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STRESS - STRAIN ANALYSIS OF HYDRAULIC CYLINDER AT EXCAVATOR BUCKET MECHANISM

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Abstract: In this paper, stress–strain analysis of hydraulic cylinder that is used at excavator bucket mechanism is presented. The stress–strain analysis was done by analytic method, and after that, the results are compared with results obtained by finite element method with 3D tetrahedral finite element discretization. For this analysis, the one half of the cylinder was considered due to symmetry conditions. For the numerical simulation software Computer Aided-Three Dimensional Interactive Application CATIA V5R20 was used. The results obtained by different methods are compared and evaluated. On the basis of the results evaluation, the critical zones at the cylinder were discovered at which potential damage could be occurred due to increase of pressure and that could result to failure of the whole mechanism.
Keywords: hydraulic cylinder, pressure at cylinder, stress – strain analysis, cylinder damage

1. INTRODUCTION

Present machines and mechanical systems are usually equipped with hydraulic and electrical control devices that regulate their function and power. Hydraulic cylinders are positive-displacement linear hydraulic motors that transform energy of working fluid flow to useful work of linear movement of active elements (pistons or plungers) [1]. In relation to constructive solutions, the hydraulic cylinders can be classified as unidirectional and bidirectional. At bidirectional hydraulic cylinders, as it is analyzed in the paper, movement of active element is linear in two directions under the pressure of working fluid. Hydraulic cylinders are used at road and rail vehicles, internal transport machines, cranes and elevators, construction and agricultural equipment, mining machinery, ship equipment, material cutting machines, process systems, power plants and general machine engineering. The aim of investigation

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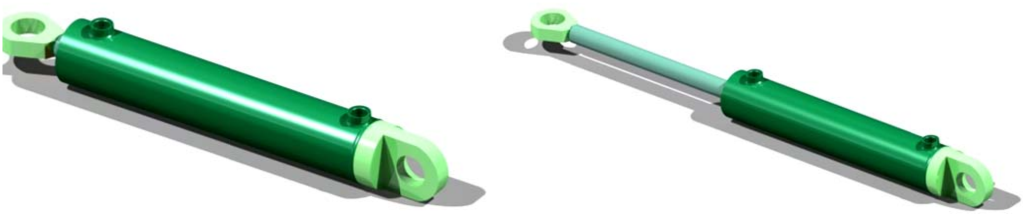
presented in this paper is to identify the optimal dimensions and form of hydraulic cylinder in relation to alterations of loads considering influence of form and stress concentration.

In the paper [2] discuses the results of the investigation of the stress states of the Bucket wheel boom (BWB) hoisting system connecting eyeplate. In the reference [3] the vibration analysis of a hydraulic cylinder subjected to dynamic loads is shown. The main topic in the paper [4] is to present results of strength and fatigue limit analysis applied to piston type hydraulic cylinders. This paper also shows advantages of application of the up-to-date digital chain of engineering analysis within which CAD tools are being used as well as strength and fatigue limit analysis. As a real case, in paper [5] appearance of typical damages of revolving platform structures for bucket wheel excavators (BWE) type TAKRAF SRs 1200×24/4 (400 kW) + VR is shown. Then, techniques for calculating their structure are presented in this paper, whose basis is made in two stages: set up of finite element mesh and analysis of loads. The paper [6] present researches of state stress of particular substructures of bucket wheel excavators (BWEs).



a) Initial position *b) Slide-out position*

Fig.1 Hydraulic cylinder at extreme positions

2. STRESS-STRAIN ANALYSIS AT HYDRAULIC CYLINDER BARREL

The analysis of stress state and determination of maximal stresses and deformations at hydraulic cylinder barrel are very important due to wide usage of those cylinders at different machine systems. This analysis and precise determination of maximal stress-strain levels also provide optimizations of hydraulic cylinders dimensions and, by that, keep stress-strain levels within allowable limits. The object of investigation presented in this paper is hydraulic cylinder at mechanism of the excavator bucket that is presented at Fig. 1 at two extreme positions. Hydraulic cylinder barrel at mechanism of the excavator bucket is loaded by internal pressure in the hydraulic cylinder, but also, by pressure due to influences of other hydraulic cylinders that form the mechanism of the excavator bucket. The pressure inside of the cylinder acts on the cylinder barrel and, by that, loads it. This pressure is equivalent in all directions and loads the cylinder barrel uniformly. The calculation of maximal stress is done by analytical method and after that, the analyses of stress-strain state is done by finite element method in order to verify obtained results.

Calculations of stresses and strains by analytic method

Mechanical capacity calculations at hydraulic cylinder are generally limited to calculations of stresses due to loads of internal fluid pressure without considerations of complex stress states due to acts of external loads. Taking into account the thickness of wall of the hydraulic cylinder barrel δ [mm], the classification of those cylinders can be define: thin wall ($D/d \leq$1.18) and thick wall (when this ratio is higher than 1.18), when D and d are external and internal diameters of the cylinder [7]. The material of the hydraulic cylinder that is considered in this paper is steel St 52-3 N according to DIN or S355 J2G3 according to SRPS EN 10025 with tensional strength of R_m= 560 MPa and yield strength of R_{eH}=355 MPa. As this type of hydraulic cilinders operate in extreme exploatative conditions, according to DIN 2448/1629 (EN 10201) and for material St 52-3 N (S355J2G3) and attest according to EN 10204-3.16 for the wall thickness of $\delta < 40$ mm, safety factor is equivalent to ν=2.5, so, on the basis of the presented data, the stress limit of σ_d =140 MPa is adopted. Maximal pressure in exploitation at hydraulic cylinder, that act as load on cylinder barrel is equivalent to p_{max} =160 bar. For calculation of wall thickness of hydraulic cylinder barrel made of material with higher toughness the following relation can be used [1]:

$$\delta \geq \frac{d}{2} \cdot \left[\sqrt{\frac{\sigma_d + p_{max} \cdot (1 - 2 \cdot \mu_p)}{\sigma_d - p_{max} \cdot (1 + \mu_p)}} - 1 \right] = 6.76 \text{ [mm]}. \quad (1)$$

In relation (1) internal diameter of the cylinder is nominated as d and it is equival to 125 mm, while μ_p is Poason ration that is for steel equivalent to 0.3. As calculated minimal wall thickness of hydraulic cylinder barrel is equivalent to 6.76 mm the next standardized dimensions are adopted as D=145 mm for external diameter of cylinder and δ=10 mm for the wall thickness. On the basis of the adopted wall thickness, the value of stress at wall of the hydraulic cylinder barrel can be calculated by following relation [7]:

$$\sigma = \frac{D^2 + d^2}{D^2 - d^2} \cdot p_{max} = 108.59 \text{ [MPa]}. \quad (2)$$

The value of stresses at maximal fluid pressure that is obtained by calculation is smaller than value adopted as maximal stress limit for selected material and exploitative conditions that confirms the constructional dimension and proper selection of material. Obtained value of hydraulic cylinder barrel wall thickness, so as obtained stress level at cylinder barrel wall due to internal pressure and pressure induced by act of other hydraulic cylinders, provide calculation of required dimensions and form. Analytic method provides relevant results for calculation of wall thickness and stress level due to fluid pressure at hydraulic cylinder barrel. For analysis of stress-strain in details at real form of the hydraulic cylinder, finite element method must be used. By this method, beside stress state, strains can be, also, determined and result stress-strain state at zones with stress concentrations can be analyzed.

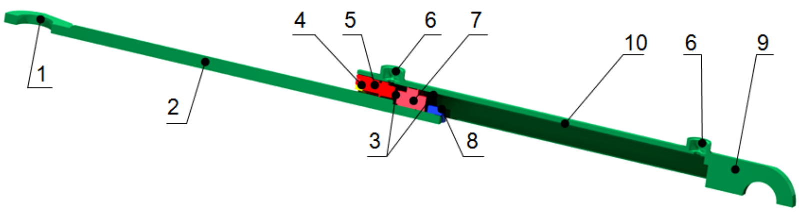


Fig.2 Main parts of hydraulic cylinder

Main parts of hydraulic cylinder, notated at one quarter of the considered cylinder, are presented at Fig. 2, where is: 1- Cylinder base, 2- Piston rod, 3- Head gland, 4- Linear bearing screw, 5- Linear bearing, 6- Plug, 7- Piston, 8- Screw, 9- Cylinder head, 10- Cylinder barrel.

Calculations of stresses and strains by numeric method

In the aim to identify the optimal constructive solution, dimensions and form of considered hydraulic cylinder, numeric analyze of stress-strain state was done by finite element method. The most of the numeric methods for calculation of stress at mechanical constructions are based on the finite element method. Finite element method can be used for precise determination of stress-strain state at critical zone on real form of machine element and obtained values are much precise than related values obtained by analytic calculations. Also, numeric method provides possibility of fast repetitions of analyzes after some alterations of details of the form [8]. Geometric Computer Aided Design (CAD) model of hydraulic cylinder is created of separate CAD elements. Load simulation at hydraulic cylinder barrel is done by using of software Computer Aided-Three Dimensional Interactive Application - ***CATIA V5R20*** and it is presented in this paper. The basic model that is used for numeric analysis is related to considered hydraulic cylinder. For material properties, the module of elasticity and Poisson ration are used as and . At first stage of generation of the numerical model, discretization is done by 3D tetrahedral finite elements with uniform distribution. The border conditions are defined in relations to theoretic considerations of hydraulic cylinder. The numeric calculations are done, firstly, at simplified model and after that, numeric analyze of stress-strain state due to different internal pressure is done.

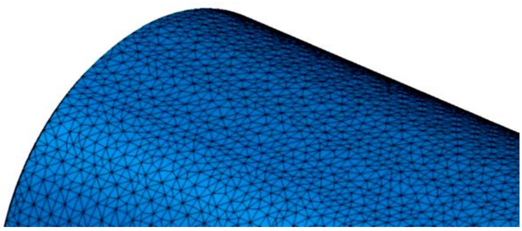


Fig.3 Discretization of one segent of the numeric model

For the every analysis, the hydraulic cylinder barrel was loaded in the same way at different values of pressure. Static system was defined by input parameters, geometric characteristics, act of loads and border conditions. After that, general problem of structural static analysis was considered.

3. RESULTS OF NUMERIC ANALYSES

In order to numeric calculation has been done, it is necessary to repeat the procedure of structural analysis for every value of pressure. The every analysis is done for different values of pressure in interval between p=160 bar and p=400 bar (160, 200, 250, 300, 350, 400 bar). As result of numeric analyze equivalent (*Von Misses*) stresses and deformations are obtained. Visualizations of results of calculations of stresses and deformation for same values of pressure are presented at Fig.4, Fig.5, Fig.6, Fig.7, Fig.8 and Fig.9.

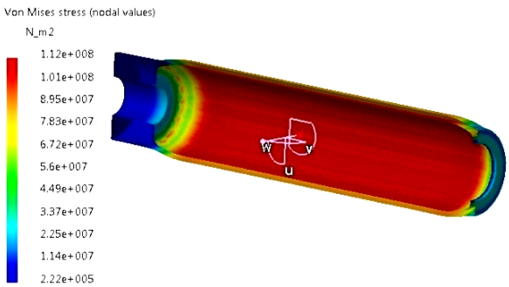


Fig.4 Stress at hydraulic cylinder barrel due to pressure

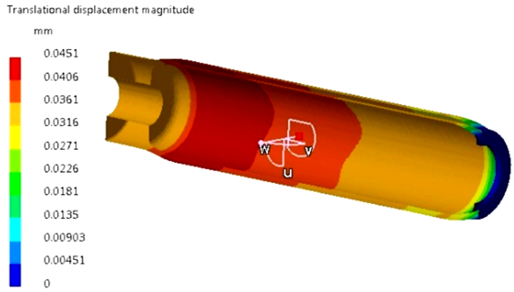


Fig.5 Strains at hydraulic cylinder barrel due to pressure

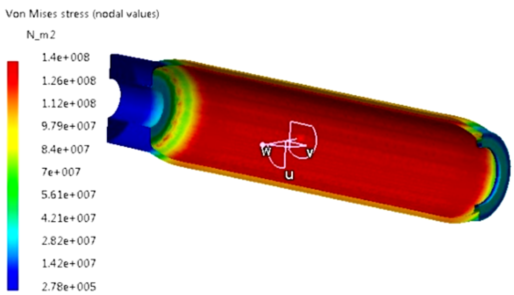


Fig.6 Stress at hydraulic cylinder barrel due to pressure

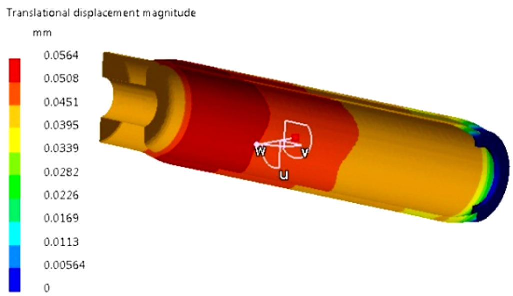


Fig.7 Strains at hydraulic cylinder barrel due to pressure

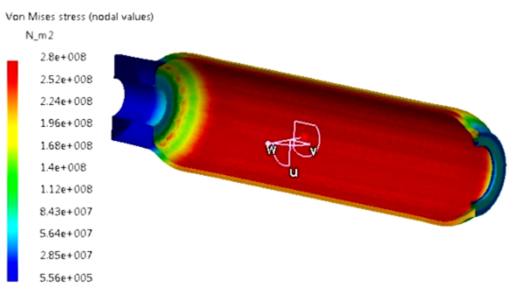


Fig.8 Stress at hydraulic cylinder barrel due to pressure

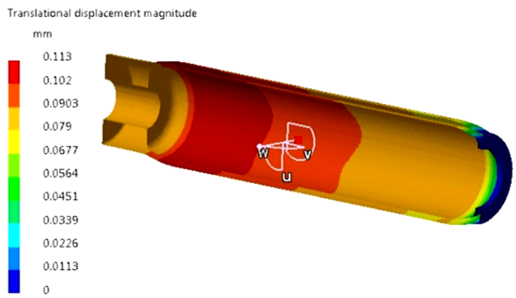


Fig.9 Strains at hydraulic cylinder barrel due to pressure

4. RESULTS EVALUATION

Evaluation of the results provides precise definition of stress-strain state at considered element of mechanical construction. Comparison of results obtained by analytic and numeric methods are presented at Fig. 10 provide comparative advantages of numeric methods due to fact that this method considers stress concentrations at critical zones. Linear increases of stress values calculated by numeric method in relation to values obtained by analytic method provide precise calculation of stresses and strains.

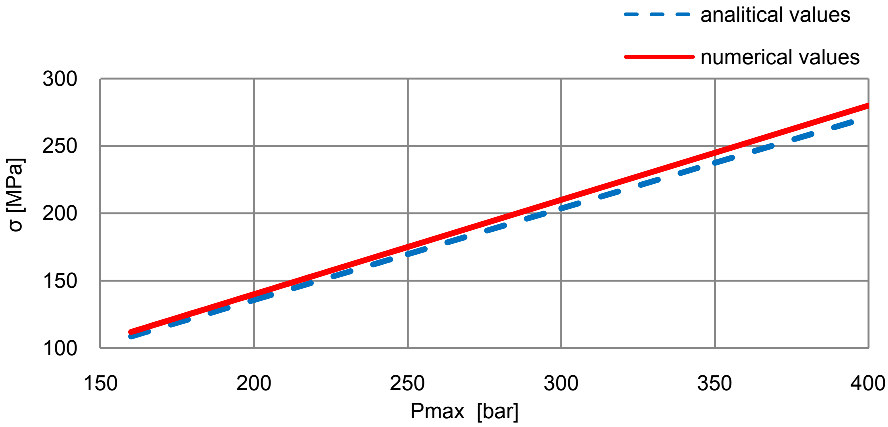


Fig. 10 Results of analytical and numerical calculations of maximal stresses and stress distribution as a function of the pressure variation

Diagram presentation of numeric analyze of resulted deformation at hydraulic cylinder barrel for different values of maximal pressure is shown at Fig. 11. Those deformations could influent to reduction of exploitation period of the cylinder and present one of the major causes of failures at excavator bucket mechanisms. The analysis of deformations implicate that at pressure higher than allowed, higher deformations are induced that overcome allowable deformations limit, so fluid pass between piston and cylinder barrel and failure at hydraulic mechanism occur.

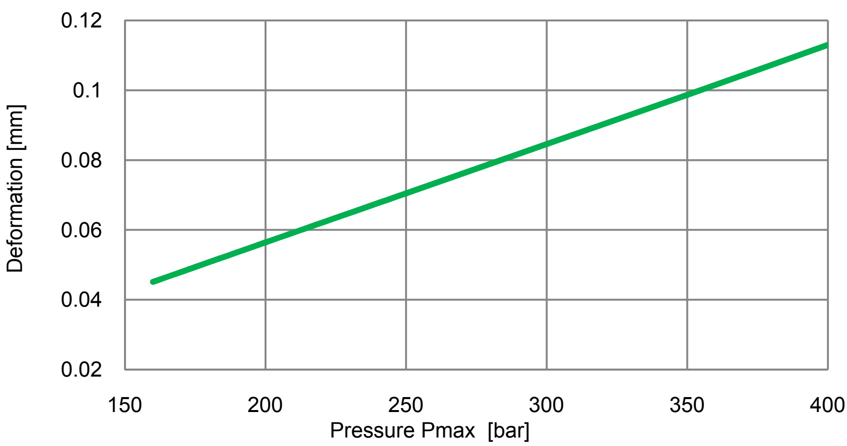


Fig. 11 Results of analytical calculations of maximal deformation as a function of the pressure variation

5. CONCLUSION

On the basis of the conducted evaluation of results, following general conclusions are implicated:

- Diagrams of stresses obtained by analytic and numeric method have the same trends, so considered model by numeric method is relevant and relate to adequate construction solution. The mathematical model that is formed can be taken for further analysis and testing in aim to obtain decrease of maximal stress level, so as dynamic and fatigue analysis.
- Values of stresses calculated by numeric method are higher than related values calculated by analytic method due to fact that this method does not consider stress concentration because of its complex determination, so it is implicated that for precise real stress state numerical method that considered real geometry and form must be used.

On the basis of those conclusions it is implicated that both analytic and numeric methods provide relevant results due to sensitivities to alterations of input parameters, but special care should be taken on influence of stress concentration at zones of the cylinders. The alterations of maximal result stresses at specific zones of hydraulic cylinder are highly influenced by alterations of maximal pressure inside the cylinder. Conducted analyses provide precise identification of optimal construction solution, so as identification of its optimal form and by that, provide prevention of damages and failures at maximal pressures during exploitation.

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