



## STRAINED VALVE-HOUSING CONTACT OF HYDRAULIC STEER

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<https://doi.org/10.26782/jmcms.spl.10/2020.06.00002>

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### Abstract

*The use of hydrostatic steerage in agricultural and construction vehicles shows that, compared to traditional hydromechanical steerage, it has better balance and no steering wheels vibrations. But in certain environments, these automobiles have to work in severe conditions and the steering breaks down rather quickly. There can be multiple reasons for this – dirt, wear, excessive turn effort. The analysis of defects of the XY 145 0/1 hydraulic steers has demonstrated that 100% of breakdowns are caused by the wear of the slide valve-housing pair, i.e. this contact is limitative. Therefore, complete wear of these parts lead to the situation when turning the vehicle requires the effort exceeding normal. To find out how to increase durability of the valve-housing pair, we conducted a research of its stress-strain state.*

*The strains in the contact can be studied with the help of the finite-element method which allows high-precision modeling of any components and mechanisms in operation. As a result, we generated a finite-element mesh with the minimal, average and maximal pressure values, transitions and deformations in elements; pressure values were presented as a graphical file with a diagram. The model of the strain state of hydraulic steer XY-145 slide valve-housing contact can be used in selecting the materials which, applied to the worn surfaces, will increase the general durability of hydraulic steers.*

**Keywords:** Steerage, hydraulic steer, fault, wear, finite-element method.

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### I. Introduction

Generally, many factors force hydraulic steerage boosters to work in rigor conditions. These include high frequency pressure pulsation of operating fluid, pollution of the fluid with dirt causing abrasive wear, and large forces passed through steer mechanism for rotating drive wheels. All these lead to fast wear of hydraulic steer boosters (Senin et al., 2013).

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Petr V. Senin et al*

*A Special Issue on “Quantative Methods in Modern Science” organized by Academic Paper Ltd, Russia.*

Fault frequency analysis of hydraulic steers of the XY 145 0/1 trademark that came to be repaired at a small innovative enterprise *Agroservis* shows that 100% of breakdowns occur because of slide valve-housing wear. The wear of housing bands and slide valve occurs as a result of back-and-forth and rotating motions of the valve in relation to its housing in the process of rotating the steer wheel. The slide valve is kept in neutral position from displacement in relation to the housing by force of a center spring. In driving, at first the operating edges of the slide valve and the housing get rounded and lopsided, then, as a result of their wearing, the edges become cone-shaped analogously to the slide valves of hydraulic steer booster distributors. At the expense of a greater working stroke of slide valve, hydraulic steers and dosing pumps have greater resource potential. However, a greater operating pressure needed for the system's work, especially on large-sized equipment, reduces their life resources. In the process of wearing of the valve-housing pair, there appears oil leakage in the overlapping edges. The leakage tends to increase proportionally to the wear resulting in reduced volumetric performance index of the hydraulic steer.

Nowadays, the repair of hydraulic steer at repair facilities is usually done by replacement of worn parts and seals. Thus, the development of a new resource saving technology of hydraulic steer recovery is seen as an important task.

Considering the analysis of existing recovery methods, as well as various researches on the topic (Burumkulov et al., 2005; 2009; 2014), we offer to apply an electric spark pad weld as a means of fixing the slide valve-housing pair. This is one of the most promising electro-physical methods of forming ultrafine coatings with high functional properties that meet the requirements of versatility, processing locality, low cost of equipment and possibility of using a large variety of electrode materials.

However, as practice shows, the use of electric spark processing entails a number of difficulties, in particular, the choice of material for the repair of worn surfaces, as well as the choice of equipment work modes.

Thus, to choose a material that would improve the life resource of the contact being tested, it is necessary to ensure that the maximum specific load  $P_{MP}$  (maximum load capacity of the contact) on the working surfaces of resource limiting parts is higher than the maximum long-term operating load on the contact, i.e.

$$P_{MPa} \gg \sigma_{z \max}.$$

To estimate the maximum load capacity of the connection, we propose to conduct mathematical modeling of the valve-housing contact under real operating conditions using the finite-element method (Galkin, 2011; Mamaev, 2013).

## **II. Materials and Methodology**

Taking into account the availability and modeling capabilities, we have chosen SolidWorks/COSMOS software from a wide range of systems of mathematical modeling as being the best on all criteria.

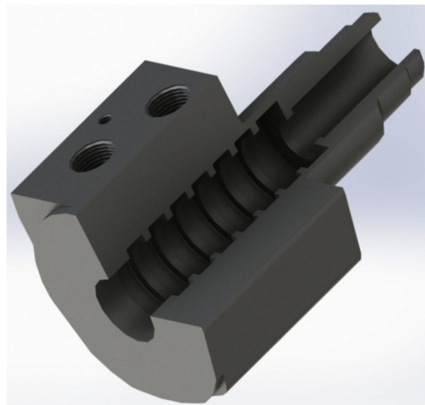
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As a model for the mathematical analysis, we have chosen *in-situ* slide valve-housing contact of the XY 145-0/1 hydraulic steer (Fig. 1).



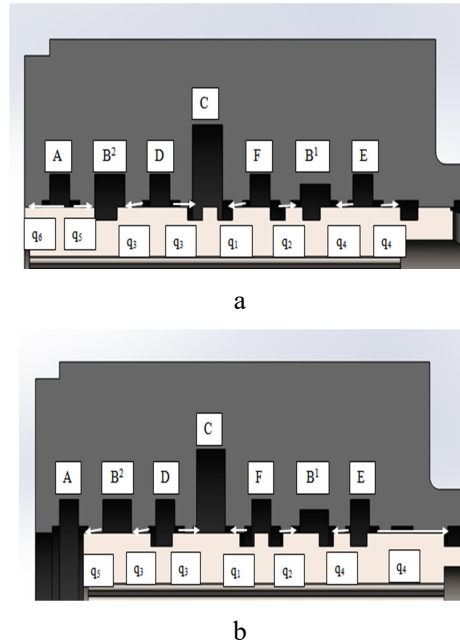
**Fig. 1:** Slide valve (a) and housing of hydraulic steer (b).

The geometric model, formed on the basis of this contact, is presented in Fig. 2.



**Fig. 2:** Geometric model of slide valve-housing components of XY 145-0/1 hydraulic steer.

Before loading the model, it is necessary to analyze the operation of the contact; Fig. 3 is used for this purpose.



**Fig. 3:** Analysis of slide valve-housing contact operation

a – left position of slide valve, b – right position of slide valve

Leakages, and thus pressure on the bands of the slide valve and housing, generally depend on the space between the sealed surfaces. Figure 3a represents the scheme of slide valve -housing contact of a hydraulic steer in the left position of slide valve. From the pump, the main fluid flow passes through the return valve to window F and farther it enters the feedback hydraulic motor through the hydraulic steer interior tubes. After the hydraulic motor, the main flow enters the cavity of the hydraulic cylinder through the tubes in the hydraulic steer (windows E and D). From the opposite cylinder cavity, the fluid goes to drain through windows C and B<sup>1</sup>. Main  $q_1$  and  $q_2$  leakages can occur, first of all, between windows F and B<sup>1</sup>, C, that is between the pump and drain. Besides, there exist  $q_3$  and  $q_4$  leakages between the drain and interior tubes of the hydraulic steer under pressure. These are extraneous flows between D and B<sup>2</sup> windows of the hydraulic steer interior cavity and window A. There are also  $q_5$  leakages between windows A and B<sup>2</sup>, and interior leakages of  $q_6$  in the hydraulic motor. The  $q_5$  and  $q_6$  leakages are of small value since they occur under small pressure differences. It should also be noted that these two are not included in the overall balance of leakages, since they go not to the drain, but to the hydraulic cylinder cavity. The amount of  $q_1$ ,  $q_2$ ,  $q_3$ , and  $q_4$  leakages is determined both by quite high pressure differences between the pump and the drain, and by wear of bands of the slide valve. It is the total of  $q_1 - q_4$  that constitutes the controllable amount of hydraulic steer leakages, which, therefore, may characterize the extent of slide valve wearing, but not feedback hydraulic motor wearing. Here we infer that the leakages

of hydraulic steer may be considered as the main parameter characterizing technical condition only of a part of the steer – its slide valve. The state of feedback hydraulic motor cannot be described using this parameter.

The pressure in the tubes is described as follows.

$A = 15 \text{ MPa}$ ,  $B^1 = 2 \text{ MPa}$ ,  $B^2 = 15 \text{ MPa}$ ,  $C = 2 \text{ MPa}$ ,  $D = 15 \text{ MPa}$ ,  $E = 2 \text{ MPa}$ ,  $F = 0 \text{ MPa}$ .

The pressure for the right position of the slide valve:

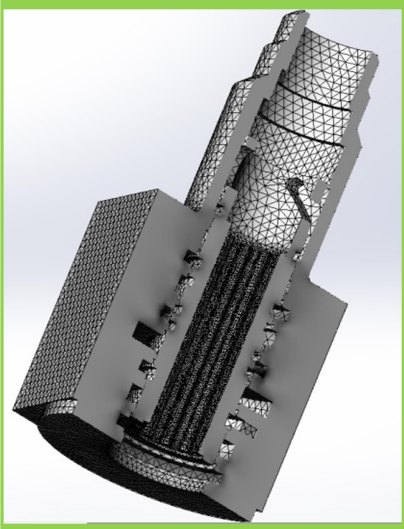
$A = 0 \text{ MPa}$ ,  $B^1 = 0 \text{ MPa}$ ,  $B^2 = 2 \text{ MPa}$ ,  $C = 15 \text{ MPa}$ ,  $D = 15 \text{ MPa}$ ,  $E = 2 \text{ MPa}$ ,  $F = 15 \text{ MPa}$ .

### III. Results

We load the slide valve-housing contact in accordance with the above specified working conditions, and further we set the following restrictions: perform housing anchorage and restrict the movement of the slide valve along the XY plane. We then form the connection of the slide valve outer surface with the housing for their fixing relative to each other.

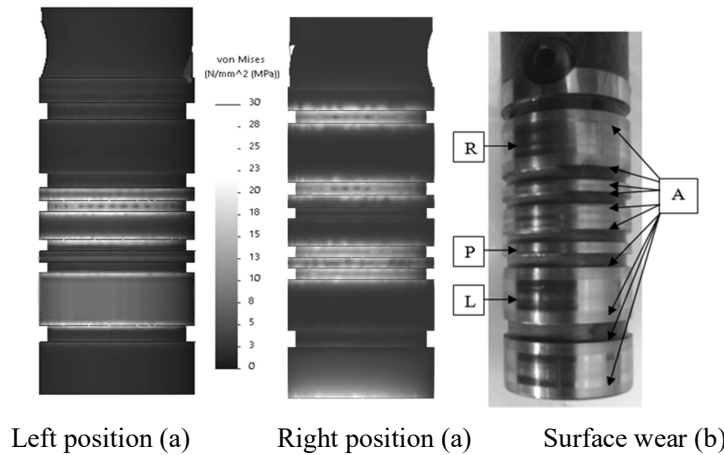
We carried out calculations that allowed us to obtain the following results. A finite element mesh was generated for the contact being studied (Tab. 1), the minimal, average and maximal values of pressure (Tab. 2, below), transitions and deformations in elements; pressure values presented as a graphical file with a diagram (Fig. 4 and 5).

**Table 1: Properties of finite element mesh of slide valve-housing contact**

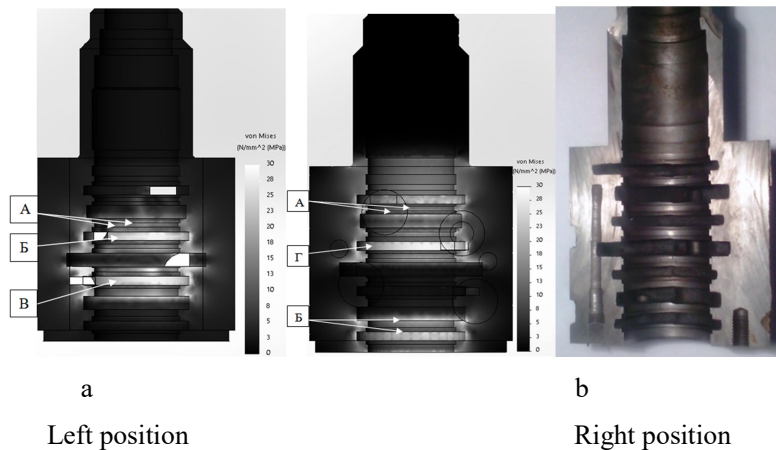
Mesh type	Solid body mesh	
Partition used	Mesh based on combined curvature	
Density factor	Fine-meshed	
Jacobian check	In nodes	
Maximum element size	3.2 mm	
% of deformed elements	0.02	
Quality	High	
Number of elements	608039	
Number of nodes	894477	

**Table 2: Data on minimal, average and maximal tension according to von Mises, MPa**

Component	Slide valve position	Minimal value	Average value	Maximal value
Slide valve	Leftmost	0.022	7.988	42.312
	Rightmost	0.073	7.302	43.340
Housing	Leftmost	0.158	10.645	39.755
	Rightmost	0.104	10.862	31.526



**Fig. 4:** Tension diagram of slide valve (a) and photograph of worn-out slide valve (b).



**Fig. 5:** Tension diagram of inside surface of housing (a) and photograph of worn-out housing (b).

To conduct the analysis, we designed materials in the SolidWorks library. The modeled properties were in agreement with real materials used for components manufacturing; for slide valve 60CrMn steel (Cr 1-1.3% Mn 0.8-1% C 0.55-0.65%)

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Petr V. Senin et al*

was used (density  $\rho = 7860 \text{ kg/m}^3$ , tensile strength  $\sigma_b=670\text{MP}$ , firmness HB 255, elastic modulus  $E = 208 \text{ GPa}$ , heat capacity  $C=500 \text{ J/kg}^0\text{C}$ ), for housing gray cast iron GCI21 was used ( $\rho = 7100 \text{ kg/m}^3$ , HB 225,  $\sigma_b=200 \text{ MPa}$ ,  $E = 1 \cdot 10^5 \text{ MPa}$ ,  $C = 480 \text{ J/kg}^0\text{C}$ ).

The given photograph of the slide valve of an out of service hydraulic steer XY-145 (Fig. 4b) shows wearing signs (marked with the letter A). Band edges are exposed to the greatest wear; these edges are located opposite to pressure (P) and delivery ports of swing hydraulic cylinders (R and L). The wear data were obtained by micro-meter survey. Analyzing the diagrams of the strain-stress state of the slide valve, we clearly see tension difference between the left and right end positions. First of all, the difference occurs when the position of the slide valve in the housing of the hydraulic steer changes, the different ports, responsible for the transfer of hydraulic power, open and close.

Most tension, as the diagram shows, occurs on edges (marked by the letter B); however, in the left and right positions these edges differ. In the left position these are edges of bands 3, 4, and 6 (count from top), and in the right position 1, 2 and edges between bands 4-6, as well as the utter edge of the 7th band. Thus, if we consider tension pattern in general, it turns out that at one time or another there occur significant tensions on all edges that reach average values of 8 MPa.

We notice as well that in Figure 4a, in the left-most position, the maximal tension occurs on edges 6, 7 and 8 (count from top) and is calculated as 42 MPa; and in the right position, on edges 2, 3, 14, the tension is about 43 MPa.

Fig. 5 shows the diagram of tension on the inner surface of housing (a) and a photograph of an out-of-service housing (b).

On tension diagrams, we should note the occurrence of circular higher tensions on edges (A), as well as in ports under pressure (B), and in the slide valve contact. The zones of maximal tension appear near the windows pushing the flow of operating fluid towards the hydraulic cylinder (B). As a result, the given housing (Fig. 5b) clearly demonstrates the zones of the most wear G (lopsided edges).

#### IV. Discussion

The results of the conducted investigation of the strain-stress state of the slide valve-housing contact of the XY-145 hydraulic steer are demonstrated by the values of contact tensions occurring in two end positions of the slide valve, which are presented in Table 2 above. Using these data, we get the upper limit of tension values. As a rule, the distribution law of average tension value is approximately described by Gaussian distribution, with variation coefficient of  $\nu \leq 1/3$ , then the upper limit of tension can be found from the following formula (Stolyarov, 2009).

$$\sigma_t = \bar{\sigma}_i + su_p,$$

where  $s$  is standard pressure deviation;  $u_p$  is Gaussian distribution quintile corresponding to probability  $p$ .

In our case, the upper tension, corresponding to  $p = 0.95$  was calculated as follows.

For slide valve  $\sigma_t = 7.988 + 0.3 \cdot 7.988 \cdot 1.65 = 11.94$  MPa.

For housing  $\sigma_t = 10.862 + 0.3 \cdot 10.862 \cdot 1.65 = 16.24$  MPa.

The values of maximal loading capacity of slide valve surface (11.94 MPa) and housing surface (16.24 MPa), obtained in our experiment, will further allow to choose such restoration materials, coating of which on worn surfaces will increase the endurance of slide valve-housing contact of hydraulic steers of the XY series.

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