How to cite this article:
Authors: Grzegorz Żywica, Tomasz Z. Kaczmarczyk, Eugeniusz Ihnatowicz
Title of article: „ Zastosowanie nowoczesnych tworzyw sztucznych do budowy wysokoobrotowych maszyn przepływowych" ("The use of modern plastics for the construction of high speed fluid-flow machinery")
Mechanik, Vol. 91, No. 7 (2018): pages 508–510
DOI: https://doi.org/10.17814/mechanik.2018.7.67

The use of modern plastics for the construction of high speed fluid-flow machinery

Zastosowanie nowoczesnych tworzyw sztucznych do budowy wysokoobrotowych maszyn przepływowych

GRZEGORZ ŻYWICA *
TOMASZ Z. KACZMARCZYK
EUGENIUSZ IHNATOWICZ

Discussed are issues related to the selection of plastics for manufacturing chosen components of high-speed fluid-flow machinery. In addition to discussing the criteria used for material selection, an exemplary strength analysis of a rotor disc made of plastic was presented. The work carried out was aimed at replacing commonly used metallic alloys with modern plastics, which in turn may shorten production time and reduce costs.
KEYWORDS: mechanical engineering, plastics, heat-resistant polymers, fluid-flow machines, microturbines

The intensive development of science and technology has made it possible in the last decades to develop many new material solutions, exceeding the properties of previously used construction and functional materials. This is particularly evident in the case of artificial plastics, of which parts manufactured so far exclusively from metal alloys are increasingly made.

Whereas in previous years selected plastics were used for lightly loaded machine parts [1], recently they have been successfully used also for more responsible components [2, 3] and protective coatings working in difficult conditions [4]. This is evidenced by the wider use of plastics in the automotive and aerospace industries [5, 6].

Such materials allow to reduce the mass of vehicles and aircraft and facilitate the suppression of undesirable vibrations and noise [6]. In addition to bodywork, suspension and interior fittings, appropriately selected plastics are also used within the engine compartment [7].

Discussing new applications of plastics, it is worth mentioning the techniques of rapid prototyping [8] using 3D printers, which are largely based on different types of polymer materials.

The growing demand for plastics results from their many advantages, the most important of which are: lightness (low specific density), chemical resistance, ease of forming and dyeing, and low price. Modern plastics, which are very often composites containing various metallic and non-metallic additives [6], can achieve very good strength properties and work for a long time at elevated temperatures. These features enable their use in various types of energy microturbines, used more and more often in distributed cogeneration [9].

In the further part of the article, an example of the selection of plastic for selected parts of the steam microturbine is presented, which, through the ORC system (organic Rankine cycle), will cooperate with the boiler used in single-family houses for heating purposes [10]. Due to the relatively low temperature at which ORC microturbines usually work, the use of appropriately selected plastics for their construction can be a very good solution.

Determination of work parameters

When selecting materials for machine parts, it is necessary to precisely define the parameters in which they will work. In the discussed case, plastics will be used for the construction of a turbogenerator operating in the ORC system. Due to the high costs of manufacturing and the long processing time of the parts included in the microturbine blade system (i.e., the rotor disc and the vanes), the greatest benefits can be obtained from the production of these elements from plastic. A good solution may also be to produce some of the elements of the turbogenerator body.

In the turbogenerator designed by IMP PAN, the most demanding operating conditions occur in the case of a microturbine blade system. According to the working parameters of the ORC installation designed, the fresh vapour of a low-boiling medium is supplied to the turbine blades at a pressure of approx. 10 bar and has a temperature of approx. 150°C. The working medium of an ORC can be various organic substances, such as, for example, methanol, ethanol, SES36, HFE-7100, MDM and many others. Due to the range of operating temperatures and the target site of the installation (single-family houses), the operating mediums taken into account, in this case, included only new generation solvents, e.g. such as HFE-7100.

* Dr inż. Grzegorz Żywica (gzywica@imp.gda.pl), dr inż. Tomasz Z. Kaczmarczyk (tkaczmarczyk@imp.gda.pl), dr inż. Eugeniusz Ihnatowicz (gieihn@imp.gda.pl) – Instytut Maszyn Przepływowych Polskiej Akademii Nauk

Available heat-resistant plastics

Due to the targeted working conditions, the choice of possible plastics is limited to such materials that can be permanently used at a temperature of at least 150°C. The maximum temperature of long-term use of the majority of high-temperature plastics is approx. 120°C. At higher temperatures, they can only be operated for a short period of time.

The table lists a few selected plastics readily available on the market, for which the long-term use temperature is at least 150°C.

TABLE. Listing of selected high-temperature plastics

Symbol	Name	Temperature of use °C	Temporary temperature °C
PTFE	Teflon	260	290
PEEK	Polyetherketone	250	310
PVDF	Vinylidene polyfluoride	150	150
PPS	Polysulfide of phenylene	240	270
PFA	Perfluoroalkoxy polymer	150	240
PSU	Polysulfone	150	180

According to the list, some materials can be used for a long time at temperatures exceeding even 200°C (PTFE, PEEK, PPS). Above this temperature, temporary work of elements made of PFA material is also permissible.

Criteria for material selection

In addition to resistance to high temperatures, materials used on machine parts must meet a number of other requirements that depend on performance. In the case of materials used for microturbine rotor discs, strength and thermal expansion properties are also of great importance.

Thermal expansion is important in this case due to the need for the turbine blades to retain complex shapes and dimensional tolerances as well as the required very small clearance over the blades. The obvious requirement is also the chemical resistance to the working of working media. The material used to make the blade system should also have good technological properties. The most important criteria that have been taken into account when choosing plastic for the rotor disc are:

- thermal resistance,
- chemical compatibility,
- strength properties,
- thermal expansion,
- technological properties (e.g. good machinability),
- resistance to flow erosion,
- lightness (low specific density),
- price and material availability.

Three plastics were selected on the basis of such criteria, which were subjected to further analysis. The own chemical resistance tests were carried out for the selected materials and the tensile strength was checked after long-term contact with working mediums.

Strength verification analysis

The next stage of material selection for the ORC micro rotor disc was to carry out strength analysis. The purpose of these analysis was first of all to check the maximum stresses and deformations of the disc and the displacement of the blade ends. Strength analysis was performed only for materials that met all the previously discussed criteria and have passed the independent tests of chemical resistance to low-boiling mediums.

The geometry of the rotor was developed by means of a parametric CAD program. The model takes into account the three-dimensional geometry of the turbine blades, which has been optimized using the CFD method for maximum flow efficiency.

The diameter of the disc was Ø36 mm and the height of the blade was equal to 3 mm. The nominal rotational speed of the turbogenerator rotor was 100,000 rpm. On one side of the disc, a neck was made, and a port was located in the axis of the disc (Fig. 1).

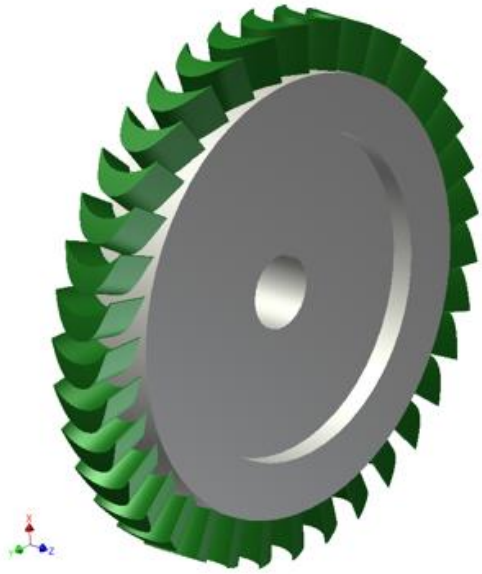

Fig. 1. Three-dimensional geometry of the microturbine rotor disc

Due to the initial character of calculations, tetrahedral finite elements were used to build a FEM model. The FEM model of the rotor disc consisted of a total of 686,000 finite elements. The disc was fixed in the central hole, the displacements in the direction of the radiation were limited on the cylindrical surface, and displacements in the axial direction were blocked on one edge of the hole on the smooth side of the disc. During the calculations, the centrifugal force acting on the rotor disc at nominal speed was taken into account.

The results of strength calculations in the form of reduced stress distributions and the distribution of displacements are presented in Fig. 2 and Fig. 3.

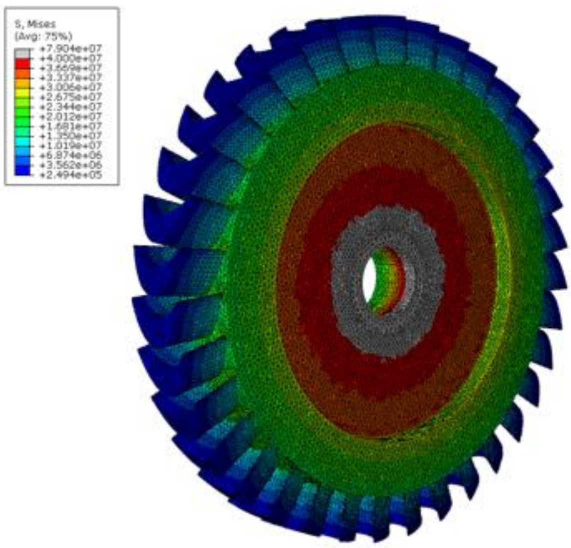

Fig. 2. Stresses in the rotor disc at nominal speed

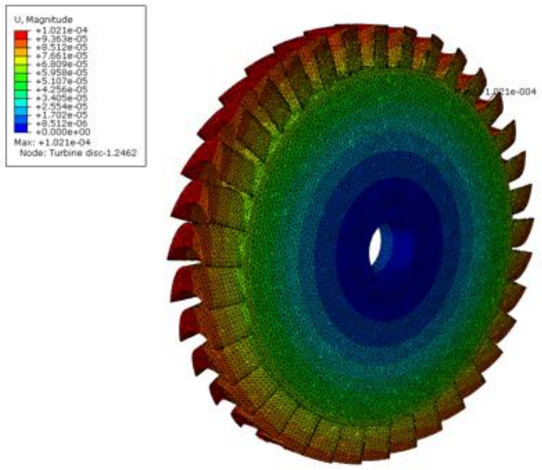

Fig. 3. Displacements in the rotor disc at nominal speed

The results of simulation calculations have shown that in certain areas of the rotor disc the permissible stresses were exceeded, which for the analysed material were determined at 40 MPa. This area is marked in grey in Fig. 2.

Exceeding the permissible stresses occurred only on one side of the disc on which the neck was made. In the other parts of the rotor disc, the obtained reduced stresses did not exceed the permissible stresses. It can therefore be assumed that after liquidation of the shield undercutting and a better, more precise mapping of restraint, the maximum stresses in any place should not exceed the admissible values. This was confirmed by subsequent calculations.

Referring to the displacement distributions obtained (Fig. 3), it can be concluded that, as expected, the maximum values were obtained at the tip of the blades. They reached 102 µm, but in the pro-radiation direction they were only 56 µm. Higher displacement of the blade end in the axial direction occurred due to the asymmetry of the disc caused by one-sided recessing. This was another argument in favour of resigning from the neck in the final version of the rotor disc.

The estimated displacement value of the tip of the blade caused by the thermal expansion of the plastic itself, in the worst case, should not exceed 60 µm. This means that the total displacement of the blade tip in the radial direction during operation of the turbogenerator should not exceed 120 µm. Considering the typical clearances over the blades in axial-flow impulse turbines, it can be stated that they are acceptable values.

The strength calculations performed at a later stage of designing took into account the changed geometry of the rotor disc (including the one-sided undercut) and the flow and thermal pressure of the rotor disc obtained as results of flow calculations using CFD software.

The results of these calculations showed that both stresses and displacements in the rotor disc were smaller than the preliminary analysis showed. The maximum reduced stresses do not exceed 20 MPa at maximum radial displacements of the tip of the blade at the level of 80 µm. This confirmed the applicability of the selected plastic.

In addition to the analysis of strength properties, the dynamic properties of the rotor disc made of plastic were also checked using the finite element method. This analysis showed that, despite the use of a material with inferior strength properties, the disc was characterized by very high stiffness.

The first eigenfrequency of the whole disc was greater than 3000 Hz, and vibrations of individual blades appeared only at a frequency close to 25,000 Hz. It can be concluded that in the analysed system there is a very small probability of excitation of the natural vibration of the rotor disc and its blades during the work of the turbogenerator.

Conclusions

The use of modern plastics for the production of flow machine components is discussed. This problem was presented on the example of a high-speed ORC turbogenerator. The possibility of using plastics was considered in relation to the rotor disc as one of the most labour-intensive and costly elements.

The work parameters of the rotor disc, examples of high-temperature plastics and selected criteria for the choice of plastic are presented. In the case of a rotor disc, the most important criteria were: thermal and chemical resistance as well as durability properties. The low thermal expansion and material density were also important.

An example of a strength analysis of a plastic rotor disc is presented. Based on the obtained results, it was found that after adjusting the design of the rotor disc, properly selected plastic will be able to replace traditional construction materials.

The article contains the results of works co-financed by PARP within the project No. POIR.02.03.02-22-0009/15, implemented by SARK from Gdynia in cooperation with IMP PAN in Gdańsk.

REFERENCES

1. Matusiak-Szaraniec A. „Analiza konstrukcyjna i technologiczna korpusów maszyn i urządzeń technicznych". *Archiwum Technologii Maszyn i Automatyzacji*. 27, 2 (2007): pp. 121–129.
2. Mao K., Langlois P., Hu Z., et al. "The wear and thermal mechanical contact behaviour of machine cut polymer gears". *Wear*. 332–333 (2015): pp. 822–826.
3. Krawczyk J., Stryczek J. „Układ hydrauliczny z elementami wykonanymi z tworzyw sztucznych". *Górnictwo Odkrywkowe*. LIV, 3–4 (2013): pp. 52–57.
4. Żywica G., Bagiński P., Banaszek S. "Experimental studies on foil bearing with a sliding coating made of synthetic material". *Journal of Tribology*. 138 (2016): pp. 011301.
5. Głowacz J., Kaczmar J.W., Nakonieczny L. „Zastosowanie kompozytów polimerowych i tworzyw sztucznych w przemyśle samochodowym". *Mechanik*. 78, 7 (2005): pp. 609–612.
6. Mayer P., Pach J. „Zastosowanie nowoczesnych kompozytów polimerowych z włóknami węglowymi i szklanymi w motoryzacji". *Przegląd Mechaniczny*. 9 (2010): pp. 30–34.
7. Bielefeldt K., Walkowiak J., Papacz W. „Wzmocnione tworzywa sztuczne w motoryzacji". *Zeszyty Naukowe Instytutu Pojazdów*. 1, 97 (2014): pp. 71–80.
8. Andrearczyk A., Żywica G. „Techniki szybkiego prototypowania w budowie maszyn". *Mechanik*. 89, 7 (2015, CD): pp. 13–20.
9. Kiciński J., Żywica G. "*Steam microturbines in distributed cogeneration*". Springer International Publishing, 2014.
10. Klonowicz P., Witanowski Ł., Jędrzejewski Ł. "A turbine based domestic micro ORC system". *Energy Procedia*. 129 (2017): pp. 923–930.

Translation of scientific articles, their computer composition and publishing them on the website www.mechanik.media.pl by original articles in Polish is a task financed from the funds of the Ministry of Science and Higher Education designated for dissemination of science.

Ministry of Science and Higher Education
Republic of Poland