

Radial Strains of Double-layer Cylinders in Hydraulic Props of Powered Supports

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Abstract. At present a lot of efforts are made to use double-layer power cylinders in hydraulic props of powered supports. To study the response of these cylinders to loads a special finite-element model has been developed and used for investigations into tension effect and double-layer cylinder thickness – radial strain relation under pressure of hydraulic liquid 50 MPa. It has been revealed that double-layer cylinders are distinguished by much lower radial strains in the zone of cup-like sealing elements as if compared with one-layer cylinders, as well as equivalent stresses are lower, and safety factor is higher. The data of the study can be recommended to calculate appropriate geometrical parameters of hydraulic props with respect to lower radial strains of a hydraulic cylinder, which improve its leak-tightness and functioning of cup-like sealing elements. The obtained results can be useful for design and construction of powered supports.

1. Introduction

A hydraulic prop is a hydraulic power cylinder; when it is exposed to loads its radial strains specify the cylinder – piston gap to be sealed affecting efficiency of a seal [1], as the consequence, leak-tightness. A numerical value of this gap is a sum total of a fit up gap, calculated on the base of piston and cylinder fabrication tolerances, and radial strains of cylinder inner surface (dR) under hydraulic liquid pressure, dependent on the value of this pressure (P), manufacturing technology [2–4], hydraulic prop structure [5, 6], its hydraulic extensibility (lp) [7], as well as on the structure of a support [8] and its external environment [9, 10].

2. Methods

A parameter-oriented model on the base of finite-element method was used to calculate radial strains and stresses in elements of the cylinder. This method is an up to date computational approach enabling precise and fast calculating complex designs by means of numerical engineering.

3. Work Description

The results of earlier investigations into radial strains of the main cylinder [7] are as follows: the curve shape is of the form depicted in Fig. 1, which becomes wider at the head end and narrows at the rod



end. The following reference points were used to compare assessment criteria of strains lengthwise the cylinder.

P. 1 has maximal radial strains at the piston (dR_1).

P. 2 corresponds with the zone of stable radial strains in the cylinder body (dR_2).

P. 3 agrees with maximal radial strains in the piston zone (dR_3) when compressing the cylinder, which can't exceed the minimal piston – cylinder fit up gap.

P. 4 is in the zone of the first seal at the head end. Radial strains in this point (dR_4) determine the gap to be sealed, which affects sealing efficiency and leak-tightness of the hydraulic prop [1].

P. 5 has maximal radial strains at the bottom of the hydraulic cylinder (dR_5).

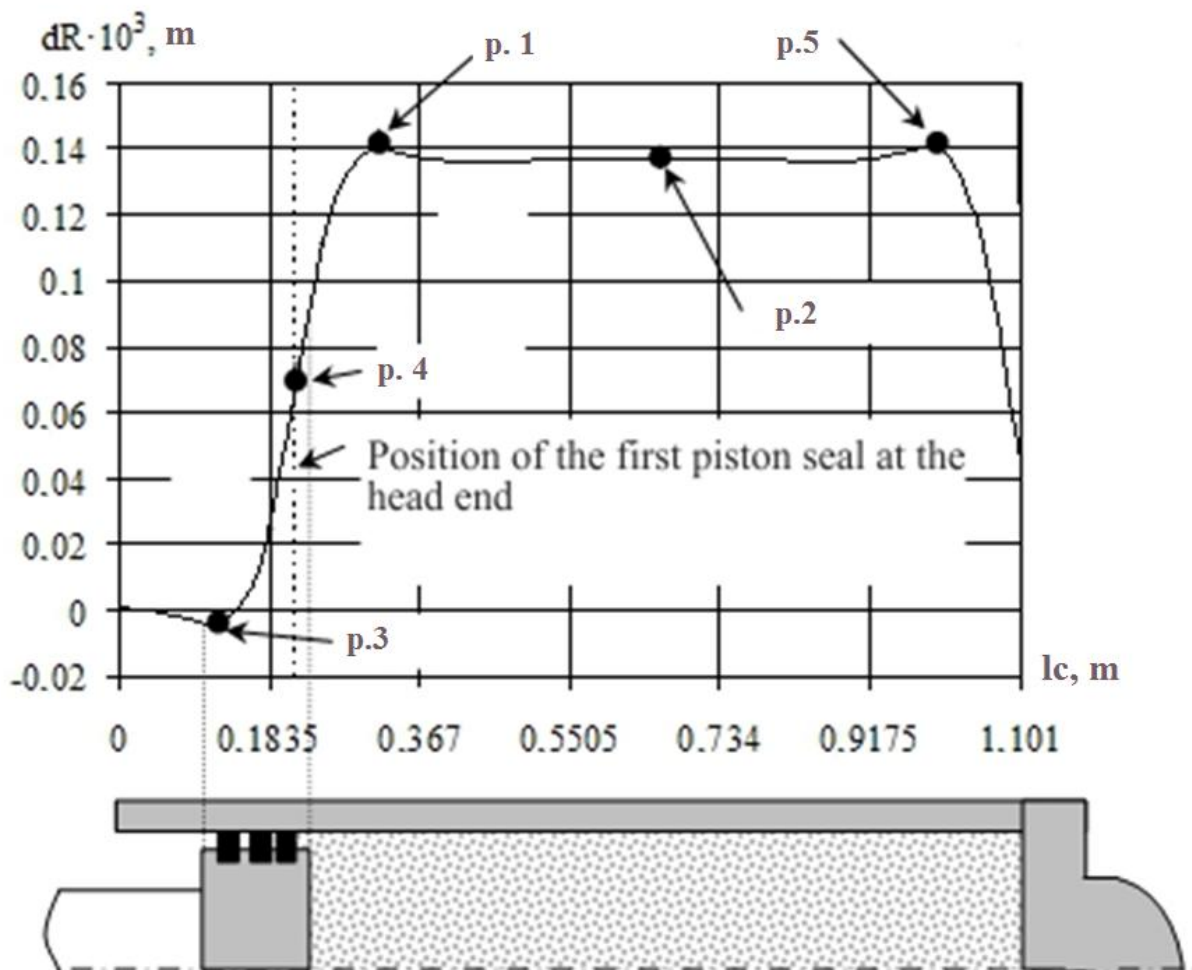


Figure 1. Radial strains lengthwise (lc) the main cylinder (dR) and position of reference points

It was proposed to fabricate the main cylinder of two layers coupled to each other by tension in order to reduce radial strains of the cylinder internal surface, which is necessary to improve operating conditions of cup-like sealing elements and leak-tightness of hydraulic props.

A special finite-element parameter-oriented model was developed to study strain in the main cylinder of the hydraulic prop in the powered support, layout and parameters of this model are outlined in Fig. 2.

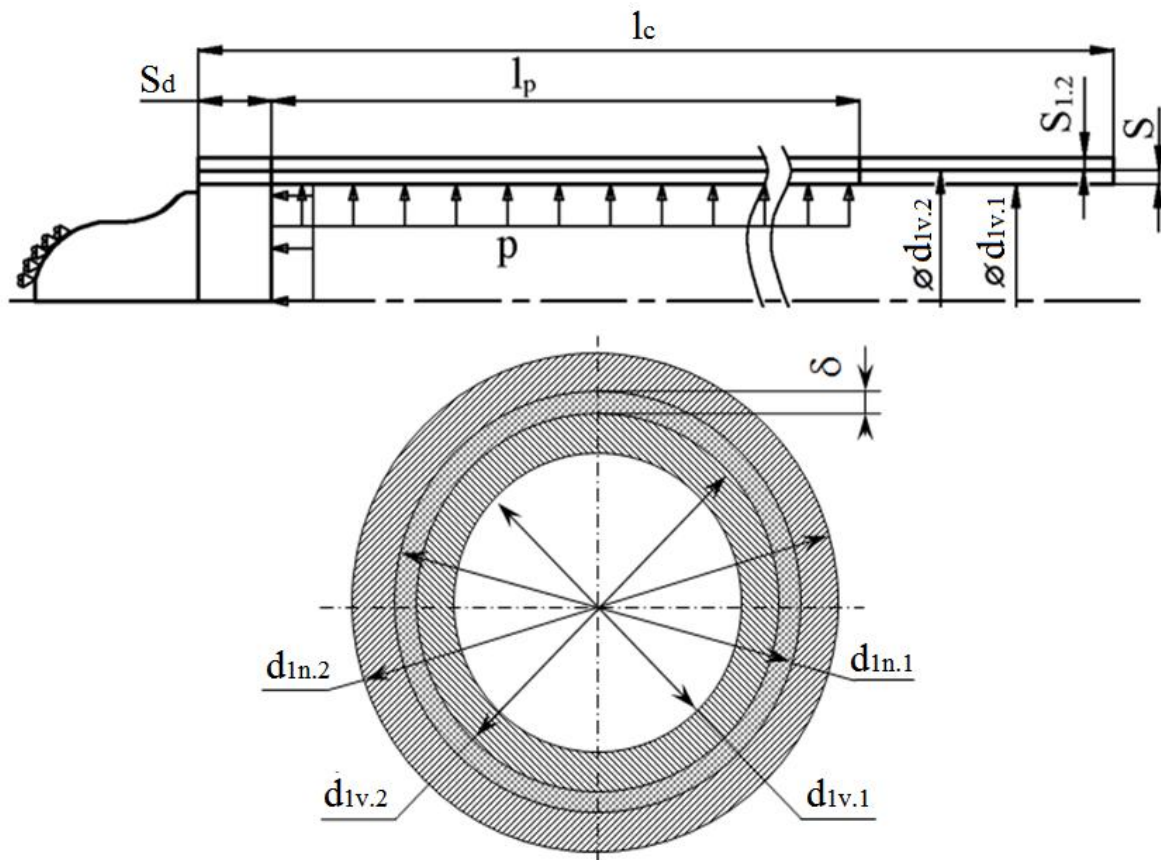


Figure 2. Layout and parameters of finite-element model for computing strains in double-layer cylinder of a hydraulic prop

Steel 9HF was admitted as material for outer cylinder, while steel 30HGSA was thought as material for inner cylinder. Properties of these materials are given in Table 1. Geometrical parameters of the model are presented in Table 2.

Table 1. Properties of materials of double-layer cylinder

Parameter	30HGSA	9HF
Yield point, MPa	490	670
Poisson ratio	0.29	0.345
Young modulus, Pa	$2.15 \cdot 10^{11}$	$2.15 \cdot 10^{11}$

Table 2. Main geometrical parameters of a hydraulic prop

Parameter	Value
Inner diameter of the cylinder ($d_{i.v.1}$), m	0.25
Thickness of the cylinder wall (S), m	0.025
Bottom thickness (S_d), m	0.032
Cylinder length (l_c), m	1.115
Extensibility (l_p), m	0.885

Radial strains of double-layer cylinders were calculated according to the developed parameter-oriented finite-element model on the base of planar linear 4-unit forming elements with axis symmetry and contact elements between layers.

The following restrictions were accepted for the research purpose: total thickness of walls – 25 mm; wall thickness relation of inner cylinder to the outer one – 10/15, 12.5/12.5, 15/10, 20/5 mm; fit up tension – 0.104 mm.

As the result, radial strains of inner surface in a single-layer cylinder of a powered support OKP 70 were calculated provided that a hydraulic prop is fully extended (Fig. 3), the same strains were also computed for a double-layer cylinder (Fig. 4). Moreover, strains for various tensions between inner and outer layer of a cylinder are depicted in Fig. 4.

The obtained radial strains in reference point 3 and reference point 4 (dR_3 and dR_4) are given in Table 3.

The following criteria are proposed to measure strains in the main cylinder.

Safety factor with respect to maximal tolerance by bulging cylinder,

$$n_{\Delta_{max}} = \frac{0.15}{dR_4} \quad (1)$$

which is to be more than one to keep operating capacity of a hydraulic prop (a gap to be sealed doesn't exceed the safe one because of leak-tightness).

Safety factor with respect to minimal tolerance by narrowing cylinder at the rod end provided there is no scuffing

$$n_{\Delta_{min}} = \frac{\Delta_{min}}{(-2 \cdot dR_3)} \quad (2)$$

This criterion is to be more than one (in most cases) or negative. When $n_{\Delta_{min}} = 1$ compression strains of a cylinder in reference point 3 are equal to the minimal possible gap dependent on piston and cylinder manufacturing tolerances, therefore, scuffing is possible on the cylinder face if units to be assembled are combined this way. If the values are negative, cylinder – piston gap gets broader relative to the fit up tolerance, as the result, scuffing is less probable than in an unloaded hydraulic prop.

The system of proposed criteria enable assessing operational capacity of a hydraulic prop under critical pressure of hydraulic liquid.

Values of criteria $n_{\Delta_{max}}$ and $n_{\Delta_{min}}$ for powered support OKP 70 with single-layer and double-layer cylinder are given in Table 3.

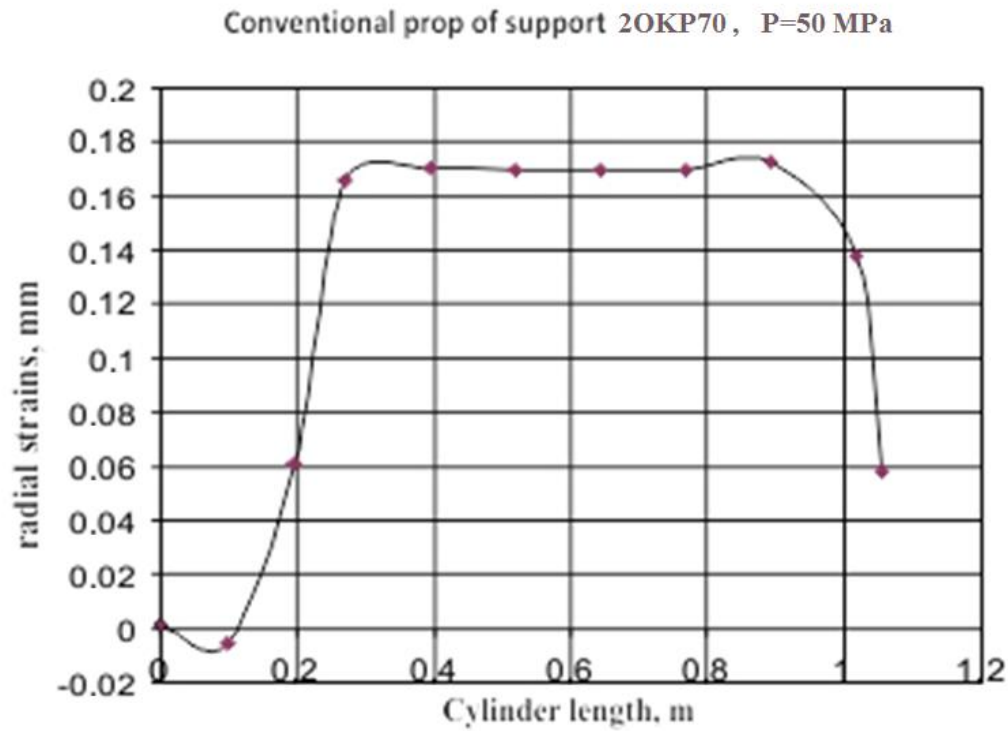


Figure 3. Radial strains of the inner surface in a single-layer cylinder, wall thickness is 25 mm and pressure of hydraulic liquid P=50 MPa

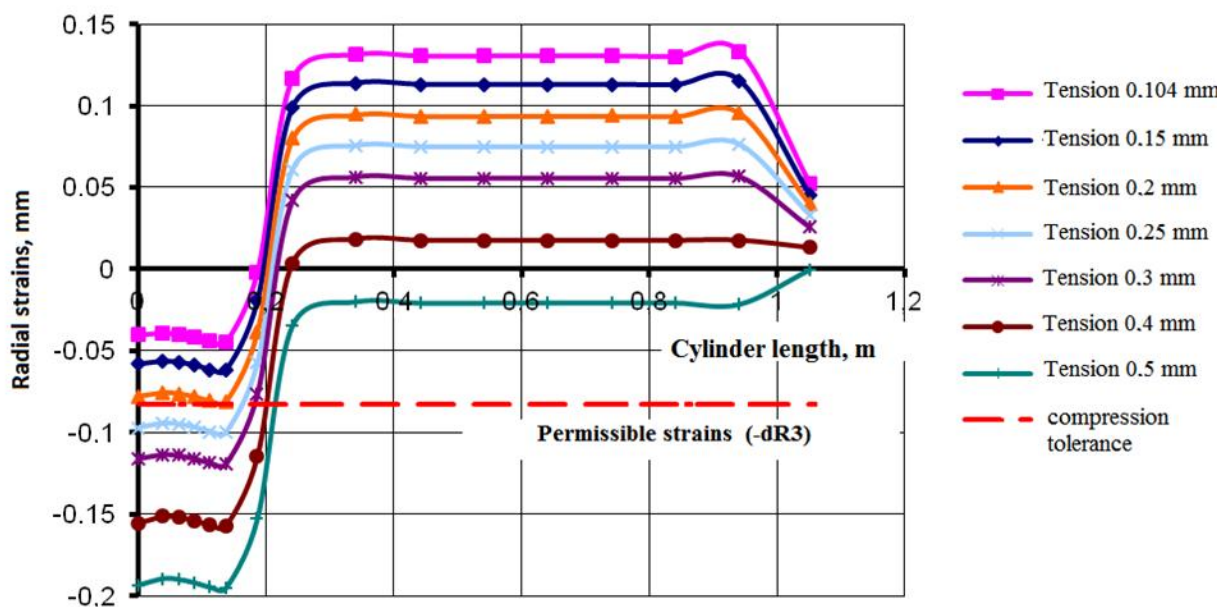


Figure 4. Radial strains of the inner surface in the cylinder, pressure of hydraulic liquid is P=50 MPa, inner cylinder thickness is 15 mm, outer cylinder thickness is 10 mm, tension is various

Double-layer cylinders are advantageous over single-layer ones in view of data presented in Figure 3 and Figure 4, as well as in Table 4, due to the increasing safety factor measured relative to maximal equivalent stresses; dimensions of the hydraulic prop and its steel intensity are equal. In this case either reliability of the hydraulic prop can be improved (e. g. under dynamic load in a longwall, as the consequence, under pressure far beyond the rated one in the head end), or wall thickness can be reduced keeping the same safety factor.

Table 3. Criteria of double-layer cylinders in the hydraulic prop of support OKP70

Thicknesses ratio, mm	10/15	15/10	12.5/12.5	20/5	Conventional
Tension (δ), mm	0.104	0.104	0.104	0.104	-
dR_4 , mm	55	65	60	75	85
dR_3 , mm	-65	-45	-51	-23	-5
$n_{\Delta\max}$	2.73	2.31	2.50	2.00	1.78
$n_{\Delta\min}$	0.38	0.56	0.49	1.09	5.00
Maximal equivalent Mises stresses, MPa	220	257	240	284	280
Safety factor	2.23	1.91	2.04	1.73	1.75

In general, double-layer cylinders used in the hydraulic prop of a powered support OKP70 enabled increasing safety factor measured according to the maximal gap as if compared with the single-layer structure, and reducing radial strains of the cylinder near the first seal (Table 3).

4. Conclusions

The following conclusions can be drawn on the base of comparative study on double- and single-layer cylinders in the powered support OKP70. All structures in double-layer cylinders, even those with minimal tension, have lower radial strains if compared with the single-layer cylinder, all other parameters are equal. It supports the seal as it operates in a lower gap to be sealed, therefore, leak-tightness of the prop gets better.

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