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Static and Fatigue Analysis of the Hydraulic Cylinder and Tensile Device from an Uniaxial Testing System

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The paper presents the static analysis and the fatigue behavior analysis of the components of a tensile test equipment (hydraulic cylinder and tensile device), designed for didactic applications. The stress and the displacements that occur in the limit-loading approaches are calculated using static FEM analysis. It is also investigated the possibility of using the hydraulic cylinder and the tensile device in a redesigned equipment used for fatigue tests.

***Keywords**: hydraulic cylinder, tensile device, stress, fatigue*

1. Introduction

Components of fatigue testing systems are subject to a very large number of load cycles. The occurrence of fracture in the components of these systems can be accentuated by stress concentrators, material defects, overloads, etc. [1, 2]. Numerical simulations based on the finite element method facilitate the decrease of stress concentrators factors and the extension of equipment life cycle [3, 4].

The paper presents the static analysis and the fatigue behavior analysis performed on the components of hydraulic tensile testing equipment [5]. A redesign process is desirable in order to use the new equipment for fatigue tests in didactic applications. The initial structure of the equipment is shown in Figure 1. The mechanical energy generated by an electric motor is transmitted to a hydraulic pump which feeds with oil (via a 4/3-way valve) the hydraulic cylinder (double acting). The piston rod of the hydraulic cylinder is connected to the mobile head of the tensile device. The fixed head of the tensile device is connected with the hydraulic cylinder left cap flange by two columns. The head of the mobile head is guided through a flange that slides over the columns. The two cylinder cap flanges are connected by four threaded rods. Attaching the equipment to the base plate is done by eight screws disposed on the fixed flange of the tensile device and the left cylinder cap flange (the right cap flange is not fixed relative to the base plate). The

3D model of the equipment is shown in Figure 2. The static behaviors of hydraulic cylinder and tensile device have been analyzed distinctly.

Figure 1. Hydraulic cylinder and tensile device.

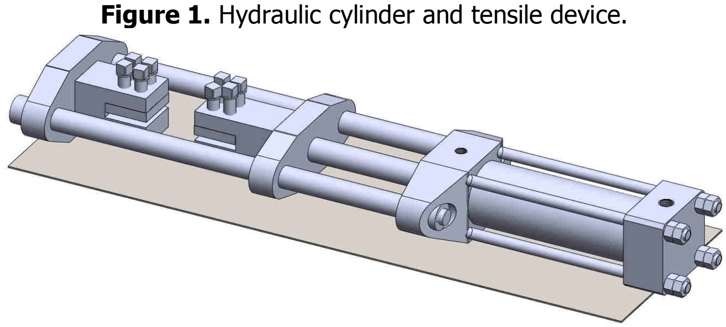

Figure 2. 3D model of the system.

2. Static analysis of cylinder

The analysis was applied to the subassembly composed of cylinder barrel, cylinder cap flanges and threaded rods that secure the caps. The cylinder was fixed on the contact surface between the left cap flange and the base plate (Figure 3). A bonded connection was applied between the elements of the assembly. For the mesh were used tetrahedral finite elements with the maximum 2 mm side size. A uniform pressure of 10 N/mm^2 was applied to the inner surface of the cylinder and cap flanges. This loading approach corresponds to the limit case in which the discharge of the hydraulic fluid in the first chamber is locked while the feed of the second chamber continues. The pressure value of 10 N/mm^2 corresponds to a maximum force developed on tensile tests F_t = 30800 N and a maximum force developed at compression tests F_c = 38000 N.

The distribution of von Mises equivalent stresses is shown in Figure 4 (general view) and Figure 5 (areas with stress over 75 N/mm^2). It can be noticed the relatively uniform distribution of stress on the barrel. The maximum value of stress occurs at the left end of the barrel close to the fixed surface. A bending stress occurs on the barrel due to the asymmetry of constraint. The maximum von Mises stress lead to a safety factor c_{cs} = 4,45 relative to the yield strength of E335 steel.

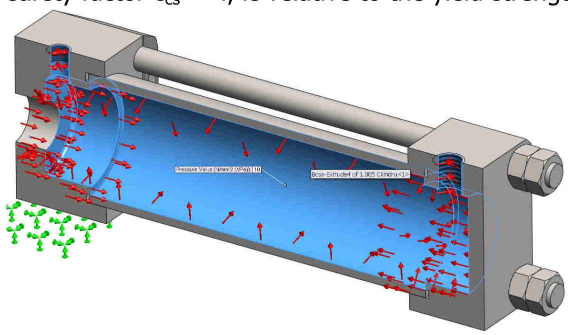

Figure 3. Loads and constraints on hydraulic cylinder

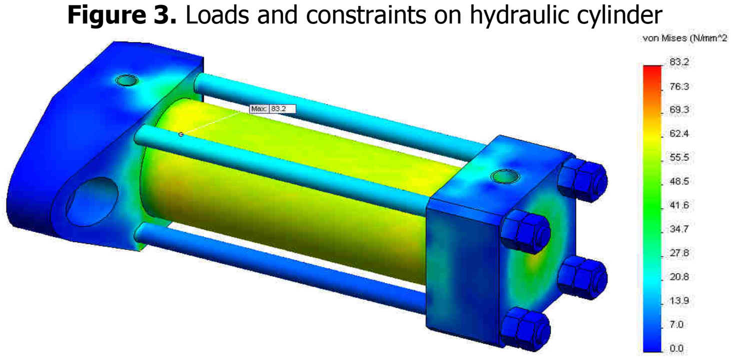

Figure 4. Von Mises stress distribution on cylinder.

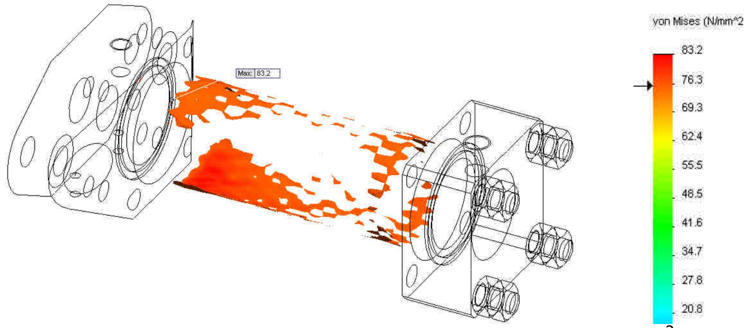

Figure 5. Area with von Misses stress above 75 N/mm^2.

As can be seen in Figure 4, the maximum stresses in the cylinder cap flanges and threaded rods are below 75 N/mm^2. The equipment is designed and manufactured in the framework of diploma projects in the years 1980-1985. The design documentation was not identified. The type of materials used for the components has not been determined yet. However, the values obtained in the FEM simulations are covered for commonly used materials. For the redesigning process will be carried out tests to determine the chemical composition.

The chart of resulting displacements is shown in Figure 6. The maximum value of displacement occurs on right cap flange. The maximum value is 6 μm. The main component of the resulting displacement is axial, being generated by the action of the pressure on the inner surface of the right cap flange.

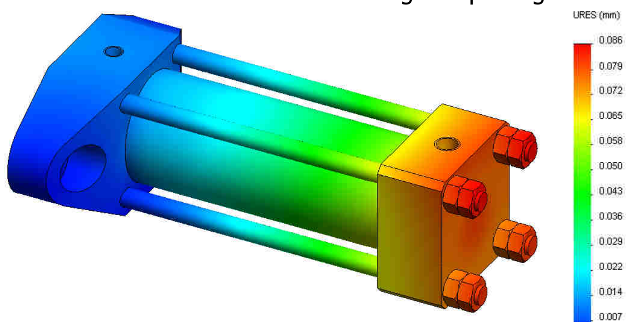

Figure 6. Resultant displacement chart on cylinder.

3. Static analysis of testing device

This static simulation was performed on the structure of tensile device shown in Figure 7. The pressure of 10 N/mm^2 was applied to the piston left surface. The bottom surfaces of device left flange and cylinder left cap flange were fixed.

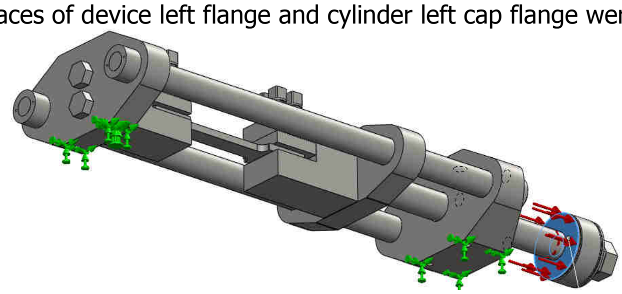

Figure 7. Loads and constraints on tensile device.

The maximum von Mises stress (484 N/mm^2) occurs on the test specimen (Figure 8). Figure 9 shows areas of the device components with stress higher than 75 N/mm^2 (the test specimen was removed from this view). The maximum value occurs on the components with stress concentrators (the maximum stress on device components is 208.2 N/mm^2). The resultant displacement is 7.88 mm and corresponds to elongation of the test specimen (Figure 10).

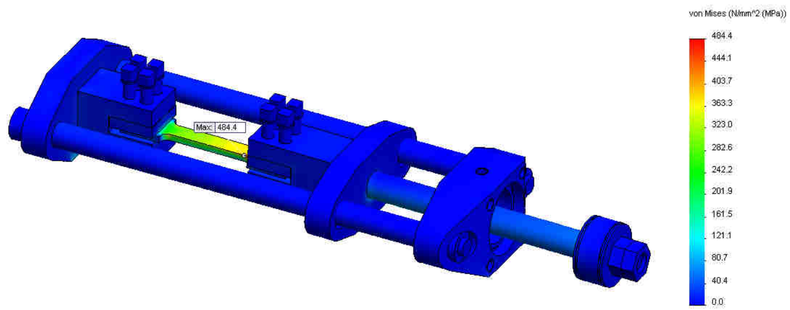

Figure 8. Von Mises stress distribution on tensile device.

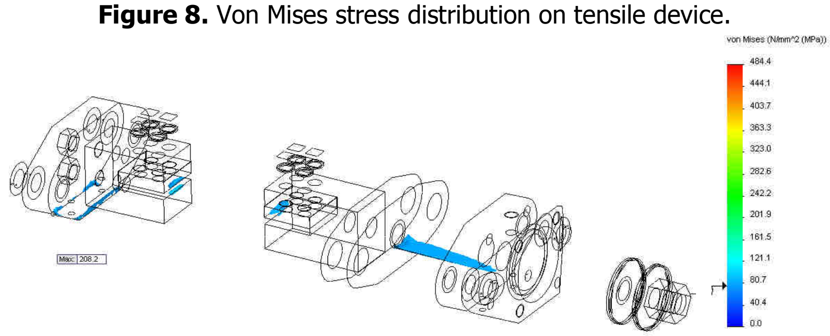

Figure 9. Tensile device. Area with von Misses stress above 75 N/mm^2.

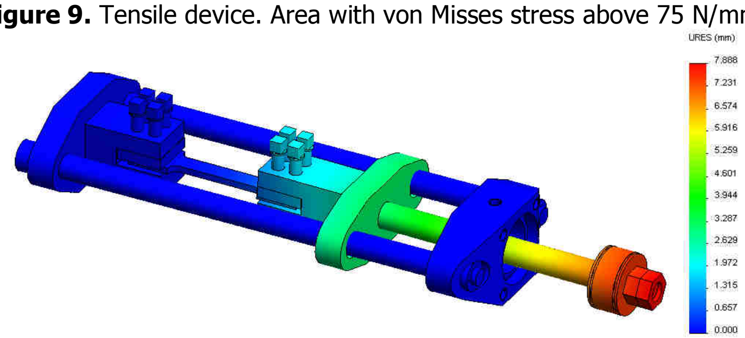

Figure 10. Resultant displacement distribution on tensile device.

4. Fatigue analysis

The hydraulic cylinder components are subjected to fatigue under pulsating tensile stress (barrel and cap flanges) or reversed tensile/compressive stress (piston, piston rod, columns). For E335 steel, fatigue limit for reversed tensile/compressive stress is 270 N/mm^2 and the fatigue limit for pulsating tensile stress is 340 N/mm^2 on 10^6 cycles [6]. Under these conditions, the minimum values obtained for fatigue safety factors are: c_{fc}=4.09 (cylinder) and c_{fc}=1.33 (piston rod). These coefficients are calculated relative to the stress obtained in the static analysis for limit-loading cases. Given that at the pressure of 10 N/mm^2 the tensile force provided by the cylinder is F_t=30800 N, it is proposed that the equipment to be redesigned for fatigue testing on non-ferrous materials and plastics with a strength limit below 300 N/mm^2 (hydraulic pressure limited to 7 N/mm^2).

5. Conclusion

The static analysis of the hydraulic cylinder and the tensile device from a tensile testing equipment has been performed for two limit-loading cases. The stresses obtained from static analysis performed by numerical simulations indicate that the system can be used for tensile tests up to a working pressure of 10 N/mm^2. If the equipment is redesigned for fatigue testing, it is recommended to limit the hydraulic pressure to 7 N/mm^2.

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