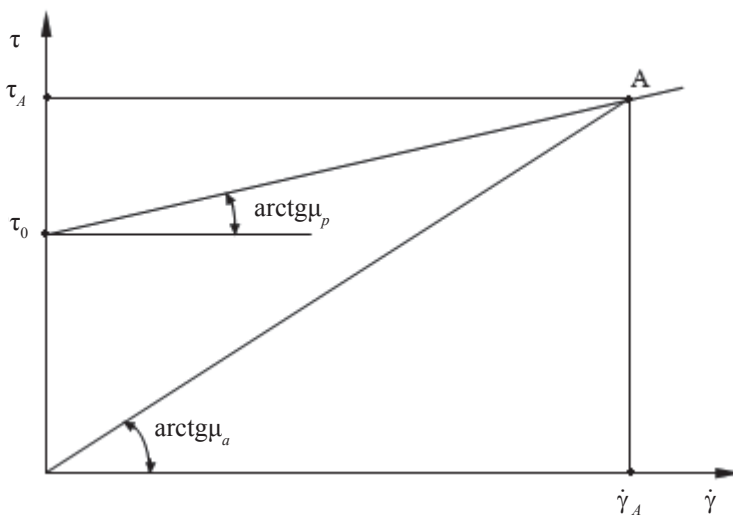

Fig. 1. A method for determining the apparent viscosity μ_a

Apparent viscosity μ_a, described by the equation:

$$\mu_a = \frac{\tau_A}{\dot{\gamma}_A} \qquad (3)$$

can also be interpreted as the angle of inclination of arcustangens line joining the origin of the coordinate system to point A. Fig. 1 shows that for the Bingham mathematical model when $\dot{\gamma}_A \to 0$ that $\mu_a \to \infty$ and when $\dot{\gamma}_A \to \infty$ then $\mu_a \to \mu_p$. In practice, in the case of low shear rate $\dot{\gamma}$ is a maximum of $\mu_a = 1000 \cdot \mu$ [9], where μ refers to the viscosity of the magnetorheological or electrorheological fluid in the absence of an adequate physical field.

For example, the differences between the flow rates of the magnetorheological fluid in a magnetic field of a rectangular channel, calculated on the basis of the analytical equations and by using the ANSYS FLUENT software (using the Navier-Stokes equation and apparent viscosity) is shown in Fig. 2 [9].
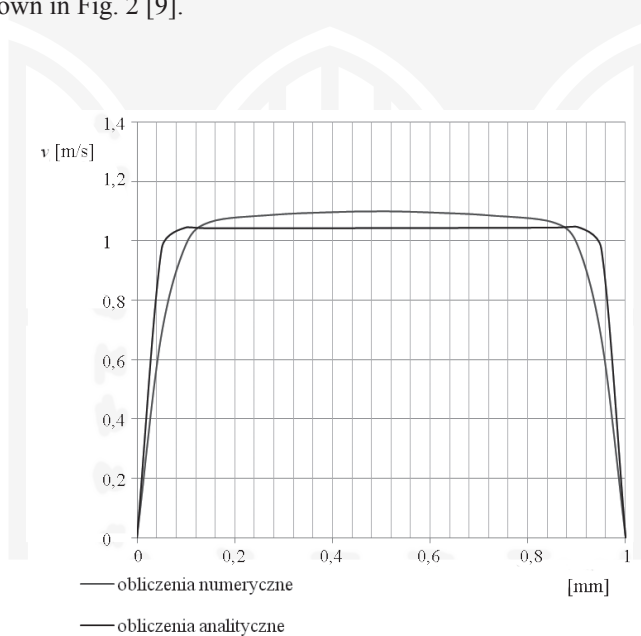

Fig. 2. The results of calculation of velocity flow in the rectangular channel with the height of 1 mm for $\tau_0 = 10$ kPa, acc. [9]

As it is shown in Fig. 2 these differences, except for the extreme points, do not exceed 10%, which is within the range of permissible errors in engineering calculations. However, for the channel with a more complex shape, the simulation errors are much greater.

The described conduct of simulation allows to omit the problem connected with the lack of accurate computational models and has a practical application in the design of automotive shock absorbers, hydraulic brakes and clutches filled with these fluids.

3. The creation of solid models

The basic element of the three-dimensional graphics used in the process of designing and manufacturing machine parts (e.g. High-speed machining, or 3D printing) is the solid model. To create solid models, computer aided design (CAD) programs are used. The most popular ones are programs designed to create technical documentation in 2D and 3D, such as Autodesk Inventor, SolidWorks, ProEngineer. These programs allow the user to introduce changes and improvements, validate the design in terms of assembly and have their own catalogues of standardized structural elements [10, 11]. However, following the practice, in spite of using the right computer program commands, errors preventing its further use, may occur.

During the solid model design, a sketch is created. To create the 2D sketch, 2D graphics or a typical technical documentation is used. Then based on the sketch part, a 3D solid model is generated by using computer program, which is stored in a computer file used by CNC machine tool or a 3D printer.

One of the errors that can occur when creating a solid model of a complex machine part may take place during the surface generating process when the 2D sketch has sharp edges [1, 11], as illustrated in Fig. 3. Another error can occur when there is improper penetration of a solid model's surface with another part's surface [1, 10] (Fig. 4).

A way to eliminate these errors is to simplify the construction by eliminating complex line connections in the sketch [1, 10, 11]. The results should be monitored on a regular basis so other errors can be avoided in the design process.
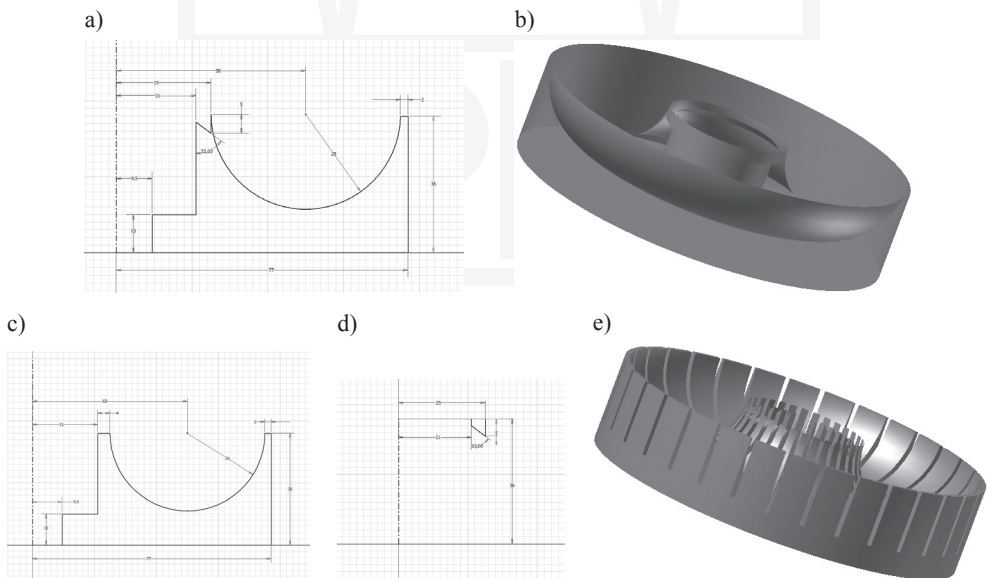
a)

b)

c)

d)

e)

Fig. 3. The incorrect generation of sharp edges after the conversion from a sketch into the solid model: a – an accurate sketch of the structure, b – the wrong model transformations, c – a simplified sketch, d – the element causing the problem as a separate sketch, e – a correctly generated solid model
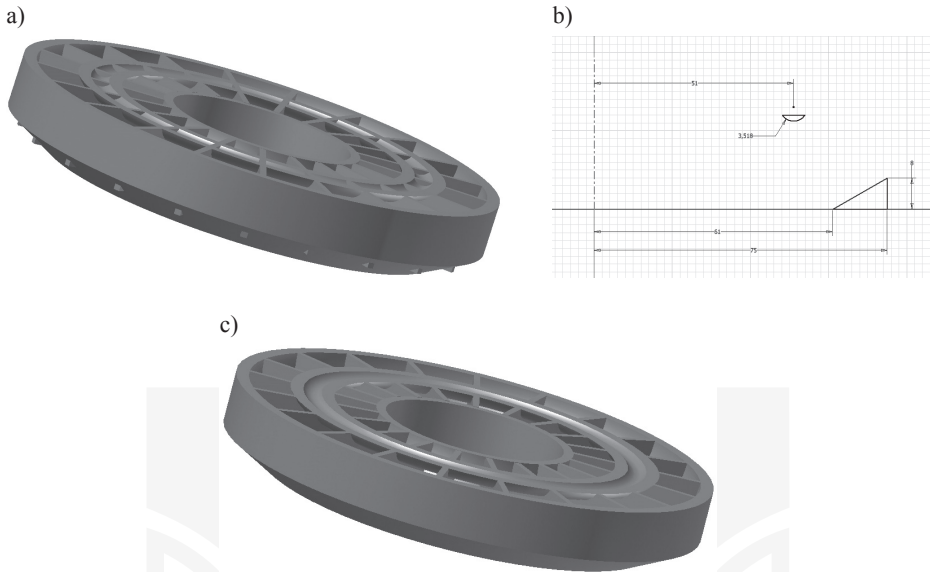
a)

b)

c)

Fig. 4. The incorrect penetration of the surface after replacing the sketch in a solid model by another
solid model: a – a solid model with the visible errors penetration surface, b – sketch fragments
in which the penetration occurs and which should be removed, c – an improved solid model

4. 3D Printing

3D printing allows for a quick manufacturing of some machinery parts, regardless of the
complexity of their shape, so 3D printing is more and more widely used in various branches
of the engineering industry, especially in aviation, but also for medical purposes [3]. Parts
can be formed from various materials, such as metal powders (iron, aluminum, copper,
titanium), plastics (polymers, nylon, polycarbonate resins) and ceramics. Due to the fact
that 3D printing is an additive creating method, and its advantage is the optimal use of the
material, which reduces the cost of part manufacturing. This technology is particularly useful
for the construction of prototypes.

3D printing is an incremental way of forming a three-dimensional object. The shape
of each layer is determined on the basis of the solid model of the manufactured parts.
First, the solid model is created as a shearer model, stored in the computer memory as
a set of coordinates of the vertices of triangles covering the surface of the part and the
coordinate vectors perpendicular to these triangles. It has been assumed that the file has
the extension ".stl".

The next step to create a layer model is the use of specialized 3D printer software. Based
on this model, a set of points forming lines for layers of the construction is created, which
enables the proper control of the 3D printer head.

In the case of manufacturing parts with complex shapes, during changing a solid model
into a longwall model, errors can occur as a result of software malfunction. These are
generally fragments of a solid model not covered by the so-called "degenerated" triangles

– the triangles whose vertices are collinear or triangles which overlap. Fig. 5a shows the hydrodynamic torque converter impeller made of nylon on a 3D printer, and Fig. 5b shows a magnified part of the rotor including blade connection with the casing, where the most "degenerated" triangles appear while creating a layered model.

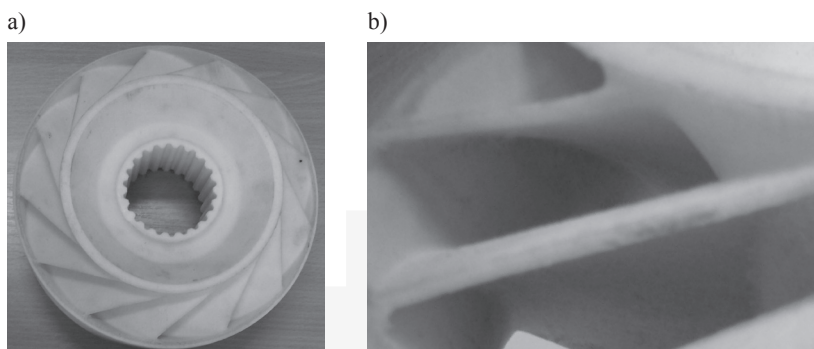a)   b)

Fig. 5. The rotor of PHM 28 hydrodynamic torque converter made on a 3D printer: a – general view, b – a view of the blades connection with casing

The removal of these errors requires the use of specialized software so the 3D printer manufacturers recommend programs that should be used, or they attach the appropriate software for their products. However, this software guarantees the correct operation of 3D printers only in the case of machine parts with simple shapes. In complicated cases, the software choice is not obvious due to a wide range of computer programs.

Problems relating to manufacturing by means of 3D printing are not limited to software malfunction, but are generally associated with the design features of machine parts such as material or dimensions and tolerances of the manufactured parts [12]. The material used in 3D printers is selected in order to meet the requirements of the printing process [13].

Currently, the most widely used metal to manufacture machine parts, using 3D printing technology is titanium and its alloys. However, titanium is a "difficult" material in the machining process as well as in welding, which significantly makes the process of part manufacturing more difficult. Applying new technologies, where unusual materials are used, makes designers predict the possibilities of the emergence of unusual properties in the manufactured part and consider this fact in the process of quality control.

The small size of 3D printer workspaces, especially those in which the working materials are metal powders, limits the size of machine parts. Parts with dimensions exceeding the workspace dimensions can be created by combining smaller fragments. However, such a solution greatly complicates the design and needs further development of joining component part methods.

During the machine part manufacturing process, using 3D printing, the dimensional accuracy of parts may depend on the machine settings as well as the kind and size of geometric elements of this part. As shown in [14], errors occurring during the manufacturing of a part made of nylon, significantly exceeded the maximum amount of errors declared by the manufacturer of 3D printers in the technical documentation of the printer. In addition,

the distribution of these errors was random and unpredictable. In order to avoid the effect of errors on the correctness of the implementation of the manufactured machine part, dimensional inspection is needed thorough the manufacturing process and, if necessary, additional machining should be used.

5. Conclusions

On the basis of considerations referring to the selected problems in the application of computer-aided methods for the design and manufacturing of machine parts, the following conclusions can be made:

1. The combination of computer-aided methods of design with the performance of manufacturing technologies and the usage of unusual materials for the manufacturing of machine parts allow for quick manufacturing of a part at a significantly reduced cost and it is an important contribution to the development of mechanical engineering;

2. The use of computer-aided methods, however helpful it may be, is associated with the occurrence of difficulties and problems that do not exist in the traditional ways of designing and manufacturing machine parts. At the same time, these problems occur during the use of computer-aided methods for the design of specific machine part manufacturing;

3. Due to the diversity and unpredictability of the problems arising in the practical application of computer-aided methods for the machine part design and manufacturing, the use of computers does not relieve engineers from continuous monitoring of the design and the manufacturing process.

References

[1] Migus M., Olszak A., Kęsy A., Kęsy Z., *Wybrane problemy komputerowego modelowania i wytwarzania podzespołów hydrokinetycznych*, III Konferencja naukowo-techniczna „Obrabiarki sterowane numerycznie i programowanie operacji w technikach wytwarzania", Radom–Jedlnia Letnisko 2014.

[2] Miecielica M., *Techniki szybkiego prototypowania – Rapid Prototyping*, Przegląd Mechaniczny, zeszyt 2/2010, 39-45.

[3] Osowski K., Kęsy A., Kęsy Z., *Expert system for 3D printing technology*, 15th Annual International Conference Rapid Product Development Association of South Africa "Talent Driver Innovation", Stias, Stellenbosch 6–7 November, 2014, Proceedings.

[4] Ławniczak A., Milecki A., *Ciecze elektro- i magnetoreologiczne oraz ich zastosowania w technice*, Wydawnictwo Politechniki Poznańskiej, 1999.

[5] Kęsy Z., *Modelowanie i badanie elektroreologicznych i magnetoreologicznych cieczy roboczych*, Wydawnictwo Politechniki Radomskiej, 2009.

[6] Wilczyński K., *Reologia w przetwórstwie tworzyw sztucznych*, Wydawnictwo Naukowo-Techniczne, 2001.

[7] Kosma Z., *Podstawy mechaniki płynów*, Wydawnictwo Politechniki Radomskiej, 2005.

[8] Jang Y.J., Suh M.S., Yeo M.S., Choi S.B., *The Numerical Analysis on Channel Flows of ER Fluids*, 5th International Conference on Electro-rheological Fluids, Magneto-rheological Suspensions and Associated Technology, Sheffield, UK, 1995, 764-771.

[9] Gołdasz J., *Magnethoreological Shock absorbers. Automotive context*, Kraków 2012.

[10] Kęsy A., Migus M., *Komputerowe wspomaganie konstruowania kół łopatkowych podzespołów hydrokinetycznych*, Mechanik, 12/2011, na płycie CD, 987.

[11] Migus M., Kęsy A., *Modelowanie bryłowe kół łopatkowych podzespołów hydrokinetycznych*, Materiały Międzynarodowej Konferencji Naukowo-Technicznej „Napędy i Sterowania Hydrauliczne i Pneumatyczne", Wrocław 2012, 143-152.

[12] Kęsy A., Kotliński J., *Mechanical Properties of Parts Produced by Using Polymer Jetting Technology*, Archives of Civil and Mechanical Engineering, Vol. X, No. 3, 2010, 37-50.

[13] Kęsy A., Sarnik P., *Przekładnia hydrokinetyczna z kołami łopatkowymi wykonanymi metodą szybkiego prototypowania*, Napędy i Sterowanie, nr 2, 2010, 12-15.

[14] Kotliński J., Kęsy Z., Kęsy A., Jackson M., Parkin R., *Dimensional deviations of machine parts produced in Laser Sintering technology*, International Journal of Rapid Manufacturing, Vol. 1, No. 1, 2009, 88-98.