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FORMING OF EXTERNAL STEPS OF SHAFTS IN THREE SLIDE FORGING PRESS

KSZTAŁTOWANIE SKRAJNYCH STOPNI WAŁÓW W TRÓJSUWAKOWEJ PRASIE KUŹNICZEJ

This paper presents the results of research concerning forming of external shafts steps in three-slide forging press (TSFP). This hydraulic press is characterized by three slides – one vertical and two horizontal. Such a design allows for economical forming of forgings of stepped axles and shafts by means of upsetting methods. The authors did the research aiming at determining limiting conditions of billet diameter enlarging in cylindrical impression.

In order to do these research, tools set with changeable elements constituting the impression was designed and made. Such a design of tools allowed for determining of the impression length and diameter influence on the upsetting process. The minimum length of the impression of a given diameter was determined by changes of the impression diameter D within the range of $D = (1.25 \div 1.6)d$ (where: d – billet diameter). On the basis of the obtained results, guidelines for the designing of forming process of external shafts steps in TSFP were worked out. Nomograms, on the basis of which the number of operations and geometrical parameters of the used tools can be determined, were made.

These guidelines were applied for designing of forging processes of external steps with different diameter and lengths. The conducted experimental verification confirmed the rightness of the assumptions – forgings of the assumed quality were obtained.

Keywords: three-slide forging press, upsetting, drop forging of shaft

W opracowaniu przedstawiono wyniki badań dotyczące kształtowania skrajnych stopni wałów w trójsuwakowej prasie kuźniczej (TPK).

Wymieniona prasa o napędzie hydraulicznym charakteryzuje się trzema ruchomymi suwakami – jednym pionowym i dwoma poziomymi. Taka budowa umożliwia ekonomiczne kształtowanie odkuwek typu stopniowane wały i osie metodami spęczania. Autorzy podjęli badania zmierzające do określenia warunków granicznych powiększania średnicy wsadu w wykroju walcowym. W tym celu zaprojektowano i wykonano zespół narzędziowy posiadający wymienne elementy tworzące wykrój. Taka konstrukcja narzędzi pozwoliła określić wpływ długości i średnicy wykroju na przebieg procesu spęczania. Zmieniając średnicę wykroju D w granicach $D = (1{,}25 \div 1{,}6)d$ (gdzie: d – średnica wsadu) określono minimalną długość wykroju dla danej średnicy, przy której proces kształtowania przebiega prawidłowo. Na podstawie uzyskanych wyników opracowano wytyczne do projektowania procesu kształtowania skrajnych stopni wałów w TPK. Sporządzono nomogramy, na podstawie których oraz w oparciu o wymiary kształtowanego stopnia można wyznaczyć ilość zabiegów oraz parametry geometryczne stosowanych narzędzi.

Wytyczne te zastosowano do projektowania procesów kucia skrajnych stopni o różnych średnicach i długościach. Przeprowadzona weryfikacja doświadczalna potwierdziła prawidłowość przyjętych założeń – otrzymano odkuwki o założonej jakości.

1. Introduction

Forgings of stepped shafts and axles are made e.g. by means of various metal forming methods. In many cases large differences of cross sections complicate manufacturing of these forgings and lead to the increase of material consumption. One of the effective methods of metal forming of shafts is cross wedge rolling method, which allows for obtaining multiple stepped shafts in one working cycle at relatively small material waste. This method is developed at the Department of Metal Forming and Computer Modelling at Lublin University of Technology [1÷4]. Research works on new forging methods, done at the same department, led to designing of a prototype of three-slide forging press (TSFP) [5÷7]. This press consists of three movable working tools (Fig.1), which guarantees large technological possibilities of metal forming. The advantages of this machine, such as the possibility of upsetting of large bars in a chosen place or at two ends simultaneously, make it useful in manufacturing of preforms

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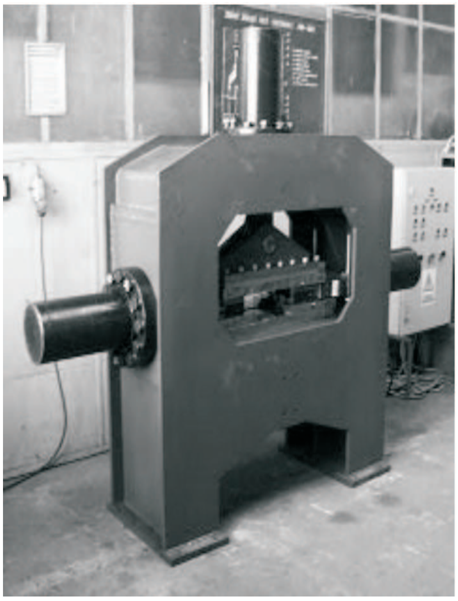


Fig. 1. Three-slide forging press

and forgings of stepped shafts and axes type. The effective forming method of stepped shafts forgings in the TSFP is forming by means of upsetting. In many cases this method allows for forming without flash. Moreover, upsetting allows for the application of long billets with small diameters (equal or close to diameters of shafts steps with the smallest section), which is favorable for decreasing losses during cutting. However, due to technological differences, upsetting processes of shafts steps should be divided into forming of external steps and forming of central steps. This paper presents the results of research works concerning the forming process of external steps.

2. Limiting conditions of upsetting in TSFP

Determining limiting conditions of free upsetting and upsetting in cylindrical impression is the basis for the designing of the forging process of external steps in TSFP. In order to reduce costs of the research determining these limiting conditions initial numerical analyses were made. However, difficulties appeared in modelling of such process conditions which guarantee kinematics of material flow similar to reality. The main phenomenon limiting the processes of free upsetting and billets upsetting in cylindrical impression with large slenderness ratio is buckling. Modelling of upsetting tools inclined at various angles to the billet head surface and buckling appearance caused by non-symmetrical tools movement did not allow for obtaining conformity of geometrical features of theoretical model and real process. Because of that, upsetting limiting conditions were determined in experimental research. The first stage of the research concerned determining limiting coefficients of upsetting $m = l/d$ (where: l, d – length and diameter of the upset part of a bar) in the free upsetting process.

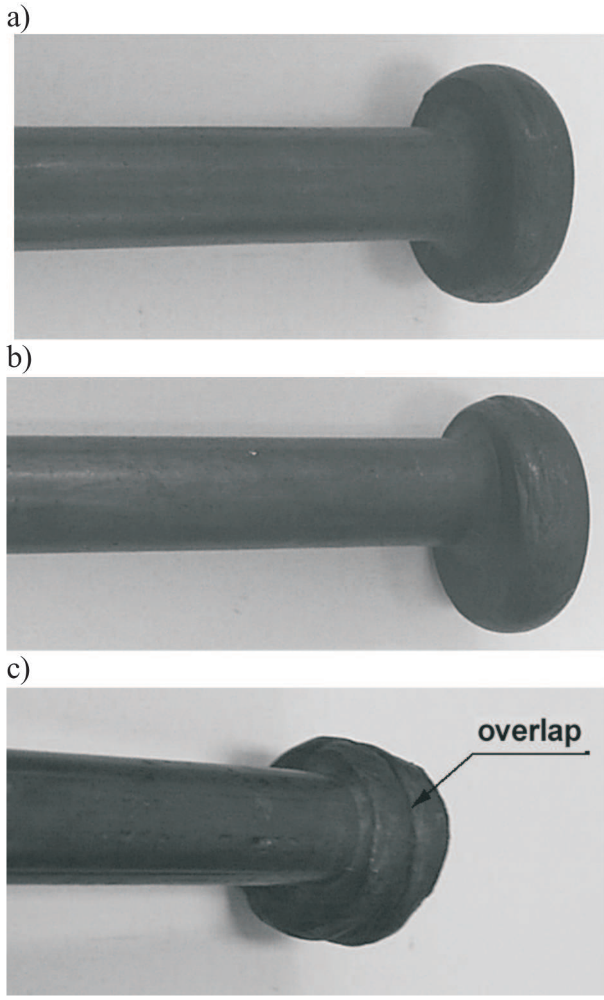


Fig. 2. Upset parts obtained at upsetting ratio : a) $m \leqslant 3$, b) $3 < m \leqslant 3.7$, c) $m > 3.7$

Figure 2 presents obtained forgings for various conditions of the experiment. The results of research showed that a proper forging can be obtained for upsetting ratio $m \leqslant 3$. The example of this forging is given in Fig. 2a. At the upsetting ratio $m > 3$, at the initial stage buckling appears and later upsetting. This course of the process results in the presence of eccentricity (Fig. 2b), yet, the larger the upsetting ratio is, the bigger eccentricity occurs. Eccentric upset parts can be qualified in certain cases as proper ones. They can e.g. constitute preforms, at forming of which the main aim is the displacement of adequate material volume and eccentricity does not exclude the further forming of the forging. After exceeding the upsetting ratio limiting value $m = 3.7$, the buckling of the upset bar is so large that lapping appears at the further upsetting (Fig.2c). The obtained upset part is a faulty product. Using it even as a preform will lead to the appearance of this fault in the forging as well.

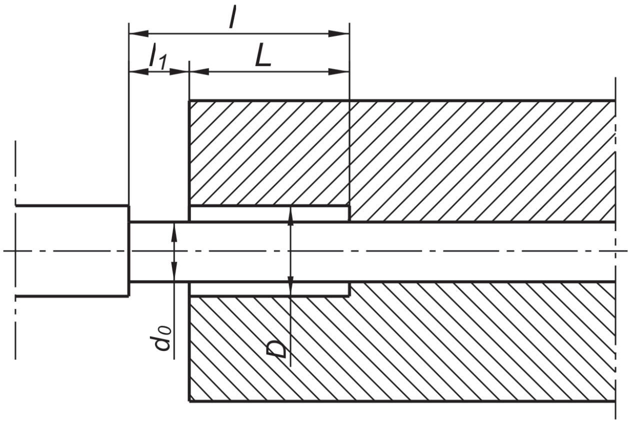
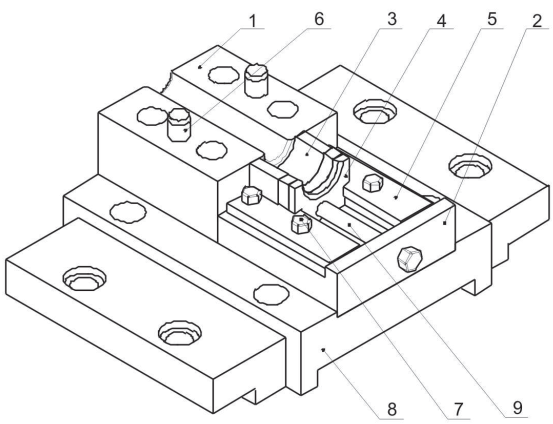


Fig. 3. Schema of a bar upsetting in a cylindrical impression

a)



b)

Fig. 4. Tools for analyzing the upsetting process in the cylindrical impression: a) schema of the lower tool b) tools elements (changeable pads); 1-basic die, 2-mounting plane, 3-changeable pads, 4-pad with phase, 5-pressing blocks, 6-guide pins, 7-screws, 8-clamp body, 9-pressing screw

The next stage of the research was determining limiting conditions of upsetting in cylindrical impression. The research were based on the upsetting of a bar with circular section in cylindrical impressions with different diameters D and lengths L (Fig. 3). Maximal upsetting coefficient m was determined for each case. Special tools allowing for changes of geometrical parameters of the impression by means of changeable semi-rings (Fig. 4) were used during the research. The value of the diameter D was changed every 1 mm within the range of 25÷32 mm (at the applied billet diameter d = 20 mm the impression diameter was changed within the range of $D = 1.25 \div 1.6d$), the length of the impression L was changed every 4 mm within the range of 30÷62 mm. The course of particular limiting curves for various impression diameters is shown in Fig. 5. On the basis of the obtained results, it was stated that three main factors limiting the upsetting process in the cylindrical impression are present.

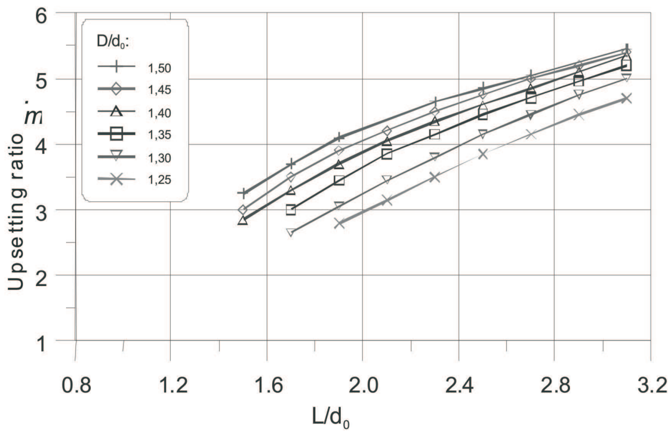


Fig. 5. Limiting values of upsetting ratio for various geometrical parameters of the impression

They include:

- upsetting outside the impression,
- bar buckling before the impression,
- overlapping in the impression.

The mentioned above phenomena limit the maximal diameter of the upset step (equal the diameter of the impression) to the value $D_{\max} = 1.5d$. However, the maximal, possible to obtain length of the step (at the condition $D \leqslant 1.5$) depends mainly on the machine force parameters, tools durability and friction between the impression sides and the billet, which makes difficult the proper filling of the impression. On the basis of limiting curves, it is possible to determine the impression length L that should be used depending on the upsetting diameter D and upsetting coefficient m.

3. Guidelines for the process designing

On the basis of the conducted research it can be stated that:

– free upsetting in one operation can be realized when the following condition is fulfilled:

$$m = l/d <= 3, \tag{1}$$

– in upsetting process in the cylindrical impression in one operation maximal upsetting diameter can be obtained, described by the equation:

$$D = 1.5d, \tag{2}$$

where:

l – length of the upset bar,

d – billet diameter,

D – maximal upsetting diameter equal the impression diameter.

If the process takes place in a few operations, the above calculations can be described as following:

– in the case of free upsetting for each operation the condition:

$$m_i = l_i/d_i, \tag{3}$$

should be preserved,

– in the case of upsetting in the cylindrical impression the maximal upsetting diameter is:

$$D_i = 1.5D_{i-1}, \tag{4}$$

where: m_i – upsetting coefficient in i upsetting operation,

l_i – length of the upset part of the material in i upsetting operation,

d_i – diameter of the upset part of the material in i upsetting operation,

D_i – maximal diameter of the upset step in i upsetting operation,

D_{i-1} – maximal diameter of the upset step in $i-1$ upsetting operation, which is equal the diameter d_i ($D_{i-1} = d_i$),

i – index.

If the formed step of the shaft has relatively small diameter and length and the condition (1) or (2) is fulfilled, it can be formed in one operation by means of free upsetting or upsetting in the impression. However, if these conditions are not fulfilled, more than one operation should be applied. The number of these operations depends on the final volume of the formed step. It should be added, that in every case the last operation may be free upsetting or upsetting in the cylindrical impression, however, in all preceding operations only upsetting in the impression should be applied. If the final operation takes place in the cylindrical impression, the cylindrical shape of the shaft step is obtained. In such a case appropriate tools with impression should be used. If, however, in the final operation free upsetting is applied, barrel-shape of shaft step is obtained. Tools designing is simple (tools are cheaper), yet the allowance must be removed, and because of that the process effectiveness is smaller. At the designing of the process this allowance should be considered.

On the basis of conditions (1)÷(4), nomogram for designing of forging processes of external shafts steps in TSFP was worked out (Fig. 6). Characteristic areas depended on the diameter D and length h of the formed step in relation to billet diameter d are marked in this figure. They correspond with the following forming conditions:

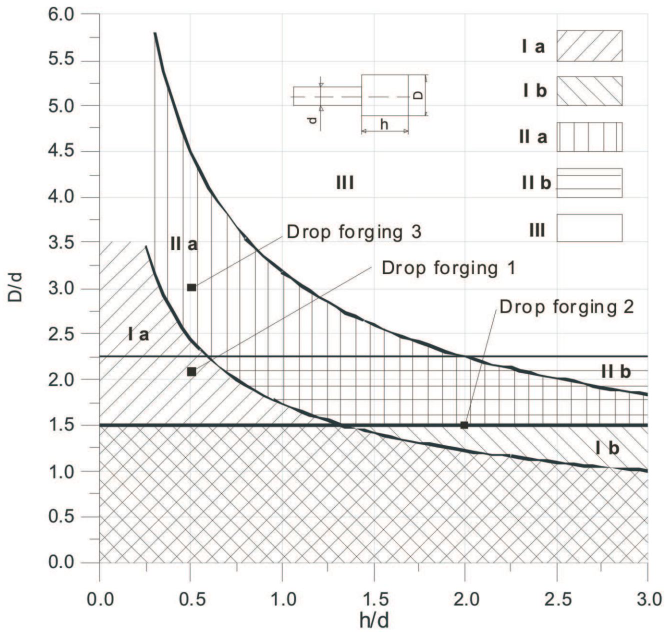


Fig. 6. Schema for determining the proper choice of the upsetting method

Ia – forging should be formed in one operation of free upsetting,

Ib – forging should be formed in one operation of upsetting in the cylindrical impression,

IIa – forging should be formed in two operations; the first one – upsetting in the cylindrical impression to diameter $D_1 = 1.5d$, the second – free upsetting,

IIb – forging should be formed in two operations; the first one – upsetting in the cylindrical impression to diameter $D_1 = 1.5d$, the second – upsetting in the cylindrical impression to final step diameter,

III – forming in at least three operations; the first one – upsetting in the cylindrical impression to diameter $D_1 = 1.5d$, the second – upsetting in the cylindrical impression to diameter $D_2 = 1.5D_1 = 2.25d$, the third operation – the kind of the operation depends on the final dimensions of the formed shaft step.

It was assumed that the process would be economical when the forging manufacturing would not exceed these three operations. Hence, the cases in which larger number of operations is necessary were not analyzed (yet, it should be noticed that this is possible).

4. Experimental examples

In order to verify the worked out designing conditions, the external upsets of the bar with circular section in TSFP were made. For the research needs, forgings with the following dimensions of the upset steps were used (Fig. 7):

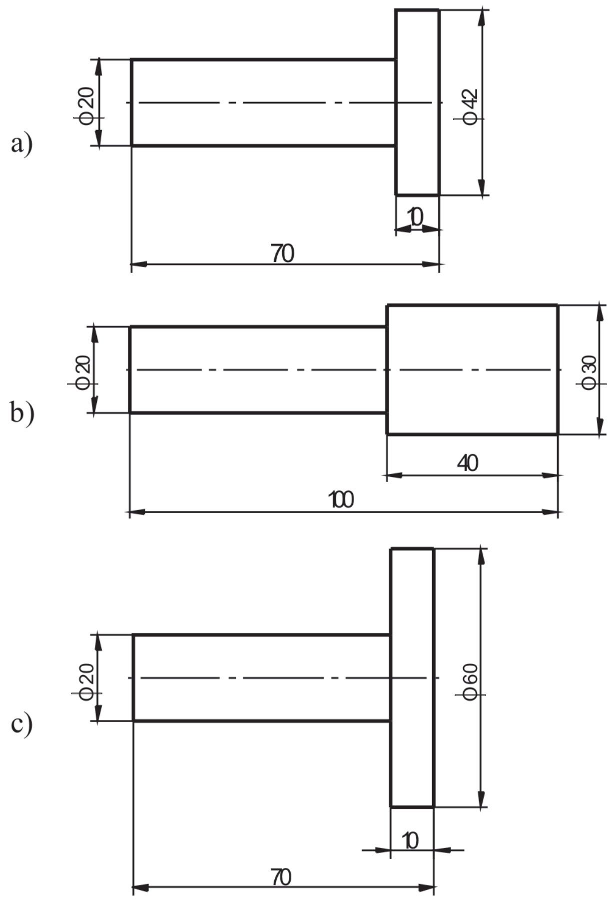


Fig. 7. Dimensions of forgings chosen for experimental results: a) forging no. 1, b) forging no. 2, c) forging no. 3

– drop forging no. 1 – ϕ42×10 mm (upsetting coefficient m = 2.205),
– drop forging no. 2 – ϕ30×40 mm (upsetting coefficient m = 4.5),
– drop forging no. 3 – ϕ60×10 mm (upsetting coefficient m = 4.5).

Given in brackets upsetting coefficients were calculated assuming the charge diameter d = 20 mm, equal the diameter of forgings bodies. On the basis of the calculated values D/d and h/d (where: h – length of upset step), points corresponding with particular forgings were marked in Figure 6. Depending on the field on the nomogram in which points are, the following way of forgings making was chosen:
– forging no. 1 – free upsetting in one operation with consideration of allowance for the removal of barrel shape (area *Ia*),
– forging no. 2 – upsetting in the cylindrical impression in one operation (area *Ib*),
– forging no. 3 – upsetting in the cylindrical impression in the first operation on the diameter D = 30 mm and free upsetting in the second operation on the final dimension with consideration of allowance necessary for the removal of barrel shape (area *IIa*).

According to the assumed technological process the analyzed forgings were made (Fig. 8). The dimensions of the obtained forgings corresponded with the values assumed in experiments. The experimental verification confirmed the rightness of the assumed guidelines for designing of the forging process of external shafts steps in TSFP.

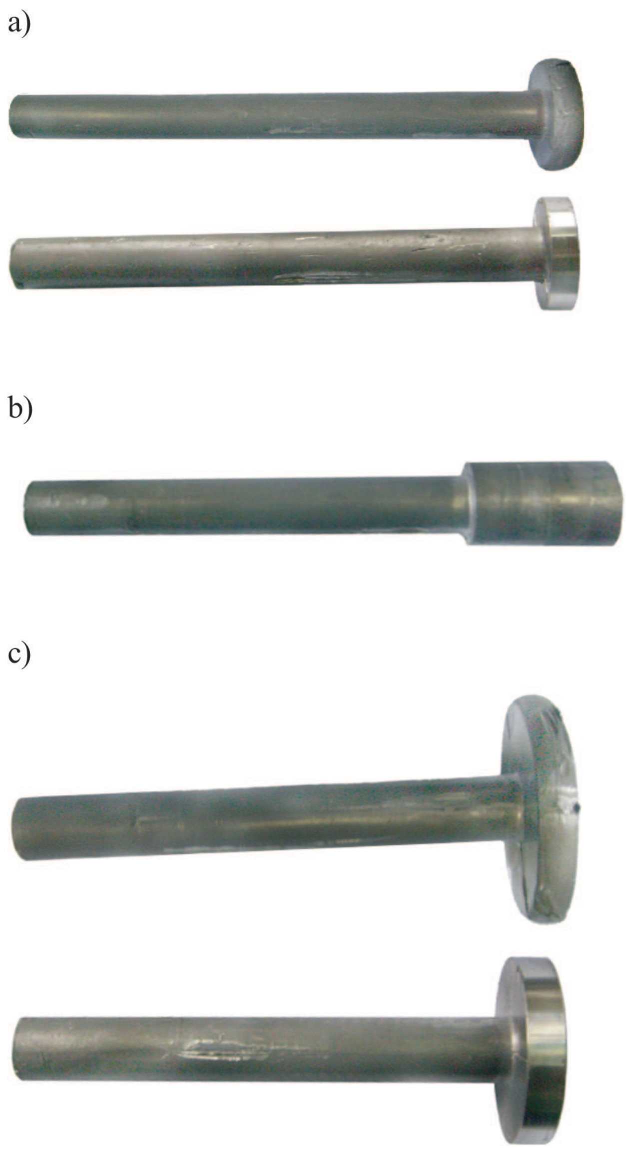


Fig. 8. Forgings made in TSFP: a) forging no. 1 after forming and machining, b) forging no. 2 after forming in the cylindrical impression, c) forging no. 3 after two upsetting operations and machining

5. Conclusions

On the basis of the conducted theoretical and experimental research the following conclusions can be drawn:

- In the result of the analysis, it was stated that shafts with external upsets can be formed in TSFP. The application of this machine allows for obtaining relatively large upsetting coefficients. The additional advantage of this forming method is the possibility of the application of billets with small cross sections, which allows for material saving during cutting and increases effectiveness.

- In order to manufacture a proper product, the process should be realized in one or a few opeline rations of free upsetting or upsetting in the cylindrical impression. The number and kind of operations should be chosen on the basis of the worked out nomogram (Fig.6), considering the dimensions of the final shaft step.
- The worked out rules of steps designing at the ends of shafts were verified in experimental way, and this confirmed the rightness of assumptions and obtained results. It should be noticed that the presented above possibilities concern lead forming as the material model. In the further research works, the worked out rules will be verified for the following materials: steel, aluminum alloys, copper, titanium and magnesium. Guidelines for designing of forming processes of shafts steps in central parts will be also determined.

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