Investigation of basic elements loading and tension of heavy hydraulic presses for metallurgical production

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Abstract
The investigation of loading and tension of such elements as frame, column, tie-rod of heavy hydraulic presses was carried out. The assurance coefficient of thermal tightening of the press tie-rods was calculated.
Keywords: PRESS, COLUMN, FRAME, TIE-ROD, LOADING, TENSION, THERMAL TIGHTENING

Formulation of the problem

In metallurgy for metal forming a wide range of hydraulic presses is used that can generate force up to 1000 MN. Their weight can reach more than 20 million tons, and the weight of the individual basic elements forming the frame exceeds hundred tons. Despite the rapid development of metallurgical technologies the large range of equipment for their implementation has a very long term of obsolescence. This applies primarily to the basic bearing structures, because the machines drive and control systems are usually subjected to upgrading. Replacement of equipment that exhausts its service life is fully connected with substantial costs. Therefore, these objects undergo the procedure of extending their life, which is substantiated by investigation of their technical condition and residual life assessment [1 - 3]. The work objective is to study the distribution of forces (external and tightening) in the presses columns and stresses in parts of complex configuration presses (ram, crown), the results of which are the starting point for the assessment of residual life.

Measurement of stresses and forces in the columns of press 100 MN. Uniform loading of press columns is the most important indicator of reliability and durability of its work. For evaluation the uniformity of columns loading the method of electro strain gauge measurements is used, which is the most accurate in the assessment of the actual loading of the press structure.

Measuring complex consisting of an amplifier TMA32 and PC with analog to digital converter, which allows you to make measurements simultaneously on 32 channels with sampling frequency on each channel of 200 Hz has been used during the work as the recording equipment.

As sensors the strain gauges of KF5P1-5-200-A-12 type with base of 5 mm and an internal resistance of 200 ohms have been used.

The main load-bearing elements of all three presses include: 1) supported on reinforced concrete foundation frame; 2) four columns attached to the frame by means of sixteen clamp spindles; the crown is attached at the top of the columns also by means of clamp spindles, in which body a movable working piston is placed; 3) the traverse put on the columns is located in the lower part of the piston.

The strain gauges were pasted on the four columns in a place above the upper clamp spindles of columns attachment to the frame. The adopted numbering of press columns, as well as the installation and the numbering of sensors are shown in Fig. 1.

The strain gauges were connected by measuring networks to the measuring equipment (TMA32 amplifier and PC). Then calibration of strain gauges was carried out and scales of measurement processes were identified.

Due to the fact that at the moment of work the wheel rolling line had not been launched wholly, the measurements were made at a nominal working pressure of the press with a “cold” workpiece.

After treatment the average measured stresses in the columns of the press we can draw the conclusions:

- The total measured press force was 79.93 MN;
- The greatest forces 25.48 MN and 26.09 MH occur in the columns number 2 and 4 respectively, accounting for 65% of the force generated by the press;
- The rest 35% of the total force are taken by the columns No 1 and 3, that is 14.84 MN and 13.52 MN respectively;
- In all columns magnitudes of deviation from the average load exceed permissible (± 15%) almost in 2 times;
- The maximum value of bending stresses to tensile stresses ratio is 45.9% in the column No 1 and exceeds the standard value by 30%.

Therefore it was decided to conduct an additional thermal tightening of the column No 1 in the frame body and repeat forces measurements in the columns of the press 100 MN.

Methods of measuring stresses and forces in the columns of the press 100 MN and adopted numbering of press columns, as well as installation scheme and sensors numbering remained the same (see. Fig. 1).

6 experiments were conducted in total.

Fig. 2 shows the directions of the maximum bending moment vectors in the columns and direction (vector) of influence of the total maximum stresses obtained by rotating counterclockwise by an angle of 90° of maximum torque vectors.

After processing the average measured stresses in the press columns, obtained after additional thermal tightening of the column No1, we can draw the following conclusions:

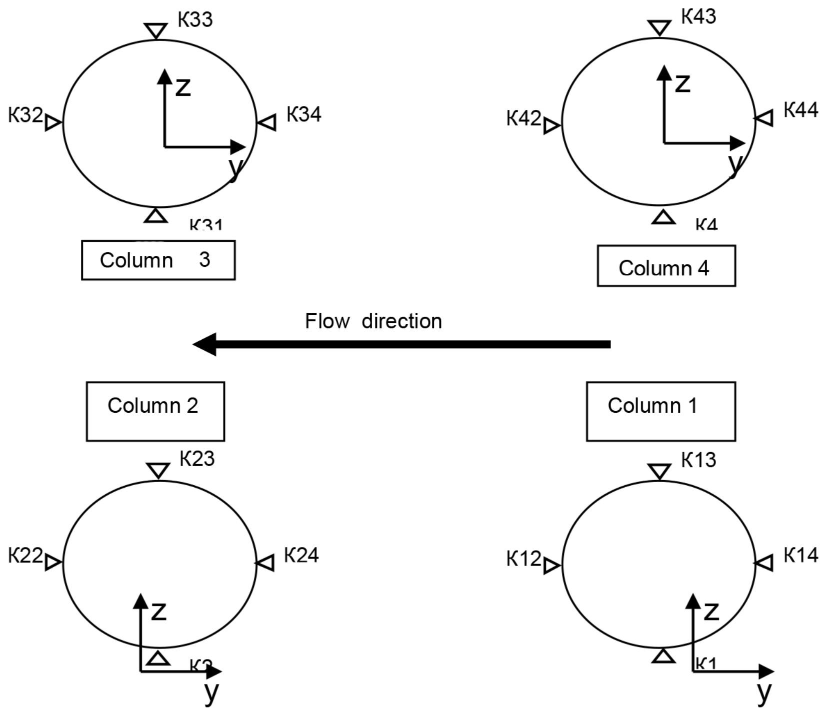

Figure 1. Layout of strain gauges on the column press 100 MN

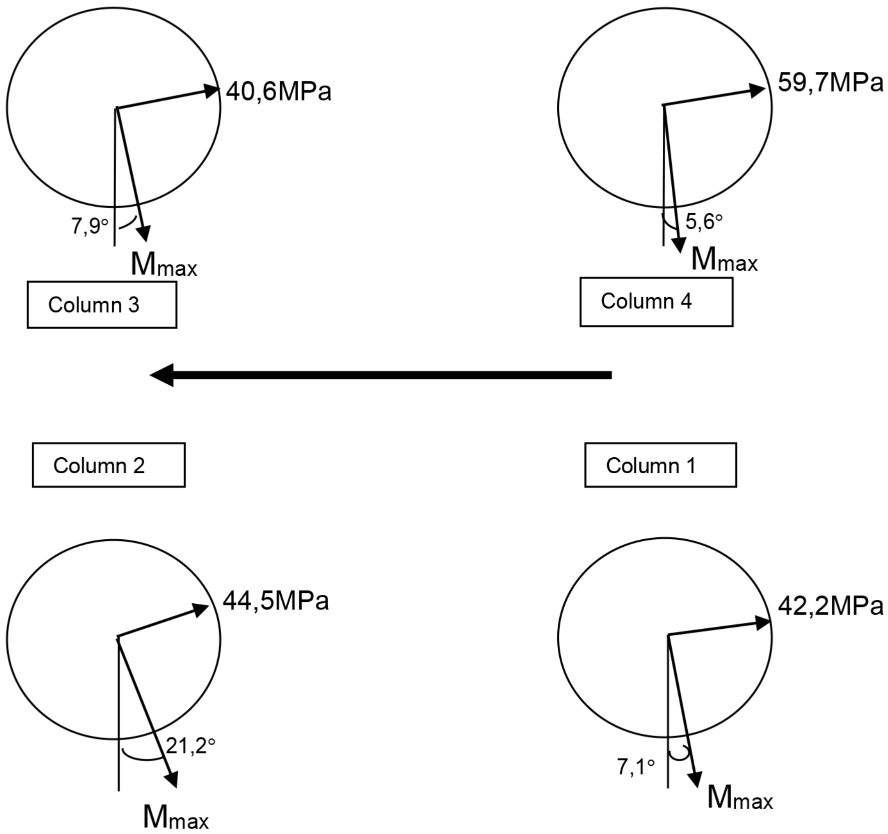

Figure 2. Directions of the maximum bending moments vectors and vectors of total of maximum stresses influence

- The total measured press force is 75.55 MN;
- Maximal force is equal to 21.21 MN and occurs in the column No 4;
- Minimal force is equal to 17.09 MN and occurs in the column No 3;
- Load deviation from the average changes from -9.5% in the column No 3 to +12.2% in the column No 4;
- The maximum deviation from the average load is within acceptable limits (± 15%);
- Maximum ratio value of the bending stresses to the tensile stresses is 41.5% in the column No 4 and exceeds the standard value of 30%, which may be due to insufficient thermal tightening of column No 3 or the press frame uneven contact with nuts.

Measurement of stresses and forces in the spacers of tie-rods of press 100 MN. Press force 100 MN generated by the pressure of master cylinder in chain order "cross bar – tie-rods - crown" is transferred to the columns.

Between the cross bar and the crown 8 cylinder spacers are mounted. 8 tie-rods are threated through the cross bar, spacers and crown, each of which is tied up by two outer nuts. This connection is a statically indeterminate system in which the force distribution between the individual elements of the power circuit is dependent on the ratio of their rigidities. The connection must ensure nondisclosure of the joints under the influence of the maximum permissible load that can only be achieved by thermal tightening of the tie-rods.

When applying to a pre-compressed connection "cross bar - spacers - crown" of the workload the compressive force is weakened (it is increased when taking into account the stress sign), and pre-stretched tie-rods are additionally stretched. Thus the force generated by pressure is distributed between the chains "cross bar – tie-rods - crown" and "cross bar - spacers - crown " according to the ratio of their rigidities.

Despite the presence in the spacers by one opening that allows us to place by one strain gauge on the tie-rods, evaluation of the force supplements in tie-rods when operating mode is not possible due to the bending of tie-rods, which presence has been confirmed by calculation on full finite element model of the press 100 MN, which will be given below. In addition, when there is insufficient thermal tightening of tie-rods between the cross bar and the spacers the gaps can occur during the press operation which is inadmissible.

The stresses measurements in the spacers of the press 100 MN was conducted simultaneously with the measurements of stresses in columns. By one sensor of stresses and displacements were installed on each spacer. Displacement sensors were attached to the spacers over the stresses sensors and they monitored the possible emergence of gaps between the spacers and the cross bar.

The layout of measuring instruments, their marking and numbering of tie-rods are shown in Fig. 3.

After the processing of the medium stresses in the spacer we can draw the following conclusions:

- The deviation of the measured stresses from the average value varies from

-79.5% in the spacer No2 to 115.1% in the spacer No3;

- In 5 from 8 spacers the magnitudes of the stresses deviation from average value exceeds the standard (± 15%).

Therefore it was decided to carry out an additional thermal tightening of tie-rods No 2, 5 and 4 and repeat stresses measurements in the spacers of the press 100 MN.

The repeated stresses measurements in the spacers of the press 100 MN were conducted along with measurements of stresses in columns.

When conducting the repeat stresses measurements in the spacers of the press 100 MN by two strain gauges were installed on each spacer. The adopted numbering of press spacers, as well as installation scheme and numbering of the stresses sensors are shown in Fig. 4.

Location of stresses sensors, as shown in Fig. 4, allows you to more accurately determine the longitudinal forces taken by spacers, while excluding their eccentric tension-compression caused by “buckling” of the cross bar (tangential bending). At the same time the eccentric tension-compression of spacers, which is due to uneven thermal tightening of tie-rods (radial bending), is controlled. Axes directions of tangential (τ) and radial (ρ) bendings for the spacer No1 are shown in Fig. 4

Displacement sensors on the spacers with repeat measurements were not installed.

The methodology of measuring stresses in the spacers of the press 100 MN remained the same.

6 experiments were conducted in total.

After processing the average measured stresses in the spacer obtained after additional thermal tightening of tie-rods No 2, 4 and 5, we can conclude:

- Total average measured force taken by spacers – 43.87 MH is 58.07% of total average operating force press – 75.55 MN measured by stresses in the columns in the same experiments;

- Maximum force is equal to 7.11 MN and is taken by spacer No5;

- Minimum force is equal to 0.63 MN and is taken by spacer No6;

- Load deviation from the average change from -88.6% in the spacer No 6 to +29.6% in the spacer No 5;

- The maximum deviation from the average force in the spacers No 1, 3, 5 and 6 exceeds normative (± 15%);

- The maximum value of the bending stresses to tensile ratio is 48.9% in the spacer No 2 and exceeds permissible value by 30%.

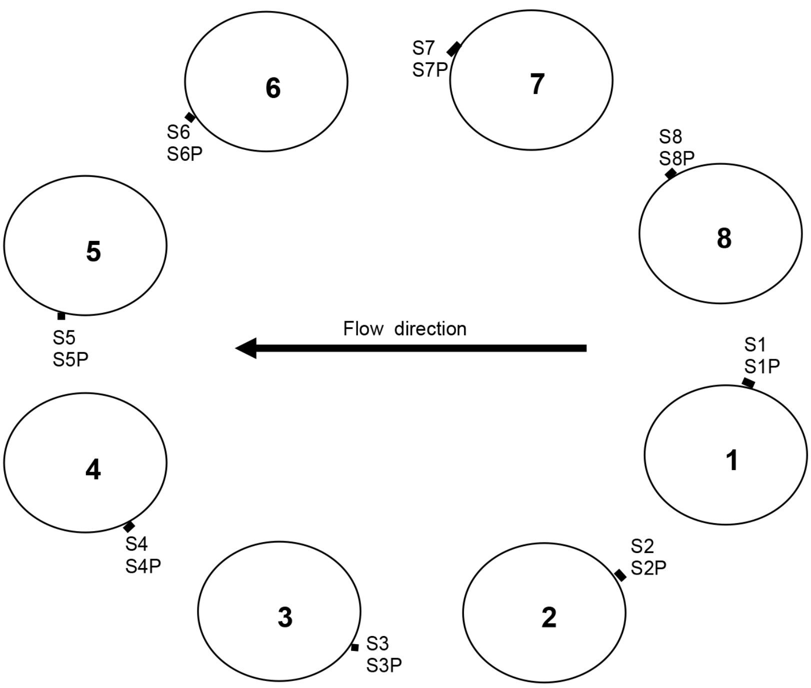

Figure 3. Layout of measuring instruments (S - stress, SP - displacement) on the spacers of the press 100 MN

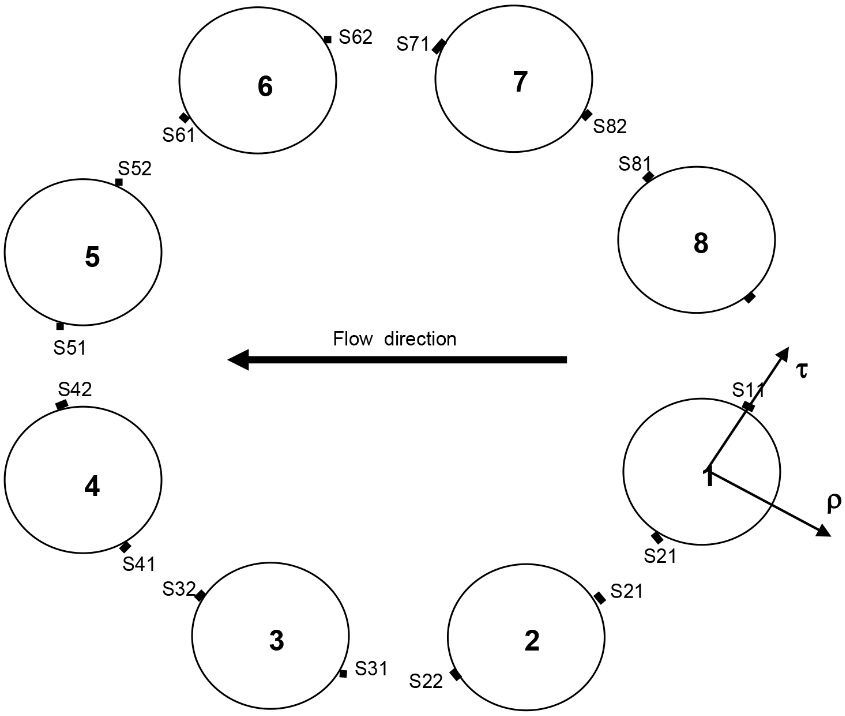

Figure 4. The layout of stress sensors on the spacers of the press 100 MN

According to the forces measured in columns and spacers we can determine the forces taken by its tie-rods using the formula:

$$N_t = (41.93/58.07)\cdot N_s = 0.72206 \cdot N_s, \qquad (1)$$

where N_t , N_s – forces taken by the tie-rod and its spacer, respectively.

It should be noted that the average thermal tightening of the tie-rods except the tie No6 is satisfactory.

When the first thermal tightening of tie-rods in order No 8,4,5,1,2,6,7,3 the thermal tightening has been performed (at the project length of the arc on the outer thread generator of 898 mm, which corresponds to the temperature of thermal tightening of tie-rods +108°C) on:

This thermal tightening of the tie-rods of the press 100 MN corresponds the thermal tightening of +85°C towards the ambient temperature.

Analysis of the results of stresses measurements in the spacers of the press 100 MN and data on levels of thermal tightening of its tie-rods allows us to conclude that the work of tie-rods depends not only on the level of their thermal tightening, but also on the sequence of it performance.

Thermal tightening of the press tie-rods in sequence No 8,4,5,1,2,6,7,3, is not optimal due to non-adherence of symmetry.

Symmetry of tie-rods thermal tightening of the press will be adherenced if it is conducted, for example, in the sequence No 8,4,2,6,7,3,5,1.

Calculation the frame strength of the press 100 MN under the influence of actual loads. Calculation the frame strength of the press 100 MN was performed by finite element method using NASTRAN software.

Two calculations were conducted:

1) with a uniform loading of the press frame by the actual (measured) load 18.9 · 4 = 75.6 MN, that was 75.6% of the nominal rating power of the press;

2) when loading of the press frame by the actual forces in the columns measured in full-scale experiments:

1st column - 19.2 MN; 2nd column - 18.1 MN; 3rd column - 17.1 MN; 4th column - 21.2 MN.

Both calculations were performed for the frame with four columns and simulation of the columns thermal tightning in the frame of 40°. The columns were simulated entirely with nuts serving for their thermal tightening in the frame and crown. At the level of the crown horizontal displacement was forbidden for the columns and respective longitudinal forces were applied to their upper ends. Vertical displacements were forbidden to the frame supports and in its middle section the total applied force was 75.6 MN. Calculation scheme of the press 100 MN frame is shown in Fig. 5.

Table 1. The value of thermal tightening of the tie-rods

1	2	3	4	5	6	7	8
700 mm	690 mm	710 mm	710 mm	720 mm	750 mm	720 mm	680 mm

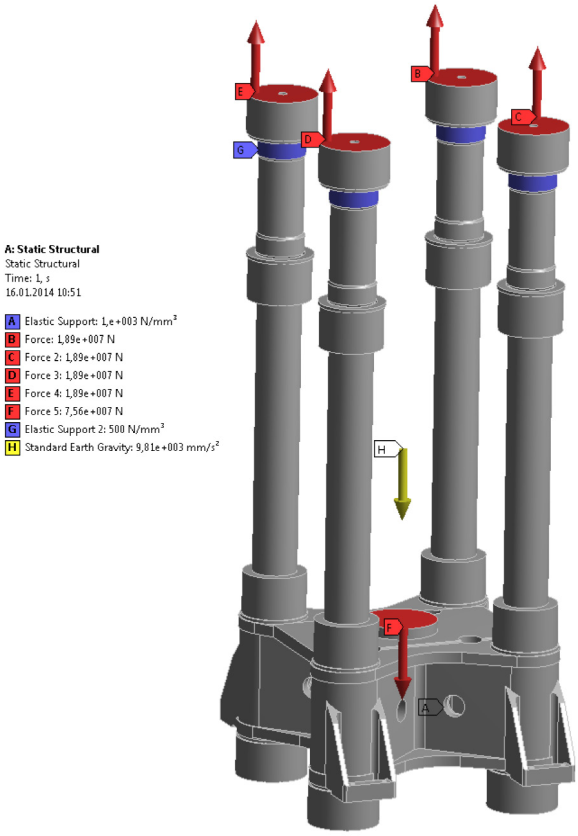

Figure 5. Calculation scheme of frame of the press 100 MN

Fig. 6 shows the equivalent stresses fields on the frame surface of the press 100 MN under the influence of the actual (measured) forces in the columns.

As can be seen from the results of calculations the maximum equivalent stresses:

- In the upper belt did not change and remained at the level of 154 MPa;

- In the openings of the vertical ribs increased from 134 MPa to 138 MPa – by 3.0%;

- In the lower belt did not change and remained at the level of 64 MPa.

It follows that the existing at the moment of columns non-uniformity loading of the press MN 100 has virtually no effect on the bearing capacity of the press frame.

The frame of the press 100 MN is made of steel 35L grade having a yield strength σ_y = 350 MPa and tensile strength σ_t = 590 MPa.

Calculation of tie-rod thermal tightening assurance coefficient of the press 100 MN. The press 100 MN force generated by the pressure of the master cylinder by the plug is applied to the lower surface of the cross bar and in chain order "cross bar – tie-rods – crown" is transferred to the columns and the frame.

Between the cross bar and the crown 8 cylinder spacers are mounted. Through the cross bar, spacers and crown 8 tie-rods are threaded, each of which is tighten by two outer nuts. This connection is the statically indeterminate system in which the force distribution between the individual elements of the power circuit is dependent on the ratio of their rigidities. The connection must ensure the non-disclosure of the joints under the influence of the maximum load that can only be achieved by thermal tightening of tie-rods.

When loading pre-compressed connection "cross bar - spacers – crown" by workload the compressive force is weakened (it is increased when taking into account the sign of stress), and pre-stretched tie-rods are additionally subjected to stretching. Thus the force generated by press is distributed between the chains "cross bar – tie-rods - crown" and "cross bar - spacers – crown" according to the ratio of their rigidities.

The assurance coefficient of the press tie-rods thermal tightening *k* is determined from the ratio of the force of spacers thermal tightening to the force of press spacers unloading in operating mode.

In order to determine the above-mentioned forces, two calculations were carried out on a complete finite element model of the press 100 MN:

- Calculation of the thermal tightening of the press tie-rods when their heating with respect to the ambient temperature by 85°C;

- Calculation of the press in operating mode at a load of 100 MN when the thermal tightening of the tie-rods by 85°C.

In the tie-rods when thermal tightening of tie-rods by 85°C the average normal stresses were 125 MPa, in the spacers – -91 MPa.

When thermal tightening of tie-rods by 85°C and implementation of the force in the press 100 MN the average normal stresses were 146 MPa, in the spacers – -41.5 MPa.

From these calculated data follows that the implementation by the press of 100 MN force and uniform

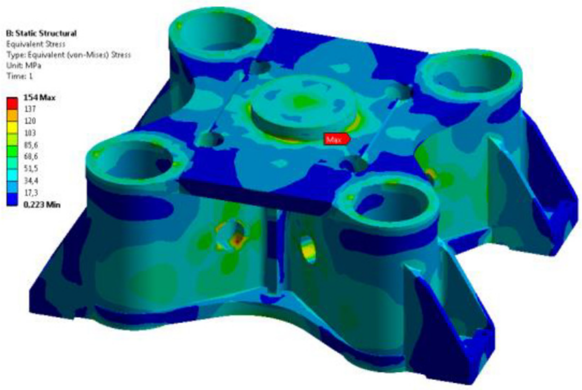

Figure 6. The equivalent stresses field in the press 100 MN frame when actual loading. Top view

thermal tightening of tie-rods the average normal stresses increase:

- In tie-rods by 21 MPa;
- In spacers by 49.5 MPa.

Therefore, when the uniform thermal tightening of tie-rods, each of 8 tie-rods takes force: $N_t = \sigma_t \cdot A_t = 21 \cdot 0.1389 = 2.92$ MN. The force taken by one spacer equals: $N_s = \sigma_s \cdot A_s = 49.5 \cdot 0.190 = 9.41$ MN. Where A_t, A_s – cross-sectional areas of tie-rods and spacers, respectively.

If to sum up the forces taken by eight tie-rods and spacers, you should get the force generated by the press in operating mode:

$$N_{press} = (N_t + N_s) \cdot 8 = (2.92+9.41)\ ) \cdot 8 = 98.64 \text{ MN}. \quad (2)$$

Thus, the assurance coefficient of the thermal tightening of press tie-rods *k*, defined as the ratio of thermal tightening force to the force of press spacers unloading in operating mode, at a temperature of the thermal tightening by 85°C and workload 100 MN equals:

$$k = 91/(91\text{-}41.5) = 1.84. \quad (3)$$

It should be noted that with a decrease in the press operating force, the assurance coefficient of the tie-rods thermal tightening *k* increases linearly.

During the repeated measurements of stresses in the columns and spacers of the press 100 MN conducted after the additional thermal tightening of column No 1 and spacers No 2, 5 and 4, the average force implemented by the press in 6 experiments was equal to 75.55 MN. Consequently, the average supplement of the normal stresses in the spacers, in case of uniform tie-rods thermal tightening should be equal to:

$$\Delta\sigma_s = 49.5 \cdot 0.7555 = 37.4 \text{ MPa}. \quad (4)$$

According to the results of stresses measurements in the columns and spacers of the press 100 MN, the average normal stresses in the spacers were increased (in brackets the stresses deviation in % from calculated value are given):

Table 2. The increase in the average normal stresses in the spacers

1	2	3	4	5	6	7	8
36.7 MPa (-1.9%)	28.9 MPa (-22.8%)	37.1 MPa (-0.8%)	28.6 MPa (-23.5%)	37.4 MPa (0%)	3.3 MPa (-91.2%)	29.4 MPa (-21.4%)	28.9 MPa (-22.8%)

Particularly noteworthy is the tie-rod No 6 that by results of measurements after additional tightening of tie-rods No 2, 4 and 5 is almost excluded from the operation of the press:

1) thermal tightening of the tie-rod No 6 was performed on 750 mm (arc rotation length of the nut on the outer thread generator) with an average value - 710 mm;

2) the results of stresses measurements in the columns and spacers of the press 100 MN, the supplement of normal stress in spacer of the tie-rod No 6 equals 54.2 MPa was grater than 51.2 MPa which was the average stresses supplements value the for 8 spacers;

3) after additional tightening of the tie-rods No 2, 5 and 4 supplement of the normal stress in the spacer No 6 in the first experiment was 9 MPa, and in the last (the sixth) experiment was only 3 MPa. On the opposite side of the spacer No 6 the stresses supplements were almost equal to 0.

Conclusion

Based on the foregoing information, it can be assumed that the tie-rod No 6 has lost its bearing capacity and is at the stage of the fatigue fracture. In order to make sure in opposite it is necessary to perform flaw detection of tie-rod No 6**.**

According to the results of the flaw detection the spacer No 6 may not be subject to fatigue failure. Then it is necessary to make its additional thermal tightening.

The above mentioned shows that the level of tie-rods loading of the press 100 MN does not depend only on the size of their thermal tightening, but also on the sequence of it performance. More preferred is a press tie-rods thermal tightening with respect to the symmetry, for example, in sequence No 1, 5, 3, 7, 8, 4, 2, 6.

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