Hydraulic shock suppression mechanism of the hydraulic drive

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Abstract. Researches show that hydraulic shock provokes premature destruction of hydraulic drive high-pressure hoses and unauthorized emission of working fluid into the atmosphere, resulting in environmental pollution. There are ways to protect the machines hydraulic transmission based on the principle of automatic disconnection from the working fluid supply at the hoses damage. However, well known protecting methods do not solve the mentioned problem completely as the hydrodynamic alternating loads caused by hydraulic impact at operation activating when the closing device of the hydraulic drive protecting system do not only destroy the hoses, but also lead to oscillatory process of the locking device shutter, decrease in speed of locking device operation, increase in closing time of the damaged hydraulic line and consequentially increase in a working liquid losses at a high pressure hoses destruction. To eliminate the above-mentioned deficiencies, theoretical and experimental research of the devices parametric characteristics was carried out and a new technical solution was developed which provides increase of closing device functional use while the cotemporaneous design simplifying.

For model formation of the hydraulic drive optimal scheme protection the existing protection methods analysis of the hydraulic drive [1,2], conditions and modes of the hydraulic transmission operation, and also lacks and advantages of various pipeline systems designs [3,4] and devices was carried out. [5–15].

Researches of parametrical properties of hydraulic transmission closing devices design show that the shut-off device is the most effective on functional purpose and it is equipped with the pneumatic camera intended for absorption of hydraulic shock energy at operation of the shut-off device [13 – 15]. Figure 1 presents the design prototype [13 – 14] of the hydraulic drive shut-off device protection system, which synthesizes the properties of the elements allowing to satisfy maximum requirements of ecological safety for the use of working machines equipped with the hydraulic drive.

In the hydraulic drive protection system, the pressure drop principle at the shut-off device working fluid inlet and outlet by the high-pressure hoses collapsing was used. The shutoff mechanism of the damaged hydraulic line is carried out by a plunger, which does not only block the pressure pipe during its destruction, but also ensures the working fluid drain into the hydraulic tank. In this case, a pneumatic cell is used to absorb the ballistic wave energy arising when a shut-off device is triggered in the shutoff structure of the hydraulic drive protection system.

The protection system of the hydraulic drive includes the hydraulic tank 1, connected to the feeding pump 2 by the pressure solid-metal hydraulic line 3, which has the strength providing the working
pressure of the hydraulic drive in the range of 20 – 45 MPa, drain into the hydraulic tank gyro line 4, hydraulic control valve 5 to control the flow of working fluid into the piston or rod end of the hydraulic motor 6 and on drain to the hydraulic tank and shut-off device 7.

Figure 1. Hydraulic drive shut-off device with pneumonic cell hydraulic strut. 1 - hydraulic tank, 2 - pump, 3 - pressure pipe, 4 - drain line, 5 - distributor, 6 - hydraulic motor, 7 – shut-off device, 8 - framework, 9 - inlet nozzle, 10 - outlet nozzle, 11 - drain nozzle, 12 - seal plate, 13 – plunger, 14 - circular groove, 15 - radial holes, 16 - axial channel, 17 – valve cone, 18 – spring-loaded valve, 19 - valve head, 20 - valve collar, 21,22 - spring, 23 - pneumatic cell, 24 - cover, 25 – seal plate hemisphere, 26 - cover hemisphere, 27,28 - screen, 29 - valve screw joint, 30 - plate, 31 - ring, 32 - pressure nipple, 33 - screw, 34 - hydraulic strut.
The framework 8 of the shut-off device is equipped with an inlet nozzle 9 attached to a solid-metal pressure pipe, an outlet nozzle 10 attached to a hydraulic drive by a flexible high-pressure hose, an outlet nozzle 11, a connecting channel through an outlet hydraulic line with a hydraulic tank, and a locking seal 12. The plunger 13 is situated in the inlet chamber A, on its outer surface a circular groove 14 is made at the distance from the drain adapter axis 11, equal to t and radial holes 15 at the distance from the vertical axis of the drain nozzle 11, equal also to the full stroke t of the plunger. In the framework output chamber B the plunger is located from the seal plate paving block at the distance of its full stroke t. The input chamber A is connected with the output chamber B and the channel C of the output nozzle10 by the means of axial channel 16 with valve cone 17 which is blocked by the valve 18. The valve is equipped with cone 19 and valve collar 20 designed for spring support. The springs 21, 22 and camera 23 are the elastic elements for plunger and valve respectively.

Pneumatic cell 23 is formed by an airtight chamber D located between seal plate 12 and cover 24, the surfaces of which are made in the hemisphere form 25 and 26, designed to absorb the energy of a hydraulic shock during the shut-off device operation. The cell chamber contains screens 27 and 28 made from elastic material. The screen 27 is fixedly connected to the valve screw joint 29, and the screen 28 is protected on both its sides by plates 30 to prevent its damage on the edge of the chamber E of hydraulic strut.

The ring 31 for the pressure nipple 32 fitting is installed between the seal plate and the cover. The seal plate, cover, screens and the ring are interconnected by screws 33. In addition, the cover is provided with a nozzle 34 for filling the E chamber with working fluid.

In the neutral position of the hydraulic control valve and inactive hydraulic drive, the pressure of the working fluid in the framework chambers A, B is the same, close to the atmospheric pressure, as the plunger is in the leftmost position, and the valve is in the equilibrium state under the spring action and the pressure force on the valve, created in the blind chamber D and E of the cell. In this case, the working fluid from the chamber A through the plunger axial channel, chamber B, the outlet nozzle channel B, the overflow valve of the hydraulic control valve and the drain hydraulic line circulate between the pump and the hydraulic tank.

When the hydraulic control valve is turned on to raise or lower the working equipment, the working fluid through the inlet channel of the plunger and the passage section x from the inlet cavity A enters the outlet cavity B and feeds the hydraulic drive under the working pressure through the channel B of the outlet nozzle. In this case, the pressure in the cavities A and B is the same and close to the nominal. The strut on the plunger from the inlet cavity A side is compensated by the spring, and the valve from the cavity B side is compensated by the pressure from the chamber D.

When the flexible hydraulic pressure hoses of the hydraulic drive break, the pressure in the outlet cavity B instantly drops due to the pressure drop of the working fluid in the cavities A and B, the plunger, overcoming the spring resistance, closes the passage section x between the axial channel of the plunger and the valve. The pressure drop in the cavities A and B is accompanied by a hydraulic shock, its shock wave energy leads to alternating loads on the valve and the plunger channel cone, to the oscillatory process of the plunger, mutual repetitive shock loads during the shock wave attenuation.

The hydraulic shock energy is absorbed by the chamber located between the valve and the hydraulic strut G. This reduces the dynamic influence on the contact surface of the plunger channel cone and the conical surface of the valve, and the contact belt formed by the surface of the cone and the valve head reduces the specific pressure in the closed position of the valve, which contributes to decrease in shock load and accordingly to valve wear.

A disadvantage of the hydraulic drive protection system is the fact that the valve is balanced by elastic elements duplicating each other: a gas chamber absorbing the energy of the shock wave when the shut-off device is triggered and a pressure hydraulic line is present, the chamber strut via the nozzle located in the chamber cover. At the same time, the high pressure hoses of the pressure support
hydraulic line, the membrane located on the inner spherical surfaces of the stop and the chamber cover, are also subjected to fatigue failure.

The disadvantage of the hydraulic drive protection system is that the ring intended for the installation of the nipple, the membrane located on the inner spherical surface of the chamber cover, the nozzle of the hydraulic seal of the gas chamber and the hydraulic line connecting the mentioned nozzle and hydraulic pump complicate the design of the hydraulic drive protection system, increase the material consumption, manufacturing cost and economic costs.

To eliminate the above-mentioned disadvantages in the hydraulic drive protection system design (Figure 2) [15], the shut-off device was modernized. In the proposed design, the outer surface of the seal plate 12 and the inner surface of the cover 23 are made in the form of hemispheres 24 and 25, respectively, forming a pressure-proof chamber G filled with gas, the purpose of which is similar to the prototype (Figure 1). The outer surface of the seal plate 12 is provided with a membrane 26 fixedly connected to the valve 18 spring rod 19 screw joint 27 protected on both sides by plates 28 made of durable material. A screw hole is made on the cover 23 of the seal plate 12 for mounting a nipple 29 intended to fill the chamber with the gas. In addition, the nozzle, the seal plate cover membrane, the strut hydraulic line cavity of the gas chamber and the ring are excluded from the design of the prototype [13-14] (Figure 1).

However, in the design (Figure 2), even with the significant modernization, common disadvantages are revealed. For example, if the discharge nipple installed on the seal plate cover for filling the chamber with the gas malfunctions, gas will leak into the atmosphere and, as the result, the pressure in the gas chamber and damping properties will drop, the absorption energy of the hydraulic shock will be reduced, which mitigates the plunger from oscillating, reducing reliable closure of the shut-off device outlet nozzle channel during the destruction of the high pressure hoses, and will lead to an unauthorized leakage of the working fluid from the outlet cavity of the device into the atmosphere.

Also, in the case of fatigue failure of the membrane in the gas chamber, its functional purpose will be lost, that is, the absorption of the hydraulic stroke energy when the shut-off device of the hydraulic drive protection system is triggered and, as the result, the oscillation process of the plunger is preserved, which will negatively affect the reliability of the shut-off device output channel closure. In this case, there will be a loss of the gas chamber depreciation properties as an elastic element, and the valve will be excluded from the working process, which will also lead to an unstable position of the plunger at the moment of the outlet nozzle channel closure and leakage of the working fluid into the atmosphere.

A disadvantage is the fact that a closed incompressible volume of the working fluid formed between the seal plate and the plunger at the end of its stroke will impede the movement of the plunger and lead to an oscillatory process caused by hydraulic stroke arising during the actuation of the shut-off device and the unstable position of the plunger in the moment of the outlet nozzle channel lock-up, and, as the result, will lead to the working fluid leakage into the atmosphere.

Also, the drawback of the hydraulic drive protection system is the complexity of the hydraulic drive protection system design due to the valve screw attachment to the membrane and the cover to the seal plate, the presence of a nipple for pumping gas into the chamber cavity.
Figure 2. Hydraulic sealer of the hydraulic drive protection system, 1- hydraulic tank, 2- pump, 3- pressure hydraulic line, 4- discharge line, 5- control valve, 6- hydraulic motor, 7- shut-off device, 8- framework, 9- inlet nozzle, 10- outlet nozzle, 11- drain nozzle, 12-seal plate, 13- plunger, 14- circular groove, 15- radial holes, 16- axial channel, 17- valve cone, 18- spring-loaded valve, 19- valve pin, 20- valve collar, 21, 22- spring, 23- pneumatic cell, 24- seal plate hemisphere, 25- cover hemisphere, 26- screen, 27- screw joint, 28- plate, 29- presse nipple, 30- screw.
Based on the analysis of the shut-off device of the hydraulic drive protection system (Figure 1, 2), the authors improved the design of the pneumatic cell and proposed a fundamentally new technical design [16].

**Figure 3.** Hydraulic drive shut-off device. 1- hydraulic tank, 2- pump, 3- shut-off device, 4- control valve, 5- hydraulic motor, 6- solid-metal pressure hydraulic line, 7,8- high pressure flexible hose, 9- control valve drain hydraulic line, 10- shut-off device drain hydraulic line, 11- shut-off device framework, 12- spring-loaded plunger, 13- seal plate, 14- valve pin, 15-17 nozzle, 18- radial holes, 19- circular groove, 20- spring, 21- toroid, 23- cover, 24- valve, 25- collar.

The proposed design (Figure 3) of the shut-off device allows to increase the functional purpose of the hydraulic drive protection and the hydraulic drive operational reliability while reducing operating costs due to the additional channel in the plunger 12 and the improvement of the pneumatic cell.

In this regard, an elastic element 21 is placed in the chamber P of the seal plate 13, made from an elastic material in the form of a toroid, the chamber H of which is filled with an inert gas, for example, air or nitrogen. The toroid, as an autonomous elastic element, has high reliability and while maintaining its functional purpose, provides absorption of hydraulic shock energy when the hydraulic drive protection system shut-off device is triggered and increases the operational reliability of the device as a whole.

To exclude the toroid 21 mechanical damage during its deformation in a hermetically sealed screw cover 23, chamber P of the seal plate 13, between the valve pin paving block 14 elastic element 21 a
safety pressure plate 22 is installed which is in contact with the valve pin 14, which transfers force to a safety pressure plate 22 and an elastic member 21, respectively.

Thus, the proposed technical design in comparison with the hydraulic drive protection system according to the prototype, due to the elastic element made from an elastic material having the shape of a toroid filled with inert gas and an additional channel in the plunger, connecting the input and output chambers of the shut-off device designed to displace the closed incompressible working fluid volume generated between the plunger and the seal plate at the end of the plunger stroke, into the inlet chamber, the hydraulic drive system operational reliability protection from unauthorized working fluid release into the atmosphere during the high pressure hoses collapse and environmental safety of the hydraulic machines use, while the device design simplifying is ensured.

References
[1] Fomenko V N 2000 Razrabotka Sistem Zashchity Gidroprivodov Mekhanizmov Naveski Tyagovyykh i Spetsialnykh Transportnykh Mashin (Thesis for the degree of candidate of technical Sciences, Volgograd) pp 4-8.
[2] Burlachenko O V Serdobintsev Yu P Skhirtladze A A 2010 Povyshenie Kachestva Funktsionirovaniya Tekhnologicheskogo Oborudovaniya (Staryi Oskol, TNT).
[3] Fomenko N A Bogdanov V I Fomenko V N Truboprovod vysokogo davleniya, pat RU 2511926 C2F15B20/00 (2006.01)
[4] Manujlov V Yu Ershov O B Kurmanbaev A E Sistema zashchity gidroprivoda pat SU 1605046 (51)5F15B20/00.
[5] Pyndak V I Strokov V L Lapynin Yu G etc 1999 Nauka -proizvodstvu M: Mashinostroyeniye 10.
[6] Perelmiter V I Giravlicheskaya sistema pat SU 1822471 A3 F15B20/00.
[7] Burshtejn R S Velickij I S Balaklo V N Gidropivod, cop. cert. SU №1071830 F15B20/00
[8] Bobkov Yu K Shevchuk V P Chernishov V G Sposob zashchity gidroprivod, pat. SU 1550255 A1 F15B20/00.
[9] Boyarkina I V Ustrojstvo zashchity gidroprivoda frontal'nogo pogruzchika pat № 2342496 E02F9/22.
[10] Burshtejn R S Velickij I S Balaklo V N Gidropivod, cop. cert. SU №1071830 F15B20/00
[11] Kukovickij F G Taskaev V V Sistema zashchity gidroprivod, cop. cert. SU 606016 F15B20/00
[12] Manujlov V.YU cop. cert. Gidropivod, pat SU №1267072 F15B20/00.
[13] Fomenko N A Bogdanov V I Fomenko V N Bogdanov S A Sistema zashchity gidroprivod, pat RU 2571240 C1F15B20/00 (2006.01).
[14] Fomenko N A Burlachenko O V Fomenko V N Sistema zashchity gidroprivod, pat RU 2642914 C1F15B20/00 (2006.01).
[15] Fomenko N A Burlachenko O V Fomenko V N Sistema zashchity gidroprivod, pat RU 2634996 C1F15B20/00 (2006.01).
[16] Fomenko N A Burlachenko O V Fomenko V N Sistema zashchity gidroprivod, pat RU 2700484 C1F15B20/00 (2006.01).