Developing a Hydraulic Machine for Effective use of Reservoir Energy in Offshore Production

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Abstract

Background/Objectives: The objective of this research is developing a new hydraulic machine for effective use of reservoir energy in offshore production. The research procedure also implies development and testing of hydraulic machine micromodels. Methods: Analytical and experimental research methods that are used aim at discovering the process of fluid flow through a permeable barrier. The uniqueness of the considered method of energy conversion is the use of a turbine, where main fluid flow is acceptable through a blade. The blade itself may be in the form of a permeable mesh that is fixed onto a hydraulic machine rotor. Findings: Research and design results proved the possibility of developing a new hydraulic machine that is meant for effective use of reservoir energy in gas and oil production. The innovation of the developed technical solutions was certified by patents. A power action of a fluid flow on a permeable barrier is usually studied in relation to thermodynamic and aerodynamic processes with a straightforward flow. This research, unlike any other known studies, deals with a shift from a straight motion to rotative motion. According to the outcomes and with regard to the rotative motion of a permeable wall, one can develop a new class of hydraulic machines having unique properties. A drastic reduction in rotor mass is achieved here, which allows developing compact turbines, pumps, compressors and dynamic separators. Simple structure and cost effectiveness of such machines make them attractive for solving production tasks in offshore gas and oil fields. Application/Improvements: Primary application of the developed machinery includes offshore gas and oil productions. We plan to use our research and design results for developing new machines and technologies.

Keywords: Hydraulic Machine, Oil Production, Reservoir Energy, Turbine, Turbine Cascade, Technical Solution

1. Introduction

Offshore gas and oil field development conditions may be considered extremely difficult. Rough weather and remote location from centralized energy systems impact on increased financial cost, associated with hydrocarbons production. Lowering cost of gas and oil production is an extremely relevant task.

One of the well-know activities is associated with the use of special turbines that run on reservoir energy,1-6 where gas and liquid flow energy is converted into mechanical energy. Energy conversion technologies rely on the application of blade-type hydraulic machines.7,8 A blade-type hydraulic machine may serve as a pump, but also as a turbine.

At the same time, there hydraulic machines available, where the blade-type working process is combined with the vortex-type working process that is accomplished in rotor channels.9 Pulse gas flow in observed in rotor channels in such case and such working process has not been studied thoroughly yet.

Reservoir energy may be used at an oil platform for generating electric energy, driving pump and compressor units, and separating gas and oil mixtures. Separators are divided into two main types, i.e. gravitational separators and dynamic separators. Dynamic separators10-18 are more compact. This design feature opens a perspective of dynamic separators to be used in offshore gas and oil fields. Processes that involve gas and liquid flowing through a permeable barrier are often implemented in separators.

Gas and liquid flow through permeable barriers is characterized by a variety of conditions and applications. For instance, permeable barriers (grids and meshes)
are used for developing heat exchange and separation units, aerodynamic solutions for aviation and space equipment.\textsuperscript{19-21} Gas flow rate in grid openings can be close to sound velocity. Under the conditions, we observe dependence of grid resistance factor on Mach number, and the grid resistance factor rises sharply with the increasing Mach number.

(Machine rotor) blade rigidity may be increased at high flow rates by using loop blades.\textsuperscript{22-25} The shape of such blades may vary with the increasing rotor speed against any elastic deformations, and such processes that involve a varying geometry are in need of further studies.

State-of-the-art capabilities of 3D-printers open up new vistas for such designs. The use of permeable mesh structures appears to be promising for developing new dynamic hydraulic machines. Design aiming at development of new machines that would be characterized by a simple structure, low mass, and low cost manufacture is quite important.

2. Concept Headings

Our exploratory research relies on the following concept: if a gas flow has a force impact on a stationary permeable barrier, one can consider a separate class of hydraulic machines, where the effects of the gas flow interacting with the permeable wall will be used for carrying out a working process of a turbine, pump or separator. One may assume that the permeable wall may have certain properties in the area of high flow rates, which are typical of a traditional blade that includes a non-permeable wall. While in the area of low flow rates, the permeable wall may be barely noticeable, due to low values of the hydraulic resistance factor. Such properties of permeable walls allow us to develop high-speed hydraulic machines, which have special properties and rather light and robust rotors. In particular, we may speak of new possibilities for developing low-noise dynamic machines, where the working process differs drastically from that of blade-type machines.

3. Objective of Exploratory Scientific Research and Design

Developing a new hydraulic machine to enhance the efficiency of gas and oil production by using reservoir energy.

4. Current Tasks

Theoretical research of the process of energy conversion at gas and liquid flow interacting with a solid permeable wall. Designing a hydraulic machine that runs in engine mode on gas and oil energy. Developing operable hydraulic machine models were for functional testing of such machine, using fluid energy.

5. Results

A theoretical study of a process of energy conversion at interaction of the flow with a solid permeable wall was done within our research and design scope. Theoretically, the overall area of holes in the permeable wall may vary from 0 to 100%. If the wall does not bear any holes, we may talk about a classic task of blade machine. If the value is 100%, we may talk about fluid moving along a channel, where the interaction of the flow and solid wall is determined solely by friction forces. Computer simulation of an operational process for fluid flows was done. Gas flow conditions were discussed at different Mach numbers. A power action of a flow on a permeable barrier, made of a mesh wire, was evaluated. A sample illustration of some computer simulation results is given in Figure 1.

According to calculations, a permeable wall may be used instead of a traditional blade in a hydraulic machine. A structure that involves a permeable rotor may be used for developing turbines, pumps, compressors and dynamic separators. Special attention was paid at the first stage of our research to solving problems of developing a dynamic separator that runs on reservoir energy in gas and oil production. At the same time and according to our calculations, it is possible to develop turbines to product electric energy. Exploratory research aims at developing a
hydraulic machine to be notable for its simple structure, low mass, and low cost of manufacturing.

A hydraulic machine that has been developed and patented26,27 (see Figure 2) is comprised of a stator 1 with nozzles 2 and turbine rotor 3 that is located in the stator. The structure may include one nozzle 2, or two or more nozzles. At the same time, turbine rotor 3 is made in the form of a permeable space honeycomb structure, which is composed of interconnected external projections and internal projections. Such rotor structure 3 can be made by using several layers of mesh. Wire mesh made of metal or other construction materials may be used. Flowing channels 4 are made between the external and internal projections in turbine rotor 3 to provide for hydraulic connection of flowing channels 4 in turbine rotor 3 and nozzles in stator 1. Stator 1 is equipped with output channels 7. At least one separating drum 8 is located in stator 1 and it is placed between rotor 3 and output channels 5 and 6.

An alternative hydraulic machine that comprises one turbine 3 and two separating drums 7 that share the same shaft is presented in Figure 2. At the same time, separating drum 7 is made in the form of a permeable space honeycomb structure, which is composed of interconnected external projections and internal projections. Flowing separating channels are made between the external and internal projections in separating drum 7 to provide for hydraulic connection of flowing channels 4 in turbine rotor 3 and output channels 5 and 6. At least one output channel 6 is placed closer to axis of rotation 8 in relation to other output channels 5.

Permeable space honeycomb structure of turbine rotor 3 and permeable space honeycomb structure of separating drum 7 can be made of a mesh material, where mesh material threads shape external and internal projections. And mesh material cells are connected into flowing channels between the external and internal projections.

Principle of operation of the hydraulic machine is the following. Stator 1 and nozzles 2 ensure generation of a flow (or several flows) of a gas or gas and liquid mixture in the direction of turbine rotor 3. Each nozzle 2 may be connected, for instance, to a separate oil producer (or gas producer); at the same time, working parameters of flows may differ for each nozzle 2 in mass flow ratio and nozzle 1 inlet pressure. The gas flow acts on the external projections of turbine rotor 3 and sets turbine rotor 3 in rotative motion. Thus and so, kinetic energy of the gas flow is converted into mechanical energy at rotation of turbine rotor 3. The gas flow also penetrates the internal surface of turbine rotor 3 through flowing channels 4. The gas flow interacts in this part of rotor 3 with the internal projections, which boosts energy conversion, as long as the gas can offset closer to the axis of rotation of turbine rotor 3, with the gas flow rate slowing down. Turbine rotor 3 is connected with separating drum 7 for further energy transmission. At the same time, mechanical energy is transferred from turbine rotor 3 to separating drum 7. Other machines can also be installed on the common shaft that rotates around axis of rotation 8 (such machines are not shown in the picture and may include additional separators, electric generator, pumps, or compressors, for instance). Separating drum 7 is placed between turbine rotor 3 and output channels 5 and 6. Turbine rotor 3 and separating drum 7 rotate around axis of rotation 8, which makes separation process possible. Fractions of higher density are pushed off to the periphery of separating drum 7 in separation due to an action of centrifugal forces. Fractions of lower density are pushed off to the center of separating drum 7 and close to axis of rotation 8. This makes separate discharging of fractions of higher density and fractions of lower density from stator 1 possible. With the length of separating drum 7 growing, time of working fluid (e.g. gas and liquid mixture) exposure to centrifugal forces in stator 1 can be increased, while enhancing separation performance, as

![Figure 2. Hydraulic machine layout.](image_url)
long as we know that the separation efficiency is increased with prolonged exposure of the working fluid (e.g. gas and liquid mixture) to the centrifugal forces. At the same time, the magnitude of centrifugal forces acting on the gas or liquid is forced-maintained constant along the whole path of motion of the working fluid through stator 1, due to the described structural specifics of separating drum 7. Mechanical energy is used in this case for maintaining high and constant rotation speed of the gas and liquid mixture (working fluid), and the energy is spent on the separation process and against the friction forces in movement of the working fluid inside stator 1 in the direction from turbine rotor 3 to output channels 5 and 6. In separation due to the action of centrifugal forces, fractions of higher density are completely pushed off to the periphery of separating drum 7 and further to output channel 5 that is located further from axis of rotation 8. Fractions of lower density are pushed off to the center of separating drum 7 and closer to axis of rotation 8, and fractions of lower density (e.g. gas) are further pushed off to output channel 5 that is located closer to axis of rotation 8.

Due to the permeable space honeycomb structure of turbine rotor 3 and separating drum 7, high efficiency of energy conversion is ensured against varying properties of the working fluid, including use of gas and liquid mixtures that differ in density, viscosity or gas fraction content. Kinetic energy of the flow is used more efficiently, as long a working process of mechanical energy production is combined with a working process of gas and liquid mixture separation, and both processes go on in the same working chamber at the same time. In addition to the above, equipment mass and dimensions can be reduced, which expands application of such machines, being quite relevant to offshore gas and oil fields, for one thing. Consequently, a technical result of developing an improved hydraulic machine structure is achieved, while ensuring growing efficiency of energy conversion for a broad spectrum of gas and liquid mixtures. The structure of the universal rotor that may be used as a turbine rotor and a dynamic separator rotor is of special interest.

Models and prototypes were built to verify the developed technical solutions. An example of mesh rotor motor is shown in Figure 3.

Hybrid machine alternatives that were equipped with loop blades were also discussed. An example of such models is illustrated in Figure 4.

Loop blades make it possible to assemble rather light rotors for turbines, pumps and air propellers. Based on our experience, air propellers made of titanium band appear to be quite interesting to drones, which so popular now. The fact that such propeller does not lose its functionality due to multiple immersions into water is also considered. We are talking about a universal propeller operating in air and under water. Such machines may be useful for metal structure status observation at an oil platform and for observations below the surface and at the upper surface part of the platform.

According to our experience, turbines may be built up, based on loop blades, where working fluid flow moves radially with regard to the turbine rotor rotation axis.
A combination of the multi-layer permeable mesh and loop blades in the same hydraulic machine appears to be promising for developing separating equipment used for gas and oil treatment at oil platforms.

Demonstration micromodels are usually produced for any new turbines that are developed. Demonstration models were also produced within this research to display the possibilities of converting kinetic energy of a gas (or liquid, or gas-liquid mixture) into electric energy. A similar model is shown in Figure 5.

According to model trials, one can possibly develop a universal rotor structure that may be used as a turbine rotor and as a dynamic separator rotor as well. Such unification is of particular interest for developing low-cost equipment that is suitable for the use of reservoir energy at offshore oil platforms.

6. Discussion

A power action of a fluid flow on a permeable barrier is usually studied in relation to a straightforward flow. According to our results, one can develop a new class of hydraulic machines having unique properties, while considering the rotative motion of a permeable wall. Thus, it can be assumed that the known theory of similarity, which is now widely used for developing blade machines, will not be applicable to the new machines. With the rotor speed changing, characteristics of the new machine will change in a different way, as compared to blade machines. The question about an impact of fluid viscosity on flow conditions through a multi-layered rotative rotor mesh is still open. Pulse gas motion in channels of such rotor has not been studied yet, and one should bear in mind the complexity of such tasks. Experimental research that includes bench tests may be the only source of reliable information about a number of questions. Apparently, one may state that the study of such new machines is in its early stages and specifics of fluid flowing through rotative permeable walls is yet to be discovered.

A drastic reduction in rotor mass will allow us to develop compact turbines, pumps, compressors and dynamic separators. Simple structure and cost effectiveness of such machines make them attractive for solving a variety of production tasks. Low mass of new machines may introduce new applications, including aviation technologies. State-of-the-art capabilities of 3D-printers open up new vistas for such designs. We plan to use our research and design results for developing new machines and technologies, e.g. power generation turbines; low-noise pumps, compressors and fans; pulsating gas flow compressors and turbines; augmented turbines for drones; and separation equipment.

7. Conclusion

Our theoretical research allowed us to develop a basic diagram and structure of a hydraulic machine. Certain aspects of practical application of technologies that are associated with energy conversion, when a flow interacts with a permeable wall, were studied. A structure of a hydraulic machine, which contains a turbine and dynamic separator running on gas and oil energy, was developed. Operable hydraulic machine models were developed for functional testing of such machine, employing fluid energy. Research findings were used for the development of design documentation of a new hydraulic machine prototype. Simple structure and cost effectiveness of such machines make them attractive for solving a variety of production tasks, including offshore gas and oil fields.

We plan to use our research and design results for developing new machines and technologies, in particular power generation turbines; low-noise pumps, compressors and fans; and separation equipment. At the same time, new applications may be discovered for the new hydraulic machines, thanks to their low weight and compactness, including aviation technologies, e.g. pulsating gas flow compressors and turbines; or augmented turbines for drones.

Figure 5.  Meshed turbine model: 1 - nozzle; 2 - meshed turbine rotor; 3 - electric generator shaft; 4 - electric lamp.
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