Typical cases of destruction of the main hydraulic cylinders, causes of destruction and engineering solutions adopted for their prevention

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Abstract. The problems of operation of hydraulic actuators in hydraulic press are considered. Design errors of hydraulic cylinders are identified. As the result of the simulation in the AnsysCFX, a new design with better strength properties is obtained, and the operational life of the hydraulic cylinder is increased. Also the pictures of the stressed-deformed state before and after structural changes are obtained.

Introduction

Powerful hydraulic presses are part of the industries, determining the military capability and industrial potential of Russia. Increasing the quantity and improving the quality of products obtained by hydraulic presses in a substantial way determine the development of the national economy. The modern technological level of present powerful hydraulic presses is provideddue to the modernization of hydraulic actuator, controlling and mechanization systems that is $\approx 20\%$ of mass and cost of the press [1–3]. The force of the hydraulic press, necessary for material processing under pressure, is created and perceived by its basic parts (main hydraulic cylinders, columns, cross-beams, elements of frame racks), that is $\approx 80\%$ of mass and cost of the press. Therefore, theessential condition for maintaining and increasing the technological capabilities of present powerful presses is the further failure-free operation of the present basic parts [4].

The method for engineering analysis of the hydraulic cylinder substantially depends on how it is attached to the press frame. The methods of attaching of the hydraulic cylinder with collars or flanges made in conjunction with the cylinder are widely used. Flanges are attached on the cylinder by threading or welding. Mounting designs are used with a split ring key. The support constructions of the cylinder by split-ring connector are used. The cylinder support on its bottom is used. After choosing the pressure P with which the pressure fluid will be supplied to the cylinder, it is necessary to determine the diameter of the piston or ram due to which the specified force T will be developed. The resulting size D is rounded off to the nearest larger size according to GOST 6540. Then, depending on the accepted design, the inner diameter of the cylinder is determined, which must also be in compliance with the standard above. When determining the wall thickness, the cylinders of hydraulic presses are calculated as thick-walled cylindrical shells. In thick-walled cylinders being under the action of internal pressure P, a complex stress state arises, as the normal stresses act simultaneously in the radial direction at a point remote from the cylinder axis in the tangential and axial directions.

Methods

Operating experience shows that the largest number of failures of powerful hydraulic presses with the most serious consequences is primarily associated with destruction and damage of the hydraulic cylinder. With an increase in operating time, the number of failures increases, that's why it is necessary to significantly increase the strength of cylinder to meet the increasing production requirements and to increase its operating time.

The occurrence and development of fatigue cracks in the fillet of the bottoms are one of the main reasons for the destruction of large cylinders of powerful hydraulic presses under the influence of a cyclic load. The operation experience of mold presses has shown that cylinders made of steel 35 (0,32 - 0,4% C, 0,17 - 0,37% Si, 0,5 - 0,8%Mn, ~ 97% Fe) are damaged along cracks in the fillet of the bottom in the same way as cylinders made of steel 25 GS (0.2 - 0.26% C, 0.6 - 0.9% Si, 1 - 1.3% Mn, ~ 96% Fe)that is shown in the Fig. 1.
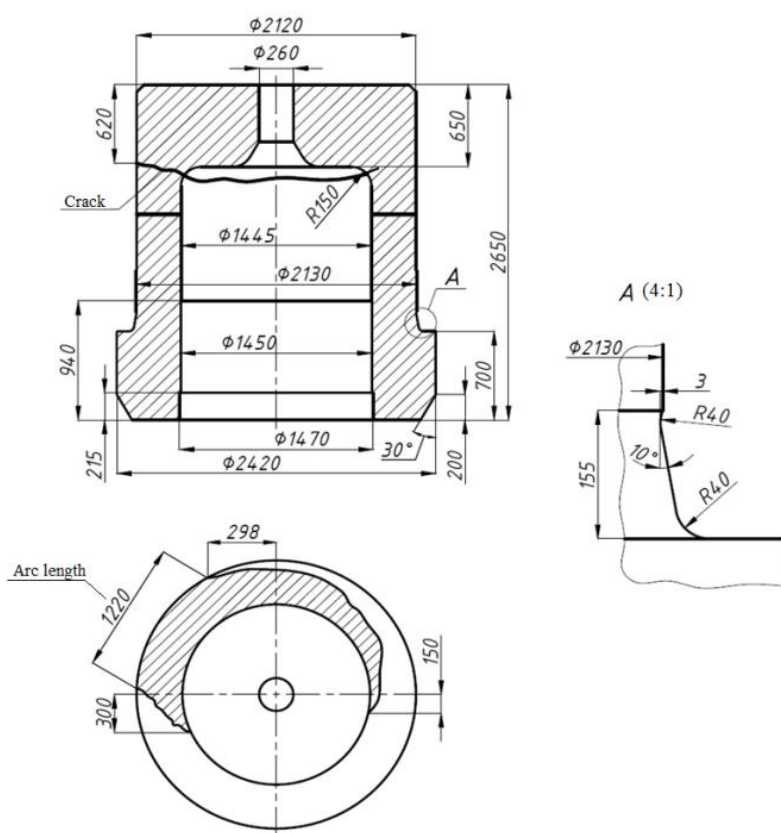

Fig. 1. Scheme of destruction of a cylinder with a force of 50 MN along a crack in fillet of the bottom

High quality structural carbon steel 35 is used for the manufacture of products of low strength, working with low stresses - cylinders, columns of presses, axles, crankshafts, rods, traverses, and other details. Steel 35 has a yield stress $\sigma = 315\,MPa$.

Steel 25 GS structural low alloyed steel is used for welded assemblies. Yield stress is $\sigma = 275\,MPa$. The properties of 25GS steel depend on the type of heat treatment, tempering temperature and section. An important difference between steel 25GS and steel 35 is good welding properties. Welding can be carried out without preheating, by any methods, without heat treatment of the welded joints. Thereby, the use of steel 25 GS is more economically feasible.

It should be noted separately that after the examination of a number of presses after repair, during which cracks in hydraulic cylinders are eliminated by welding and the yield stress of welding material

is $\sigma = 450\,MPa$, destruction of hydraulic cylinders in the fillet area directly along the welding joint is observed.

To determine the causes of the destruction of the cylinders, their FEM was made. The stress state of the main cylinders of mold presses with a force of 35 MN and 50 MN obtained from Ansys is shown in Fig. 2, the maximum primary stresses σ_1 in the fillets of the cylinder bottoms are 140.1 MPa and 130.5 MPa, respectively.

In cylinders made of 25GS steel and 35 steel, fatigue cracks occur in the same zone (fillet of the bottom) at maximum stresses of 130-140 MPa. It means, that the cause of fatigue cracks and of the destruction of the cylinder bottoms is determined not by the grade of steel, but by the technology of manufacturing the bottoms, which was the same with different grades of steel. Different cases of fatigue cracks occurrence are described in [5–7].
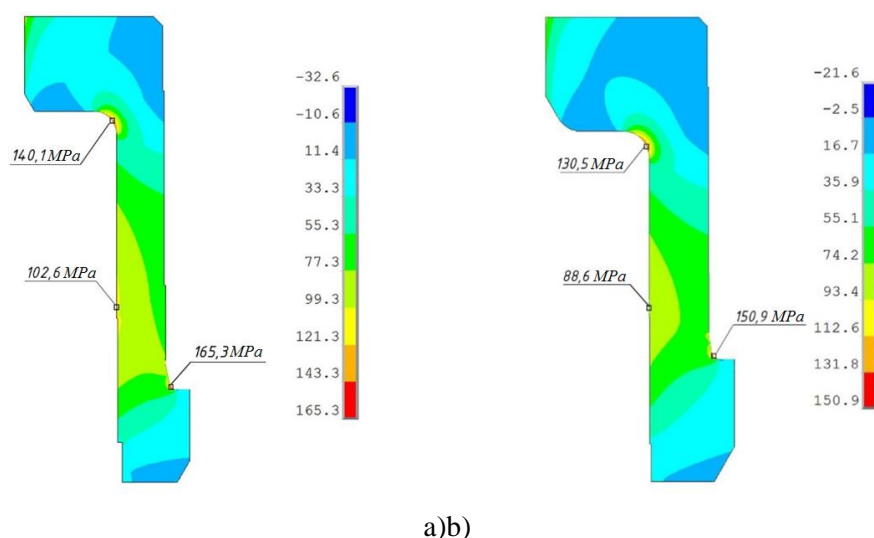

a)b)

Fig. 2. The stress state of cylinders with a force of 35 MN and 50 MN made of steel 35: a) — cylinder with a force of 35 MN; b) — cylinder with a force of 50 MN
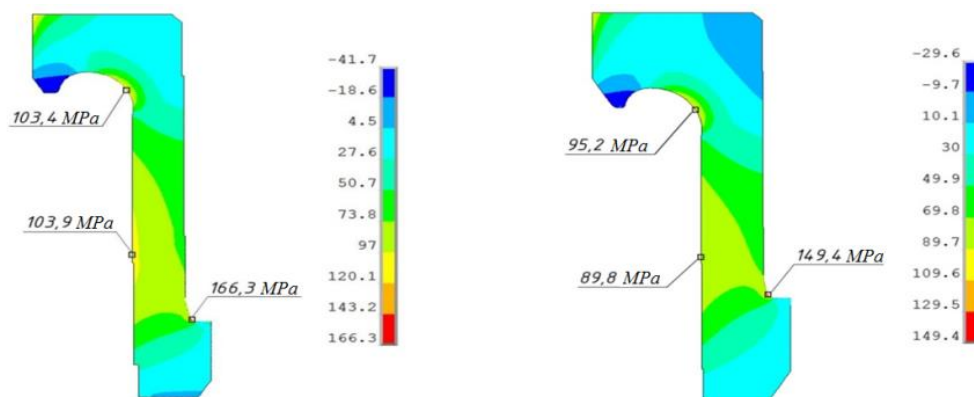
The proposition of the connection of the cause of the cylinder bottoms destruction with the adopted technology of blanks forging confirms the results of fatigue tests. The weight of the shell ingot (79 tons) is more in 1,4 times than the mass of the bottom ingot (57 tons), therefore, with the same forging technologies, the working intensity and endurance of the bottom material should be greater than the shell material. But the fatigue limit of the bottom in the fillet zone is $\sigma_{0bottom} \leq 130\,MPa$, the fatigue limit of the shell is σ0 $\sigma_{0shell} = 235 - 250\,MPa$.

A modern, more intensive technology for forging the bottom blank significantly increases the fatigue limit of the fillet zone. But the maximum stresses in the fillet of the bottom are higher than the stresses on the inner contour of the shell. So, for a cylinder with a force of 35 MN and 50 MN, the stresses on the bottom fillet contour are in 1,4–1,5 times more than the stresses on the inner shell contour (Fig. 2). This, in the general case, significantly reduces the cylinder's factor of safety for fatigue and, due to the corrosive attacks of the pressure fluid, or due to accidental damagesof the fillet surface, leads to fatigue cracks and destruction of the cylinder.

Results

A significant decrease in stresses in the fillet is achieved by its embedding in the cylinder bottom with an increase in the fillet radius [8]. The maximum stresses in the fillet decrease in 1,4 times, from 140,1 to 103,4 MPa for a cylinder with a force of 35 MN and from 130,5 MPa to 95,2 MPa for a cylinder with a force of 50 MN (Fig. 3). These stresses practically coincide with the stresses acting on the inner

contour of the shell and provide unlimited durability of the inner surface of the cylinder even when using fresh water as a pressure fluid [9].

a)b)

Fig. 3. The stress state of the inner surface of the cylinders with a force of 35 MN and 50 MN with the new design of the fillets of the bottom: a — cylinder with a force of 35 MN; b — cylinder with a force of 50 MN

Cylinders, the bottoms of which are manufactured using the new design and technology solutions presented above, have been working in hydraulic presses of the railway wheel production line at OMK since 2005. The line's capacity is 820,000 wheels per year, which is the world record for productivity for powerful hydraulic presses. For ten years of operation, the occurrence of cracks in the fillets of the cylinder bottoms has not been recorded.

Discussions
This optimization with Ansys CFX allows increasing the operation life of the hydraulic actuator through the strength analysis. The destruction of the main cylinders caused by fatigue cracks in the fillet of the bottom, are explainedby structural and technology errors made during the creation of the cylinders.The discussed problem can be solved during a scheduled repair without significant financial costs. Besides the optimization of hydraulic systems, Ansys CFX can solve a number of problems caused in any technical devices. More problems occurring in technic devices solving with AnsysCFX are described in [10–20].

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