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High-Pressure Positive-Displacement Hydraulic Pumps in Concrete Sample Testing Machines

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Abstract: This article discusses a way to solve the problem of operational quality control of concrete in the construction of critical structures with the use of small-sized testing machines. To reduce the testing machines size, it is proposed to use a high-pressure hydraulic drive. As a promising way to control the machine, the practical experience is described of using a pump with a constant displacement, the drive of which uses an electronic frequency converter.

Introduction

In the construction of hydroelectric power plants (HPP), the quality of concrete is of great importance, since it largely determines the strength of all supporting structures. It is equally important to ensure a short construction time. In this regard, an urgent task is to carry out operational control measures. As practice shows, methods based on the control of the chemical composition of the mixture are not sufficiently effective and reliable. Therefore, methods based on the destruction of control samples remain the most acceptable [1–10]. In this case, verification of compliance of the material with the requirements occurs during testing of the samples for compression, bending, tension and a number of other indicators, on which the durability and bearing capacity of the structures depend.

Currently, these activities are usually carried out in specialized laboratories, since they require special testing equipment. However, this approach leads to a significant increase in the time required for quality control, which is due to the need to deliver samples to the testing laboratory, process delivery, etc. In these conditions, the use of small-sized testing machines that meet modern standards and can be used in temporary laboratories directly at the construction site is promising.

Methods

The specifics of the testing machines allows us to divide them into two main classes: tensile testing machines and compression testing machines. These classes differ significantly in terms of the speed of working body movement, and the requirements for the measured parameters. This article considers only compression testing machines for concrete samples [11–19]. Also promising is the modernization of other types of testing machines and technological devices, for example, machines for pre jacking.

Testing directly at a construction site in a temporary building requires the use of small-sized testing machines. Moreover, such machines must fully comply with the requirements of the standard[2]. In addition, the use of high-strength concrete in construction makes it necessary to test samples with a breaking force of up to 1000 kN inclusive. The need to ensure minimum dimensions with significant developed forces requires a transition to high working pressures in the hydraulic drive of testing machines. At the same time, a pressure level of 60 MPa and higher is considered promising.

In addition to the above requirements, the design of small-sized testing machines should have a low cost, not require a significant amount of routine maintenance on the hydraulic system, and therefore the level of staff qualification can be lowered.

In the process of testing, continuous loading of the samples should be implemented at a rate that ensures an increase in the design stress in the sample until it is completely destroyed within (0.05±0.02) MPa with automatic measurement of forces [2]. At present, it is not particularly difficult to solve the problem of ensuring the necessary measurement accuracy. At the same time, the need to control the pressure in the hydraulic drive of the loading device for a wide range of efforts faces the problem of the shortage of available high-pressure proportional hydraulic equipment necessary for the implementation of regulation.

In the study of the possibility of creating small-sized testing machines in order to reduce costs, it was considered equipped with typical purchased items. The current situation in the domestic market of hydraulic equipment often stimulates the increased use of foreign equipment, which is due to the lack of domestic analogues [3]. This situation is typical, in particular, for low-flow pumps (less than 5 l/min) and pressures above 60 MPa, which are necessary for the implementation of small-sized testing machines. Therefore, equipment manufactured by domestic firms (jacks, hydraulic tools, etc.) for a given pressure level is usually equipped with hand pumps or foreign pumps (BIERI, HAVE).

Therefore, BIERI radial piston pump HRK was selected as a source of hydraulic energy, according to a combination of technical and economic criteria. Pumps of this type provide pressures up to 70 MPa and are available with capacity range of 0.12...4.52 cm^3 and a drive shaft speed range of 500...3600 rpm.

A feature of the selected pump is the presence of only two plunger pairs, which usually causes an increase in pressure pulsation in the discharge line. The latter circumstance leads to the fact that these pumps are practically not used in a traditional hydraulic drive.

However, they are structurally simple and cheap enough. In addition, if applied in test machines, the resulting pressure pulsation can be leveled due to the large volumetric displacement of the actuating hydraulic cylinder. Further tests showed that the level of the total error in measuring pressure, including the pulsation component, does not exceed 0.3% at an acceptable level of 1% [2].

A double-acting jack DG100G150 manufactured by ZAO NPO Enerprom was used as a loading device, developing a force of up to 100 tf and providing a piston stroke of 150 mm. Its volumetric displacementis 2200 cm^3, and the mass is 48.5 kg.

The operation of the loading device during the compression test involves ensuring the movement of the output link in the following sequence: a relatively fast supply of the loading plate to the sample, testing of the sample at zero speed of movement of the hydraulic cylinder rod and removal of the plate to its original position. To control the pressure level in the actuator, and therefore the loading force, a typical circuit was used with parallel installation of a throttling device. As a throttling device, a high-pressure direct-acting proportional valve type PDV700-P-6-700-2 from BIERI was selected. The electromagnet current was controlled by pulse width modulation with pressure feedback.

Results

In this work, a prototype of a test machine of the proposed design was created and its full-scale tests were performed at the scientific and production base of OOO Firma VNIR. During the tests, the explosive destruction of samples of high-strength concrete (grades above M500) was observed. Analysis of the working process showed that at the time of destruction there is a sharp decrease in the opposing load on the piston rod. As a result, the speed of movement of the output unit increases significantly and the flow rate of fluid entering the actuator hydraulic cylinder increases spasmodically. As tests have shown, this causes erosion of the shutoff-regulating element of the proportional valve and a significant decrease in its resource.

The traditional way to solve this problem is to limit the flow of fluid at the time of destruction, which can be achieved by installing the appropriate hydraulic equipment. So, for example, in the design of similar stationary-type machines, in particular IP-1000 manufactured by PKC ZIM (Armavir), the use of a three-line flow controller is provided. It is also possible to use a circuit that includes two pumps. However, these approaches lead to construction that is more expensive.

With this background, it was suggested to use an additional speed control of pump shaft to limit the flow rate. Thus, the proposed option has dual control: proportional and precise control of load growth is carried out by a high-pressure proportional valve, and the required flow rate is provided by a variable-speed pumping station with speed control. This pumping station contains a pumping unit of constant supply controlled by a variable frequency electric drive.

The circuit implements a mode of operation with constant power N at which the flow rate Q changes inversely with the pressure downstream the pump p::

$$Q = \frac{N}{p}$$

The use of an electrically controlled pump allows to increase the efficiency of the system, reduce energy consumption and reduce heat generation, which allows to reduce the tank volume and the overall size of the structure.

To implement this solution, a Vesper E2-MINI E2-MINI-SP5L single-phase frequency converter was used, which has a relatively low cost. Tests have shown that to ensure high-quality destruction of the sample and compliance with the required operational characteristics of the testing machine, it is necessary to have a speed control range within 60% ... 200% of the nominal speedwhile maintaining the required moment on the pump shaft.

At present, a design of the HP70 pump has been prepared (Fig. 1) and is undergoing technological development.

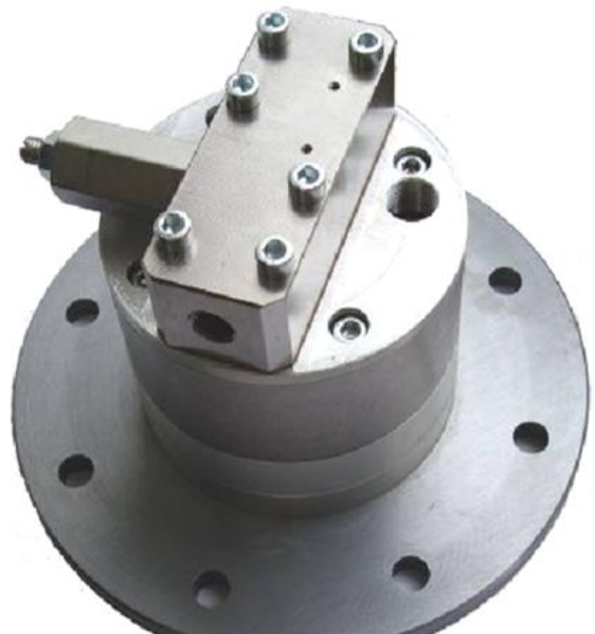

Fig. 1. ExterioroftheHP70 pump (Maximum pressure 70 MPa, capacity 0.34 cm^3)

Due to the modular design, this pump can be equipped both with domestic motors with a power of 1.5 kW and a mounting flange with a hole diameter of 165 mm, and with foreign-made engines with power from 1 to 1.5 kW.

The study has also begun of the design of the proportional valve similar in connection size and operating pressure to the PDV700-P-6-700-2 (BIERI) valve. Fig. 2 shows the exterior of a three-dimensional model of a valve with an electromagnet. This valve has longer lifetimethan the analogue and uses the domestic proportional electromagnet EM-25 GOST 19264-82 (NPP S pets electromagnit) as a control.

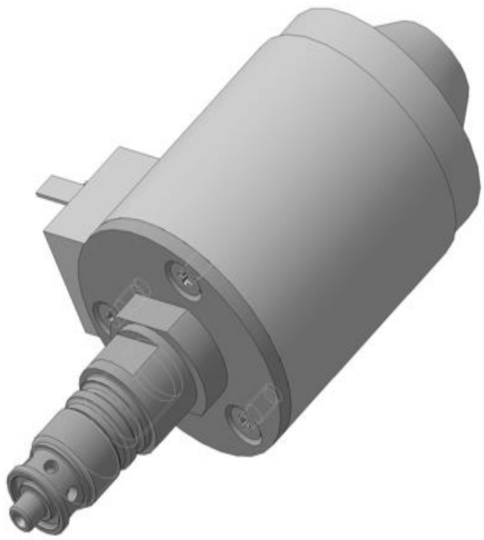

Fig.2. Model of the electromagnetic proportional valve
(Maximum pressure 70 MPa, working flow 10 l/min)

Discussion

The operation of such machines with a high degree of automation in the construction industry confirmed the promise of switching to high pressures.

At the same time, the experience of using BIERI pumps in small-sized testing machines revealed a number of disadvantages. These pumps are poorly aggregated in pump units with domestic electric motors. In this regard, it is required to either equip them with imported analogues, or addto their structure additional elements (coupling, bushing). This leads to an increase in the cost of the aggregate. In addition, the prices of these pumps are subject to changes in exchange rates. Thus, the further direction of work involves the development of a set of high-pressure equipment devoid of these shortcomings.

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