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The development of the vortex gas pressure regulator

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Abstract

Following the analysis and preliminary numerical calculation of the gas flow in the working cavity of the vortex pressure regulator its geometric parameters were defined and three-dimensional model was developed. The prototype of the vortex regulator was made with the application of additive technologies. A test bench to be used for testing the developed vortex pressure regulator was prepared. According to the experiment results, nomogram gas flow at the regulator's outlet by the control flow for different power pressures was composed. Moreover, the locking pressure value in the experiment was compared to the value obtained by numerical calculation.

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Keywords: vortex regulator, vortex amplifier, vortex chamber, the control stream, locking knob.

1. Introduction

Pressure (or gas consumption) regulators are the devices that provide working body with the pressure maintenance to the specified accuracy or the flow rate at the constant level or vary its value according to the given program. The appearance of the inkjet pneumatic automation (new advanced technical branch), which is based on the jet elements that have no mechanical moving parts, is possible to be referred to the 60-70 years of XX century.

Interaction of the gas streams in the regulation process of the working environment parameters by applying the vortex gas pressure regulators that have a number of application benefits is important today. The relevance of issues concerning regulation of aggressive media parameters during different technological processes is undeniable in pneumatic systems used in aerospace, aviation, oil and gas, chemical and other industries, where the gas may be at high temperatures and could be contaminated by various inclusions, such as metal vapor or have chemically active particles.

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2. State of the art and patent review

On the ground of scientific literature and patents review the status of vortex gas pressure regulators application and development issue was examined. Diagram showing the operation of the controller is depicted in Fig. 1.

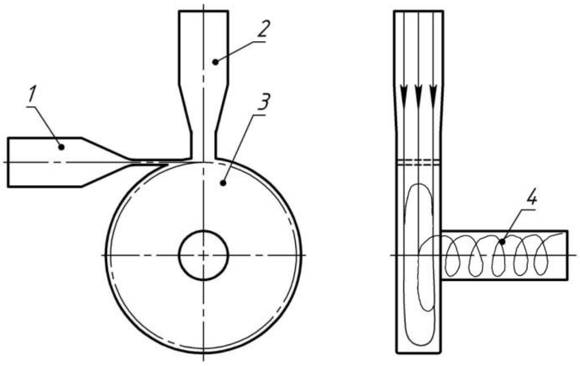

Fig. 1. Scheme of the vortex regulator

1 - control channel; 2 - supply channel; 3 - the vortex chamber; 4 - output channel.

The literature analysis [1-4] showed that this type of regulator has a wide range of applications. The advantages of vortex regulators are durability, resistance to radiation, resistance to the effects of electromagnetic fields, explosion and fire, the ability to work with different kinds of gases, mixtures thereof as well as arbitrary liquids. These also include high reliability, simplicity of design (absence of moving and sensitive to shock elements and seals, which are exposed to wear and corrosion during operation), consequently low manufacturing (production) and operating cost as well as efficiency, when working on low supply pressure (at a pressure supply 0.1-0.2 MPa, one element is able to consume only 0.01-0.03 W).

In comparison with mechanical pressure regulators, vortex regulator has several drawbacks - essentially lower speed, presence of noise due to turbulent flow in the vortex chamber and vortex regulator cannot be used as locking element.

The first publications and patents [7-32] on the subject appeared in the late 60s, the 70s of the 20th century. Germany, USA and UK also worked in this area at the same time.

For example, it was suggested to use knobs to control the flow of fluid from the oil and gas fields in oil industry. These devices are required to maintain constant flow rate, regardless of pressure fluctuations in the hydraulic line. The liquid stream may be a mixture of oil and gas and solids such as sand grains. Multiphase flow forms an abrasive environment, which is detrimental for the mechanical regulators, based on the moving elements. To control such fluid flow, the most reliable part is control device, which is based on the vortex regulator.

The patent [8] proposes to use vortex regulator to control the flow of refrigerant depending on the temperature difference between inlet and outlet of the evaporator.

Another application area of the vortex regulators is helicopter engineering. The license [9] proposes to use vortex regulator as a locking element in the engine cooling system.

The patent [10] proposes to use vortex regulator in rocket construction, in particular in a fuel injection system in a rocket engine. During operation, some rocket engines need to be provided with two levels of thrust: thrust level of greater magnitude, called boost, and thrust level of lesser magnitude. The problem which is solving in the patent is an improved simple and reliable system for the injection of liquid propellant into the combustion chamber in a rocket engine.

Second application area of the vortex regulator is ventilation systems, glove boxes ventilation in particular [12]. Radioactive and toxic materials are elucidated in glove box is a device. This unit is equipped with a ventilation system that can provide emergency evacuation in case of breach of containment, for example in case of rupture of a glove. The ventilation system works with dry and sometimes dusty air, which is unacceptable for the operation of the regulator. The author suggests using a vortex regulator in a ventilation system.

In addition, in a rocket engineering the vortex control can be used in a thruster control system [15]. The author's goal was to provide an improved control system and develop method to control thrust vector.

Vortex controller can operate in trigger mode. An example of this is a patent [19]. The practices mentions pipeline systems, which sometimes fail due to rupture of the pipeline, caused by the pulsation of liquid in it. For example on ships, submarines' pipeline rupture can lead to great destruction because of a spill of a large volume of water toward the interior of the vessel. Substantially, serious damage could be avoided by covering the water flow in the pipeline upstream to the break. Problems to be solved in this paper by the author is to provide a flow control system, which is triggered as a result of a breakthrough pipeline.

The vortex control application in nuclear reactor control system is discussed in the patent [20]. According to the author, the vortex regulator may be used to regulate the flow of the electroconductive liquid cooling, an alkali solution of sodium or potassium.

The patent [23] proposes to use a vortex amplifier for controlling the fluid flow in a gas turbine engine. In a gas turbine engine, it is often necessary to control the secondary flow of fluid, such as air-cooling system or an oil stream. Supply channel can be connected, for example, to a low-pressure compressor. The control channel is proposed to connect to high-pressure gas compressor. The outlet may be connected with a turbine or compressor of a gas turbine engine.

The main dependencies of consumption in the outlet elbow from the flow rate in a control nozzle are laid in papers of Zalmanzon LA [1]. The author proposed a mathematical model describing the fluid flow in the vortex chamber with an analytical solution that can be used in practice as a first approximation for calculating the parameters of the supplying and controlling flows. Due to lack of computing power in 60…70 years of the last century, the calculations on distributed parameters were not carried out. The mathematical model which is based on the differential equations of fluid flow is most accurately described: continuity equation, conservation of energy, conservation of angular momentum, as well as the turbulence model [5]. This system has no analytical solution and can be solved only by numerical methods. For the development of new constructions of vortex regulators by using modern software packages and based on the existing computer equipment, mathematical model of the processes occurring inside the vortex chamber is created [6]. Vortex pressure regulator parameters were calculated and the main design elements were determined basing on the mathematical model. The three-dimensional model of the vortex gas pressure regulator was developed in result (Fig. 2a). By using additive technologies prototype of the vortex pressure regulator has been made (Fig. 2b).

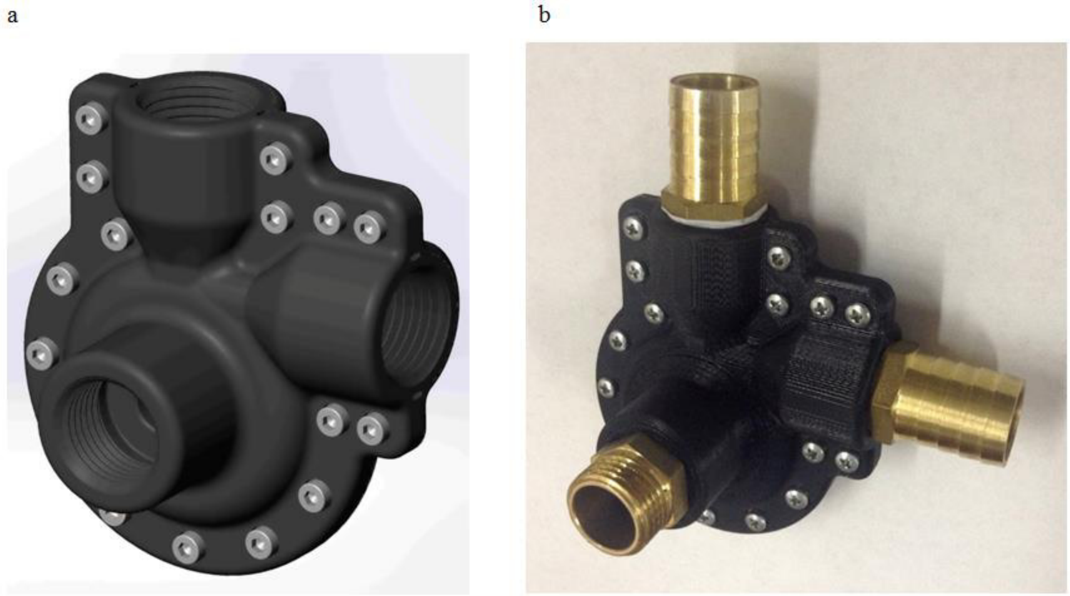

Fig. 2. (a) three-dimensional model of the vortex control; (b) experimental model.

3. Experimental research

To confirm the adequacy of the mathematical model [6] and the validity of its further use in the numerical studies of working processes in the vortex pressure regulator, as well as for testing vortex regulator in the chair of "Vacuum and compressor equipment" Bauman MSTU created an test stand, the scheme of which is shown in Fig. 3.

Locking of the regulator means that the power consumption becomes zero. In this case, the regulator output rate will be equal to the control flow, which is called a locking rate Q bonds.

According to the literature review, closing the feed channel occurs, if on the control channel is applied pressure greater than the supply channel. On the periphery of the vortex chamber is forming a region of high pressure, which obstructs the flow of gas from the supply channel.

The results of calculation of gas movement in the working chamber [6] of vortex regulator using ANSYS Fluid flow (CFX) showed that the locking effect occurs when the control pressure is of 4 bar, and the braking pressure in the supply channel must be equal to 2 bar.

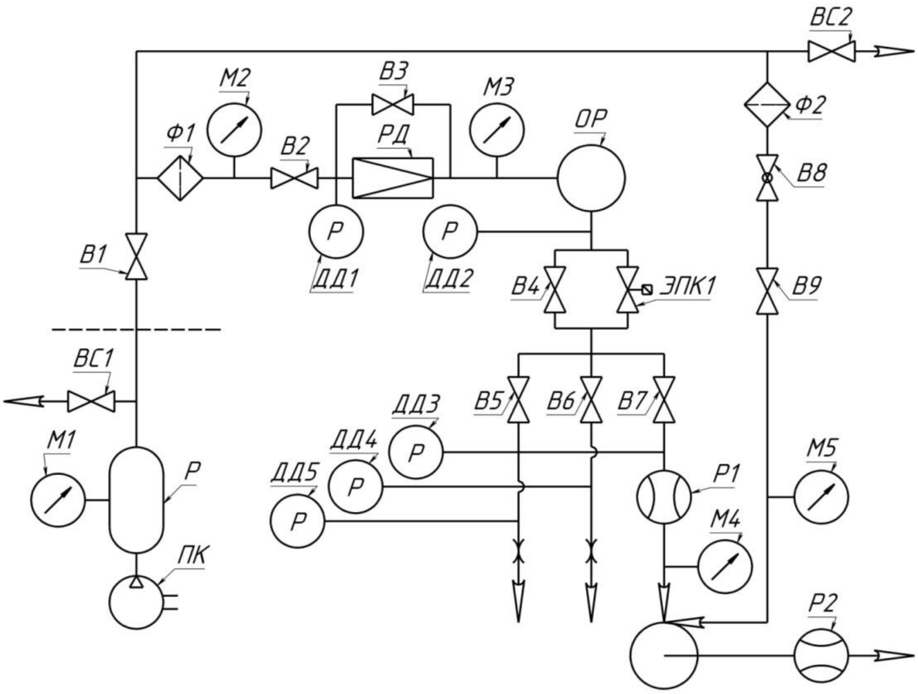

Fig. 3. The test stand scheme.

Structurally, the scheme consists of: PC is piston compressor; P is receiver; M1…5 are pressure gauges; BC1…2 are relieving globe valves; РД is diaphragm pressure regulator; OP is object of regulation; ЭКП1 is electropneumatic valve; B1…9 are globe valves; ДД1…5 are pressure sensors.

Designed stand is intended to determine the characteristics of the vortex pressure regulators of different configurations. Conception of the properties of the vortex control are given from characteristics of dependence between its output parameters Q_{out} and P_{out} and the control flow parameters Q_{contr} and P_{contr} at a constant pressure of braking in the supply channel. To construct the required dependencies of developed vortex regulator, according to the calculations, it is necessary to maintain a constant pressure P_{supply} = 2 bar in a supply channel, and adjust control pressure in the range of 2…4.25 bar also it is necessary to measure the $Q_{control}$ and Q_{out} of a regulator. Provision of these parameters is achieved as follows: M3 gas pressure in the supply channel is maintained constant by a regulator diaphragm РД. Gas from the receiver P of reciprocating compressor PC through the Ф1 filter and diaphragm regulator РД enters the sphere-balloon OP and further through an electronic flow meter P1 enters the vortex regulator supply channel. M5 control pressure varies with the help of smooth throttling by valve B9. An outlet flow controls by differential pressure flowmeter P2. Preliminary was performed pre-calibration of flowmeter P2. The electronic flowmeter P1 (PF2A706H with measurement range 300-6000 l /min) was chosen as a model of the flowmeter. Calibration was performed by sequentially connecting flowmeters P1 and P2. As a result of calibration obtained curve of dependence of height differential Δh liquid columns in the U-shaped differential manometer P2 meter aperture from Q_{out} of the flowmeter. Explicitly measure control consumption with the help of P1 flowmeter is not possible, because $Q_{control}$ can reach lower values than the measuring range of the flowmeter P1. In this regard, the control flow value measured indirectly, as the difference between the flow at the outlet of the regulator and the supply consumption: $Q_{control} = Q_{out} - Q_{supply}$.

To provide better measurement' accuracy stand is equipped with pressure sensors (ДД1...ДД5) as well as with additional channels of supply B5 and B6.

4. Results of experiment

The experiment was conducted as follows: the supply pressure was kept constant at 2 bar, and control pressure ranges from 1.75...4.25 bar in increments of 0.1 bar. With the help of the flow meter P2 and pressure gauge M5 readings were taken at the output flow and pressure control, respectively. Analogously were obtained experimental values of the flow output from the pressure control while maintaining constant supply pressure of 1.5 bar, 1.75 bar. and 2 bar (Fig. 4).

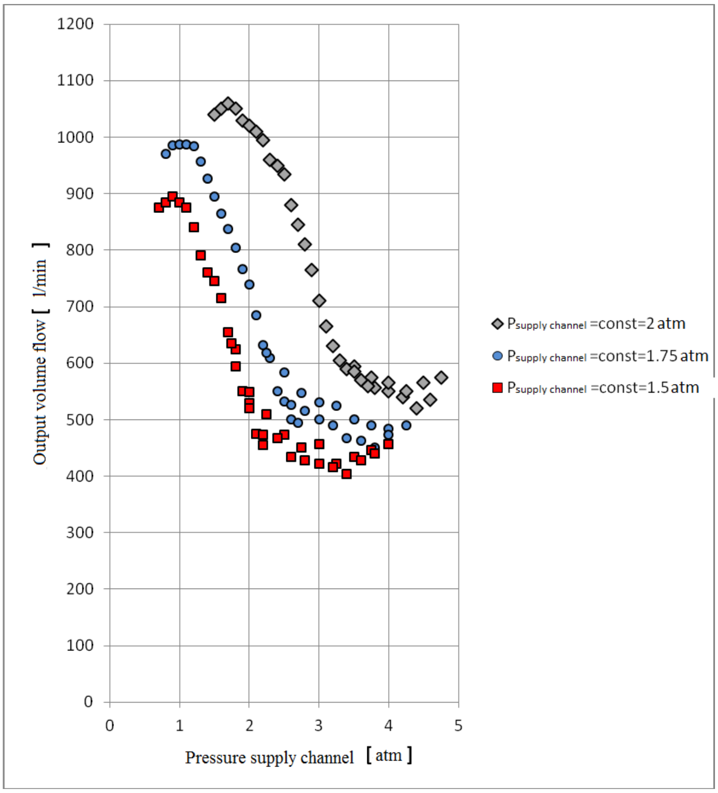

Fig. 4. Dependence the outlet flow from control pressure.

To confirm the calculated pressure control value at which the lock of supply channel will occur, a monogram of dependence of flow at the outlet from the flow control consumption was built (Fig. 5).

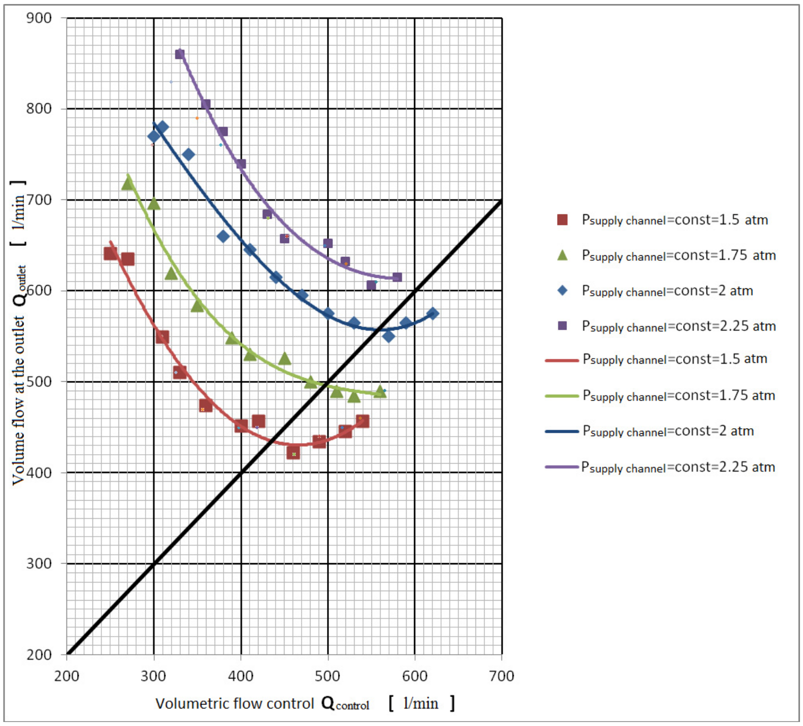

Fig. 5. The dependence of flow at the outlet from the flow control consumption at different supply pressures.

Monogram represents a family of specifications $Q_{out} = f(Q_{control})$ for a variety of supply pressures.

By connecting the dots at constant control pressure $P_{control}$ = const we will obtain the dependence of the flow at the outlet from the flow control with different control pressures (Fig. 6).

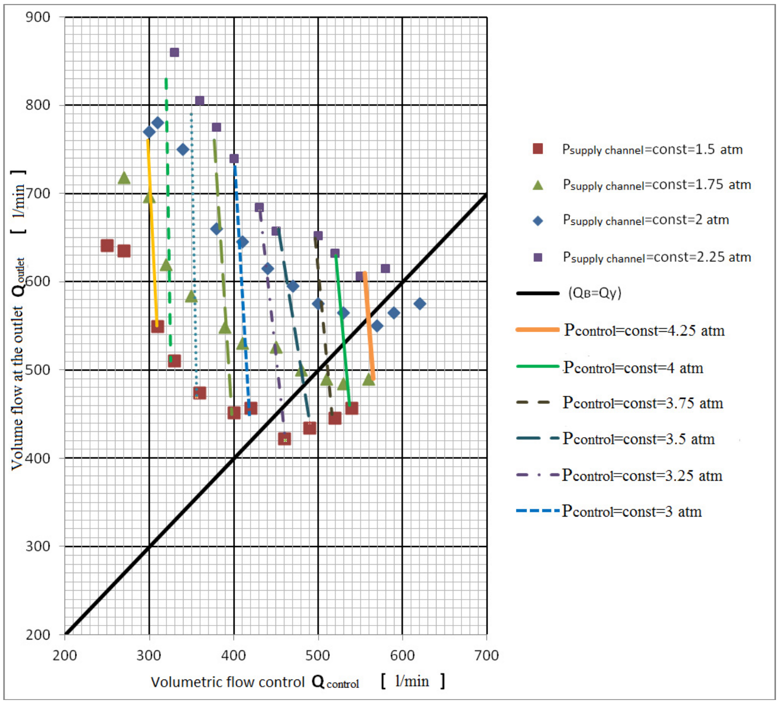

Fig. 6. Dependence of the flow at the outlet of the flow control for different values of the control pressure.

Dot that characterizes the time of closing the supply channel by flow control is the point of intersection of the characteristics $Q_{out} = f(Q_{control})$ at a constant pressure of 2 bar with straight $Q_{out} = Q_{control}$.

This point, according to the monogram in Fig. 5 corresponds to the locking control flow $Q_{control}$ = 560 l/min. This point on the monogram Fig. 6 corresponds to a pressure control 4.25 bar.

Consequently, according to the experiment, locking occurs at a higher control pressure than the settled control pressure (equal to 4.25 bar). This can be explained by imperfection of 3D prototyping devices, namely the roughness of the walls of the vortex chamber, since this factor in the mathematical model are not taken into account. After the interaction of the gas stream in the real vortex chamber occurs greater dissipation of control stream than in the mathematical model, which does not consider rough walls of the vortex chamber. The error of calculation is $\Delta = \frac{p_{\text{control.exp}} - p_{\text{control.calc}}}{p_{\text{control.exp}}} \cdot 100\% = \frac{4.25-4}{4} = 6.25\%$ that is valid for gas-dynamic calculation.

5. Conclusion.

The patent review was carried out, the issue status on the application and development of vortex regulators was examined up to the date, the diagram of the vortex regulator was designed as result of this work. The three-dimensional model was developed basing on the analysis and preliminary numerical calculation of the gas flow in the working cavity of the vortex control. Prototype of the vortex regulator was constructed by using of the application of additive technologies. The test stand for testing the vortex regulator was created. According to the results of an experimental study for the regulator nomograms were constructed Fig. 5, Fig. 6 which helps to determine the control flow at which the effect of locking the vortex regulator $Q_{control}$ at different values of the supply pressure. Moreover, the experimental locking pressure value was compared to the values obtained by numerical calculation. The error of calculation was 6.25%, which confirms the adequacy of the mathematical model.

References

[1] L.A. Zalmanzon, Theory elements pnevmonics, Science, Moscow, 1969.
[2] I.V. Lebedev, S.L. Treskunov, V.S. Yakovenko, Elements of jet automation, Mechanical engineering, Moscow, 1973, pp. 289–314.
[3] V.F. Bugaenko, Pneumatic automation of rocket and space systems, in: V.S. Budnik (Eds.), Mechanical Engineering, Moscow, 1979.
[4] Proceedings of the Moscow Higher Technical School №244. Investigation and calculation of ink jet elements and circuits of automatic control systems. 1977.
[5] O.V. Belova, A.A. Starodubtsev, A.V. Chernyshev, Calculation of the vortex gas pressure regulator, Engineering Journal: Science and Innovation, 2013, available at: http://engbul.bmstu.ru/doc/740398.html. (Accessed 5 May 2016).
[6] O.V. Belova, A.A. Starodubtsev, A.V. Chernyshev, Swirling the gas pressure regulator, Engineering Journal: Science and Innovation, 2014, vol. 5, available at:: http://engbul.bmstu.ru/doc/740398.html. (Accessed 5 May 2016).
[7] US4887628, Fluidic apparatus.
[8] US3488975, Refrigeration flow controller employing a vortex amplifier.
[9] US5063733, Engine cooling system protection device.
[10] US3417772, Rocket motor propellant injection system.
[11] US3545468, Liquid level controller employing vortex valve.
[12] US4584930, Ventilation systems for glove boxes.
[13] US3195303, Vortex valve.
[14] US3717176, Hydraulic valve.
[15] US4413795, Fluidic thruster control and method.
[16] US3612442, Fluidic proportional thruster system.
[17] US3324891, Flow regulator.
[18] US3366370, Control apparatus.
[19] US3515158, Pure fluidic flow regulating system.
[20] US3654943, Vortex fluid amplifier circuit for controlling flow of electrically conductive fluid.
[21] US3707159, Fluid pressure ration sensing device.
[22] US3722522, Vortex fluid amplifier with noise suppresser.
[23] US7712317, Flow control systems.
[24] SU1434141, Hydraulic system.
[25] SU842239, The vortex amplifier.
[26] SU1305457, The vortex amplifier.
[27] SU1298433, The vortex amplifier.
[28] SU510593, Jet vortex amplifier.
[29] SU744155, The vortex amplifier.
[30] SU363817, The vortex amplifier.
[31] SU586423, The vortex flow regulator.
[32] RU36904, Hydraulic vortex regulator.