Economic and theoretical study of the power supply from a pump-battery based on a discharge machine

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Abstract. The article discusses the control system of a hydraulic power source of constant pressure, which is a pump-storage power source, equipped with the original design of the automatic unloading of the hydraulic pump, which provides relay switching of its operation mode. A mathematical model is proposed, obtained using a modeling technique based on the application of the theory of volumetric rigidity of hydraulic systems and their elements. The results of a numerical experiment carried out by numerically solving the equations that make up the mathematical model of a power source are also presented. As a result of a numerical experiment, the main technical capabilities of the considered power source and the influence of its main structural parameters and functional features of the system on operational properties are revealed. The results showed that due to changes in various design parameters of the unloading machine, you can not only change the upper (maximum) and lower (minimum) values of the battery charging pressure, but also adjust their difference depending on the requirements for the power source.

1 Introduction

Some believe that the use of hybrid models is most effective by combining the precise and energy-efficient operation of an electric motor with the well-established ability of hydraulic systems to create pressure. And all this at a price average for both types of installations. They are also alternatives to knee link systems for those molders who prefer to “feel” directly the direct hydraulic compression of the mold. (It is said that some non-lever electric clamping devices of “direct pressure” have such an advantage).

Hybrid designs began at first to be created simply by “electrifying” the screw plasticizers, “the largest energy absorbers,” according to Hicks of Sumitomo. Suppliers of all types of installations say that this statement remains true for all types of installations. When working on a typical hydraulic press, “less than 21% of the energy is spent on injection. About 7% goes to the clamping device, and another 5% to the extraction,” explains Hicks. “Thus, 66% of the energy that can be used to extract the screw remains. At

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each stage, savings are possible when using electrical technology. ” Nevertheless, it is obvious that the most cost-effective separate step is the “electrification” of screw rotation, which, according to sources from Battenfeld and other manufacturers, increases injection uniformity and also improves control of screw speed and back pressure.

For these reasons, Boy Machines, a staunch adherent of hydraulic technology, offers an electrically powered auger option on the market. And at Husky they say that their Hybrid and Hypac hybrid presses, which are hydraulic with the exception of the auger drive, currently account for 70% of the company's sales (excluding PET preforms).

The category of hybrids has expanded and now includes several design configurations with various hybrids of hydraulic and electrical functions, in particular, some installations from Demag, Meiki, Mitsubishi, and Sodick, which are equipped with an electric movement of the clamping device, but a self-functioning hydraulic system in the moving plate to create pressure clamping device. They use a small amount of oil and a short-stroke clamping cylinder for high speed and energy efficiency. However, Krauss-Maffei abandoned this design because of its relative high cost.

Some so-called hybrid plants use technology that has been around for 20 years and has been used to increase the efficiency of hydraulic presses: replacing a fixed speed DC pump motor drive with a variable speed AC drive. Thanks to this, the pump only works when there is a need for it (like an electric servomotor), and pumps only the necessary amount of oil. This technology is used in hybrid plants of companies such as: Mitsubishi, Milacron, Nissei, and Demag.

In fact, the new Nissei FNX series of hybrids is a hydraulic series with an X servo pump. It is reported that this modification of the hydraulic press uses 55% less oil and 40% less energy than the traditional hydraulic system from the Nissei FN series. The installation gives an injection response time of 40 milliseconds, which, according to available data, is comparable to the high response rate of an electrical installation, as well as an injection rate of 400 mm per second, which is almost 50% higher than that of a hydraulic installation. Unlike claims from other suppliers, Nissei claims that its facilities have logistical benefits because they are equipped with parts such as ballscrews that wear out more often than others. FNX already accounts for 15% of Nissei's global sales, compared with 47.5% for electrical installations and 37.5% for hydraulic. Hydraulic power sources used in modern technological equipment and mobile machines are usually of two types - power sources for constant flow of working fluid and power sources for constant pressure. Among the constant pressure power sources, the most widely used are pump-accumulator hydraulic power sources, operating as follows. The working fluid from the flow source (pump) is supplied to the consumer, at the inlet of which a hydraulic accumulator is installed. When the consumer is operating, its power is supplied from the battery, in which the pump compensates for the loss of liquid and, thus, at the inlet to the consumer, the pressure is always maintained at the same level - equal to the pressure in the battery.

The disadvantage of such power sources is that when the consumer is not working, the battery is recharged and the safety valve opens, on which all the energy transmitted by the pump fluid is lost. In order to prevent the safety valve from tripping, the so-called relief valves [1] are used, which automatically open when the pressure at the pump outlet reaches the specified maximum (upper) value, ensuring idle operation. The consumer at this time works due to the energy stored in the battery. If the pressure in the accumulator drops below a predetermined minimum (lower) value, the discharge valve closes, putting the pump into operation.

Most of the currently known relief valves have significant dimensions and weight, are complex in design, but most importantly, as operating experience shows, they tend to freeze - stop the shut-off element in the intermediate position when the pressure in the hydraulic system and the pressure drop on the closing or opening shut-off valve are the same. In this

case, throttling occurs on the shut-off element of the overflow valve, which leads to significant energy losses and heating of the working fluid.

2 Methods

The creation and design of hydraulic drives is connected with the fundamentals of the force interaction between a liquid and a solid and provides such advantages as: developed large forces and capacities with small dimensions, flexibility, simplicity and subtlety of regulation, protection against overloads, high reliability.

As a hydraulic drive, mainly high pressure plunger pumps and, in rare cases, multistage centrifugal pumps are used.

In order to reduce the power of electric motors driving powerful high-speed hydraulic drives, high-pressure liquid accumulators (pump-battery drive) are used.

In addition to pumps, for some types of drives, simple devices are also used - multipliers that work with steam, compressed air, an electric pump or an electromechanical transmission.

In a hydraulic reciprocating drive, the full cycle of work is divided into idle, working and returning the actuator and the operation of auxiliary devices. Moreover, the indicated stroke of the hydraulic reciprocating drive can be carried out using various drives.

Hydraulic drives for idling are often equipped with filling tanks with low-pressure liquid. Filling tanks are closed, the liquid in which is under the pressure of compressed air, or open, installed above the level of the working cylinder. Along with filling tanks, small cylinders and low pressure pumps are also used for idling.

2.1 Non-accumulator pump drive

With a pump drive without battery, high-pressure fluids of the speed of the plungers have a definite value corresponding to the pump flow, and the pressure on the pump flange corresponds to the force acting on the actuator.

The work developed by the pump corresponds to the useful work performed by the drive.

The non-accumulating pump drive has a high efficiency; its average value during the stroke in modern hydraulic drives is 0.6-0.8. The pressure in the hydraulic system is precisely controlled.

The ability to control the pressure can be used to control the actuator, that is, the maximum pressure in various periods of operation can be used as pulses for switching control equipment. The hydraulic system is not constantly under pressure, which facilitates the operation of the drive. It also has a relatively small size.

Along with the indicated advantages, a non-accumulator pump drive has the disadvantage that the power of the pumps with this drive is selected according to the maximum power of the driven mechanism.

For mechanisms developing great efforts and operating at high speeds, the pump powers are excessively large.

The pump motor power is also calculated from the maximum drive power, since with a non-accumulator pump drive mainly high-speed pumps are used, which are directly connected to the motor shaft.

The operating speed of the actuator with a pump drive rarely exceeds 50 mm / s;

In hydraulic drives intended for certain technological operations, during the implementation of which the force increases sharply at the end of the stroke, and for the most part it remains much less than the maximum, it is advisable to use a variable-flow pump.

2.2 Battery-driven drive

The presence in the hydraulic system of the accumulator allows the hydraulic drive to consume a large amount of liquid in a relatively short time and, therefore, the operation of the hydraulic drive with high speeds of its body. The stroke speed in hydraulic drives with a pump-accumulator power source reaches 5 m / s or more.

The presence of a battery in the hydraulic system changes the fundamental characteristic of the pump drive.

In hydraulic drives with a battery, the speed of the moving parts during the working stroke depends on the resistance it overcomes. The amount of energy consumed by the hydraulic actuator during the stroke depends on the stroke size and does not depend on the nature of the change in resistance, since it consumes a liquid of almost constant pressure.

The efficiency of a hydraulic drive with a battery, taking into account fluid friction losses in the pipeline and in the controls, has an average value that is many times lower compared to a hydraulic drive with a non-accumulator pump drive. Its value is the lower, the less resistance the moving parts of the hydraulic drive overcome.

When there is no load, all the energy given off by the battery is spent mainly on overcoming the friction resistance of the liquid in the pipeline.

Loss of energy due to deformation of the system (liquid, bed, etc.) is twice as much with a pump-accumulator drive compared with losses with a non-accumulator pump drive.

Thus, the pump-accumulator drive has significantly better speed characteristics compared to the pump drive, but at the same time, greater energy loss than that of the pump drive.

In this paper, we propose to consider a system for automatic control of a constant pressure power source equipped with a hydraulic pump unloading machine [2, 3], which contains a differential valve, which virtually eliminates the likelihood of the operation of the unloading machine in hovering mode. The article also provides information about the device of the proposed unloading machine, its mathematical model and the results of studies carried out in the form of a numerical experiment.

The power supply circuit equipped with the proposed automatic unloading of the hydraulic pump is shown in Figure 1. Its operation is as follows. The working fluid from the hydraulic pump 1 through the check valve 2 is directed to the consumer. If the supply of the hydraulic pump is greater than the flow rate of the working fluid used by the consumer, then its excess is sent to the hydraulic accumulator 3, the pressure of which rises. If the pressure at the inlet to the hydraulic accumulator 3 (pressure at point 2 of the hydraulic system) exceeds the setting pressure of the shutter of the regulator 10 of the unloading machine, then its shutter will move to the right and part of the working fluid will go to the control chamber 8 of the unloading machine, the pressure of which will increase, which will lead to moving the plunger 7 to the right and opening the shutter 5 of the drain line of the unloading machine, and therefore the working fluid from the pump under drain pressure through the channel 1-6-7-8-9 will go to the drain tank 4 - the hydraulic pump is unloaded.

Fig. 1. Hydraulic diagram of a battery pack with automatic discharge.

The non-return valve 2 in this case will close and the consumer will only be supplied with the liquid in the hydraulic accumulator 3. The pressure in the hydraulic accumulator 3 will decrease, which will lead to the outflow of the working fluid through the non-return valve 11 from the control chamber 8, and, accordingly, to close the shutter of the overflow valve 5. The pump returns to operating mode.

The dynamics of the pump-accumulator power supply equipped with the proposed unloading machine can be represented by a system of differential equations describing the behavior of various elements of the system in the process of its transition from one stationary state to another. To describe the functioning of the hydraulic system of the power supply under unsteady conditions, we use a technique based on the concept of volumetric stiffness of the hydraulic system [4 ,6,8,9], which makes it possible to calculate the behavior of the drive system in real time with subsequent analysis of its operational properties, identifying , the influence of design features and technological features of the system on its properties [3,5,7]. Mathematical models developed using the theory of volumetric rigidity greatly simplify and accelerate the analysis of hydraulic drive systems, which makes it possible to use the “partial synthesis method” in designing [6,8], which greatly simplifies the design process and improves its quality.

3 Results

In order to identify the main functional capabilities of the control system of the pump-accumulator hydraulic power source equipped with a pump unloading machine of the proposed design, a numerical experiment was carried out. The experiment was a numerical solution of the above mathematical model of a power source. During the experiment, the influence of various structural parameters of the hydraulic pump unloading machine and the functional parameters of the power supply system as a whole on its dynamic properties was revealed.

4 Discussion

The results showed that the functional properties of a power source equipped with an unloading machine are most affected by the force of the pre-compression of the working

spring 6, the outer diameter of the shutter of the regulator 10 and the diameter of the plunger 7.

At the same time, a change in the force of pre-compression of the spring 6 and the diameter of the plunger 7 leads to a change in both the value of the upper pressure of the trigger of the unloading machine, and the difference between the upper and lower pressure of the trigger.

A change in the outer diameter of the shutter of the regulator 10 and a change in the force of the pre-compression of the spring of the shutter of the regulator 9 leads to a change in only the value of the upper operating pressure, leaving its lower value unchanged.

The main property of a power source with an automatic unloading device of the proposed design, confirmed as a result of a numerical experiment, is that the automatic unloading device provides a clear relay switching of the pump operation mode from unloading to operating mode and vice versa.

Thus, the proposed design of the hydraulic pump unloading machine ensures the operation of the pump-accumulator power supply of the hydraulic actuator in a given mode with a high degree of on and off accuracy at specified upper and lower pressure values. In order to set the response interval of the unloading machine and the value of the upper (lower) response pressure, it is most convenient to use the setting of the pre-compression force of the spring 6, as well as the shutter spring of the regulator 9, which can be adjusted during assembly, or create a regulator design with the ability to control these forces during operation of the machine unloading.

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