

# Self-contained process module with flow swirling for downhole equipment power supply

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**Abstract.** The present paper is dedicated to the development of resource-saving technologies for oil and gas complex, namely to the development of power supply for downhole equipment. The relevance of this research is caused by the acute lack and high electricity costs for downhole devices which are widely-used both in drilling and in hydrocarbon production. The traditional methods used to power these devices, namely batteries and power cables are unreliable and short-lived and they require capital and time expenditure for production process, tripping operations, etc. shutdowns. There is a solution to this problem consisting in use of autonomous downhole power supply system including a hydrodynamic module with an electric power generator which converts well flow energy. An assessment of the device operability was made in which its high performance is highlighted.

## 1. Introduction

Use of the increasing number of the devices intended for controlling technological processes during hydrocarbons drilling, production, preparation and transportation meets serious difficulties in electricity supply. Application of traditional power supply ways for such devices as batteries and extended power cables is connected with their insufficient reliability and durability and also demands regular technical maintenance and repair operations. It leads to financial and time expenditure including expenditure on technological processes shutdowns, for example, in connection with tripping of drill strings, equipment repair and elimination of emergency situations effects. Therefore, the finding of practical solutions in effective power supply field for downhole devices is a relevant problem of oil and gas industry.

## 2. Power consumption for downhole devices

There are several main groups of downhole devices that require power supply:

- Wireline Data Logging - geophysical logging sondes that are lowered into the well and receive information by means of gamma radiation, vibrations, seismic, electromagnetic or acoustic waves [1].
- Intelligent Completions include packers, inflow or intake equalization tools for dual operation or injection of wells, downhole monitoring systems (pressure and temperature sensors, downhole flow meters), and well monitoring and emergency shutdown systems [2].

- Measurement-While-Drilling (MWD) and Logging-While-Drilling (LWD) are installed in the bottom of the drill string during drilling and providing control over the position of borehole axis in space, its curvature, lithology, rock saturation and operational control of the drilling process [3].
- Other, less common devices requiring electric power for their operation, for example, electromagnetic dampers [4]. It is obvious that the development of downhole power supply devices will give impetus to the development of downhole equipment in different activities.

MWD/LWD device energy consumption is 600-900 W. From this energy source sensors use 80-200 W from which navigation requires only 40-60 W. Other energy (500-700 W) is used for data transmission to a surface by means of conductive, electromagnetic or, most often, hydraulic transmission links [5].

The energy consumption of downhole devices used in hydrocarbon production is slightly lower. In particular, it is noted in the work [6] that the most energy-consuming Wireless Intelligent Completions systems consume from 30 to 50 W, Flow Meters from 10 to 20 W and Flow Control Valves from 5 to 15 W.

However, despite the above-mentioned amount of power consumption dynamic indicators in the well often change slowly, so the downhole devices operating cycle, i.e. the ratio of device operation time to total time can be sufficiently short that it is possible to use low power sources for their supply. At the same time it is also important to provide efficient downhole power storage devices.

### **3. Traditional power sources for downhole equipment**

Let's consider the downhole devices power supply by means of the batteries installed near devices or cables. No rechargeable Li-ion batteries are frequently applied having high voltage and capacity indicators, but not having a possibility to recharge and therefore require regular replacement that leads to increased costs for tripping operations. In addition, they have the property of passivation, a negative consequence of which is a voltage delay when the load is applied.

Operating range of these batteries is from -30 to 125 °C whereas temperatures registered in wells increasing with a depth (a geothermal gradient) [7] are usually in limits of 20-100 °C, but they can reach 200 °C [8], i.e. considerably exceed operating temperatures ranges of these batteries. Heating of Li-ion battery above operating values is fraught with growth of a charge current to the value close to value of a short-circuit current, i.e. to thermal acceleration of the battery that can cause short circuit emergence and even explosion.

Besides, Li-ion batteries are unsafe in operation since polar waterless solvents in their electrolytes are volatile and explosive especially at increased temperatures.

Unlike batteries, a power cable has no restrictions on number of energy supplied. When drilling, cables extend along the outside of a drilling string and are subject to severe friction, shear force, cable rupture and also to high temperatures and pressure. Placement of cables on the outside of a drilling string reduces the volume of drilling mud which carries cutting to a surface that may interfere with normal drilling mode. Application of cables for directional and horizontal drilling is especially dangerous. Also cables are subject to corrosive attack of drilling mud or oil.

Thus, in spite of the fact that batteries and power cables give the chance of power supply, they have serious restrictions and are short-lived and high-cost.

The energy of a moving fluid flow can be converted into electrical energy by means of a turbine generator. Its principle is based on the fact that under the influence of flow rotation of the turbine rotor creates an alternating magnetic field which influencing excitation winding creates electric current. Advantage of turbine generators is high generated power. Shortcomings of turbine generators are decrease in effective diameter of the drilling string, and, therefore, and decrease in moving flow pressure as well as its discontinuity. It should be noted that there is a low resource of turbine generators due to fast wear of mechanical parts in an aggressive environment. Turbine generator activities during well

operation with ESCP (electrical submersible centrifugal pump) can cause cavitation in the well which is unacceptable.

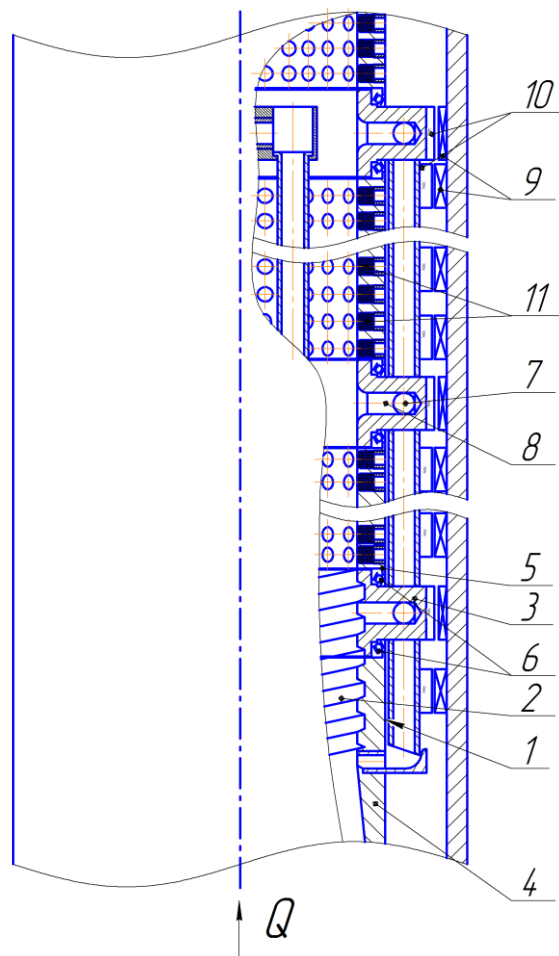
Due to these disadvantages use of turbine generators is possible only during drilling where frequent tripping operations are carried out. At the same time, the use of the turbine generator requires high-quality cleaning of drilling mud from drill cuttings. In production conditions the equipment is required to operate without maintenance for several months, this type of generator cannot provide.

#### 4. Developed system of autonomous power supply for downhole devices

The solution to the problem of power supply for downhole equipment is to use in the well independent power supply systems which include a generator converting various energy sources existing during well drilling and operation into electric ones.

The autonomous power supply systems have to meet the following main requirements: compactness, long continuous operating time, and vibration resistance, resistance to high temperatures and drilling mud corrosive environment or extracted fluid. On the basis of these conditions, an autonomous technological device was developed which converts and redistributes fluid flow kinetic energy [9].

The device operates as follows. The pressurized fluid flow  $Q$  is fed into the cavity of hollow cylindrical body 1 (for example, a pipe), where, by entering on the relief 2 tangentially located to the flow, it is swirled itself and bring to rotation the moving parts of the hollow cylindrical body1 (figure 1).



**Figure 1.** Self-contained process module with flow swirl: 1 – hollow cylindrical body; 2 – relief 3 – rotating part; 4 – non-rotating part; 5 – end face; 6 – bearings 7 – nozzle; 8 radial hole; 9 – winding; 10 – permanent magnets; 11 – piezoelectric elements.

Additional swirling to fluid flow  $Q$  is imparted when it hits rotating part 3 (blade-free turbine) from non-rotating or rotating part 4. At the ends 5 of hollow cylindrical body 1 on the external side of part 3 and on the internal side of part 4 there are annular platforms for installation of bearings 6. Further, from part 3, the flow enters the next part 4 in the direction of the flow. These actions form one cycle of flow swirling. The above cycle repeats the number of times laid down by the designer depending on the required flow swirling as the flow passes through the alternating parts 3 and 4.

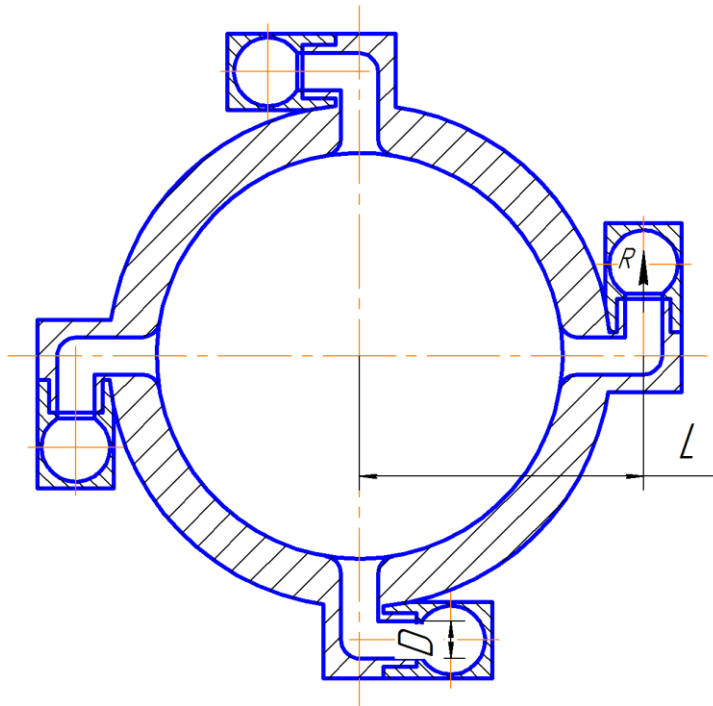
Entry of flow onto rotating parts with relief results in redistribution of axial velocity of flow towards increase of its angular velocity. To vary effect degree on the flow the relief 2 of different profiles, in particular macro relief or micro relief, can be used. And if selective flow action is required, a partially regular relief 2 may be applied.

When the flow passes through point-to-point radial holes 8 in part 3, it and the flow are given additional peripheral speed due to the reactive action of the jets leaving the nozzles 7 and swirling a bladeless turbine 3. To control the turbine rotation parameters 3 and, accordingly, to control the flow swirling parameters nozzles 7 of the required diameter and radius link curvature are set.

Energy Conversion is carried out as follows. On the one hand, flow energy of the fluid through the fluctuations stimulated by a flow will be partially transformed to the energy of elastic piezoelectric elements deformation 11 which leads to the generation of electricity due to the direct piezoelectric effect. In this case, the steady-state fluid flow forms the cascade nature of turbulent layers leading to pressure fluctuations in a wide range of frequencies and amplitudes in the cavity of the cylindrical body 1. On the other hand, the kinetic energy of the flow is partially converted into the kinetic rotation energy of the parts 3. Permanent magnets 10 mounted on the rotating parts 3 stimulate currents in the windings 9.

## 5. Parameters evaluation of the developed device

Obviously, the electricity bulk generated by the device will be generated by converting the kinetic flow energy into the kinetic energy of the bladeless turbine rotation. In this case, the main interest is to find the frequency of its rotation. To evaluate this parameter, we composed a calculation model (figure 2).



**Figure 2.** Calculation model for determining the number of revolutions of a bladeless turbine.

Value of reactive force  $R$  flowing from nozzle [10].

$$R = \frac{Q\rho}{z}(u - w) = \frac{Q\rho}{z} \left( \frac{Q}{\mu Sz} - 2\pi nL \right) \quad (1)$$

where  $\rho$  – density of fluid flow;  $z$  – number of nozzles;  $u$  – velocity of jet at nozzle outlet;  $w$  – circular velocity of nozzle;  $S = \pi D^2/4$  – nozzle area of outlet section,  $D$  – diameter of nozzle outlet section;  $L$  – distance to nozzle axis;  $\mu = 0.87$  – discharge coefficient from a nozzle [11].

For turbine torque, you can write the expression

$$M = zRL = \frac{Q^2 \rho L}{\mu Sz} \left( 1 - \frac{\mu Sz}{Q} 2\pi nL \right) \quad (2)$$

Expression (2) is made to the canonical form for the known moment equation [12] based on the Euler equation for turbo machines

$$M = M_T \left( 1 - \frac{n}{n_x} \right) \quad (3)$$

where  $M_T$  – decelerating torque;  $n_x$  – rotating speed on idling mode.

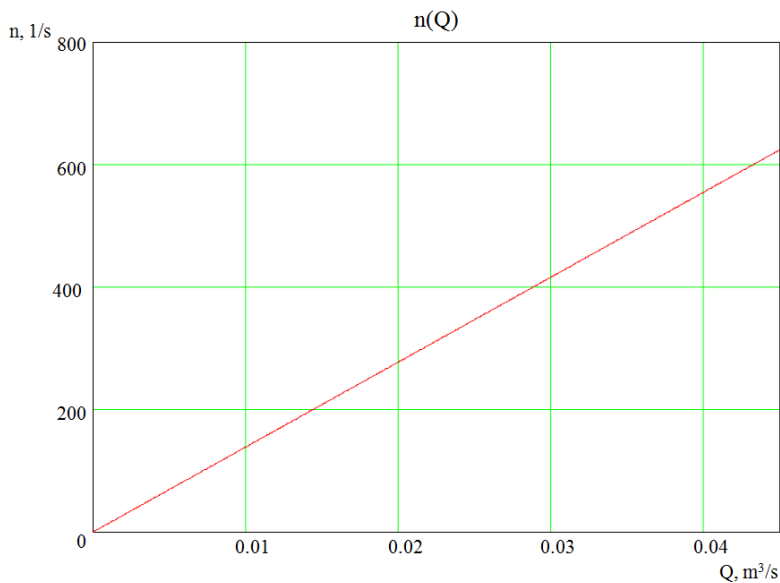
Comparing expressions (2) and (3) we find rotating speed of a bladeless turbine

$$n_x = \frac{Q}{\mu Sz 2\pi L} \quad (4)$$

The expression (4) shows linear directly proportional dependence between  $n_x$  and  $Q$ , and inversely proportional for  $\mu$ ,  $D$ ,  $z$ ,  $L$ . The dependence diagram  $n_x(Q)$  is given in figure 3, the data for its construction in table 1.

**Table 1.** Parameters for construction of blade-free turbine RPM dependence on well fluid flow

Parameter	$D, mm$	$z$	$L, mm$
Value	10	4	42



**Figure 3.** Influence of fluid flow on rotating speed of turbine.

Dependence (4) is of an evaluative nature, for example, mechanical friction in bearings was not taken into account here, in view of which the real values of the velocity will be slightly less. It can be seen from the graph (figure 3) that even at low flow rates (oil flow or mud flow) observed in the wells significant revolutions (RPM) of the bladeless turbine can be obtained, and, consequently, the power received from it.

## 6. Conclusion

High relevance of efficient resource-saving technologies development for well conditions was revealed. The main disadvantages of traditional power sources for downhole equipment are described. The design of an autonomous hydrodynamic module with swirling of the flow converting energy of the well fluid flow is shown. The parameters of the developed device were evaluated. This evaluation showed its high efficiency in terms of power generation by converting the flow energy into kinetic energy of turbine rotation.

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