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Development of a Turbine Prototype for the Use of the Compressed Gas Energy at the Oil and Gas Fields

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Abstract

Background: The relevance of the study is determined by the search for new1 ways to generate energy without burning hydrocarbons. The article is aimed at revealing opportunities for additional energy during gas expansion. **Method:** The main methods for studying this problem are the analytical and experimental methods that allow considering comprehensively the issues of compressed gas energy conversion into thermal energy. Experimental turbine prototypes with loop blades are used for the bench studies. Uniqueness of the problem under consideration lies in the fact that the gas flow penetrating into the inner cavity of the turbine impeller repeatedly interacts with the impeller blades. **Findings:** The article presents a developed and patented turbine design, demonstration micro-models with electro-mechanical transmission options, discloses the possibilities of the turbine impeller weight reduction, identified new opportunities to address the issue of the rotor balancing, and confirmed experimentally the performance of the created turbine. It also describes the trends in research and development related to the use of loop blades. **Improvements:** The research results are of practical interest for the development of energy-saving technologies in oil and gas production, especially in the offshore fields and can be used for solving power engineering and robotics tasks.

Keywords: Energy Conversion, Gas, Generator, Loop Blade, Oil, Turbine

1. Introduction

Obtaining energy without burning hydrocarbon fuel is one of the most relevant tasks. In the process of oil and gas production, the additional energy can be obtained by means of the compressed gas energy. This additional energy without combustion of gas is converted into heat or electrical energy for the use in the process systems. However, these research activities are still very poorly developed, because of the lack of cheap and reliable turbine equipment. In this regard, the works on the creation of reliable and simple turbines to convert gas flow energy into the other types of energy are quite relevant.

The development of a turbine prototype for the use of the compressed gas energy is an essential part of the conducted research and development work[1-4] as part of the heat generator creation. The turbine provides the conversion of the compressed gas energy into the mechanical energy. Next, in the processing chain, the mechanical energy is converted into hydraulic energy in the pump, which pumps the coolant. The micro models of the new turbine are created to verify the performance of the future machine. The principles and processes of conversion of the compressed gas energy into mechanical energy are checked. The principles of converting the mechanical energy into the electrical one and further into the heat energy are also tested using the electromechanical transmission.

2. Literature Review

Significant and still unused potential of the clean energy is enclosed in the compressed gas and the experts consider the possible variants for the rational use of this energy. There are technical proposals for the use of the compressed gas energy for the operation of the pumps and electrical generators[5–12]. The development of such works is possible, provided there is cheaper and more reliable turbine equipment. In this regard, the turbines belonging to the class of active turbines[13,14] in the classification are

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of interest. The turbine blades should be thin-walled, but robust, and therefore the loop-shaped blades are advantageous[14–16]. With low weight of blades, the issue of the turbine rotor balancing weakens. In terms of technology, the cheap to manufacture equipment can be obtained using sheet material[17-20]. The developers of the power-generating and aviation equipment pay their attention to the possibility of creating low-noise bladed machines with the use of the loop-shaped blade[14,21–24]. The question of the blade profile configuration is a separate issue[25]. The analysis of the patent literature reveals that modern designers are returning to the ideas that were born over a hundred years ago. When using the latest developments in the field of ultra-light and ultra-strong materials, as well as using new features of 3D-printers, the old ideas gained momentum for their development.

As part of the conducted development work, a special value is placed on the results of the patent research. The technical solution of the patent[13]is considered as a starting material for obtaining new geometries and performing new and more diverse functions, when using different fluids, such as various gases, liquids, and gas-liquid mixtures.

3. Concept Headings

Talking about the concept of the development of the turbine prototype using the compressed gas energy, one can note that the idea of creating the simplest turbine design was the guiding one. The simple design should have the minimal number of moving parts, while maintaining a high level of adaptability at both the manufacturing stage, and the turbine operation stage. Based on this feature of the developed turbine the strategy of actions to perform the research and development work is scheduled. The lack of the full-fledged theory should not stop the designers in the creation of the new machines; the missing information can be obtained by conducting bench tests of various models and experimental prototypes. The theory in most cases is developed later and numerical experiments complement the main scientific results obtained in the course of the physical experiments.

4. Results

The design of the new turbine is based on the patented technical solution[4]. Figures 1–4 schematically show the turbine rotor. The main task which this technical solution is aimed at is the decrease of the rotor weight and the increase of the hardness of its structure. At this it is planned to simplify the process of static and dynamic balancing of the rotor. In the course of the rotor manufacturing the use of the rolled sheet of aluminum alloy and titanium is provided. The technologies with the application of 3D printers are used for the manufacture of the hub and other elements of the turbine.

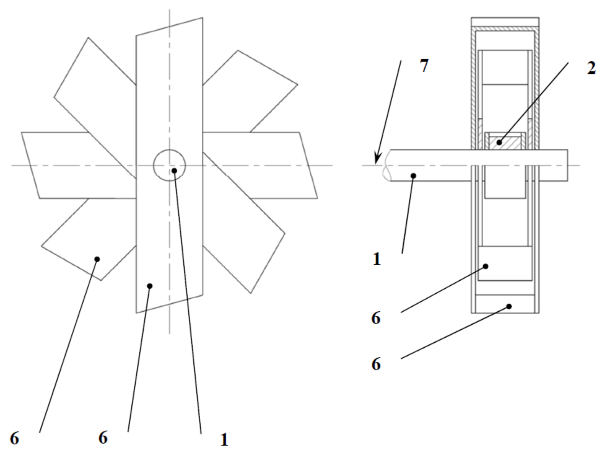

Figure 1. The turbine rotor diagram.

The rotor comprises shaft 1, disk 2 and blades 3 having U-shape comprising two feathering parts 4 mounted with clearance relative to each other and connected by flange 5. The blades 3 are combined pairwise in separate ring-shaped sections 6. Wherein each section comprises two U-shaped blades 3 arranged on shaft 1. And in each section 6 one U-shaped blade 3 is arranged with angular offset relative to the second U-shaped blade 3 by the angle of 180 degrees when rotating around the rotation axis 7 of shaft 1 (the indicated angle α = 180 degrees as shown in Figure 3). Moreover, feathering parts 4 of blades 3 contain apertures 8 through which shaft 1 extends. The rotor can be used in the dynamic type bladed machines, including the blade turbines and impeller pumps or impeller compressors (taking into account the known principle of reversibility which is characteristic for dynamic machines).

The rotor operates as follows. When using the rotor in the turbine (for example, in gas turbine), the working fluid stream is directed to the U-shaped blade in the tangential direction similar to of the patent[13] embodiment. The working fluid (gas in this example) exerts a force

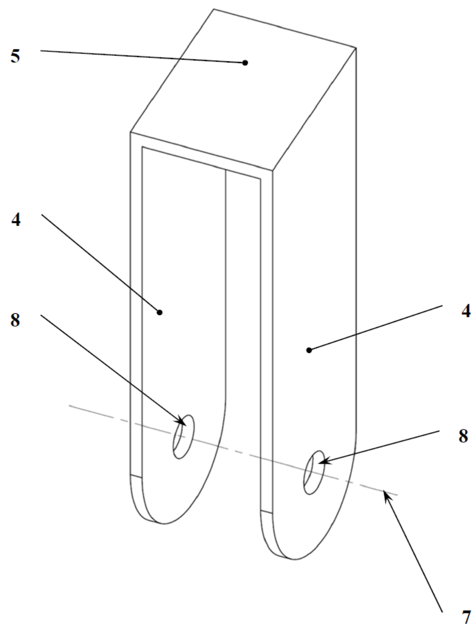

Figure 2. The U-shaped blade diagram (option).

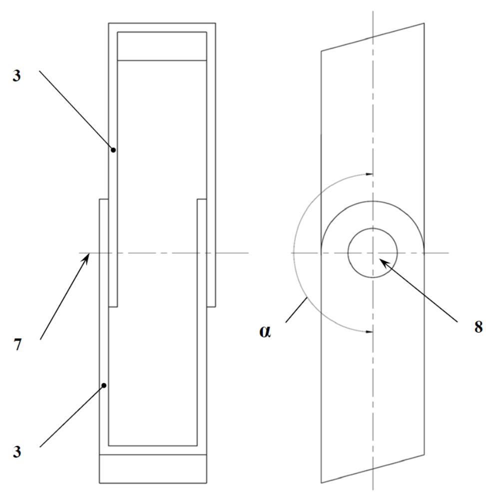

Figure 3. Section of two blades, for the assembly rotor.

impact on feathering walls feathering 4 and flange walls 5, while the kinetic energy of the working medium flow is converted into mechanical energy transmitted to shaft 1, and shaft 1 at this is involved in the rotational movement. Disc 2 provides a mechanical connection of blades 3 to shaft 1. Blades 3 are formed as separate annular sections 6. Wherein each section comprises two U-shaped blades 3 arranged on shaft 1. And in each section 6 one U-shaped blade 3 is arranged with angular offset relative to the second U-shaped blade 3 by an angle of 180

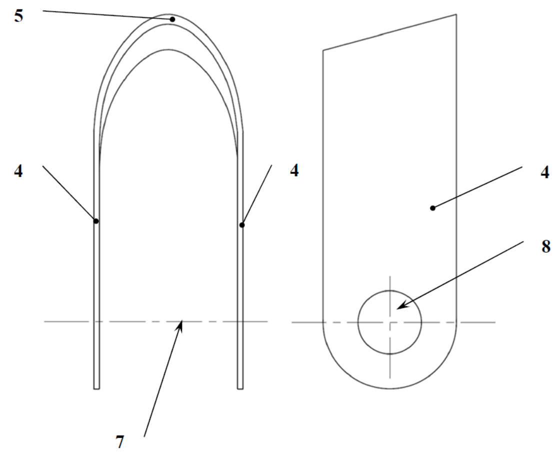

Figure 4. The U-shaped blade diagram (option).

degrees when rotating around rotation axis 7 of shaft 1, which provides conditions for balancing section 6 and the rotor as a whole, when the center of mass of each section is located on rotation axis 7. Annular section 6, consisting of two U-shaped blades, allows eliminating the cantilever-fixed feathering part feathering, thus reducing the weight of the elements located on the periphery of the rotor. Feathering portions 4 of blades 3 contain apertures 8 through which shaft 1 extends. Two blades 3 can be connected to section 6 by using the known techniques, such as by welding or using the adhesive compounds, but also it is possible to manufacture the annular section from a tubular billet (or a ring blank) using known cutting techniques. When using separate sections 6 of the annular form, the rigidity of the structure increases and the weight of the elements located on the rotor periphery decreases. This embodiment simplifies the solution of the issues with rotor balancing and thus opens the possibility to increase the rotor rotation speed, which is particularly important when using the sheet material for the production of the blades and the rotor in general. The blades, as it is known, can have flat and curved working surfaces; Figure 4 represents the diagram of the U-shaped blade embodiment, where the flange connecting two feathering portions has curved surfaces. The number of sections 6 is selected depending on the specific application of the rotor and operating conditions.

A set of micro-models is prepared for the laboratory tests. Figure 5 represents a demonstration micro-model of the turbine made of plastic. Figure 6 shows a demonstration micro-model of the turbine, made of aluminum alloy.

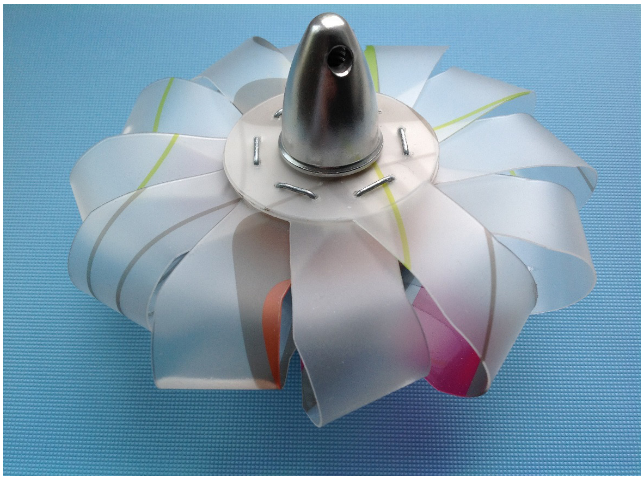

Figure 5. Turbine micro model (option). Blades material is plastic sheet.

Figure 6. The turbine micro model with electromechanical transmission (option). The blade material is aluminum alloy sheet.

Figure 6 shows the electromechanical transmission elements including a three-phase electrical generator, the electrical wires connected to the three-phase electric motor (to the right). This system in operating condition is shown in Figure 7. The nozzle apparatus (made of red plastic and located to the right of the turbine rotor in Figure 7) forms a gas flow directed tangentially to the turbine rotor, similar to the patent embodiment[13]. Part of electric energy, in this case, is converted into thermal energy and used to heat the filament which can be seen in Figure 7 at the bottom on the left. In this test, the filament performs the indicator functions for visual demonstration of the process of thermal energy generation.

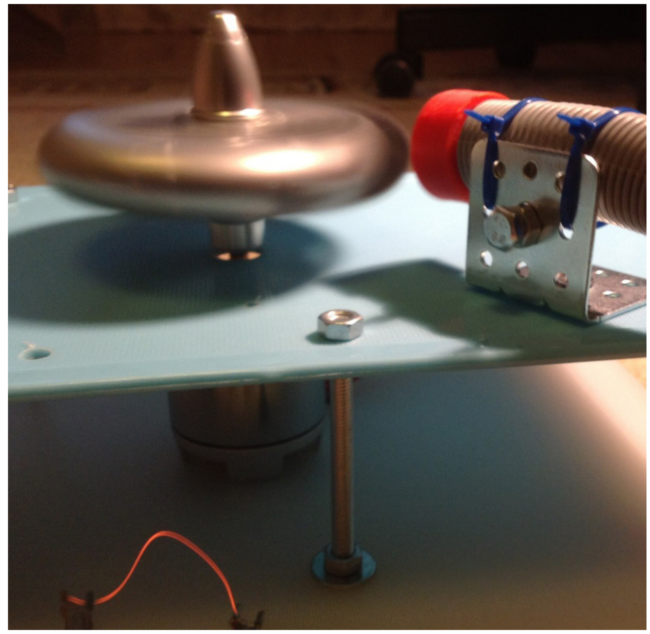

Figure 7. Testing the microscopic model of the turbine with electromechanical transmission (option). The blade material is aluminum alloy sheet.

Some experiments have been conducted with the loop blades with the axial direction of the gas flow. The option of such a micro-model is shown in Figure 8.

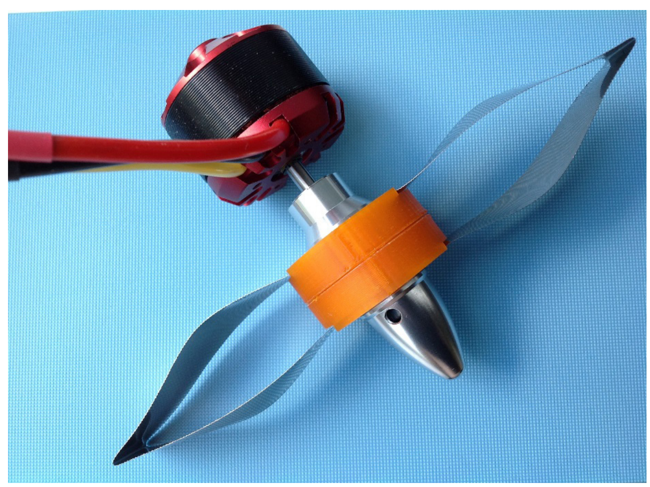

Figure 8. Turbine micro model (option). Material of the blades is titanium sheet.

The model of the blade machine, similar in the structure to the embodiment of Figure 8 was tested previously[15] when operating in the turbine mode and in the propeller mode. These tests confirmed the ample opportunities for practical application of the loop blades, including the fact that the results of the work can be used in the robotics industry which is developing now.

5. Discussion

After developing a turbine prototype the interim conclusions can be made: the created turbine design is efficient and can be used to create cleaner technologies for oil and gas production; the turbine design is simple and one can expect that the manufacturing and operating costs will be low.

Preliminary calculations show that such a turbine can have the efficiency factor at the level of 60 percent, and possibly higher. However, it should be noted that a complete theory for such machines is missing, and a number of open questions and unsolved theoretical problems can be presented. The number of nozzle units affects the conditions of the gas flow within the rotor. The gas flow rate at the outlet of the rotor is not constant and differs for each output channel. It is impossible to determine by calculation the trajectory of motion of each portion of gas which has got into the internal space in the rotor; it is possible, for example, that separate molecules of gas, having got into the rotor, will remain there, performing a rotary motion in the central part of the rotor. It is a very difficult calculation task to determine how the gas flow will be having at a supersonic flow velocity at the inlet of the rotating rotor. With the increase of the rotor rotation speed, the gas leaving the rotor starts to exert a force impact on the gas stream leaving the nozzle unit, wherein the gas stream at the nozzle outlet begins deviating from the initial direction. Such a deviation of the jet leaving the nozzle unit weakens the energy supply to the turbine, and this effect is already recorded when performing the laboratory tests. It appears that it will be quite difficult to evaluate the effect of this kind quantitatively by calculation. This effect with the gas jet deflection can be suppressed, but it can also be used for automatic rotor rotation speed control. Since it is known that the uncontrolled increase in the turbine rotation speed may lead to its destruction. Instead of gas the fluid flow can be directed from the nozzle into the turbine and in this case the new list of questions can be formed. The liquid-gas mixture can also be directed from the nozzle to the turbine instead of gas, and in this case another list of questions can be formed. Separately, one can consider the issue of additional energy supply directly inside the rotor in order to increase the velocity of the gas at the rotor outlet, but this topic has already got the interdisciplinary nature and is related to the topic of heat engines or internal combustion engines. The turbine is capable of performing useful work even without housing. However, if a rotor is considered in a single system with housing, the housing shape can seriously affect the working process inside the rotor. It is possible to accommodate two rotors in one case; the calculation task in this case will become significantly more complicated. What conclusion can be made after these preliminary considerations? The considered turbine is simple in design, inexpensive to produce, capable of performing useful work, so it is advisable to deal with theoretical questions in spite of the complexity of the gas-dynamic and hydrodynamic processes occurring in the channels of such a turbine.

The patent[13] represents a turbine and a nozzle unit, which generates a jet of gas directed tangentially to the turbine rotor; in this technical solution, the energy is converted mainly by friction forces. Such energy conversion method is not highly effective. However, it is possible to change the blade profile, reduce the volume of the internal cavity in the rotor and move the implementation of the main working process into the channels between the blades. This transformation of the turbine will allow increasing the efficiency of its operation, and taking into account the principle of continuity, one can talk about the development of the well-known idea and well-known design intention, but at a new technical level. Modern methods of prototyping with the use of 3D-printers allow fairly quickly finding answers to complex technical issues, if theoretically the task cannot be solved yet.

The developed technical solution can be used when creating various blade machines, including turbines, pumps, compressors, ventilators, and propellers. They can be large machines for the industrial facilities and micro machines for robotics.

As a perspective line in the field of research and development, it is seen as the direction for the creation of the turbine which is simple in design, and does not require maintenance and repair. In this case, at a low price, it will be possible to talk among others on the disposable turbine, which will be more advantageous to replace than repair, with regard to the solution of separate practical tasks.

6. Conclusion

In the course of the research and development work the turbine prototype has been created and tested, which allows modeling the process of converting the compressed gas energy is. The research topic is related to the issues of oil and gas production and processing. The micro models of parts and assemblies are prepared to verify the performance of the created heat generator elements. The principles and processes of the compressed gas energy conversion into mechanical energy are tested. The principles of converting mechanical energy into electrical energy and further into thermal energy are checked using the electromechanical transmission.

The continuation of the research is connected with the tests of the developed prototype under the conditions where the fluid flow is directed into the turbine rotor, followed by the assessment of capabilities for the turbine operation by means of the multiphase flow energy.

The main field of application of the obtained results is related to the energy-saving technologies for oil and gas production. The issues of rational use of energy resources are particularly relevant for the offshore oil and gas fields where the hydrocarbon production cost is particularly high. Some results of the work done can be used to solve practical tasks in other industries, such as, for example, energy sector, transportation, and robotics.

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8. References

1. Sazonov IA, Mokhov MA. Design of thermoelectric generators for oil and gas production systems. Indian Journal of Science and Technology. 2015 Nov; 8(30):1–12.
2. Sazonov IA, Mokhov MA, Frankov MA, Biktimirova DR. Studying issues of compressed gas energy recovery. Indian Journal of Science and Technology. 2016 May; 9(19):1–7. DOI: 10.17485/ijst/2016/v9i19/93904.
3. Bondarenko VV, Mokhov MA, SazonovIA. On the development of thermal generators for oil and gas extraction. Oil Industry. 2015; 12:127–9.
4. Sazonov IA, Mokhov MA. The rotor of the blade machines. The patent of the Russian Federation No 163491; 2016. Bulletin No. 20.
5. Sarwar N. UK gas pipeline to generate renewable energy through geo-pressure technology. Climatico. Independent analysis of climate policy. 2009 Jan 10.
6. Kaupert K. Use better designed turbo-expanders to handle flashing fluids. Hydrocarbon Processing. 2012 Jan 04.
7. Favilli S, Leitempergher G, Scibola L. A method and an apparatus for obtaining energy by expanding a gas at a wellhead. European Patent. EP 2467568 b1. Date of publication and mention of the grant of the patent: 2013 Sep 18.
8. Wiseman BW. Method and apparatus for generating electricity from the flow of fluid through a well. United States Patent No.4369373. Date of patent: 1983 Jan 18.
9. Hofmann H. Method and equipment for obtaining energy from oil wells. United States Patent No.5117908. Date of patent: 1992 Jan 2.
10. Turchetta JM. Gas energy conversion apparatus and method. United States Patent No.6907727. Date of patent: 2005 Jun 21.
11. Turchetta JM. Gas energy conversion apparatus and method. United States Patent No.7043905. Date of patent: 2006 May 16.
12. Amir N, Rigal M, Gilon Y. Energy recovery, pressure reducing system and method for using the same. United States Patent No.5606858. Date of patent: 1997 Mar 4.
13. Adair CW. Rotary steam friction motor. United States Patent 2043788. Publication Date: 1939 Sep 06.
14. Yoshida M. Fluid machinery. United States Patent 7018167. Publication Date: 2006 Mar 28.
15. Sazonov IA. The basics of calculating and designing the pumping and ejecting plants. Moscow: State Unitary Enterprise Oil and Gas, Russian State University of Oil and Gas named after I.M. Gubkin Press; 2012.
16. Brewster FW. Screw-propeller. United States Patent 0680671. Publication Date: 1901 Aug 13.
17. Ljungstrom F. Fan. United States Patent 1868113. Publication Date: 1932 Jul 19.
18. Hoenrkamp F. Fan. United States Patent 2273756. Publication Date: 1942 Feb 17.
19. Wethern RJ. Propeller construction. United States Patent 4445817. Publication Date: 1984 May 01.
20. Silvano D. Blade apparatus. United States Patent 5890875. Publication Date: 1999 Apr 06.
21. Moser J. Wind-powered rotor. United States Patent 5269647. Publication Date: 1993 Dec 14.
22. Goldberg S. Vertical-axis wind turbine with a twisted blade configuration. United States Patent 5405246. Publication Date: 1995 Nov 04.
23. Egolf AT. Ovate loop for rotary-wing blades. United States Patent 6260809. Publication Date: 2001 Jul 17.
24. Gratzer LB. Spiroid-tipped wing. United States Patent 5102068. Publication Date: 1992 Jul 04.
25. Vanmoor A. Blade and wing configuration. United States Patent 6899525. Publication Date: 2005 May 31.