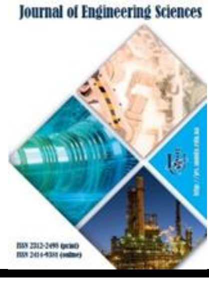
JOURNAL OF ENGINEERING SCIENCES

Volume 10, Issue 1 (2023)

Lymarenko A., Kurgan V., Bazhanova A., Khamray V., Ponomarenko A., Karabegović I. (2023). The stress state of a thick-walled hydraulic press cylinder with concentrators. Journal of Engineering Sciences, Vol. 10(1), pp. D15-D19, doi: 10.21272/jes.2023.10(1).d3



The Stress State of a Thick-Walled Hydraulic Press Cylinder with Concentrators

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Article info:

Submitted:	March 1, 2023
Received in revised form:	May 11, 2023
Accepted for publication:	May 22, 2023
Available online:	May 26, 2023

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Abstract. The article deals with modeling and calculations of volumetric machine-building structures with complex geometry. The relevance of the work lies in the fact that its methodology and results can help design massive structural elements complex in shape, including cylinders of powerful hydraulic presses. Attention is paid to the problems of reducing the metal content of machine-building products and the safe conditions of their operation. Theoretical and applied work is based on numerical methods using analytical solutions to assess the reliability of computer calculation results. The choice of research method is because analytical solutions for massive parts of such a configuration are too complex for numerical implementation. Experimental methods are too expensive and not so universal as to sort out possible variants of shapes and sizes. For the actual model of the press, the capabilities of the finite element method implemented in the ANSYS multipurpose complex were selected and rationally used. The results of the calculations are summarized in the table and shown on the graphs of the stress distribution. Based on the performed calculations (with a reliability check based on the formulas of the theory of elasticity for simplified calculation schemes), conclusions were made to ensure a more even distribution of stresses and a reduction in the metal content of the product.

Keywords: theory of elasticity, finite element analysis, hydraulic press, cylinder, stress-strain state.

1 Introduction

The need to perform a verification calculation of the cylinder strength is because the main cylinder of the D-0843 press has recently undergone structural changes. The shape of the main cylinder of the press is quite complex.

During the test, the internal pressure in the cylinder is 40 MPa, and the load by axial forces in the places where the cylinder is attached to the press columns is evenly distributed along the length of the four side brackets.

During the development of projects of previous models, there was no sufficiently reliable and precise method of calculating three-dimensional details. Therefore, methods were used that made it possible to determine stresses in structural elements very approximately.

In addition, the material of the cylinder (Steel 1.0501, EU) has low mechanical characteristics, and therefore, taking into account the insufficient quality of the production of such thick-walled parts, the allowable stresses were assumed to be low enough.

2 Literature Review

The control of the position of the main drive of the press in terms of flatness is considered [1], and the design of the hydraulic press is described [2]. A methodology for calculating the total service life of a structure is presented [3], applicable to actual engineering structures [4].

Determination of the critical buckling load obtained by the energy method is compared using ANSYS finite element analysis [5] with different mounting conditions [6].

Numerical calculations were carried out using ANSYS Mechanical 19.0 software [7]. The stress-strain state of a cylindrical shell with a circular cutout is considered [8]. The stress distribution over the cutout contour and the wall thickness of the shell is investigated

[9], as well as the geometric nonlinearity, which determines its stress-strain state [10].

A method of calculating the strength, reliability, and resource of cast parts operating under conditions of variable loads of a random nature has been developed [11]. The three-dimensional model of the supporting system of the vehicle is considered [12].

Two different finite element packages of different complexity are used for verification [13]. The object of industrial engineering with a change in wall thickness is considered [14]. The stress-strain state of the traverse of the hydraulic press was investigated using the finite element method [15].

The influence of the structural parameters of the cylinder on stress, deformation, and margin of safety is studied. Analysis of FE of the CAD model is carried out in the ANSYS software [16]. Linear and non-linear finite element methods were introduced in [17]. Moreover, the finite element method is presented as the primary tool for predicting and modeling the physical behavior of complex engineering systems [18].

3 Research Methodology

After considering various methods for studying the stress-strain state of massive bodies, including through laboratory tests in polarized light, it was concluded that the calculation of the strength of the main cylinder should be performed using the finite element method.

To assess the reliability of the results obtained on a personal computer using two programs that implement the finite element method (the specialized program “Prism” and the multipurpose package ANSYS), the stress in the elements of the ideal schematic cylinder (Figure 1) was determined using the foundations of the theory of elasticity [19].

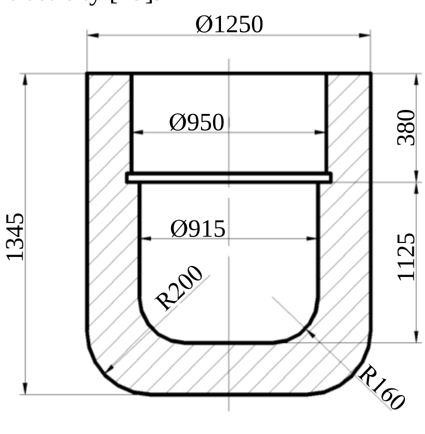

Figure 1 – Schematization of the cylinder

In such calculations, the cylinder is considered a body of rotation without brackets, holes, or supports. In the lower part, the cylinder connects to the bottom as a round plate, which is considered rigidly fixed on the contour, the radial transition with rounding from the cylinder wall to the bottom is not considered.

4 Results and Discussion

Determination of stresses in the cylinder wall is realized using the Lamé solution. The input data is as follows: the radius of the inner surface of the cylinder $r_1 = 0.4575$ m; the radius of the outer surface of the cylinder $r_2 = 0.6250$ m; the internal pressure of the liquid is taken as a single, dimensionless one ($p = 1.0$) since all stresses are within fractions of this unit.

Calculation formulas and the value of unit stress on the inner surface of the cylinder wall (Figure 2) are as follows:

– radial normal stress:

$$\sigma_r = -p = -1; \tag{1}$$

– normal circular stress in the direction tangent to the cylindrical surface:

$$\sigma_t = p \cdot (r^2{}_2 + r^2{}_1)/(r^2{}_2 - r^2{}_1); \tag{2}$$

equivalent stress according to the 4th energy theory of strength:

$$\sigma_{equiv} = \sqrt{\sigma_r^2 + \sigma_t^2 + \sigma_y^2 - \sigma_t\sigma_r - \sigma_t\sigma_y - \sigma_r\sigma_y}. \tag{3}$$

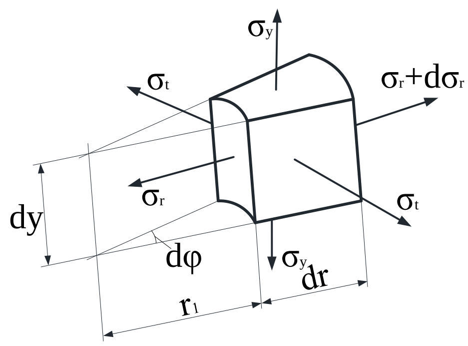

Figure 2 – The stressed state of the thick-walled cylinder element

Determination of stresses in the center of the bottom. We consider the bottom of the cylinder as a round plate, rigidly clamped on the contour and loaded with a uniform unit dimensionless pressure p.

Initial data is as follows: plate radius $r_1 = 0.4575$ m; plate thickness $h = 0.22$ m.

Radial bending moment:

$$M_r = \frac{pr_1^2}{16}\left[1+\mu\cdot\frac{(3+\mu)r^2}{r_1^2}\right], \tag{4}$$

and circumferential bending moment:

$$M_t = \frac{pr_1^2}{16}\left[1+\mu\cdot\frac{(3+\mu)r^2}{r_1^2}\right], \tag{5}$$

where r is the current radius vector of a point in a circular plate.

For a long shell with a bottom at μ =0.333, we have

$$M_r = pr_1^2\left[0.0833 - 0,2083\frac{r^2}{r_1^2}\right]; \qquad (6)$$

$$M_t = pr_1^2\left[0.0833 - 0.125\frac{r^2}{r_1^2}\right]. \qquad (7)$$

In the center of the plate, the relative bending moments and stresses will be as follows:

$$M_r = M_t = 0.0833pr_1^2 = 1.7435\cdot10^{-2}; \qquad (8)$$

$$\sigma_r = \sigma_t = \left|\frac{6M_r}{h^2}\right|. \qquad (9)$$

Equivalent stress, according to the energy hypothesis:

$$\sigma_{equiv} = \sqrt{\sigma_r^2 + \sigma_t^2 - \sigma_r\sigma_t}\,. \qquad (10)$$

Study of the stress-strain state of cylinder D0843 using the finite element package ANSYS.

Initial data: cylinder material – Steel 1.0501 EU; yield strength σ_{str} = 250 MPa; strength limit σ_{lim} = 470 MPa; modulus of longitudinal elasticity $E = 2.0\cdot10^5$ MPa; Poisson's ratio μ = 0.333; working pressure R_{pres} = 32 MPa; test pressure P_{test} = 40 MPa; the maximum force of the press is $2.7\cdot10^4$ kN.

The preparatory stage of work on the model is presented in Figure 3.

To solve the problem by the numerical method, it is first necessary to build a geometric model of the part, and for this, ANSYS has a three-dimensional modeling tool.

Our problem selects a three-dimensional SOLID 92 tetragonal element with 10 nodes (Figure 3b) from the library of standard ANSYS elements. Control over the construction of the discretization grid of the research object on finite elements (Figure 3a) is carried out by the ANSYS program by default: Preprocessor – Meshing – Mesh – Volumes – Free.

The solution stage begins with the assignment of boundary conditions, as well as specifying the calculation method and parameters, and ends with obtaining results both in tabular and graphical form. The boundary conditions include: displacements, applied loads (pressure, concentrated forces, load distribution).

After all the relevant parameters are set, the solution itself can be executed. Using the SOLVE command, the program requests information about models and loads from the database and performs calculations. The program solves the defining equations and obtains results for the selected type of analysis. From a computational point of view, this is the most intensive part of the analysis.

In the ANSYS program, the post-processing stage follows the stages of preprocessor preparation and obtaining a solution. The solution results include values of displacements, stresses, and strains. The results of the program's work at the post-processing stage are presented in Figure 4.

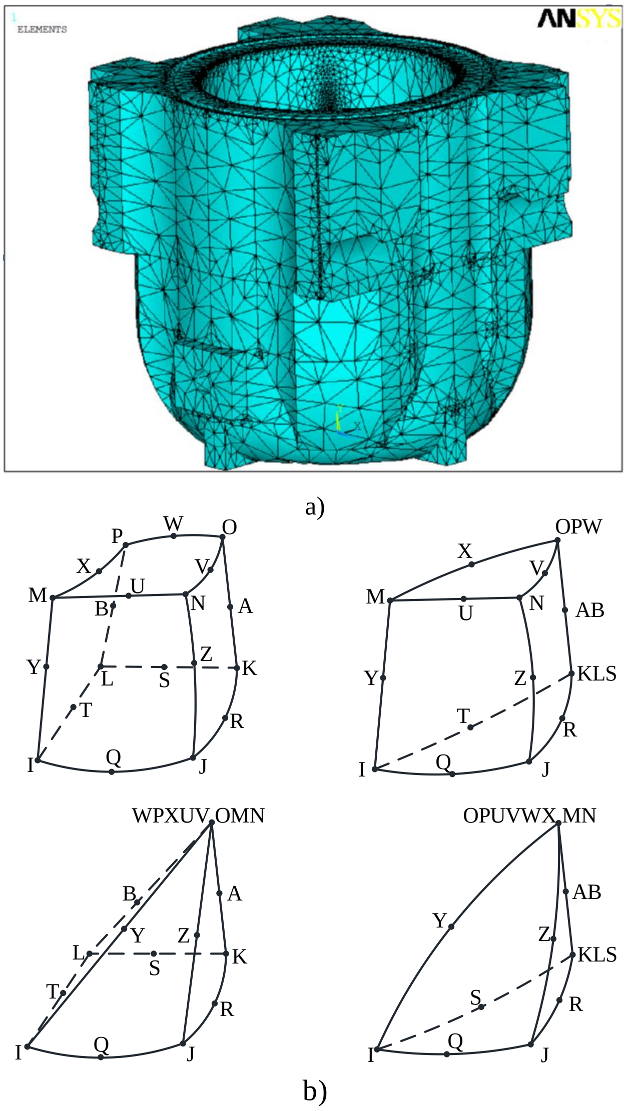

Figure 3 – The design model: a – model of the main cylinder of the D-0843 press with a finite-element mesh; b – finite elements of normal and degenerate forms

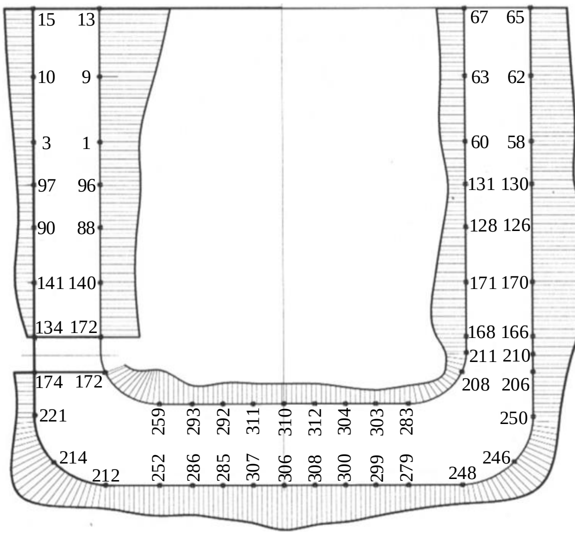

Figure 4 – Plots of equivalent stresses in the longitudinal section of a cylinder

In the study of the stress-strain state of the cylinder based on the “PRISMA” software, one of the four identical (due to biaxial symmetry) parts of the D-0843 cylinder was discretized into finite elements. The X, Y, and Z coordinates of each 312 nodes were determined 36 elements; selected boundary conditions of their interaction and load in nodes; calculations were carried out on a computer.

The results of determining the equivalent stresses using the ANSYS and the “PRISMA” software packages are shown in Table 1.

Table 1 – Comparison of numerical calculation results in the “PRISMA” and ANSYS programs

No. of nodes “Prism”	σ_{equiv} , MPa at R_{pres} = 32 MPa	No. of nodes “ANSYS”	σ_{equiv}, MPa at R_{pres} = 32 MPa
3	61.5	8225	50.2
97	42.6	8227	65.9
90	40.3	8330	52.1
286	86.1	20 728	66.0
285	97.6	20 727	80.5
307	111.0	20 726	81.5
306	128.6	20 725	83.5
1	101.8	1460	83.8
96	104.0	1513	111.4
88	95.0	1507	121.2
140	89.6	1499	111.3

5 Conclusions

Analyzing the stresses obtained from the cylinder calculation allows for summarizing the following conclusions. The strength of the cylinder walls is ensured. However, there is an uneven distribution of stresses along the height of the cylinder, which does not satisfy the conditions of uniform strength of the structure. The strength of the flat part of the bottom is ensured, which follows from a comparison of the maximum stresses with the yield strength.

Some discrepancies in the distribution features of σ_{equiv} according to the two methods are, to a certain extent, caused by the fact that during the calculations in “ANSYS”, the internal pressure p was considered to be spread from the bottom to the annular groove, where the wall thickness changes. When using the “PRISMA” program in connection with the “manual” breakdown, it was impossible to isolate too small volumetric elements in the groove zone and the lower tides of the supporting ribs.

6 Acknowledgment

The authors appreciate the Department of Machine Dynamics and Mechanical Engineering and the “Presmash” industrial association.

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