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Research Article

Regarding the Issue of Application of Advanced Polymeric Materials while Designing Low-Powered Turbo-Machines

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ABSTRACT.
The immediacy of the problem under study is due to the fact that the process solutions used in the design of turbo-machines of centralized energetics are not optimal for turbo-machines of distributed power generation. The purpose of the article is to show the possibility of applying new process solutions in the design of low-powered turbo-machines used in distributed power engineering. The development of turbo-machine design with the use of a polymeric material and carrying-out of a series of sample physical and mechanical tests enabling to confirm the design parameters of turbo-machine parts being designed is the leading method for studying this problem. The result is that polyamide (PA-12) properties produced by means of selective laser sintering SLS method were obtained, and recommendations for the application possibility of these process solutions were given. The article materials can be useful for engineers and designers while designing low-powered turbo-machines with the use of polymeric materials.

Keywords. Distributed energy production, design of turbo-machines, polyamide, physical and mechanical tests, selective laser sintering (SLS).

INTRODUCTION

Low-powered turbo-machines are set apart into special class in distributed power generation because of significant influence of the engine size on the output power, the identification of parameters and engine design, which determine the economic efficiency to a large extent. To achieve this goal, it is necessary to use alternative process solutions [3]. In the world, research groups explore various application methods of alternative process solutions and materials, and works on the application of powder metals and ceramics are the most widely used in terms of machine engineering. [15,16]

The use of polyamides is one of the alternatives. In Russia, a lot of research teams are engaged in the application issues of polyamides, since polyamides (PA) are one of the commonest polymer classes produced by Russian industry, and are known as the trademarks ‘capron’, ‘caprolon’, ‘nylon’, etc. The demand for polyamide based materials on is on the rise in the world production and consumption of construction materials. They successfully compete with metals and glasses in some scopes of application by such characteristics as strength, corrosive resistance, and lightness [9, 10]

The issues of physical testing are described in sufficient detail in the works of Russian and foreign authors. [12,13,14] However, under circumstances where there are many equipment and material manufacturers at the market, additional physical and mechanical studies regarding specific brands of equipment and material should be conducted during design of turbo-machines, considering the features of the parts being designed.

MATERIAL AND METHODS

Subject of research - an experimental sample of a turbo-expander with electrical power of 1 kW (Fig. 1). The turbine and generator form an integral part of the model. The turbine is single-stage one with a rated power of 1.2 kW at a speed of 3,000 rpm. The turbine consists of an inlet branch pipe, a turbine part itself and an outlet branch pipe. There is an adjustment device with the inlet side connected to the gas supply pipeline at the input of the inlet branch pipe. Outwardly, the inlet branch consists of a Flange, a reducing sleeve and a Flange, via which it is connected to the main body. Internally, the inlet branch is a part of a turbine wheelspace. Externally, the main body represents two flanges connected by means of a shell ring. There are support stands at the bottom on the shell ring from the outside. The immovabilitytowards foundation frame is provided by means of the abovementioned.

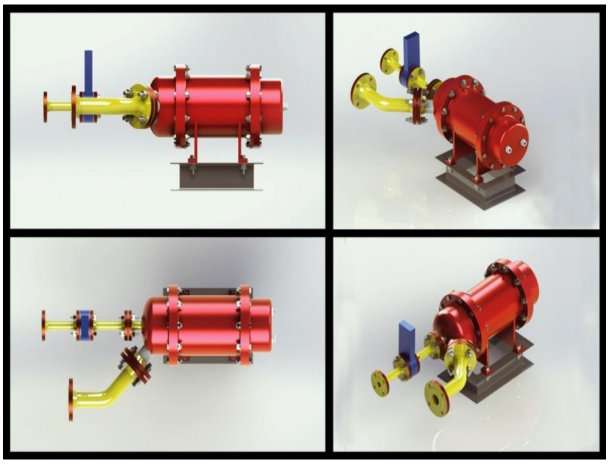

Fig. 1 – Turbo-expander 1 kW experimental sample.

The turbine main part and the generator stator are placed in the main body. The rotor is common. The impeller is located on the shaft in cantilever fashion. The bearings are on both sides of the generator stator. The thrust and radial bearing is located between the impeller and the generator rotor. The impeller and generator rotor minimum axial movement is ensured by this, which provides a minimum change in the axial clearances between the turbine wheel and the turbine stator parts when changing pressure (axial force) and temperature (due to working fluid cooling). The gas burnt within the turbine washes the generator stator cooler and passes through the flanged hole in the inlet branch into the gas pipeline leading to gas consumers. There are junction boxes with terminals to which the generator stator low voltage wires and power cables are connected on the side of the supporting bearing inside the main body. The cover with pressure-tight pass-through bars is attached to the main body via the flange connection. The axial stage longitudinal cross section with axisymmetric nozzles is shown in Fig. 2.

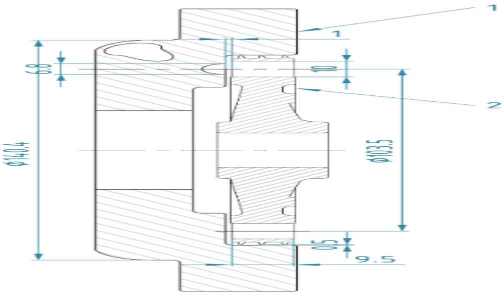

Fig. 2 – Axial stage with axisymmetric nozzles: 1 – nozzle diaphragm; 2 – impeller

Only two parts of the turboexpander, specifically nozzle diaphragm and impeller are planned to be manufactured in an alternative method, using selective laser sintering from polyamide.

Methods of theoretical calculations

To obtain design characteristics of the nozzle diaphragm and impeller being designed, the FEM finite element method implemented in the ANSYS WB program, was chosen. The strength calculation was performed at a rotational speed of 2,093 rad/s (20,000 rpm). To reduce the counting time, calculations were carried out for a segment in 1/12 part of the disk with setting a special boundary condition on the section planes – 'sliding without friction over the surface.'[1]. When performing calculations, certain

[1] Sukhanov A.I. Report Materials regarding the second stage of the Federal Targeted Program 'Research and development by the priority development trends of the Russian science and technology sector for the years 2014-2020' on the subject 'Development and creation of turbo-generator sets with electrical power of 1 and 30 kW

properties of the proposed material were laid down; these data was taken from technical documentation received from polyamide producers (See Table 1).

Table 1 − Materials characterization

Basic data	**Value**
Average size of granules, ISO 13320-11	56 μ m
Volume density, EN ISO 60	0.45 g/cm^3
Completed part density, EOS method	0.93 g/cm^3
Mechanical properties of parts	
Tensile modulus, EN ISO 527	1,700 MPa
Ultimate tensile strength, EN ISO 527	48 MPa
Percent elongation at failure, EN ISO 527	24 %
Flexural modulus, EN ISO 178	1,500 MPa
Ultimate bending strength, EN ISO 178	58 MPa
Charpy impact strength, EN ISO 179	53 kJ/m^2
V-notch Charpy value, EN ISO 179	4.8±0.3 kJ/m^2
Izod impact strength, EN ISO 180	32.8±3.4 kJ/m^2
Notched Izod impact strength, EN ISO 180	4.4±0.4 kJ/m^2
Brinell hardness number (ball), EN ISO 2039	78 N/mm^2
Shore hardness D, DIN 53505	75
Thermal properties of parts	
Melting point, EN ISO 11357-1	172…180°C
Vicat softening temperature B/50, EN ISO 306	163°C
Vicat softening temperature A/50, EN ISO 306	181°C

Methods of experimental research

Physical and mechanical tests for compression, bending and tensile strength have been conducted in accordance with GOST 14359-69 Plastics. Methods of mechanical tests.General Requirements (as amended No.1). SHIMADZU equipment, the universal tensile-testing machine of AG-X plus series with an accuracy of 0.5%, was used for test performance. This equipment isnoted for simplicity and reliability; the performance characteristics meet the requirements of research being performed. [1,2]

All samples have been fabricated in accordance with GOST 12019. PA12 material.Basic characteristics of printing. The printing layer thickness is 0.1mm. The equipment declared accuracy is 0.1...0.2 mm per 100 mm, depending on the part geometry. The printer chamber size is 200 × 250 × 330 mm. The minimum wall thickness is 0.5mm. Bone-white color.Mat, rough surface.

Hardness tests were carried out in accordance with GOST 4670-70 according to the Brinell method with measurement of the depth of indentation into a ball sample made of hardened steel with the diameter of 5 mm. [1,2]

RESULTS

Theoretical results

The results of calculating the segment in equivalent stresses and deformations in the von Mesis are shown in the figure.

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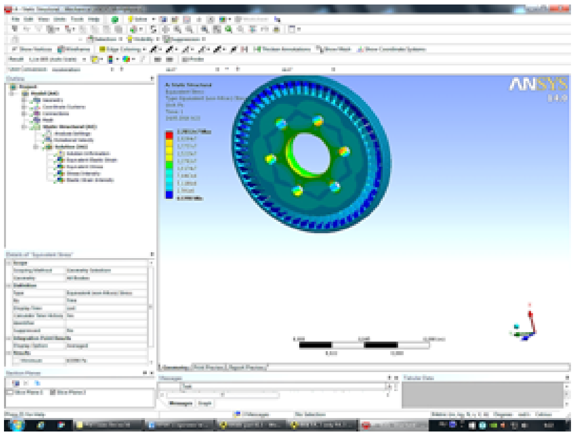
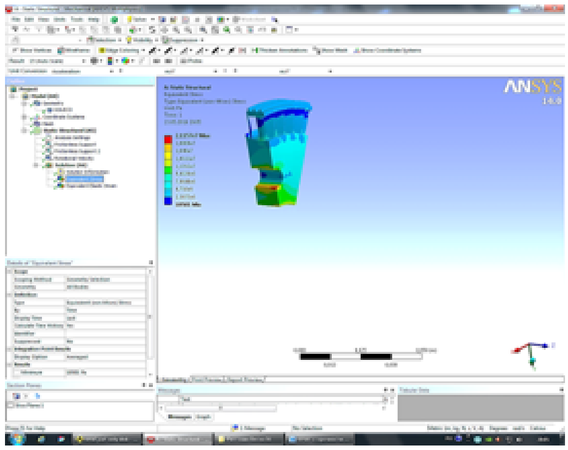
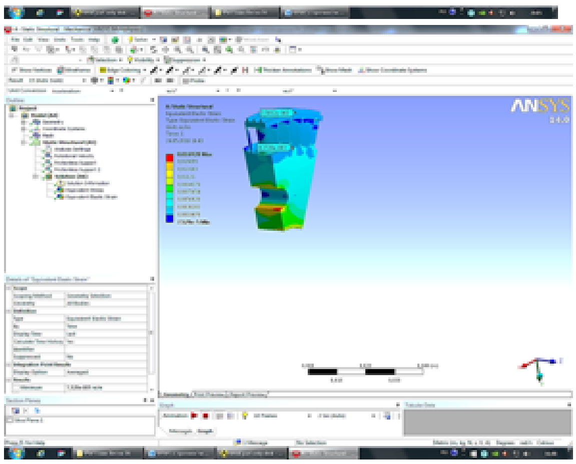


Fig. 3 – Plastic disc stress state at a rotational speed of 20,000 rpm (view of the blade trailing edges)



a)



b)

Fig. 4 – Stress (a) and strain (b) state of the plastic disc segment (view of the blade trailing edges)

The central plastic disc is the most stressed element of the composite impeller. A single plastic impeller (without side steel discs) can maintain the speed of 20,000 rpm with a margin of 1.8 by maximum stresses.[2].

Experimental results

Compression tests results of 4 samples are shown in Fig. 6.

[2] Sukhanov A.I. Report Materials regarding the second stage of the Federal Targeted Program 'Research and development by the priority development trends of the Russian science and technology sector for the years 2014-2020' on the subject 'Development and creation of turbo-generator sets with electrical power of 1 and 30 kW using compressed natural gas energy of the Russian gas pipeline system' Grant Agreement as of October 27, 2015. No.14.578.21.0127

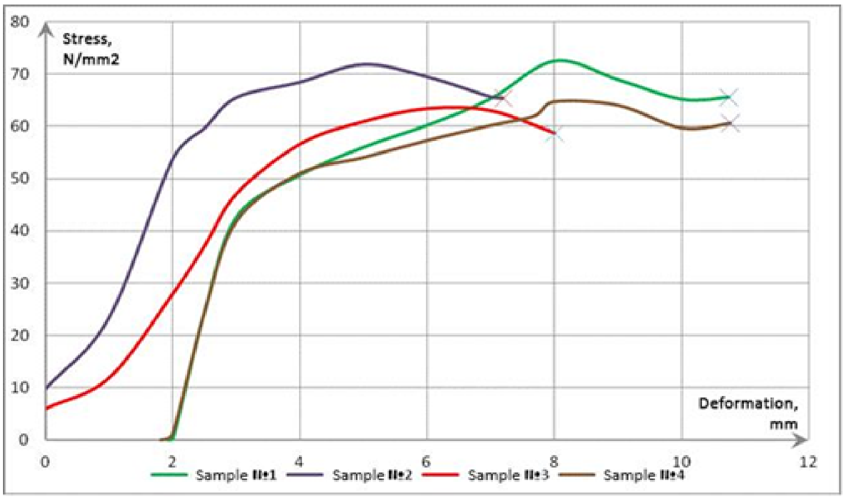


Fig. 5 – Compression test results, symbol □ - moment of sample complete destruction.

Table 2 – Results of compression tests.

S. No.	σ_{comp}, MPa	Sample dimensions, mm
Sample No.1	65.52	11x15 mm
Sample No.2	65.39	
Sample No.3	58.62	
Sample No.4	6065	
Average value	62.54	-

Although, externally the sample in compression is under uniaxial loading, however, the resulting stressed state has a complex nature of a simultaneous manifestation of not only compressive deformation, but also of shearing and even tensile deformation. The compressive strength prior to the appearance of visible deformations and microcracks is more than 50 MPa. Due to fundamental features of tests, the deformation of compressible samples is geometrically limited. In this regard, the processes of recrystallization or forced high-elasticity have no time to become apparent [1,2]

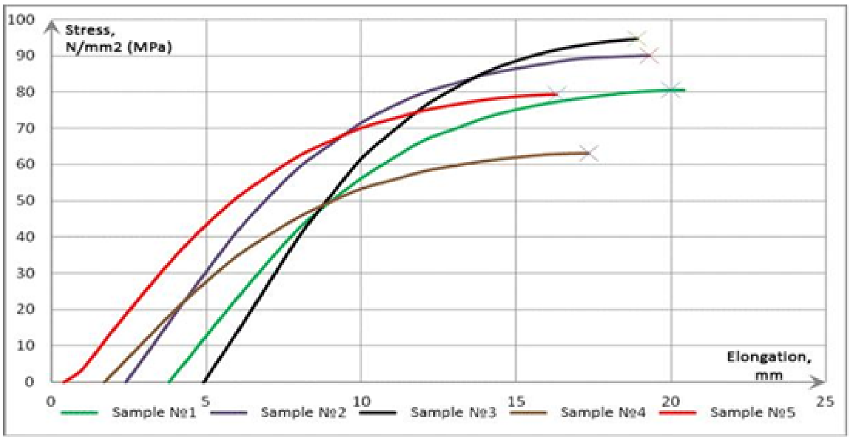


Fig. 6 – Bending test results, symbol □- moment of sample complete destruction.

Table 3 – Bending test results.

S. No.	σ_{bend}, MPa	Sample dimensions, mm
Sample No.1	80.61	9.8x2.8 mm Operating length 108 mm
Sample No.2	90	
Sample No.3	94.76	
Sample No.4	63.15	
Sample No.5	79.34	
Average value	81.572	-

Deformations are elastic ones, there is a deviation from straightness, and the bending breaking stress differs fundamentally from the compressive strength and tensile strength values.

Hardness tests results are presented in Table 4

Table 4 – Brinell hardness values (HB)

S. No.	H_B, MPa	Penetration depth, mm
Sample No.1	31.44	0.29
Sample No.2	33.77	0.27
Sample No.3	33.77	0.27
Sample No.4	35.07	0.26
Sample No.5	33.77	0.27
Average value	33.56	0.272

Due to the peculiarity of sample fabrication technique, some difficulties have arisen in determining the indentation depth during testing, since the surface roughness is sufficiently high, which is the reason for the contact zone uncertainty at a small depth of indentation. The contact zone uncertainty decreases with a deeper indentation, at most, the indentation depth uncertainty is proportional to the arithmetical mean value of the surface profile irregularity. [1,2]

Tensile strength test results of 5 samples are shown in the Fig. 7.

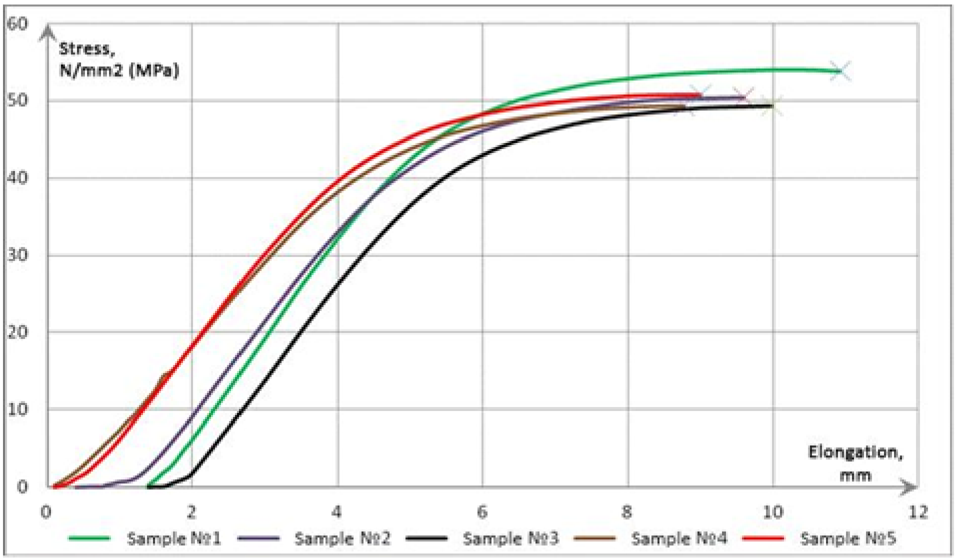


Fig. 7 – Tensile strength test results, symbol □- moment of sample complete destruction(b point).

Table 5 – Results of tensile strength tests.

S. No.	σ_{tens}, MPa	Sample dimensions, mm
Sample No.1	53.84	10x14.8 mm
Sample No.2	50.4	
Sample No.3	49.35	
Sample No.4	49.34	
Sample No.5	50.78	
Average value	50.742	-

Deformations are elastic ones, there is a deviation from straightness, which is indicative of a plastic component appearance, which contribution increases as it approaches the ‘b’ point. [1,2]

DISCUSSIONS

In order to construct a competitive low-powered turbo-machine it is possible to apply an affordable technological solution, i.e. to manufacture a part of the turbo-expander parts using 3D printing method. 3D printing method is in stark contrast to traditional methods of part fabrication by means of material removal (lathe turning, milling) or changing the workpiece shape (forging, milling), which makes it possible to speak of possible economic effectiveness. SLS technique is best suited for single-piece production of complicated parts, as well as carrying out of various tests for operational performance of a product prototype.

The advantages of polyamide printing technology:

- Short production time
- High accuracy of construction
- Very high thermal properties of obtained prototypes (melting point 172...180°C)

- Satisfactory strength characteristics
- Thin-walled prototypes printing possibility (from 0.5mm).

CONCLUSION

The conclusion regarding conventional possibility of application of PA12 produced by the SLS method for the manufacture of the turbo-expander plant parts being designed has been drawn as a result of the conducted tests. There is a need to conduct additional tests in order to make a final decision with due regard to the experience gained in carrying out the above described tests. It is also necessary to make an assessment of the proposed technique economic effectiveness.

RECOMMENDATIONS

The article materials can be useful for engineers and designers while designing low-powered turbo-machines with the use of polymeric materials.

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