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ELASTIC COMPRESSION JOINTS AND POSSIBILITIES OF THEIR TESTING

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ABSTRACT: Assemblies with self-tightening (elastic) are made by tightening caused by the elastic deformation of the joined parts. Depending on the degree of tightening, resulting from the tolerances adopted and the mounting technology, self-tightening assemblies can be removable or non-removable. Self-tightening assemblies can be: According to the constructive form of the assembly can be: Assemblies without intermediate clamping elements; Assemblies with intermediate clamping elements. According to the mounting technology: Pressed assemblies, executed at the environment temperature; Shrinking assemblies, executed by heating the enclosing part or cooling the enclosed part. The tightening assembly is used on the active plates from the extrusion dies, the mounting of the rolling wheel bandages, the crown gears, the bearings, the execution of the crankshafts of separate elements, etc.

KEYWORDS: Tightening assembly, pressed assemblies, shrinking.

1. INTRODUCTION

Assemblies without intermediate elements are assemblies with elastic tightening, made by forced introduction of a part into the bore of the part with which it is secured.

The forces opposing the undoing of such an assembly are the frictional forces on the contact surface. They increase with the pressure between the parts and with the coefficient of friction.

The important advantages of direct tightening assemblies are: the possibility of transmitting large moments and, in particular, variable moments; good centering of the parts; weight and space saving, combined with low cost, by the lack of additional foreign parts.

Disadvantages include: difficulties in assembly and disassembly; the possibility of damaging the contact surfaces during disassembly; obtaining different tightening at the same nominal dimensions and at the same adjustment, due to the tolerance fields of the assembled parts.

During the execution of the pressed assembly, there is an enlargement of the bore with “Δa”, figure 1, reaching after assembly the common diameter “d” of the two parts.

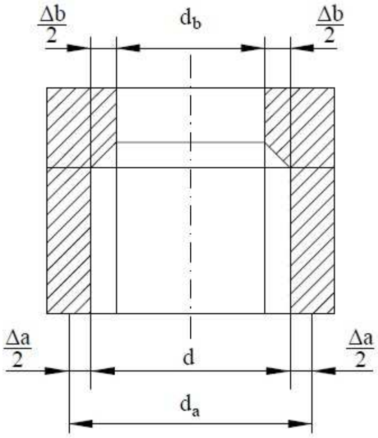

Fig. 1 Assembly by tightening without intermediate part

Characteristic of pressed assemblies is the tightening (tightening) S, defined by the difference between the initial diameters d_a and d_b:

$$S = d_a - d_b = \Delta_a + \Delta_b \text{ [um]} \qquad (1)$$

The notion of relative tightening is often used:

$$S_r = \frac{d_a - d_b}{d} * 1000 = \frac{S}{d} * 1000\ [‰] \quad (2)$$

Elastic tightened assemblies reduce the fatigue strength of the shafts, due to the concentration of the unit loading and the contact corrosion in the adjustment. However, this reduction is more easily compensated than the reduction caused by key or groove joints. The increase of the fatigue resistance of the shafts assembled by pressing is obtained by rolling with rollers of the part under the hub of the shaft, by nitration, cementing or hardening by high frequency currents, by executing on shafts near the hub or on the front faces of the hubs of some discharge grooves, which reduce the concentration of unit loads. An effective measure is to make the underside hub of the shaft at a diameter increased by about 5% and with uniform connections.

Elastic clamping assemblies are usually included in the group of non-removable joints. However, the practice of operating these assemblies shows the possibility of multiple depressions and new pressings without damaging the surfaces and significantly reducing the strength of the assembly.

Typical examples of clamping assembled parts are: cranks, crank bolts, compound crankshaft elements, wheel discs and bandages – railway rolling stock disc, crown gear and worm wheel crowns, turbine discs, electric motor rotors, bearings, etc.

2. EXAMPLES OF TIGHT-ASSEMBLED PARTS

a) A steel bar is fastened by shrinkage in a steel plate, as in figure 2 [4]. The tightening is Δ = 0.03 mm, the diameter of the bar 2b = 60 mm, the thickness of the plate h = 50 mm. Calculate the traction force Po required to remove the bar from the plate.

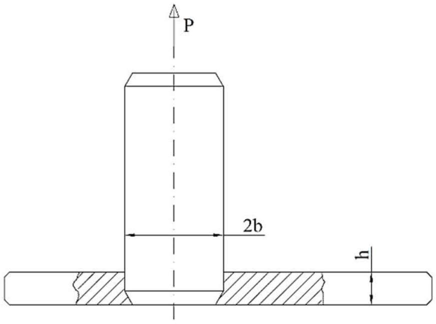

Fig. 2 Bar fixed in the plate by shrinkage

$$p_f = \frac{E * \Delta}{2b} = 1050\ daN/cm^2 \quad (3)$$

The traction force P must overcome the friction force:

$$P = \mu * p_f * 2\pi * b * h = 24740\ daN \quad (4)$$

b) In the construction of gears, severe conditions of resistance and durability to wear are imposed only on the teeth, i.e. the element that actually works.

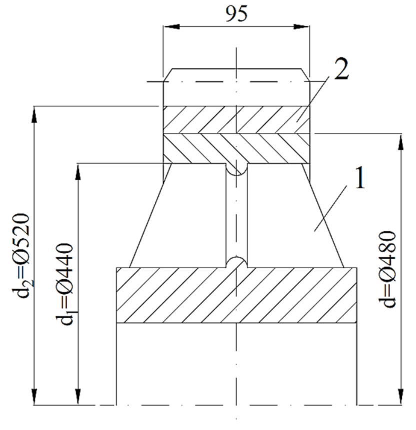

Fig. 3 – Construction of a gear wheel:1 – cast iron (EN – GJL-100; 2 – Steel (41Cr4)

In the case of large dimensions, the execution of the entire wheel from expensive materials, often deficient, would be a waste. The economical constructive solution is given in figure 3, the toothed steel crown is pressed on the cast iron wheel body. The tightening must be sufficient both to transmit the working moment and to withstand axial forces in the case of inclined teeth, at the same time it is necessary to check the resulting deformations in order not to exceed the permissible limits related to the geometric dimensions of the teeth.

c) Calculate the tightening of the crank on the shaft (fig. 4) so that it can transmit a torque of M_t = 12 kNm [8].

The problem of assembly by tightening can be considered a problem of shrunken tubes. The shrinking-on pressure required to transmit the torque is determined by calculating the peripheral force to be transmitted, so:

$$P = \frac{M_t}{\frac{D_2}{2}} = 160\ kN \quad (5)$$

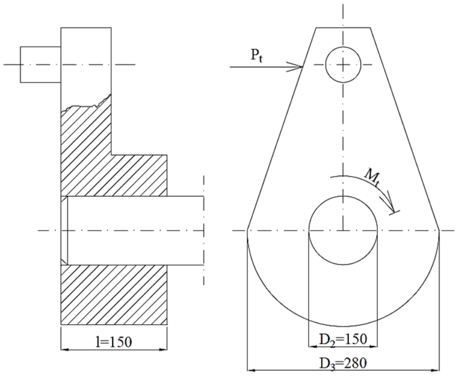

Fig. 4 Connecting the crank on a shaft

The corresponding clamping force can be calculated taking into account the friction. For a coefficient of friction μ = 0.15, it results:

$$F = \frac{P}{\mu} = \frac{160}{0.15} = 1066.67\ kN \quad (6)$$

The required shrinkage pressure is determined by relating the clamping force to the contact surface:

$$p_{nec} = \frac{F}{\pi * D_2 * l} = 15.09\ N/mm^2 \quad (7)$$

If a safety factor of "5" is taken, the effective shrinkage pressure is:

$$p = 5 * p_{nec} \cong 75\ N/mm^2 \quad (8)$$

The tightening "S" is calculated with the relation:

$$S = \frac{p * R_2}{E} * \left(\frac{R_2^2 + R_1^2}{R_2^2 - R_1^2} + \frac{R_2^2 + R_3^2}{R_3^2 - R_2^2}\right) \quad (9)$$

In this case we have: $R_1 = 0$; $R_2 = 75$ mm; $R_3 = 140$ mm; $E = 2{,}1.10^5$ N/mm^2.

With the above data, the value obtained for tightening is:

$$S = 7.51 * 10^{-2}\ mm \quad (10)$$

d) A wheel is fixed on a shaft by cold pressing (fig. 5) [5]. The shaft is made of steel with E1 = 106 daN / cm^2 and $\mu_1 = 0.3$, and the brass wheel with E2 = 106 daN / cm^2 and $\mu_2 = 0.35$.

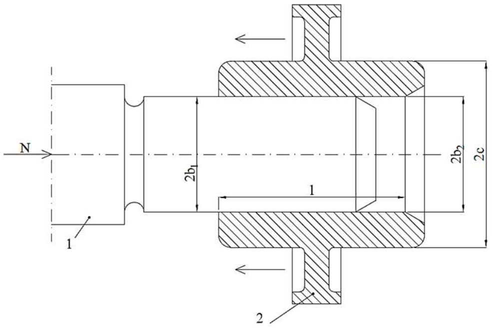

Fig. 5 Assembling a manual wheel on a shaft: 1 - shaft; 2 - wheel for manual operation

The shaft was turned and ground to a diameter of $2b_1 = 57.6^{+0,05}_{+0,03}$ mm, and the wheel bore to $2b_2 = 57.5^{+0,02}$ mm. The outer diameter of the wheel hub is 2c = 82 mm and the length of the contact surface in the mounted state, l = 80 mm. It is required to be calculated:

- The moment of torsion which will be able to transmit to the shaft in the mounted state (μ = 0,2);
- The maximum pressing force N;
- The maximum tension produced through shrinkage in the shaft and in the wheel.

Execution tolerances make it possible for the tightening "S" to be between two limit values:

Smax. = b1max – b2min = 0,075 mm (11)
Smin. = b1min – b2max = 0,05 mm (12)

The maximum shrinkage pressure, corresponding to the maximum tightening is calculated taking into consideration a = 0, b = 28,8 mm și c = 41 mm, so:

$$p_{f\,max} = \frac{S_{max}}{b}\left[\frac{1}{E_1} * (1 - \mu_1) + \frac{1}{E_2} * \left(\frac{c^2 + b^2}{c^2 - b^2} + \mu_2\right)\right]^{-1} = 7.17\ daN/mm^2 \quad (13)$$

And the minimum pressure:

$$p_{f\,min} = \frac{S_{min}}{S_{max}} * p_{f\,max} = 4.78\ daN/mm^2 \quad (14)$$

The moment of torsion which the mounted assembly can transmit is:

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$$M_{t\,min} = \mu * p_{min} * 2\pi * b^2 * l \cong 4 * 10^5\ daN/mm^2 \quad (15)$$

And the maximum pressing force:

$$N_{max} = \mu * p_{max} * 2\pi * b * l \cong 20\,800\ daN \quad (16)$$

The highest tension in the shaft has the value:

$$\sigma_a = \sigma_r = -p_{f\,max} = 7.17\ daN/mm^2 \quad (17)$$

and in the wheel hub:

$$\sigma_{a\,max} = \frac{c^2+b^2}{c^2-b^2} * p_{f\,max} = 21.1\ daN/mm^2 \quad (18)$$

e) Active plate for extrusion with axial and radial pre-tightening.

Figure 6 [9] shows an active plate for reverse extrusion, which allows a pressure p = 160…200 daN / mm2, the active plate consists of four parts.

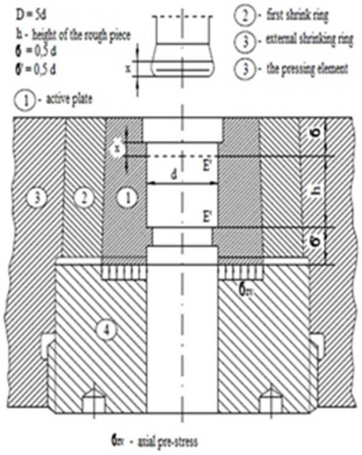


Fig. 6 Active plate for extrusion with axial and radial pre-tightening

The plate itself (1) - with the portions without load f and f 'is shrunk with two rings, (2) and (3). The pressure pad (4) has a fine-pitched thread that produces an axial pre-tightening force σ_{zw} in the plate (1). This avoids longitudinal cracking and as well as transverse fatigue cracking, which frequently occurs at points E and E' in active plates of this kind.

Pressing by self-tightening can be carried out by means of hydraulic presses for large parts, with screw presses, with machines for static testing of metals at traction and compression, etc.

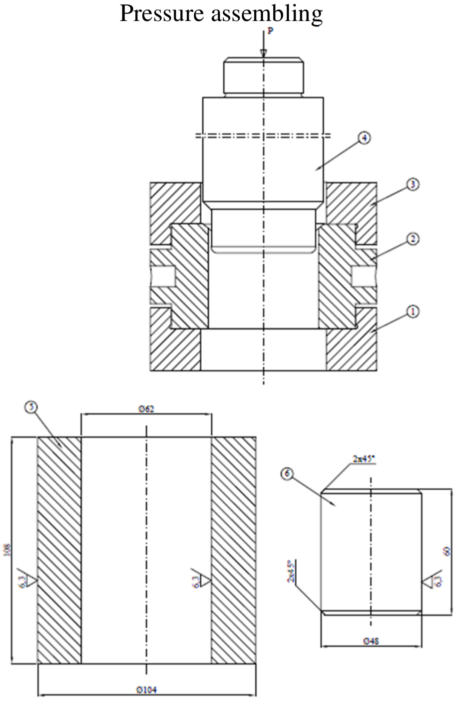
By lubricating the adjusted surfaces, the required axial force is reduced and the mounting in better conditions is ensured, avoiding scratches.

Shrinkage tests can be performed at 20ºC, at low temperatures up to -72ºC with solid carbon dioxide and in conditions of deep cold -196ºC using liquid nitrogen (N2). The pressing speed must not exceed 5 mm / s.

3. EQUIPMENT FOR TESTING THE ELASTIC TIGHTENING JOINT

The experiment includes defining the problem to be solved. There are certain situations, both in productive practice and in research, which require quick decisions in relation to the causes that generate certain deficiencies in meeting certain expected parameters or quality indices.

Pressure assembling



Legend:

1 – Support ring 4 – Pressing hub
2 – Pressing ring 5 – Depressing ring
3 – Centering ring 6 – Bolt for depressing

Fig. 7 Experimental model for press assembly

Assemblies by elastic tightening are usually included in the group of non-removable joints. However, the practice of operating these assemblies shows the possibility of multiple depressions and new pressings without damaging the surfaces and significantly reducing the strength of the assembly.

For the experimental study of shrinkage, an isomorphic experimental model was physically designed and realized that preserves all the essential constructive and functional characteristics of the shrinkage assembly.

Figure 7 shows an experimental model for press assembly.

It is known that the dimensions of the parts are made with certain deviations from the nominal size, these being between the two limit dimensions: d_{max} and d_{min} (for shaft) and D_{max} and D_{min} (for bores). In this sense it can be written:

$$S_{max} = d_{max} - D_{min} \quad (19)$$

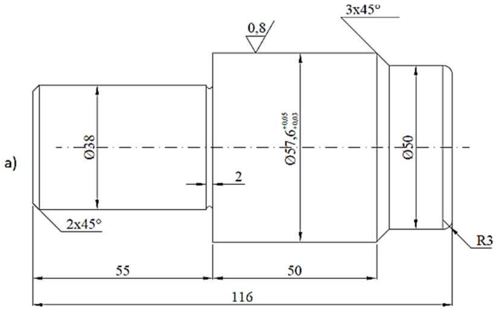
$$S_{min} = d_{min} - D_{max} \quad (20)$$

To achieve the tightening, you must:

$$S_{min} > 0 \quad (21)$$

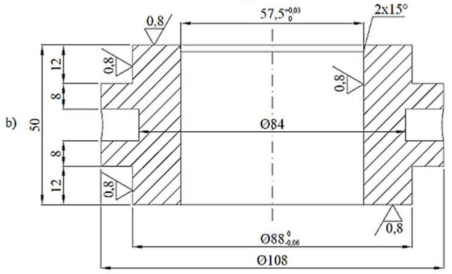
To perform the tightening (tightening) "S" the dimensions for the shaft and bore are shown in figure 8 (from fig. 7).

Pressure hub



Material X210CrW12(C120) SR EN ISO 4957:2002 hardened, annealed to 58 . . . 62 HRC

Pressing ring



Material X210CrW12(C120) SR EN ISO 4957:2002 hardened, annealed to 58 . . . 62 HRC

Fig. 8 The parts that form the tightening in figure 7

4. EXPERIMENTAL RESEARCH

The whole calculation is carried out in the hypothesis of maintaining in the elastic field

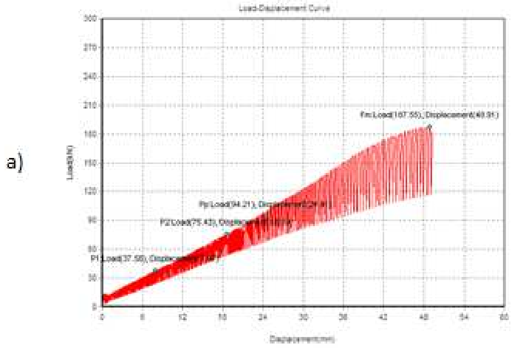
The experimental researches were carried out in conditions of dry pressing of the bores and the hub, to facilitate the pressing the lubrication of the surfaces soaked in oil was used and the pressing in cryogenic conditions.

The pressing was performed on a machine for static testing of metals at tensile and compression type WEW – 600D, maximum force 600 kN. The pressing speed must not exceed 5 mm/s.

4.1 Elastic tightening assembly using dry surfaces

Depending on the size of the tightening, elastic, elastic – plastic or plastic deformations may occur in the parts.

Figure 9 shows the diagram of the variation of the pressing forces depending on the length of the adjustment and time.



Maximum time 409,6 s

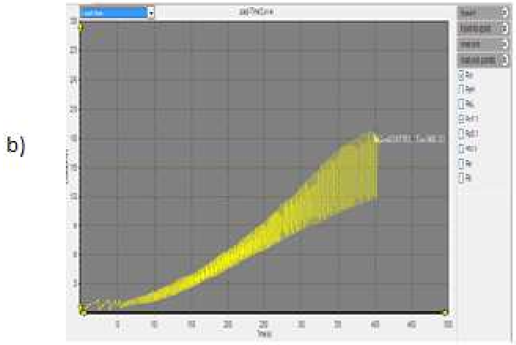


Fig. 9 Diagram of the variation of the pressing forces depending on: a) the length of the adjustment, l = 48.91 mm; b) pressing time, t = 409.6 s. The speed of the cross-beam was, v = 0.12 mm / s, F_{max} = 187.55 kN

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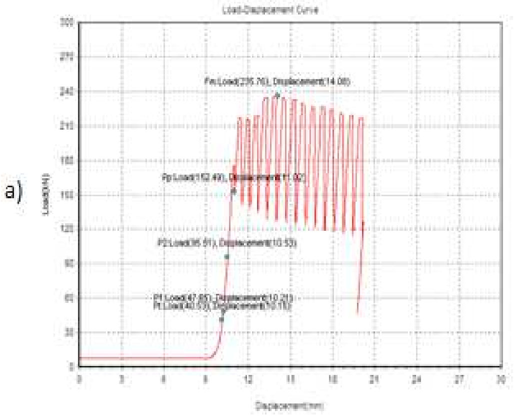
Elastic clamping assemblies are usually included in the group of non-removable joints. The practice of operating these assemblies shows the possibility of multiple depressions and new pressings. Figure 10 shows the diagram of the variation of the depressing forces depending on the length of the adjustment and time.



$F_{instant}$; F_{max}; Time; Displacement

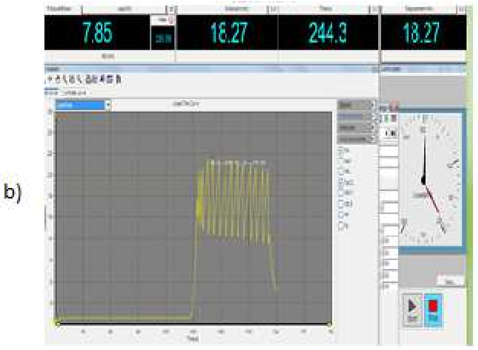


Fig. 10. Diagram of the variation of the depressing forces according to: a) length, l = 48.91; b) time, the cross-beam speed was v = 0.11 mm/s

The variation of the axial force (fig. 9) required for the pressing operation is different from that during the depressing operation (fig. 10). At depressing, in the first moment, the static friction force F'= 235.76 kN, greater than the force F''= 208.2 kN corresponding to the sliding friction, must be overcome.

4.2 Elastic tightening assembly using surfaces lubricated with Liqui Moly 10W40 oil

The pressing force increases in proportion to the length of the pressing. The displacement force at the first moment of the operation is much higher than during the depression process, due to the fact that the coefficient of static friction is higher than the coefficient of friction in motion. As the hub comes off the shaft, the depressing force decreases.

By lubricating the adjusted surfaces, the necessary axial force is reduced and the mounting in better conditions is ensured, avoiding scratches. The variation of the axial force (fig. 11) required for the pressing operation in case of lubricating the surfaces with Liqui Moly 10W40 oil is smaller.

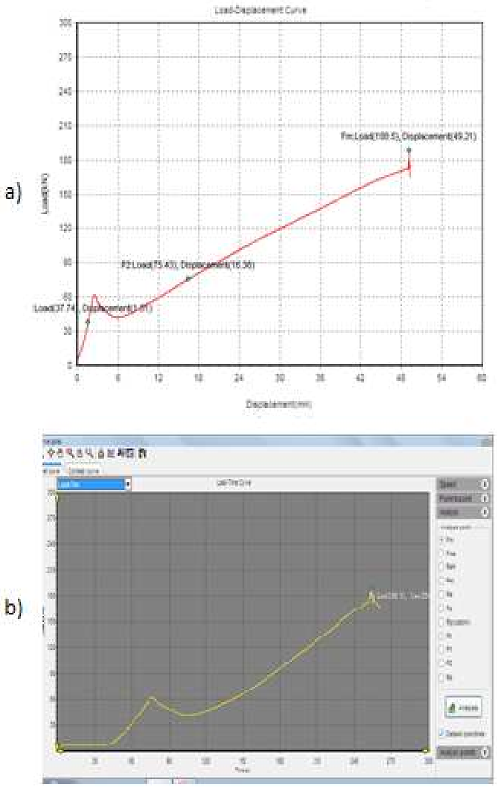


Fig. 11 Diagram of variation of pressing forces in case of surface lubrication
with Liqui Moly 10W40 oil depending on: a) length; b) time, v = 0.20 mm/s.

In this case the maximum pressing force F_{max} = 185 kN, on the length l = 49.21 mm, time 254.6 s, it is observed that the maximum force has decreased (see fig. 9), and the deformation of the adjustment at the beginning is elastic.

Figure 12 shows the diagram of the depressing forces in case of lubrication of surfaces with Liqui Moly 10W40 oil.

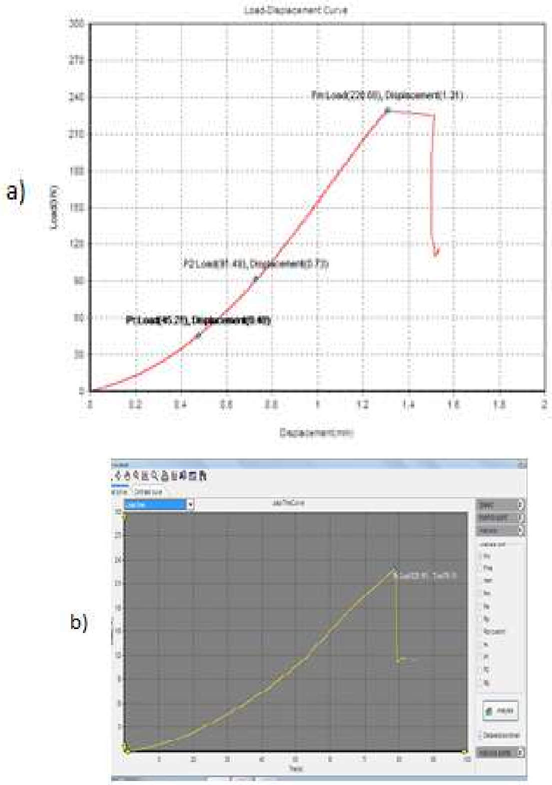


Fig. 12 Diagram of variation of depressive forces according to: a) The length of the adjustment (F' = 228,68 kN and F" = 173,24 kN); b) time

Analyzing the variation of the depressing forces in figure 10, without lubrication and the forces in figure 12 with lubrication, it is observed the decrease of the forces in case of lubrication of the surfaces.

4.3 Elastic tightening assembly using surfaces greased with Vaseline

The lubrication of the adjusted surfaces was done with graphite Vaseline with additive molybdenum.

By lubricating the adjusted surfaces, the required axial force is reduced and the installation in good conditions is ensured. Figure 13 shows the diagram of the variation of the pressing forces.

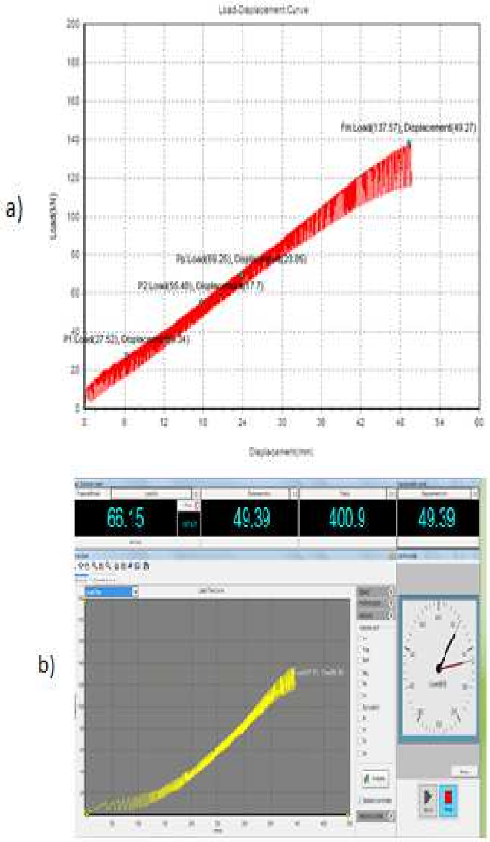


Fig. 13 Diagram of the variation of the pressing forces in the case of lubrication with Vaseline according to: a)The length of the adjustment (l = 49,27 mm); b) time (400 s), v = 0,13 mm/s.

Comparing the maximum force in figure 9 (F_{max} = 187.55 kN), with the pressing force in figure 13 (F_{max} = 137.57 kN) there is a substantial decrease in the pressing force.

When depressing, the resting force "F'" must be defeated first, superior to the force "F" corresponding to the sliding friction. The displacement force during the depression process increases at the first moment due to the fact that the coefficient of static friction is higher than the coefficient of friction in motion. As the hub exits from the shaft, the pressing force decreases.

Figure 14 shows the variation of the depressing force in the case of lubrication of the adjustment.

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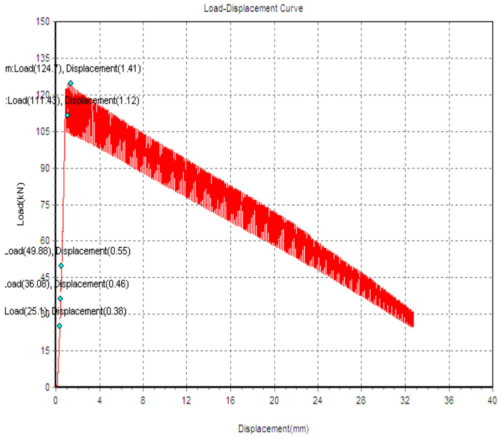


Fig. 14 Diagram of variation of depressing forces according to the length of the adjustment in case of lubrication of the adjustment (l = 43,17 mm, v = 0,14 mm/s).

4.4 Self-tightening assemblies (tightening) made in cryogenic conditions

The cryogenic shrinkage process has a low energy consumption, transforms the residual austenite into martensite and stabilizes the martensite, at the same time it does not reduce the hardness of the bore and of the part with which it joins.

Cryogenic shrinkage, compared to the classic ones, has advantages such as: higher resistance of the assembly, realization of the assembly with low pressing forces, simple installations etc.

When a material cools, a contraction of the material occurs and therefore a variation in volume. If the material belongs to the category of austenitic steels, at which the temperature M_s is below 273 ^{0}K, then when this temperature is reached there is an increase in volume due to structural changes that occur at this temperature.

As a result of the above, two cryogenic shrinkage procedures can be defined:

-The procedure in which the contact pressure arises from the expansion of the contained part, cooled before assembly;

-The procedure in which the contact pressure arises from volumetric expansion, as a result of the irreversible transformation of residual austenite into martensite.

Depending on the above in industrial practice, three technological versions of cryogenic assembly are recommended:

-Version I – It refers to the shaft – bore couple when the shaft is made of a material that has residual austenite and the bore does not. The shaft – bore assembly is inserted into the cooling chamber with liquid nitrogen. Following the transformation of the residual austenite into martensite in the shaft, its volumetric expansion occurs and a tight adjustment is obtained, the bore not suffering any change

-Version II – It refers to the shaft-bore couple when both the shaft and the bore are made of materials that show structural transformations at low temperatures. In this case we have two situations:

a) The assembly is performed, as in the first method;
b) If the structural transformation to the bore is not desirable, in this case it is necessary the dimensional stabilization of the bore.
c)

-Version III – Refers to parts where no structural changes occur at low temperatures due to the material. In this situation, the shaft-type part is cooled, inserted into the bore, and the tightening will be obtained after the temperature returns to 20°C.

Self-tightening assemblies (tightening) in cryogenic conditions can also be obtained if the phase transformations take place both in the enclosed part and in the encompassing part.

The tests in this paper applied Version III of cryogenic assembly. A machine for static testing of metals at traction and compression was used for pressing, having the maximum pressing force F_{max} = 600 kN, type WEW - 600D (fig. 15).

Fig. 15. Machine for static testing of metals at traction and compression

Liquid nitrogen (N_2) stored in a dewar vessel shown in Figure 16 was used to cool the shaft.

Fig. 16. Dewar vessel for storing liquid Nitrogen (N_2)

The diagram of the variation of the pressing force in the case of cryogenic assembly is presented in figure 17.

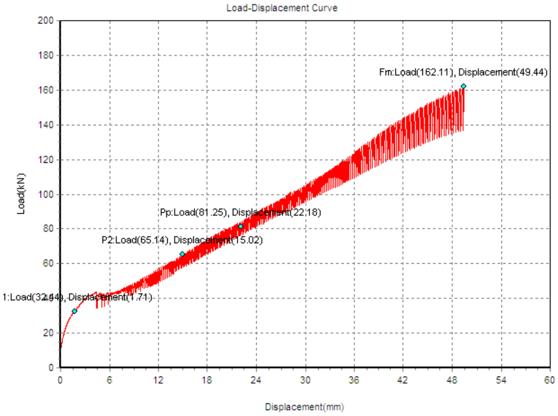
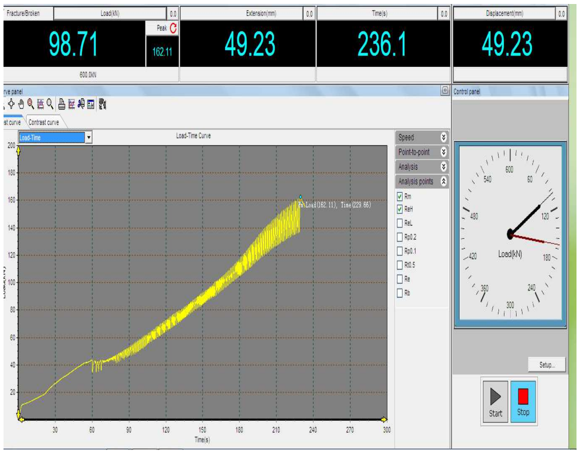


Fig. 17. Diagram of the variation of the pressing force depending on the length of the adjustment (l = 49,44 mm, v = 0,21 mm/s)

Comparing the diagram in figure 9 (F_{max} = 187.55 kN) with the diagram in figure 17 (F_{max} = 162.11 kN) there is a substantial decrease in the pressing force. The deformation of the adjustment begins with a deformation in the elastic range, followed by a deformation in the plastic range.

The diagram of the variation of the depressing force according to the length of the adjustment is presented in figure 18.



Fracture/Broken

Load(kN) 0.0: 98.71

Peak: 162.11

Extension(mm) 0.0: 49.23

Time(s) 0.0: 236.1

Displacement(mm) 0.0: 49.23

Fig. 18. Diagram of the variation of the depressing force depending on the length of the adjustment (l = 49,44 mm, v = 0,20 mm/s)

From the diagram shown in figure 18 it results that the depressing force is F_{max} = 184.9 kN, compared to the maximum depressing force in figure 10, which is F '= 235,776 kN, so there is a substantial decrease.

5. SURFACE QUALITY IN ASSEMBLING PARTS BY ELASTIC TIGHTENING

The quality and precision of the surfaces from the assembly of the parts by elastic tightening represent a criterion of maximum importance in the conditions of raising the quality of the assemblies by self-tightening.

The forces opposing the undoing of such an assembly are the frictional forces on the contact surface. They increase with the pressure between the parts and with the coefficient of friction.

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During axial pressing, some of the surface roughness (roughness) is deformed, but others are sheared, with a negative effect on the size of the achievable friction moment.

The roughness of the initial cylinder was Ra = 0.878 µm (fig. 19) after finishing processing.

Through experimental research, informative data were obtained that indicate the roughness of the cylinder surface after pressing (parameter Ra') (fig. 20).

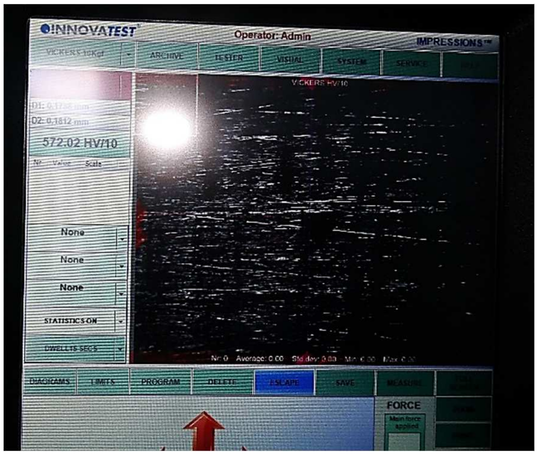
Fig. 19. Recording the initial roughness of the cylinder before pressing

Fig. 20. Cylinder roughness recording after assembly (Ra = 0.560 µm)

Like any adjustment, a pressed assembly is characterized by tightening and accuracy class, the latter expressing the size of the adjustment tolerances related to the tolerances prescribed for machining the parts to be assembled. As previously shown (fig. 19 and fig. 20), in this case the size of the surface roughness Ra is also taken into account, so its quality.

In order that the assembly process by self-tightening to take place in conditions of stability, and the productivity, the costs, the assembly accuracy, the energy consumption to have prescribed values, it is necessary to perform measurements on the hardness of the cylinder.

The initial hardness of the cylinder was 543.35 HV / 10, and after assembly it was 572,02 HV/10 (fig. 21).



D2: 0,1812 mm

572.02 HV/10

Nr: 0 Average: 0.00 Std dev: 0.00

Fig. 21. Cylinder hardness recording after assembly

The important advantages of self-tightening assemblies are: the possibility of transmitting large moments and, especially, variable moments, a good centering of the parts, weight and space saving, combined with a low cost price, by the lack of additional parts.

6. CONCLUSIONS

In technology, in general, and especially in the field of machine building technology, an important weight in scientific research has experimental research, which is on the one hand a basic criterion for verifying the truth about the hypotheses of scientific theories, and on the other hand a source of detection of new knowledge in the studied field.

Through the problems addressed and the solutions presented, the paper contributes to the development of knowledge in the field of self-tightening assemblies.

Figure 22 presents a summary of the research presented in the paper on self-tightening assemblies.

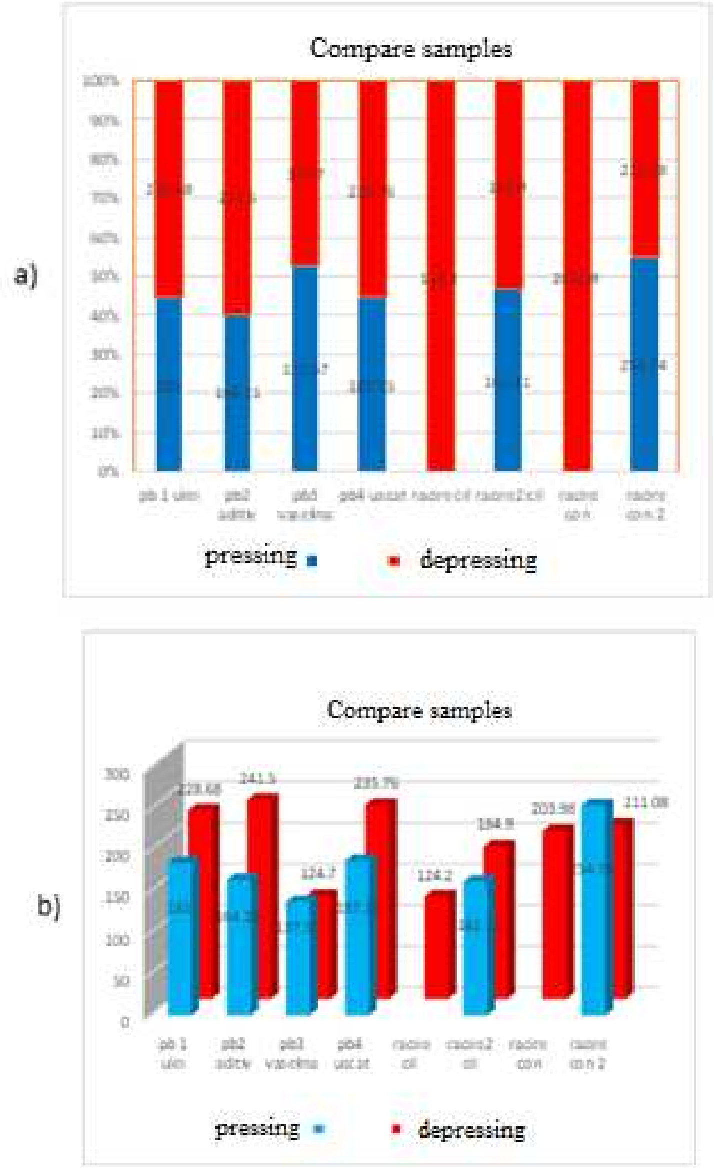


Fig. 22. Research synthesis, depending on.

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a) percentage test; b) comparison of samples

Due to the complexity of the self-tightening system, experimental research is the only way to obtain satisfactory results necessary for the use and continuous improvement of self-tightening technologies.

7. REFERENCES

[1] Buzdugan, Gh. Resistance of materials, Technical Publishing House, Bucharest, 1970

[2] Buzdugan, Gh. Resistance of materials, Technical Publishing House, Bucharest, 1980

[3] Cândea, v.ș.a Classification and symbolization of ferrous and non-ferrous alloys, UT-PRESS Publishing House, Cluj-Napoca, 2010

[4] Chișu, Alex, ș.a. Machinery Parts, E.D.P. Publishing House, Bucharest 1976

[5] Deutsch, I. Resistance of materials, E.D.P. Publishing House, Bucharest, 1976

[6] Drăghici, I., ș.a. Machinery Parts, Problems, E.D.P. Publishing House, Bucharest, 1980

[7] Manea, Gh. Machinery Parts, Technical Publishing House, Bucharest, 1970

[8] Păstrăv, I. Resistance of materials, Vol. 2, I.P.C-N. Publishing House, Cluj-Napoca, 1983

[9] Tăpălagă, I. ș.a. Cold Extrusion of Metals, Dacia Publishing House, Cluj-Napoca, 1986

[10] Tăpălagă, I. ș.a. Cryogenics in the Machine Building, Dacia Publishing House, Cluj-Napoca, 1988.

ÎMBINĂRI PRIN STRÂNGERE ELASTICĂ ȘI POSIBILITĂȚI DE TESTAREA LOR

Rezumat: Ansamblurile cu auto-strângere (elastică) se fac prin strângerea cauzată de deformarea elastică a părților îmbinate. În funcție de gradul de strângere, rezultat din toleranțele adoptate și tehnologia de montare, ansamblurile cu auto-strângere pot fi detașabile sau nedetașabile. Ansamblurile cu auto-strângere pot fi: În funcție de forma constructivă a ansamblului pot fi: Ansambluri fără elemente intermediare de prindere; Ansambluri cu elemente intermediare de prindere. Conform tehnologiei de montare: Ansambluri presate, executate la temperatura mediului; Ansambluri de micșorare, executate prin încălzirea părții de închidere sau răcirea părții închise. Ansamblul de strângere este utilizat pe plăcile active de la matrițele de extrudare, montarea bandajelor roților rulante, angrenajele coroanei, rulmenții, execuția arborilor cotit ai elementelor separate etc.

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