ULTRA-HIGH-PRESSURE PUMP ASSEMBLIES FOR THE MANUFACTURE OF POLYETHYLENE

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Many contemporary technological processes in various branches of industry take place at pressures above 100 MPa, which are arbitrarily called ultra-high. Thus, in the chemical industry, equipment in industrial installations for the manufacture of polyethylene operates at pressures of 160–250 MPa or more, and investigative work in this area is carried out at pressures up to 700 MPa.

With the objective of intensifying the polymerization of the ethylene supplied by compressors, and reducing the energy consumption, a gaseous or liquid initiator is fed into the technological assembly reactor. To supply liquid initiators, which are solutions of organic peroxides in perfumery oil, the VNIIgidromash has developed pump assemblies GNPT 0.04/2500 and GNP 0.04/2500 for a pressure of 250 MPa, with a maximum delivery of up to 0.06 m³/h, which are used in manufacturing low-density polyethylene at a capacity of up to 12,000 metric tons/year. For high-pressure polyethylene installations of capacity 50,000 metric tons/year, the assemblies GNPT 0.1/2500 and GNP 0.1/2500 have been developed. The pump assemblies are direct-acting, horizontal piston pump installations having a regulatable delivery. Control is carried out remotely, using automated devices and a computer.

Pumps with a slotted piston packing are part of the make-up of the pump assemblies; they are provided with means for measuring the pressure and temperature of the pumped liquid, preventive valves, and an electrical-contact manometer, and there are a hydraulic drive system with a diaphragm-actuating mechanism and intake and delivery main lines. The GNPT 0.04/2500 and GNP 0.1/2500 assemblies are additionally combined with a thermostat for maintaining a constant temperature of the working liquid.

The pumps have an opposed scheme of high-pressure cylinder disposition; these are connected by the use of intermediate connectors to a unified double-action hydraulic drive cylinder having a two-position pilot and a four-way main valve, intended for alternate feed of oil through main valve plate channels into the left and right chambers of the hydraulic cylinder. On attainment of the extreme positions by its piston rod, the pilot valve is displaced by use of a lever mechanism and cams, which ensures back-and-forth motion in the hydraulic cylinder of the two-way piston, which is sealed by piston rings 76 mm in diameter. Use of the hydraulic drive cylinder of the GNP 0.04/2500 pump in the construction of the GNP 0.1/2500 pump became possible as a result of the use of a hydraulic system of greater capacity as the drive, which made it possible to increase the drive liquid pressure from 6 to 14 MPa, and, as a result of this, by increasing the piston area, to bring the maximum feed rate to 0.1 m³/h.

For the drive mechanism of the ultra-high-pressure pumps in the assemblies, hydraulic systems are used whose basic element is a double-stream radial-piston pump with a regulatable feed, which is brought into motion from a two-way explosion-proof electric motor. Feed is regulated by use of check valves and pneumatic reversible valves, which are switched off by overflow to one of the two sections of the radial-piston pump. Under manufacturing conditions this regulation is effected as a function of the temperature in the polyethylene polymerization reactor. A signal from the temperature sensor is transformed into a pneumatic signal, which passes into the diaphragm-actuating mechanism, displacing, in turn, the radial-piston pump valve. Thereby feed to the hydraulic system is smoothly regulated, and, consequently, feed to the ultra-high-pressure pump.

The reliability of pump assemblies depends mainly on the construction of the ultra-high-pressure cylinder and the operating life of the piston seal. It is necessary that stress concentrators which cause fatigue failure of the cylinder should be absent in the cylinder. Since the level of instantaneous stresses in the metal and the stress cycle depend on the level and range of the pressure deviations under which the cylinder operates, the limit of fatigue strength of the material is a very important design factor.


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The theoretical basis for the design of cylinders which operate under ultra-high pressure is the solution of Lamé for a thick-walled cylinder [1], according to which the maximum allowable pressure in a single-layer cylinder is given by

\[ p \leq \frac{[\sigma] (\beta - 1)}{2 \beta} \]

where \([\sigma]\) is the allowable material; and \(\beta\) is the coefficient of thick-walledness (the ratio of the external diameter to the internal diameter).

However, experience in devising and operating pumps at pressures over 100 MPa has shown that fulfillment of condition (l) is not sufficient to ensure cylinder strength, since the circumferential stretching stress acting on its internal surface is higher than the liquid pressure in the cylinder and causes deformations which lead to the formation and opening of microcracks in the metal. Under the ultra-high pressure, the pumped medium penetrates into the microcracks, which leads to a rapid growth of the microcracks and even to failure of the part. Consequently, to ensure cylinder strength, it is necessary that there should be circumferential compressive stresses on its internal surface. This condition is fulfilled only in a multilayer construction consisting of cylindrical shells pressed on onto another with a definite tension, the optimum construction being that in which the equivalent stress in a danger point of each layer is equal to the allowable stress of the material in this layer. For pressures up to 250-300 MPa, a two-layer construction is optimum which has an outer layer diameter

\[ d_2 = d_0 \sqrt{\frac{\sigma_1}{\sigma_1 + \sigma_2} \left( \frac{\sigma_1}{\sigma_1 + \sigma_2} - \frac{1}{2p} \right)} \]

where \(d_0\) is the internal cylinder diameter, \([\sigma]_1\) and \([\sigma]_2\) are the allowable stresses in the materials of the first and second layers.

In selecting materials (with respect to allowable stresses) and to ensure compressive circumferential stresses on the inner surface of the cylinder, the following condition should be fulfilled: \(p > [\sigma]_1; [\sigma]_1 < [\sigma]_2\).

The strength and service lifetime of an ultra-high-pressure cylinder are also determined by the correctness of the choice of the construction and fabrication technology. Starting here, for the GNP 0.1/2500 pump an ultra-high-pressure cylinder was developed which consisted of two two-layer sleeves and wrapped pressure and intake valves having identical external diameters, located coaxially with the piston and compressed by ground ends by use of flanges and bolts. In the seat of each of these valves there are two axial holes of different diameter: one for passage of liquid from the cylinder to the neighboring valve, the other for sealing the valve or passage of liquid. The parts of this cylinder are constructionally and technologically simple, which makes it possible to design their elements accurately.

Sealing of the immobile elements of the cylinder against flat ground surfaces has a number of advantages as compared with sealing against the annular conical projection which is widely used in ultra-high-pressure pumps and multipliers; it is simpler in execution and does not require additional mechanical treatment in pump repair. However, the dimensions of the flat sealing surfaces of the parts should be so chosen that, on one side, hermeticity of the butt joint is ensured, and, on the other, the nut tightening force is minimal (to eliminate the