# Structure Design of Self-limiting Hydraulic Cylinder

Zhen-Nan Ren[1,a],Ming-Fu Yin[2,b *]

[1]Mechanical Engineering, Tianjin Polytechnic University, Tianjin, 300387, China

[2]Mechanical Engineering, Tianjin Polytechnic University, Tianjin, 300387, China

[a]email:18710885924@163.com, [b]email:yinmingfu@163.com,[*]corresponding author

**Keywords:** rocky pressure machine, hydraulic cylinder, Solidworks, Ansys analysis

**Abstract.** In recent years, characteristic of rocky pressure machines is developing from low-pressure and static to heavy-duty and revolving. In order to make the pressure chamber of rocky press rotate precisely, this paper puts forward to introduce hydraulic cylinder as a support of the workbench, thus satisfying the reposeful operation of the press over heavy loading. The feasibility was verified by Solidworks modeling and Ansys analysis. This research lays a foundation for the design of the rocky pressure machines in the future.

## Introduction

Recent years, as the rapid development of engineering construction, the engineering geological conditions we encounter become more and more complex. The direction tunnels head lies on the large section, and for mine roadways, it lies on depth above 1km[2][3]. More geological hazard such as project collapse, water inrush and rock burst happens frequently. Researchers of the geotechnical engineering are facing an unprecedented challenge. This requires a deep research on mechanics and engineering properties of the rocks. Rock pressure machine is a vital tool for studying rock mechanics properties. In order to realize the visualization of conditions and features when rock specimen fracturing, geological scientists hope to combine a pressure machine with a pressure chamber that can rotate precisely with high energy accelerator imaging and Three-Dimensional Image Restructure Techniques to obtain their goal.[1] This provides new information about exploiting underground oil and gas and earthquake studying.

## Overall Structure Design of the Hydraulic Cylinder

**The Hydraulic Cylinder Structure Design.** Figure 1 shows the structure of the hydraulic cylinder. When the toothed belt wheel is rotating, the workbench will be driven by linear bearings. By oiling the under oil chamber of the cylinder, the piston rod can achieve a slight vertical displacement, meanwhile, the forming hydraulic oil film can be used as a medium to reduce friction between the piston rod and the bottom of the cylinder.

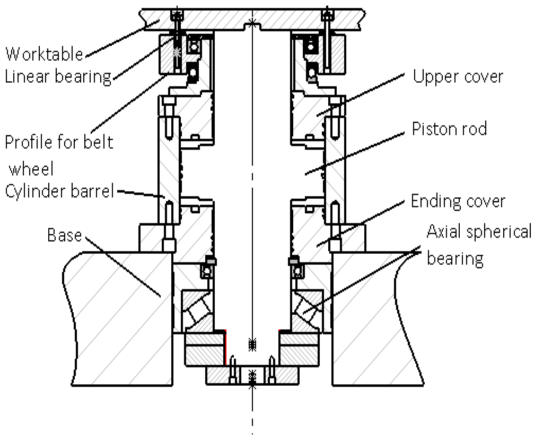



Fig.1 Assembly drawing of hydraulic cylinder

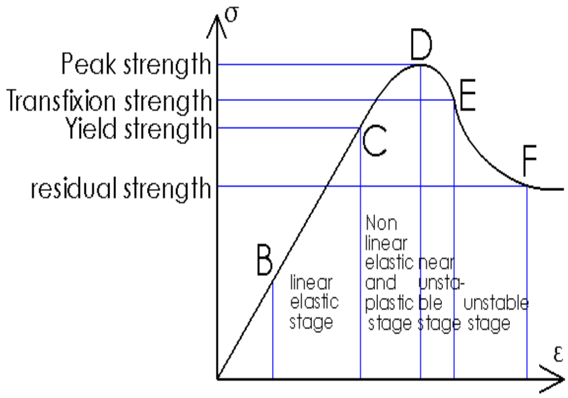



Fig.2The curve of rock specimen after the peak

Figure 2 gives the curve of rock specimen after the peak. When the deformation of rock reaches to point D, sharp decline of the rock strength will impact the testing machine and the experimental results. Based on this problem, a thrust center-adjusted bearing was installed beneath the hydraulic cylinder which could offset the impactive load when going through point D[4]. The form of the friction is rotational friction which can make rock test experiment go on successfully.

**Stress Analysis Of A Hydraulic Cylinder As A Whole.** As shown in Figure 1, when the hydraulic oil is filled into the subjacent oil chamber, it will offer a downward force to the bottom components. The bottom of the cylinder is rigidly connected by a bolt. According to the force of action and reaction, the bottom components suffer an upward force. Hence, bottom of the hydraulic cylinder suffers merely an internal pressure rather than shear force.

## Hydraulic Cylinder Structure Parameter Design

**Inner Diameter Design of Hydraulic Cylinder.** With a certain operating pressure, principles of determining the internal diameter are ensuring the enough output of cylinder to drive the workload. When the piston rod drive the load with thrust:

$$D=\sqrt{\frac{4P_1}{\pi(p-p_0)n_g}-\frac{d^2p_0}{p-p_0}}. \tag{1}$$

Where*P1*is the thrust, it promotes the smalldisplacementof the pistonrod inalinedirection.The *p* and*p0* are the working pressure and return oil back pressure of hydraulic cylinder, respectively. The $n_g$is the overall mechanical efficiency,$n_g$ =0.95.

**Cylinder Wall Thickness Design.** Based on the thin film theory, it is believed that the tensile stress caused by hydraulic pressure of the cylinder in the circumferential direction is equal. Its strength condition is the main stress, the loop tensile stress is less than or equal to the allowable stress.

$$\sigma=\frac{PD}{2l}\leq[\sigma]. \tag{2}$$

Therefore, the Wall thickness is

$$l=\frac{PD}{2[\sigma]}. \tag{3}$$

Where $P$ is the working pressure of hydraulic cylinder. $D$ is the inner diameter of the cylinder. Materials of thekey parts of hydrauliccylinder is 40Cr.Allowable stressof the 40Cris785Mpa.

It should be noted, the pressure P of the formulation is not the rated working pressure, but the test pressure of the hydraulic cylinder. In order to assess the strength of the hydraulic cylinder, test pressure of the hydraulic cylinder in the factorial test is often higher than the rated pressure. When the rated pressure is less than or equal to 15.69Mpa, the test pressure is 1.5 times the rated pressure. When the rated pressure is greater than 15.96Mpa, the test pressure is 1.25 times the rated pressure. But in actual calculation, we often use the work pressure.

**The Design of End Cover.** Assuming the liquid pressure is fully covered by the end cover.

$$h=\sqrt{\frac{\pi D^2}{4}p\frac{4}{\pi}\frac{d_H-d_m}{[\sigma]（D_e-d-2d_H）}}\ . \tag{4}$$

When the $\sqrt{p/[\sigma]}$=A, therefore:

$$h=AD\sqrt{\frac{d_H-d_m}{D_e-d-2d_H}}\ . \tag{5}$$

The parameters in the formula are shown in Figure 3.

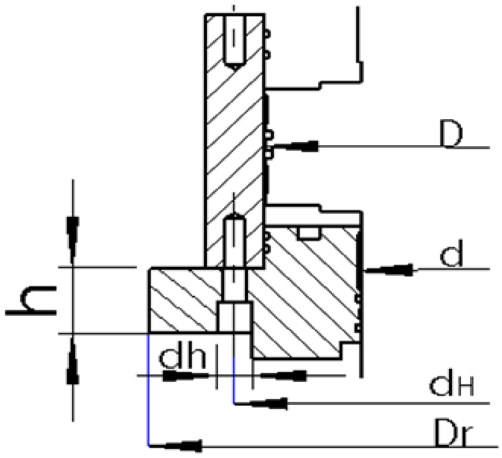
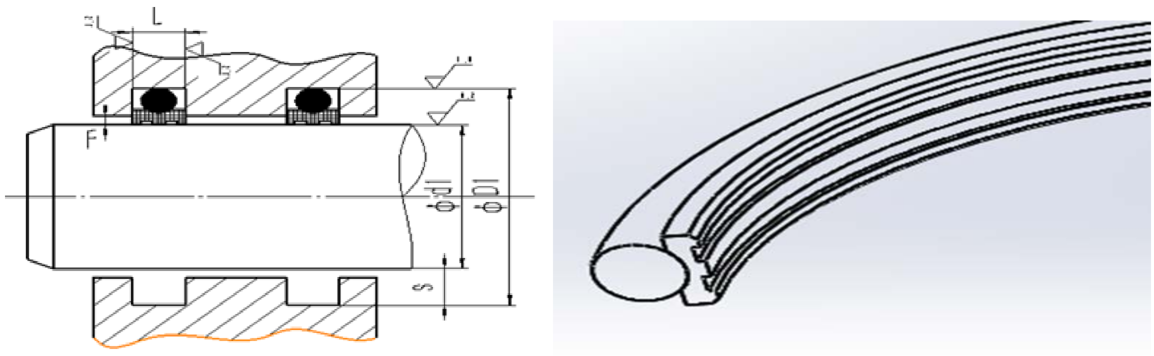



Fig.3Hydraulic cylinder size

**Seal of Hydraulic Cylinder.** Straightly move of the piston rod accompanies with the rotating movement of workbench. Therefore, we must use a special structure for sealing to ensure the smooth operation of the hydraulic cylinder.

Figure 4 shows a combined type rotary pressure seal. It can seal the rotation and reciprocating motion at the same time. The main material is PTFE additives.




(a)structure (b)pressure seal

Fig.4 The rotary pressure seal

**Table1**.The parameters of the seal

<table>
<tr><td colspan="2">Speed</td><td colspan="3">2m/s</td></tr>
<tr><td colspan="5">temperature range℃</td></tr>
<tr><td colspan="5">Nitrile rubber O-circle：-30～110</td></tr>
<tr><td colspan="2">surface finish.</td><td>$R_a$（μm）</td><td colspan="2">$R_t$（μm）</td></tr>
<tr><td colspan="2">$\emptyset d_1$</td><td>⩽0.3</td><td colspan="2">⩽4</td></tr>
<tr><td colspan="2">$\emptyset D_1$</td><td>⩽1.8</td><td colspan="2">⩽10</td></tr>
<tr><td colspan="2">$\emptyset L$</td><td>⩽3.2</td><td colspan="2">⩽16</td></tr>
<tr><td>Pressure（bar）</td><td>$S$（mm）</td><td>$\emptyset D_1$（mm）</td><td>$L$+0.2（mm）</td><td>$F$ (mm)</td></tr>
<tr><td>300</td><td>2.45</td><td>d1+4.9</td><td>2.2</td><td>0.05</td></tr>
</table>

## Finite Element Statics Analysis

We analyzed the key parts of hydraulic cylinder with finite element static analysis module. The stress concentration and maximum deformation was analyzed and we got its safety factor finally. There are great differences between the finite element analysis and production practice. In order to make the actual safety factor bigger than or equal to 5, it is necessary to make the finite element safety factor bigger than 5 to meet the actual demand.

**Finite Element Analysis of End Cover**. Figure 5 gives the nephogram of total deformation, stress deformation, the middle-section stress deformation and the safety factor of the cylinder's end cover. Material of subjacent end cover is 40Cr, tensile strength (σb/MPa):≥980, yield point(σb/MPa):≥785. Seeing from the figure that the concentration area of integral stress located in the port and the maximum deformation is 0.014mm. The maximum stress concentration can't be higher than 24Mpa and the safety factor should be about 15. Fortunately, this structure meets the requirement of strength completely.

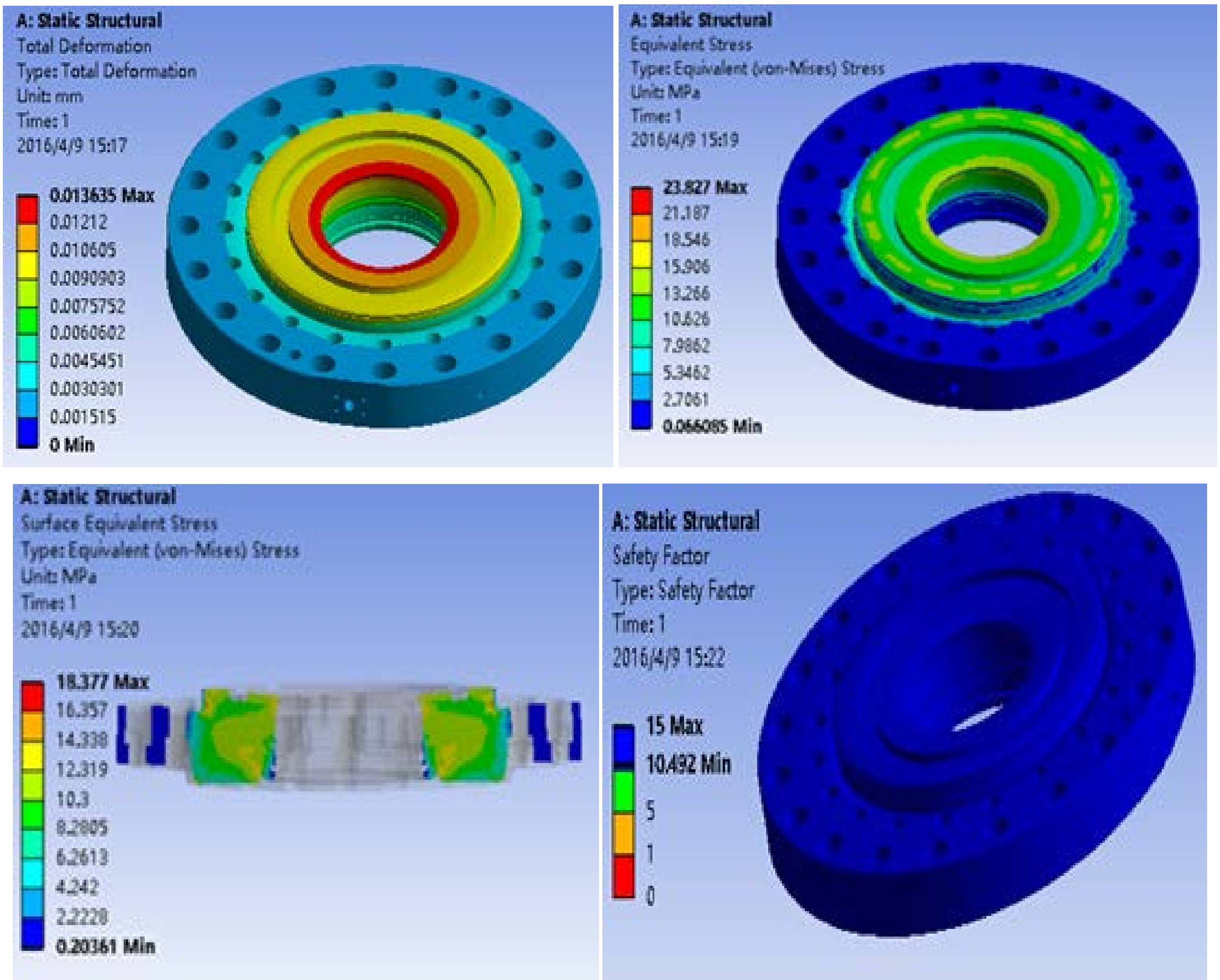
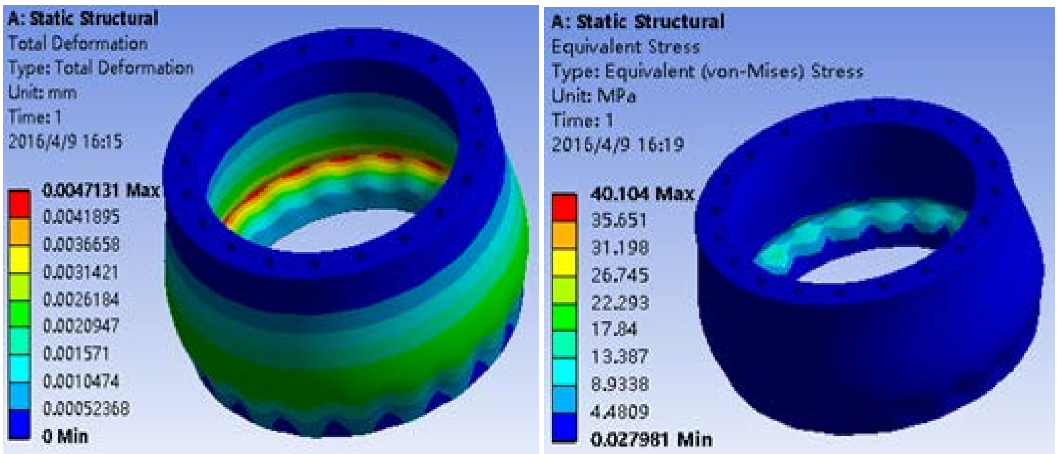



Fig5. Finite element analysis of end cover

**Finite Element Analysis of Cylinder Barrel.** The material of the Cylinder barrel is 40Cr. It can be seen from the figure that the maximum deformation occurs at the pressure part. The deformation can't exceed 0.01mm. Due to the maximum clearance of the rotary pressure seal, *F*=0.05, it can ensure the sealing performance of the sealing ring. Maximum stress does not exceed 40Mpa. Thus it can meet the actual production demand.



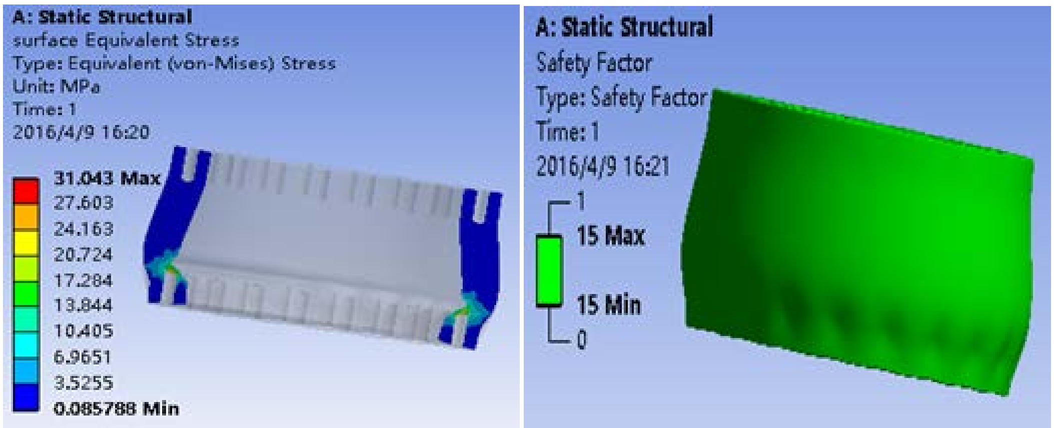



Fig6. Finite element analysis of Cylinder wall

## Summary

This article designed a new type of self-limited hydraulic cylinder based on Solidworks model, thus making the workbench rotate smoothly. Finite element statics analysis was applied. When 40Cr was adopted, deformation between end cover and cylinder barrel did not exceed 0.01mm. Thus, the rotary sealing could prevent oil leak effectively when the hydraulic cylinder rotating. Finite element statics analysis was used to analyze the stress of crucial parts of the hydraulic cylinder, then found that all the stress can meet the strength requirement and it could be applied to practical production.

## References

[1]V.N. Ashikhmin, M.B. Gitman, P.V. Trusov, Optimal design of hydraulic cylinders subjected to autofrettage, J. Strength of Materials,1999,306.

[2]K.W. Liao,C. Ha, Application of reliability-based optimization to earth-moving machine: hydraulic cylinder components design process, J.Structural and Multidisciplinary Optimization,2008,365.

[3]Berglund L,Samson M,An K N, Four axial structural and material test machine, J. Biomedical sciences instrumentation,1994,30.

[4]F. Rummel, C. Fairhurst, Determination of the post-failure behavior of brittle rock using a servo-controlled testing machine, J. Rock Mechanics Felsmechanik Mécanique des Roches, 1970,24.

[5]V.Ya. Martenson, I.Kh. Kaplan, V.D. Ser'ga, A.A. Kholodov, Ways to create and improve high-parameter hydraulic drives for hydraulic structures, J. Hydrotechnical Construction,1988,2112.