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The Numerical Analysis of Accuracy of Hydraulic Leg Cylinder in Modeling Using Solid Works Simulation

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Abstract: The research work on the influence of an angle α at centre and the finite element sizes in modeling a hydraulic leg cylinder has been done to determine the stress-strain state by FEM using SolidWorks Simulation software. Based on the analysis results the reasonable values of the central angle and finite elements for the cylinder and weld have been defined in terms of the smallest error and maximum performance computation.

Introduction

Russia is one of the major coal producers in the world. The Russian Federation possesses the third biggest coal reserves. The country is estimated to hold 193.3 billion tons of proved coal reserves, accounting for about 20% of the world's total with 101.2 billion tons of lignite, 85.3 billion tons of black coal (including 39.8 billion tons of coking coal) and 6.8 billion tons of anthracite. Industrial reserves of operating coal companies make nearly 19 billion tons, including about 4 billion tons of coking coal [1].

Coking coal is produced mainly in mines with longwall coal mining processes. For the last 14 years the share of coal produced by longwall mining has been steadily increasing, with the number of coal longwall mines decreasing. Therefore, the reliability and long service life of longwall mining equipment is a prime consideration.

Mechanized roof supports are used for longwall mining extraction, with a hydraulic leg being a basic bearing element (Fig. 1) [2]. In this connection, the enhancing of hydraulic leg performance is a subject of high priority for the study.

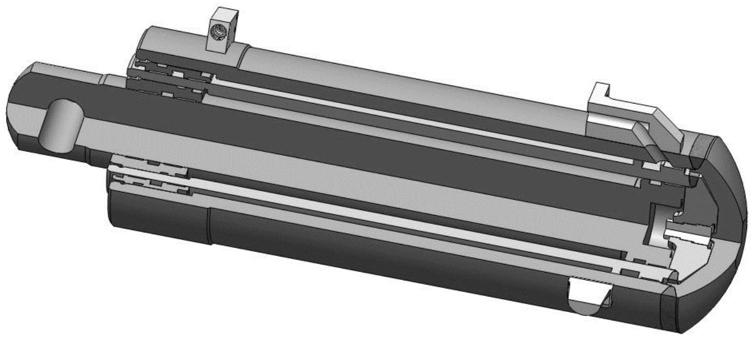


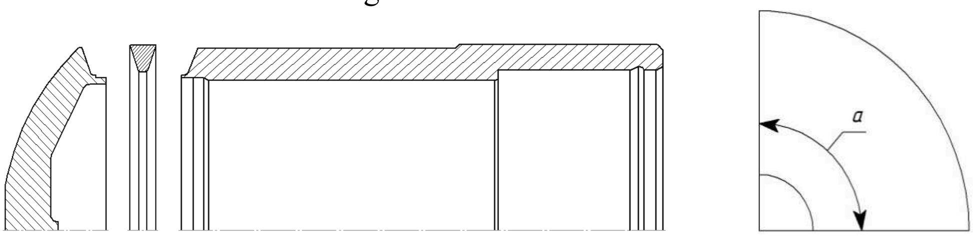
Fig. 1. Hydraulic leg M138

Currently, the finite element method (FEM) is widely used to solve practical problems of a solid body by numerical algorithms. To investigate the stress-strain state (SSS) and define the basic parameters of hydraulic legs the finite element model was developed using Solid Works Simulation package. This software provides simulation tools to create a 3D product design and carry our the required analysis. This application is widely used in the field of computer engineering calculations to solve various problems in the context of solid mechanics. Besides, using an additional module of SolidWorks Flow Simulation, this package enables easy simulation of interactions between liquids with metal structures [3, 4].

To obtain reliable results of research it is needed to study parameters of 3D models and boundary conditions, otherwise the calculation process can take a longer time, and the results of modeling can have a low level of accuracy. The main task for the study of hydraulic leg stress-strain state is specifying the central angle α of the model (Fig. 2) and defining the amount of final element over cylinder thicknesses.

The influence of angle α on the accuracy of the finite element solution to a leg cylinder model

A M138 hydraulic leg cylinder was taken as a simulation model for performing the researches. The construction of 3-D model was created by rotation of the symmetrical contours, head and welding seam of a working cylinder around the longitudinal axis about a central angle α (Fig. 2). For comparison of quality of the models the angles of 90º, 180º and 360º were taken. 30HGSA steel was used for all these components of the hydraulic cylinder. The steel had the following properties: the modulus of elasticity $E=2.05\cdot10^{11}$ Pa, yield strength $[\sigma_T]=830\cdot10^6$ Pa, Poisson's ratio $\mu_{П}=0.3$. The modified models are described in Fig. 3.



a) b) c) d)

Fig. 2. Contours of the hydraulic cylinder model
(a - cylinder head; b – weld; c – cylinder barrel; d - angle α at center)

To compensate the influences of the neglected parts in structure on the surfaces of the simulation model for the angles α = 90º, 180º, the boundary condition "Symmetry" was applied. The boundary condition "on the spherical faces", with the exception of motions along the longitudinal axis of the cylinder, was applied to spherical potions of the cylinder head for all models. In simulating interaction conditions for components in assembly, the contact condition "No interference" with "surface to surface" option was specified. The weld to connect the barrel and the head of the cylinder is modeled by a separate unit [5-9]. The element size in the finite element analysis was specified in accordance with the recommendations in [10] and was 6 mm with the type of mesh being "Solid Meshing", with "Curvature-based mesh". Meshing was performed automatically.

a) b) c)

Fig. 2. The finite-element models of the hydraulic leg cylinder M138
(a – α=90º; b – α=180º; c – α=360º).

For loading the cylinder model, a pressure corresponding to the operating fluid test pressure was applied to internal surfaces and the head of the cylinder; the value of test pressure P_{tp} was 60 MPa according to the technique and program used for the strength tests for this type of hydraulic legs. Four variants of cylinder extension: 0.25N, 0.5H, 0.75N, H were used for loading each model, where H is the piston rod extension in first stage of hydraulic leg M138 (Fig. 4).

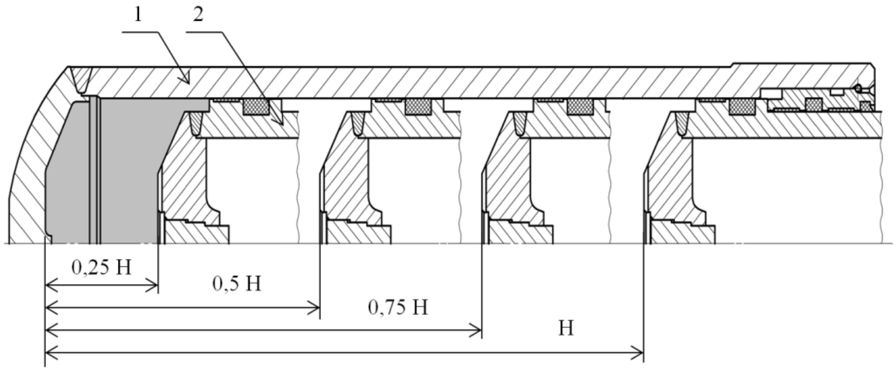


Fig. 4. Position of the piston rod in the first stage of hydraulic leg cylinder M138 during various extensions (1 - cylinder 2 – first-stage rod)

The simulation resulting readings were taken for each model in certain locations depending on the central angle (Fig. 5). The locations for taking readings for the model with α = 90º were No. 1, No. 2; for the model with α = 180º were No.1, No. 2, No. 3; and for the model with α = 360º were No. 1, No. 2, No.3, No. 4.

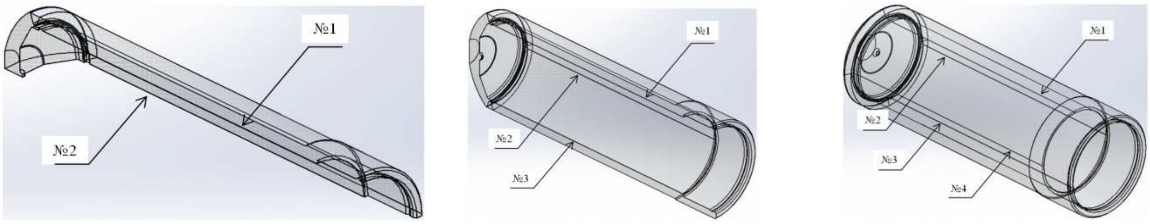
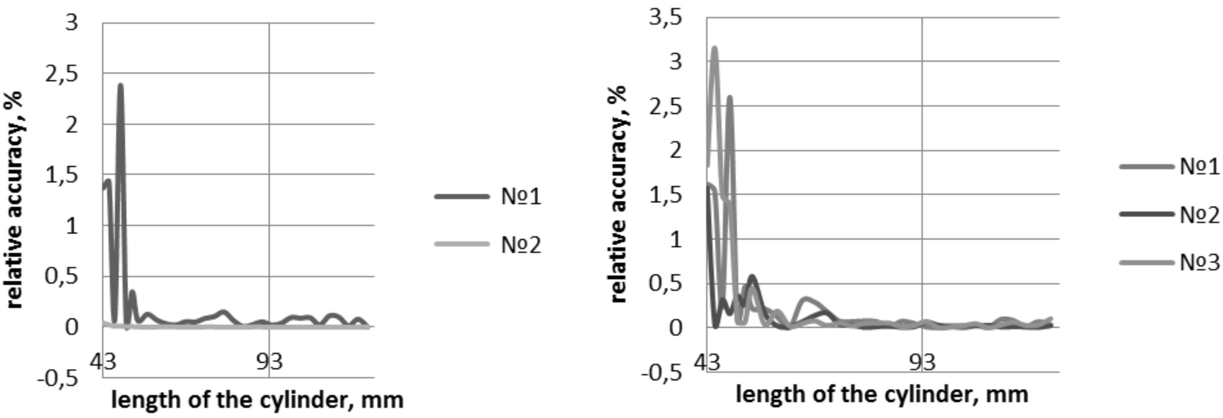


Fig. 5. Locations for reading data on models with angles at center α =90º, α = 180º, α = 360º.

As a result of the finite element solution to the models described above, von Mises stresses were defined; and errors for various locations, where readings were taken, were defined based on those stresses (as shown in Fig. 6). Errors were calculated by comparison with the results obtained for the model with central angle α = 360º, as this model is considered as the complete one.

Fig. 6 shows the examples of distributing the computational errors along the cylinder length within the applied pressure with the extension L = 0.25H



a) b)

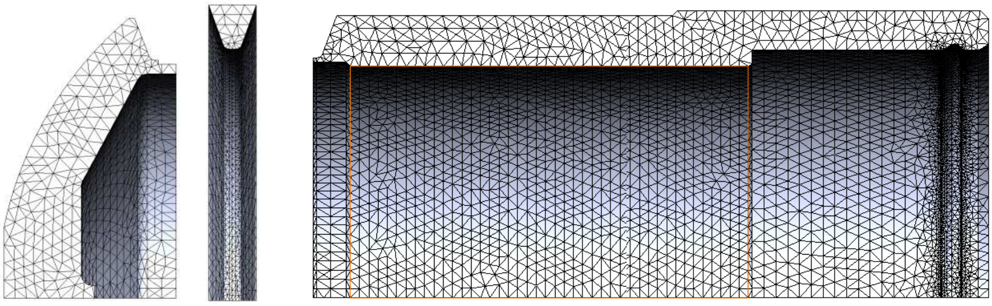
Fig. 6. Example of plotting percentage errors for models with an angle of: α= 90º (a) and α= 180º (b) under cylinder pressure loads in terms of L= 0.25N

The analysis of errors obtained for all model variants shows that their maximum values are between 2.2 and 3.8% for models with α = 90º and between 2.0 and 4.2% for models with α = 180º, in these cases the maximum values are located close to the weld.

For further researches the model with an angle α = 90º at center has been accepted, because it is more exact and its use requires fewer components that reduces the calculation time.

Influence of the finite element mesh

With the meshing done automatically and the element size been exact, the meshing was generated throughout the model geometry with one element size (Fig. 7). As it is seen from the figure that the contact areas were not condensed by the program on default that indicated the maximum error in the results was obtained at the areas where the welds were in contact with the cylinder and cylinder head. It is necessary to determine an element size for the cylinder, cylinder head and welds separately.



a) b) c)

Fig. 7. Automatic mesh generation for leg cylinder model
(a - cylinder head; b – weld; c- cylinder barrel)

The finite element value was determined as the ratio of cylinder wall thickness (h) to the quantity of whole numbers of elements (Δ) fit in the cylinder wall (h / Δ). For the hydraulic cylinder under consideration a wall thickness is 24 mm; thus, for numerical simulations in meshing the finite element sizes of 24 mm, 12 mm, 8 mm, 6 mm, 4 mm, 3 mm, 2 mm 1 mm can be taken for a cylinder and a head, and 24 mm, 12 mm, 8 mm, 6 mm, 4 mm, 3 mm, 2 mm, 1 mm, 0.8 mm, 0.5 mm, 0.4 mm for a weld.
The simulation exercises were conducted to determine the von Mises stresses to prove that an element size of 4 mm was optimal for the cylinder and cylinder head and 0.4 mm for the weld. The decrease in the finite element size caused the increase in errors during the study and extended a computation time.

Conclusion

As a result of our research on a FE model of hydraulic leg cylinders used for roof supports it has been established that in order to obtain the smallest error and highest performance computation the model with an angle α=90º at centre is the most reasonable. In this case, the well-proportioned size of a finite element must be 1/6 of wall thickness of the working hydraulic cylinder for the cylinder and head, and 1/60 of wall thickness for the weld.

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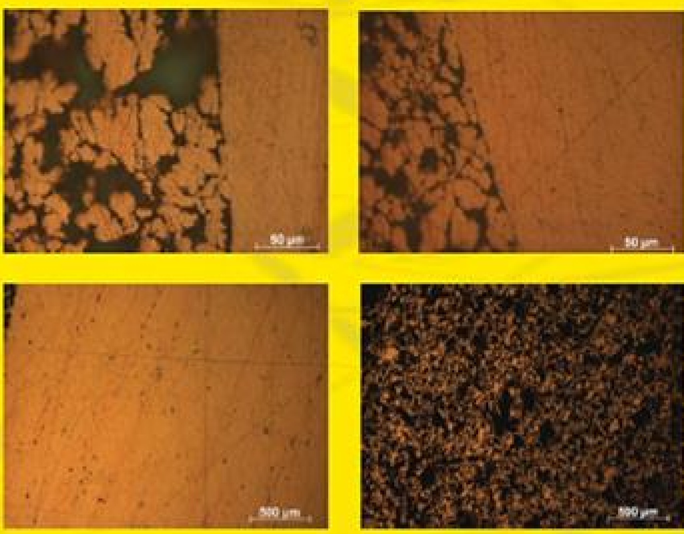

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