TRANSACTIONS OF THE INSTITUTE OF FLUID-FLOW MACHINERY

No. 133, 2016, 3–11

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A concept of a test stand for the investigation of a 3D printed turbochargers and selected fluid-flow machinery

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Abstract

The paper describes the general concept of using the rapid prototyping methods and their application to manufacturing of selected components of rotating machinery. Chosen rapid prototyping technology (multijet printing) allows precise manufacture of rotor models with complex geometry, without the need for their further processing. The research is planned to be performed on designed test rig, which is described in the paper. 3D printed elements will be pretested using air from a high performance compressor. Basic preliminary testing and own experience has shown that this technology is faster, cheaper and more accurate than conventional manufacturing. This fact can significantly contribute to the development of production and research of prototypical fluid-flow machines. The tensile strength testing of the two materials which are used in a 3D printer in different printing directions has been also discussed.

Keywords: Rapid prototyping; Polymeric resin; Fluid-flow machines

1 Introduction

Rapid prototyping technologies are currently undergoing dynamic development. These technologies have a wide spectrum of application which ranges from forming the enclosure for a device (also as a decorative element) and replacing worn

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or damaged machine components, to structural testing of upper and lower limb prostheses [1–3]. Nowadays rapid prototyping is the most commonly used in biomedicine and dentistry [4,5]. Rapid prototyping is also used to manufacture parts of aircraft engines by the GE Aviation. The Department of Turbine Dynamics and Diagnostics at the Institute of Fluid-Flow Machinery of the Polsh Academy of Sciences (IFFM PAS) is fully engaged in the research and development works concerning the prototypical fluid-flow machinery, including sophisticated microturbines. After preliminary analysis of manufacturing costs and duration of prototypical turbines by means of conventional methods, it was decided to employ a 3D print technology called MJP (multijet printing), which was not previously used for production of microturbine components. This is an inkjet 3D printing process used in the case of printouts that require highly precise production and complicated shapes as well as serial production. The multijet printing is one of the top ranked technologies for this type of production. During the printing process, either photocurable plastic resin or casting wax material (supporting material) is deposited layer by layer. Printing materials are available in different varieties, each one being defined by its specific physical and chemical characteristics. The choice of this technology arises from a need to provide high repeatability of details for printed elements. The ProJet 3500 HDMax printer – which uses multijet printing technology – was employed as a tool to manufacture the components to be examined. It can works in four modes: high definition (HD), high speed (HS), ultra high definition (UHD) and extreme high definition (XHD). In each mode the print speed and are very accuracy different. The differences between the four operating modes can be summarized as follows:

- HD – single layer thickness 32 μm, printing speed 3 mm/h;
- HS – single layer thickness 32 μm, printing speed 4 mm/h;
- UHD – single layer thickness 29 μm, printing speed 2 mm/h;
- XHD – single layer thickness 16 μm, printing speed 1.5 mm/h.

Each operating mode allows to fully utilize the workspace with the dimensions of 298 mm × 185 mm × 203 mm, which provides printing of machine components that are slightly larger than microturbines' components. Cartridges installed in the printer contain approximately 2 kg of polymeric resin (building material) or 2 kg of the supporting material. The printing device described is the basic piece of equipment of the Rapid Prototyping Laboratory at the IFFM PAS (shown in Fig. 1.) The major advantage of printing machine components using the MJP technology is the excellent precision of representation of complex surfaces and edges. In the case of XHD mode, the printhead deposits printing material layer by layer (with layer thicknesses as low as 16 μm), until the finished product is

Figure 1: The printer that uses MJP technology, which is situated in a laboratory at the Szewalski Institute of Fluid-Flow Machinery PAS [8].

built. Thanks to the positioning of material depositing nozzles over the entire printhead width and the use of a supporting material (wax), this 3D printing machine is able to cope with elements of any geometry, even the most complicated one. Ultraviolet-curable liquid photopolymer (plastic resin) is used as a building material. This material and its UV-curing method are currently tested for adhesion strength and rheology [6,7]. One of the two available kinds of this material has been tested to estimate its tensile strength in two directions [8]. Depending on the printout direction the tensile strength was 47 MPa and 41 MPa. The specification annexed to the material states that the maximum operating temperature is 56 °C. It is supposed that the tensile strength of the second stronger kind of the photopolymer will be around 65 MPa, where its maximum operating temperature is 88 °C according to the technical specification [9]. The above information on the building materials provides assurance that the elements printed by means of the rapid prototyping will be able to perform their function during research on prototypical turbines.

2 Research concept

The experimental research on elements manufactured by the multijet printing technology has been undertaken as part of the work on the development of rapid prototyping techniques and the verification of a selected technology. During the first step, the correct performing of the elements created by means of the adopted printing technology will be tested. If the preliminary tests will pass successfully, the prototypes made of the photopolymer will be tested under increasingly more demanding operating conditions. The subject of this research will be an automotive turbocharger made by Renault. The turbocharger shown in Fig. 2a has been dismantled, and all individual structural components were measured. Based on this technical specifications of a three-dimensional turbocharger model was created, using the Autodesk Inventor Professional 2015 software, presented in Fig. 2b.

(a) (b)

Figure 2: Turbocharger used in the studies: (a) – photograph , (b) – 3D model.

The first step of further research will be to determine the basic operating parameters of the original turbocharger. Then the two main turbocharger components, namely the compressor wheel and the turbine wheel, will be printed using the MJP technology. Both wheels will be fixed on a steel shaft, which will be mounted inside the turbocharger body. The 3D models of these components were obtained by means of a structure sensor 3D scanner and a 3D laser scanner. Figure 3 shows a three-dimensional model of the turbocharger's turbine wheel.

Figure 3: Turbine wheel which is a component of the tested turbocharger.

The research will be performed to demonstrate whether the elements created by means of the rapid prototyping techniques can be used with similar effect on the target machine (i.e., the basic operating parameters of the turbocharger have similar values to those obtained during the operation with original parts). The main emphasis will be placed on the verification of flow characteristics and overall performance of the machine containing components made of a plastic material. The dynamic performance tests of the two rotating systems created using different methods will be also carried out. Ultimately, rapid prototyping processes are to be applied during the first testing phase of new constructional solutions for fluid-flow machinery such as microturbines, positive displacement expanders or compressors. The ability to manufacture elements with complex shapes (e.g., turbine wheels equipped with vanes of varying cross-sections) in a fast and cost-efficient manner allows to significantly speed up some of the time-consuming processes such as construction optimization and numerical model verification. Manufacturing of the most complex turbomachines' components by means of 3D printers situated at in-house laboratories allows production of small elements to be carried out independently of specialized external providers (i.e., companies that offer machining services), moreover, the time needed for researching designing, and building is considerably reduced, thus enabling quick implementations. The photograph of a 3D printing device that will be used for production of machine components required for the experimental research described above is shown in Fig. 1.

3 Test rig

The test rig has been designed to conduct research on the turbocharger. Its schematic diagram is shown in Fig. 4. The test rig's frame is drafted in such a way as to enable simple and trouble-free disassembling of the turbocharger (e.g., when replacing its rotor or the complete device).

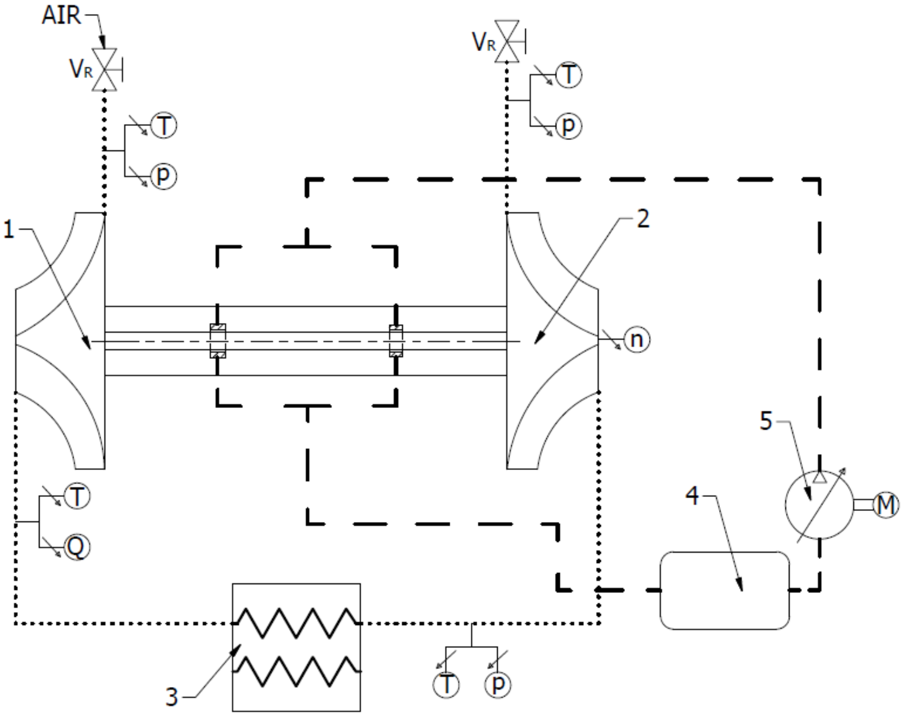

Figure 4: Schematic diagram of the test rig for research and development of turbines: 1 – turbocharger, 2 – compressor, 3 – buffer tank, 4 – oil tank, 5 – oil pump, V – throttling valve.

As one can see in Fig. 1, the turbocharger is supplied with compressed air. For this a compressor with a maximum working pressure of 1 MPa was used. A buffer tank acting as a heat exchanger allows to reduce the air temperature directly before the compressor inlet. Forced air circulation takes place along the circuit denoted by a dotted line. A pump circulates oil in a closed circuit. The oil in the storage tank before the pump provides correct lubrication of the turbocharger's bearings, in order to prevent damage to the machine due to dry-running bearings. The turbocharger has an oil outlet, adjacent to the bearing supply system, which allows maintaining continuity of lubrication. The oil circulation is indicated by a broken line in the schematic diagram shown in Fig. 4. An indicative arrangement of the measuring sensors is also illustrated in this figure. All elements of the test rig are installed on a rigid steel baseplate equipped in rubber feet. The turbocharger will be mounted on slide rails allowing to locate it in any position, and in the future to change a research facility.

To be able to determine the operating characteristics of turbocharger the measurement system will comprise 9 measuring points to automatically measure selected parameters such as temperature, pressure, rotational speed and air flow rate in the circulation of the installation. In the later stages of the research, the vibrodiagnostics of the running machine will be performed using acceleration sensors installed at the measuring points. This is to investigate the proper operation of the machine. The presence of a flow regulating valve (the throttling valve) installed at the turbine outlet allows varying the rotational speed. Temperature and pressure measurements will be implemented by K-type thermocouples and pressure transducers (providing absolute pressure range from 0 to 1.6 MPa), respectively. The air flow rate at the turbocharger outlet will be measured by means of a Coriolis flow meter. Each measuring point is connected to a data acquisition module (National Instrument model NI-6210). The swchematic diagram of the measuring system is shown in Fig. 5.

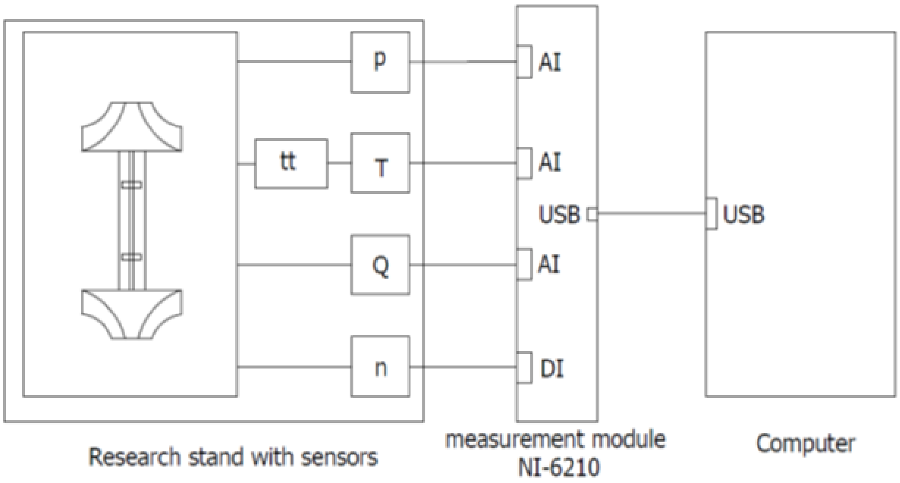

Figure 5: Schematic diagram of the measuring system for the test rig used for testing turbines.

As indicated in the schematic diagram, the sensors installed on the test rig are connected to the measurement module. Thermocouple signals processed by programmable temperature transducers (TMD-20 model, manufactured by Czaki

Thermo-Product) – denoted by the symbol ‘tt’ – are being sent to analogue inputs (AI) of the measurement module. The pressure transducers and flow meter output current signals, so it is necessary to connect them to the measurement module by means of the resistor that has a resistance of 240 Ω. The rotational speed sensor is connected to the impulse counter, which is one of the digital inputs (DI) available on NI-6210 measurement module. The measurement module is connected to a laptop via the USB cable. It is planned to create a computer application for integrating the entire measurement process, i.e., acquisition of data from the sensors, their processing and storing as well as remote monitoring of the selected operating parameters of the turbine (online access).

The test rig is versatile enough to enable running tests on other fluid-flow machinery with similar dimensions and power capacities, such as vapour microturbines or scroll expanders intended for operation in ORC (organic Rankine cycle) systems. An additional strong point of this test rig is also the possibility of integrating it with other test rigs used in the Department of Turbine Dynamics and Diagnostics (e.g., test rigs for carrying out research on ORC cycles, heat exchangers and pumps).

4 Summary and conclusions

The paper presents the concept of research aiming to develop prototypical fluid-flow machinery incorporating parts manufactured by means of rapid prototyping techniques. The test rig equipped with a measurement system has been designed and built. The turbocharger has been prepared for experimental tests and is ready for replacement of its elements with 3D printed elements. In recent years, the 3D printing technology described has contributed significantly to the development of many fields of science. Following the research carried out on the building materials and also on the elements printed using this technology it can be presumed that the results of the planned studies will facilitate and speed up the entire development and production process of prototypical machinery, particularly in the light of high accuracy of printouts and their good tensile strength. The manufacturing of elements needed for particular tests has permitted an accurate study of the multijet printing technology and its inbuilt benefits and drawbacks. An additional asset of this technology is quick printing of small elements of any shape which can be used as interchangeable parts in various machines (e.g., in microturbines).

Received in July 2016

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