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# Theory and practice of asymmetrical longitudinal rolling

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**Abstract.** In the national and international literature of the rolling theory, it is usually presented the plastic distortion between cylinders with equal diameter, meaning the symmetrical rolling, although this process represents only an abstract opposed to the normal conditions, because there exists a difference between the working diameters of the cylinders, and sometimes right after construction the rolling mill is equipped with cylinders of different diameters.
It is worth mentioning that for a series of aspects like: the distribution of the unitary pressure on the contact surfaces, the reduction between the cylinders, the bending of the bar exiting from among the cylinders and many others, there are contradictory opinions which are explained through the difficulties that the experimental study of these phenomena imposes, but also because of the different factors which influence or modify the volumetric pressure scheme of the metal material at rolling.
For the research of these difficult phenomena the author of the paper conceives an original appliance which allows experiments in order to reach conclusions for the rolling theory among equal diameter cylinders, but also for the industrial practice.

**Keywords:** symmetrical longitudinal rolling, asymmetrical longitudinal rolling, unitary pressure, force captures, reduction.

## 1. Introduction

The known disadvantage of the plastic processing of metallic materials through rolling is, in the majority of cases, the absence of the estimation of the adopted abstractions, of simplifications and of hypotheses from which many are not discussed or mentioned by the authors.
This hypothesis does not correspond to the real conditions of rolling in all the practical cases of this process, or of the typical scheme of rolling of the ingots

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with rectangular section between cylinders with smooth surface - the deviations are especially big in the case of the more complicated schemes when the rolling takes place in calibers, and also in a series of special cases (different diameters of the working cylinders, rolling the stratified ingots, etc.).
It is worth mentioning that the development of the theory and the practice of the rolling process, and especially of the asymmetrical rolling there is a continuous need of thorough analysis of the different phenomena with the aim of clarifying the essence of this complicated process [1,2].
With all the accomplishments so far, there are still unclear some aspects of distortion of the metallic material, of kinematics and of dynamics of the rolling process. As a result there is the fact that in some cases are received important practical solutions without a sufficient scientific base. Also, a whole series of theoretical solutions need experimental confirmation. This refers to asymmetrical rolling where the following phenomena remain still unclear [3]:

- the allocation of the pressure on the length of the contact spring from every cylinder;
- the influence of the side forces which appear at the asymmetrical rolling upon the allocation of normal pressure on the length of the contact spring from every cylinder;
- the study of the particularities which are introduced in the process, the transmission of the action moment through only one coupling ingot.

Without the clarification of these phenomena through experimental works it is not possible the formation of one correct theory of distortion at the asymmetrical rolling. In the same time for practical calculus one must know the parameters of speed and force of the process. Studying thoroughly of the mentioned phenomena presents also scientific interest, because it gives the possibility to understand the nature of complicated phenomena, which take place in the symmetric process and asymmetric process [4,5].
The literature of rolling theory usually presents aspects which characterize the symmetric rolling process, although this process does not constitute only but an abstraction from the normal rolling conditions, because, practically, there exists a difference between the working cylinder's diameters, and sometimes after the construction the rolling mill is equipped with cylinders with unequal diameters.
In this way, the researches made in the last years at trio profile rolling mills, which function as duo reversible, the rolling mills for cold rolling, the trio rolling mills for board and others, show that the distortion process of the metallic material between cylinders runs asymmetric, firstly due to the inequality between the working diameters of the cylinders, fact that complicated the whole picture of the tension status from the distortion area [6]-[11].
In the present paper the data according to the symmetric process are presented only with the aim to clarify better the asymmetric process [12].
Until now there have been studied the distortion conditions of the metallic material in the trio Lauth stands, at which, as known, the middle cylinder of smaller diameter is not actioned [13].

It is worth mentioning that for one series of aspect as: the distribution of reduction between cylinders, bending the ingot at exiting from the cylinders and others, there are contradicting opinions which are explained though the difficulties which the experimental study of the phenomena implies, but also because of the different factors which influence or modify the volumetric tension scheme of the metallic material [14].
In this situation, the research is difficult and must clarify first of all the way in which the unitary pressure is distributed on the length of the contact spring from every cylinder, taking into consideration the influence of the kinematic distortion area [15].

## 2. Conceived equipment

In the "The theory and technology of plastic processing processes" laboratory from the Faculty of Engineering Hunedoara I have realized though self-equipping a duo rolling mill, with the diameter of 170 mm, destined to the learning and scientific research process, presented in figure 1.
After, the author of the paper, with the aim of assuring at the asymmetrical rolling a wide range between the working diameters of the cylinders and for including all the cases from the current practice, conceived and realized a special construction installation presented in figure 2, which allows the measurement in the same time of the force parameters, special bearings, coupling ingots, captors for the unitary contact pressures, for the total and side force of rolling, and for the tension moments.
In this way, in the place of regular cylinders there have been built 2 other experimental cylinders, one with the diameter of 140 mm, the other of 170 mm, presented with two longitudinal grooves, with the width of 90 mm, situated diametrically opposed.

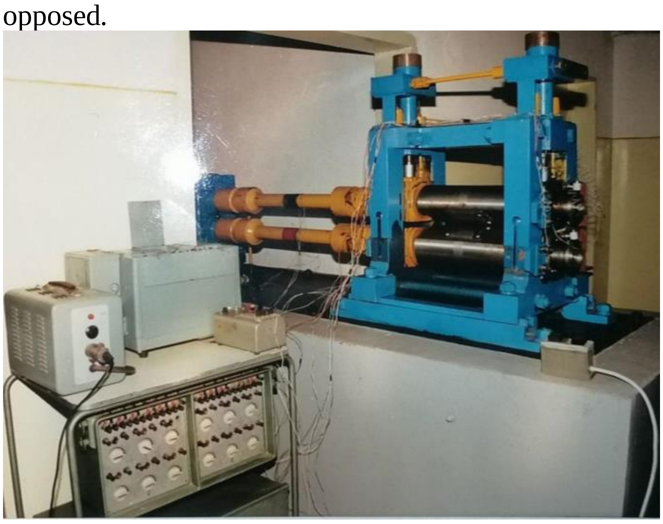


Fig. 1. Overview of the rolling mill with 170 mm diameter.

Through the center of these grooves from the cylinders there has been executed an aperture with the diameter of 24 mm for the installation of the unitary pressure captors.
On the axis of the spindles 1 and 2 (fig.2) from the heads "A" and "B" to the center of the board there have been made apertures with the diameter of 25mm, which serve for the removal of the conductors from the unitary pressure captors.

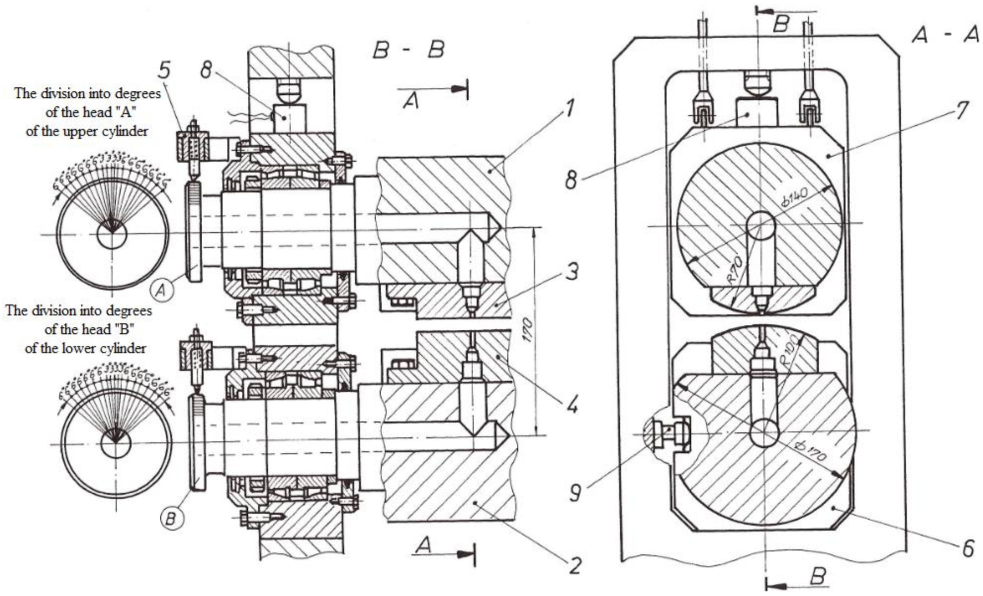



Fig. 2. Components made by the author for the research of the asymmetrical rolling process: 1 - superior cylinder Ds, 140mm diameter, with the head divided "A"; 2 - inferior cylinder Di, 170mm diameter, with the head divided "B"; 3 - R=70mm segment for the superior cylinder; 4 - R=100mm segment for the inferior cylinder; 5 - device for real registering of the contact spring; 6 - inferior frame bearing; 7 - superior frame bearing; 8 - captor for the total rolling force; 9 - captor for the side forces.

The "A" heads of the 1 cylinder and "B" of the 2 cylinder were divided in grades with the help of a divider system with a mill disc of 0,5mm, making divisions with the depth of 4mm, in which was poured epoxy raisin, as insulating material. The determined order of the angular distance between the divisions allows with sufficient precision the fixation on oscillograms of the geometric exhaust plan of the metallic material from the cylinders. This vertical plan passes through the axis of the bolt aperture, with the diameter of 1,13mm of the captors for the unitary pressure mounted in the segments of the inferior and superior cylinders.
The grade division of the heads "A" and "B" of the cylinders is showed in figure 2. In the same figure it is observed that in the longitudinal groove of the superior cylinder 1 are fixed the segments 3, destined for the working diameters of 170, 160, 150 and 140mm, and in the longitudinal groove of the inferior cylinder 2, the segments 4 for the diameters of 170, 180, 190 and 200 mm.

In this way there are possible the following combination between the rolling working diameters: $\frac{D_s}{D_i} = \frac{170}{170}; \frac{160}{180}; \frac{150}{190}; \frac{140}{200}$

The cylinders are mounted in this way so that the measurement of the unitary pressure is made in only one plan. In those grooves the segments are fixed with the help of four screws M8 and two conical bolt.

The captors for the contact unitary pressure are an original concept of the author and their installation in the segments of the cylinders is given in figure 3.

Their constructive particularities are the following:

- the diameter of the unitary pressure taking studs is 1,3 mm, which shows on the oscillograph band the pressure in final unit measures ($N/mm^2$);
- between the stud's rod and the body of the captor there is a loose on the ray equal to 0,5 mm, which eliminates the possibility of stiffness of the calibrated part of the stud in the opening of the segment at installing the captor in the segments;
- the body of the pencil captor, made from brass, has four longitudinal openings, diametrically opposed, with the width of 2 mm each to assure the needed sensitivity and the uniform distribution of the unitary pressure per section.

These captors are screwed in the superior and inferior segments of the cylinders, being fixed in the working position with the lock-nuts 8 from figure 3.

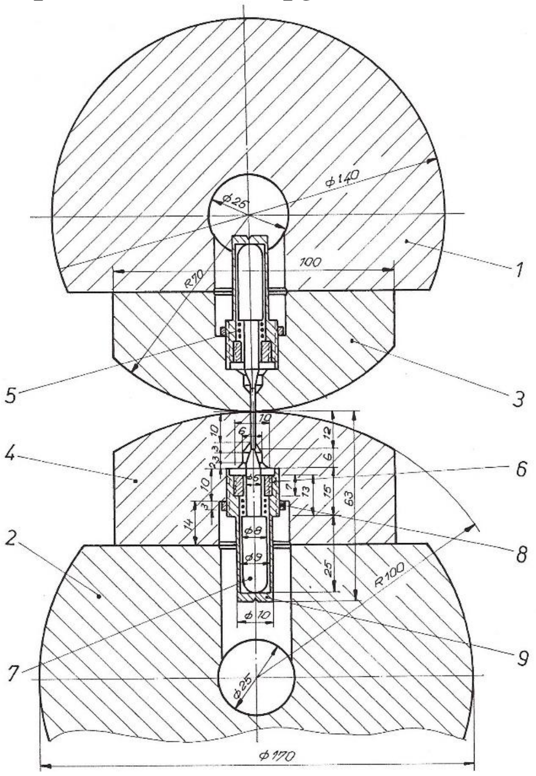



Fig. 3. The installation of the captors for the contact pressure in the cylinders 'segments
1-superior cylinder; 2-inferior cylinder; 3-segment for the superior cylinder; 4-segment for the inferior cylinder; 5-spring; 6-cork; 7-steel pivot; 8-lock-nut; 9-the body of the pressure captor.

Also, from figure 3 it can be observed that the stud 7 of the steel pivot for the unitary pressure captor 9, made from brass, comes out to the surface of the segments and into contact with the metallic material subject to deformation.
This stud must have the same hardness as the segments have, the reason why it is made from the same quality of steel. After mounting, the adjusting of the stud's head is made through polishing together with the work surface of the segment.
In this way, with the equipment created in the figures 2 and 3, the next step was the simultaneous research of the main rolling parameters, in the symmetric process and also in the asymmetric one, meaning that the rolling forces of the two roll stands, from right and left ($F_d$ and $F_s$), the side forces at asymmetric rolling ($X_d$ and $X_s$), the unitary pressure on the contact surfaces between the metallic material and the inferior and superior cylinder ($p_i$ and $p_s$), the real length of the contact spring ($l_i$ and $l_s$) and also the rolling moments ($M_i$ and $M_s$).
In figure 4 it is given an overview of the roll stand after inserting in the place of the regular cylinders, the equipment made for research.
It must be mentioned that all the parameters of the process were recorded on strain gauge scheme without amplification, with the fixing of the impulses on an oscillograph with 14 channels, directly on the picture band with the width of 120mm.
In the measuring installation the sensitive elements are represented by the force captors and the universal coupling ingots which transform the pressure and the torsion moments in line and angular movements.

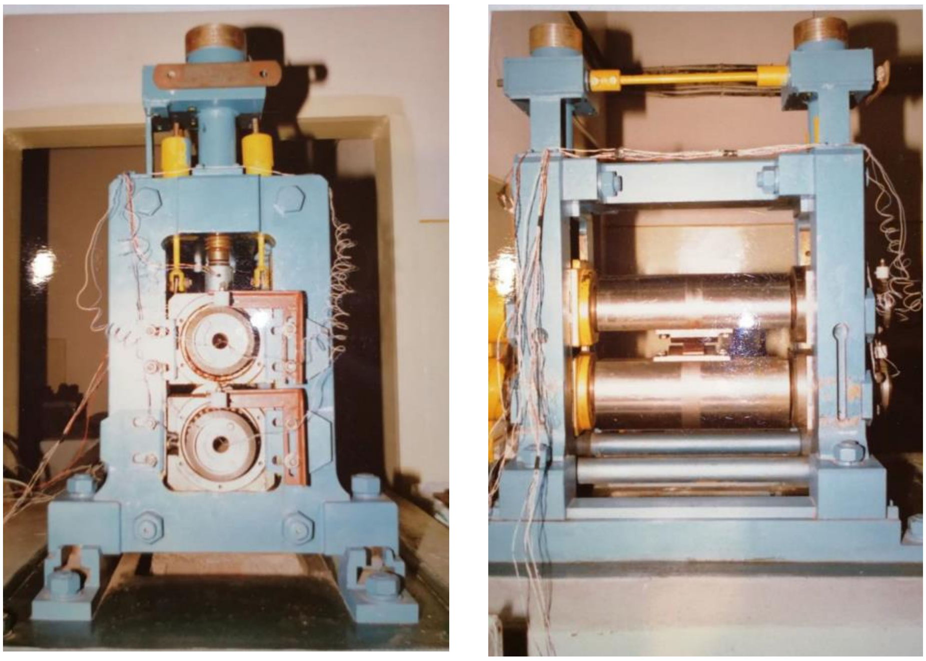


Fig.4. Overview of the roll stand after introducing the equipment made for research.

As first convertor from the scheme there are used electrical conductors made from wire which convert the deformations into changing the ohmic resistance. The second converting link is represented by the electric bridge which transforms the ohmic resistance changes into electricity.
Measuring the previous mentioned parameters the working elements of the deck are represented by two opposed arms $R_1$ and $R_3$ (fig. 5) that have transducers weld parallel with the direction of the main deformation, other two transducers from the opposed arms $R_2$ and $R_4$ are for compensation, being situated on a separate board, which is conditioned by the limited welding place, tied to the small dimensions of the force captor.

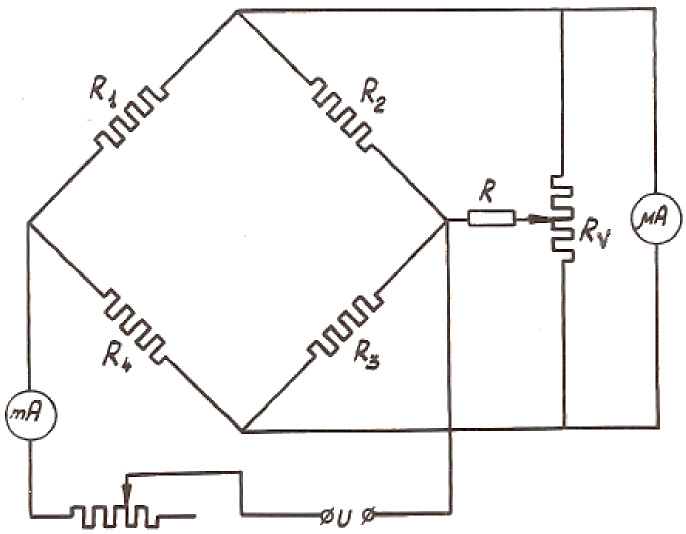
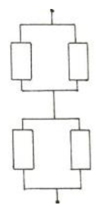
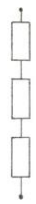
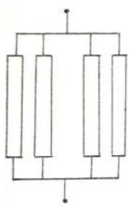



Fig. 5. Electric measuring scheme.

The measuring the torsion moments on the coupling ingots ($M_s$ and $M_i$) al the arms of the electric bridge are for work, but the transducers of one pair from the opposed arms which work simultaneously are weld in a 90° angle as opposed to the transducers from the other pair.
The stability of the bridge is made with the help of a variable resistance $R_v$, which is chosen depending on the final imbalance of the bridge, but not less than $10R_b$ ($R_b$-the resistance of the arm). The constant resistance R is introduced in the scheme to prevent the short circuit of the deck's arms at balancing, reason for which it may appear the turning off of the galvanometer; this must not be smaller than $10R_b$.
The diagonal of the deck is supplied with DC (continuous current), with the help of chargers, or with special rectifiers linked to the network through the stabilizer and which allows adjusting the supplying current (tension) in wide limits.
For an indicator it is used M001.1 cm galvanometers with the sensitivity of 1400mm/ma.m.

Table 1. The characteristics of the sensitive elements from the force parameters measuring scheme

| Measures parameter | | Fs, Fi | Xs, Xi | ps, pi |
|---|---|---|---|---|
| The sensitive element | Name | Force captor | Force captor | Pencil force captor |
| | Material | 90VMoCrl5 | Brass | Brass |
| | The maximum effort of calculul, [kN] | 100 | 20 | 1 |
| Transducer resistance $R_T$ | | 250 | 200 | 50 |
| Connecting scheme of the resistive transducers in the electric bridge | |  |  |  |
| No. of work arms | | 2 | 2 | 2 |
| Balance resistance, $R_e$ | | 10 | 22 | 0,5 |
| Constant resistance | | 5 | 10 | 0,5 |
| Supply source | | Rectifier | Rectifier | Battery |
| Supply intensity [mA] | | 100 | 90 | 300 |
| Bright spot deviation on the screen, at maximum effort, [mm] | | 50 | 40 | 40 |

Choosing the construction and the materials for the sensitive elements, of the transducers and the their link scheme in the arms of the electric bridges, of the supplying installation and of the recording device allowed accurately the measurement of the rolling process' parameters without amplifying, removing the errors introduced by amplifying and those connected to the influence of the exterior magnetic fields, excluding in the same time the necessity of fixing the measuring schemes using the poor shielded transducers. The characteristic of the elements of the measuring scheme is presented in table 1, and in figure 5 it is presented the electric measuring scheme.

## 3. Experiments and results

The aspects that implies de deformation among cylinders of unequal diameters at trio profile rolling mills which are functioning as duo reversible, rolling mills for cold rolling, trio rolling mills for metal sheet are due to the particularities introduced by the uneven distribution on the ingots' section of the tensions and deformations.

The research of these phenomena was made with an installation created in the paper and the data regarding the symmetric process are presented only with the aim to emphasize the particularities of the rolling between cylinders of unequal diameters.

For experiments there were used samples of copper, aluminum and "armko" iron, with the initial dimensions $h_o$=1, 2, 6 and 12mm, $b_o$=40mm and $l_o$=150mm, applying relative reductions $\varepsilon_h$, up to 50%.

In the theory of rolling it is frequent the characterization of the shape of the deformation area through the parameter $l/h_m$ (the length of the contact spring/ average thickness of the metallic material in the deformation area), but this parameter can characterize the tension status which is created only if the factors which determine its modification consider.

In unfolded form, the mentioned report can be written under the form of:

$$\frac{l}{h_m} = \frac{l}{h_0\frac{(2-\varepsilon_h)}{2}} = \frac{l}{\frac{\Delta h}{\varepsilon_h}\cdot\frac{(2-\varepsilon_h)}{2}} = \frac{l}{\frac{\alpha\cdot l}{\varepsilon_h}\cdot\frac{(2-\varepsilon_h)}{2}} = \frac{2\varepsilon_h}{\alpha(2-\varepsilon_h)} = \frac{1}{\alpha}\cdot\frac{2\varepsilon_h}{2-\varepsilon_h}$$
$$= f(R;\Delta h;\varepsilon_h)$$

Because $\alpha = \sqrt{\frac{\Delta h}{R}}$ means that in the case of admittance of the $l/h_m$ parameter, it must be mentioned due to which measures ($R$; $\Delta h$ or $\varepsilon_h$) the researched modification is produced.

For comparison, the force parameters of the deformation through rolling were researched starting with the symmetric process, the aim being the research of the particularities connected to the asymmetry of the process.

In figures 6 and 7 there are presented the characteristic oscillograms for the force parameters' variation registered at rolling in the mentioned cases.

From the analysis of over 300 registered oscillograms results that at asymmetric longitudinal rolling, with the increase of difference between the work diameters of the cylinders the unevenness of the deformation grows on the height of the deformation area and distorts its whole shape. The real values of the contact springs, also of the main tension $\sigma_1=p_x$ on those surfaces will be different.

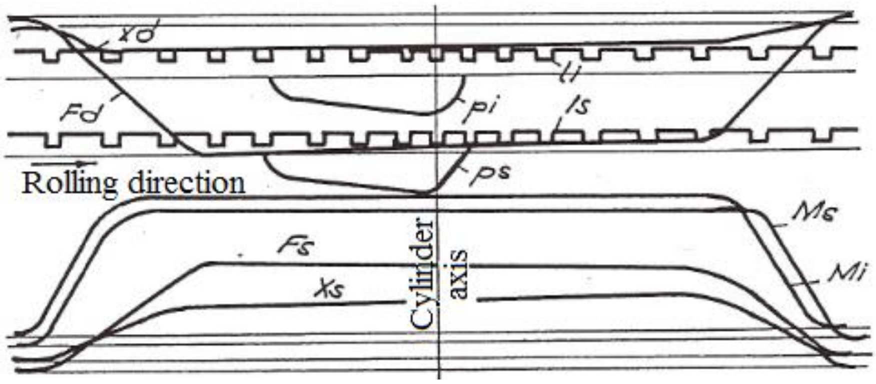



Fig. 6. Characteristic oscillogram for the symmetric process.

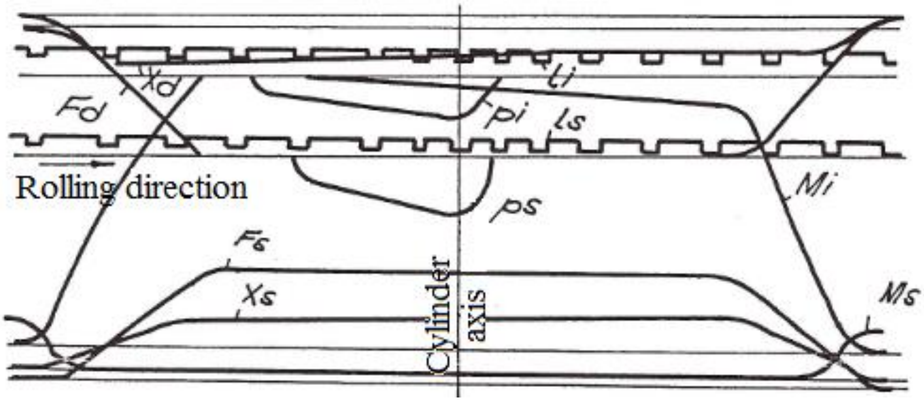



Fig. 7. Characteristic oscillogram for the asymmetric process.

On an experimental basis, the paper establishes the functional relations between the distribution *s* of pressure and real length of the contact spring for the case of asymmetric rolling, which clarifies certain contradictions regarding this process. Also it was found the lawfulness of the qualitative pass between the symmetric and asymmetric process depending on the rolling conditions' change, confirming the idea that the symmetric process is nothing else than a particular case of the asymmetric process, which usually takes place in the current practice.

An overview image of this lawfulness can be formed after examining the dependences from figures 8, 9 and 10. From the analysis it results that the pressures from each cylinder and also the real lengths of the contact springs, depending on the initial thickness $h_0$ and the relative $\varepsilon_h$ reduction have approximately the same meeting point.

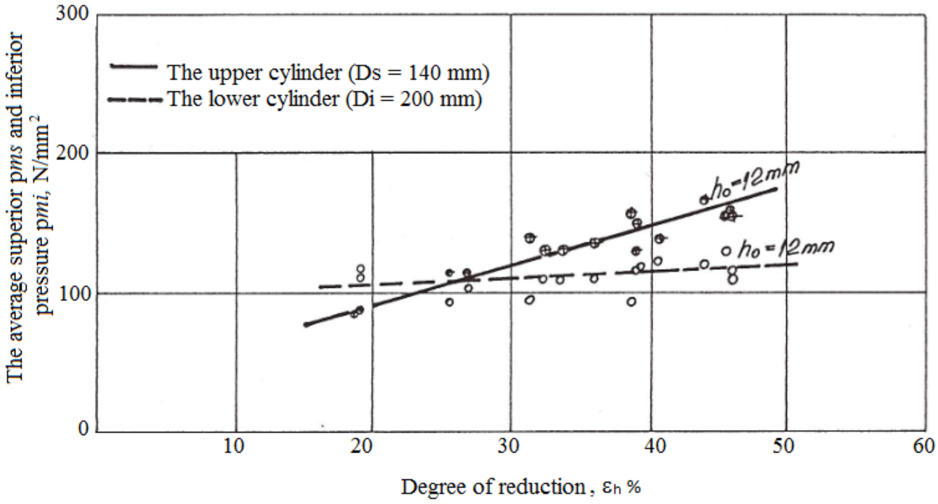



Fig. 8. The dependence of average superior and inferior pressure depending on reduction, at asymmetric rolling $\frac{D_s}{D_i} = \frac{140}{200}$

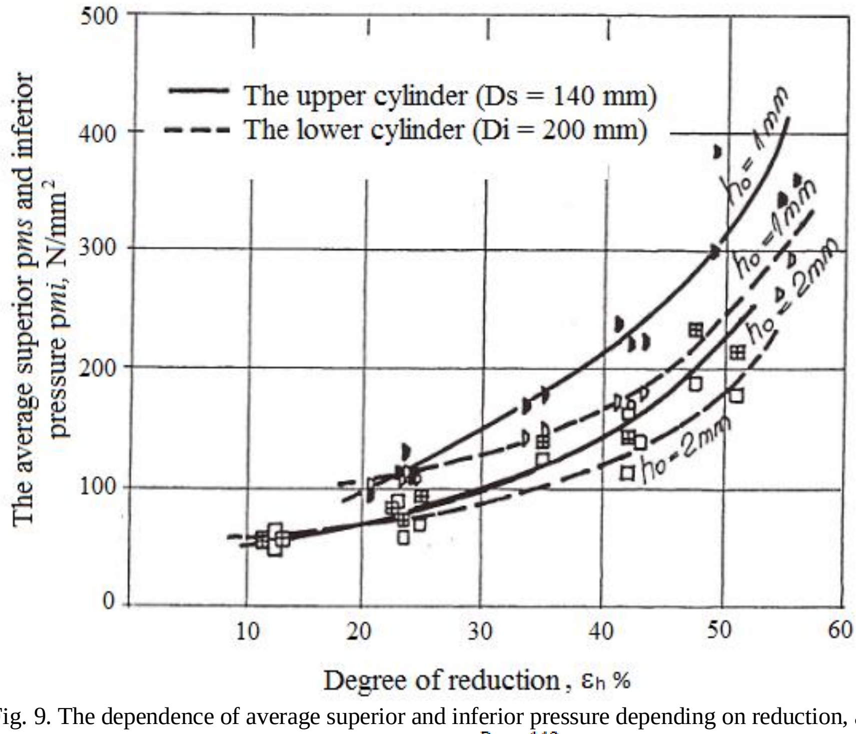



Fig. 9. The dependence of average superior and inferior pressure depending on reduction, at symmetric rolling $\frac{D_s}{D_i} = \frac{140}{200}$

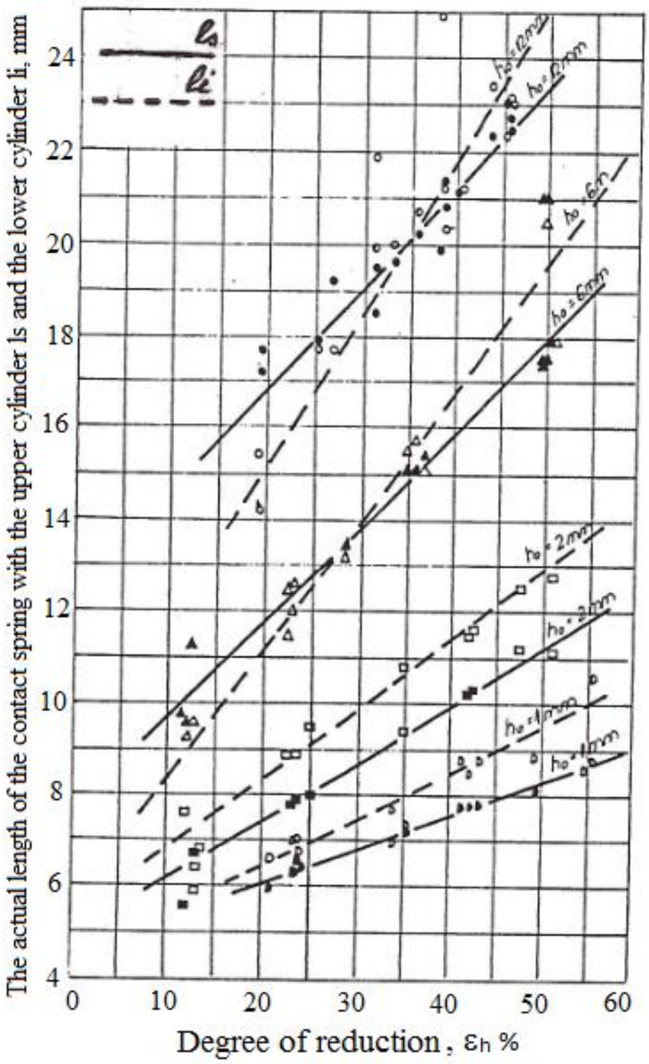



Fig. 10. The dependence of real length of the superior and inferior contact spring depending on reduction, at asymmetric rolling $\frac{D_s}{D_i} = \frac{140}{200}$.

Proceeding to the union of the meeting points and of the real length of the contact springs, for the cylinder with small and big diameter, we obtain the parable which passes through the zero point of the coordinate axis, presented in figure 11.

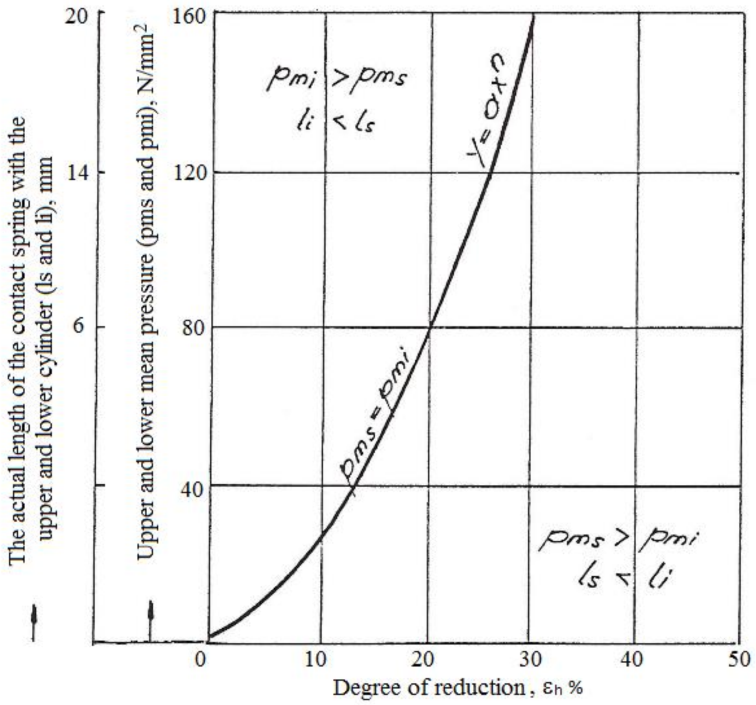



Fig.11. The dependence of average superior and inferior pressure and of real lengths of the contact spring depending on reduction, at asymmetric rolling $\frac{D_s}{D_i} = \frac{140}{200}$

This curve represents the geometric place of the points which represent the conditions of the symmetric rolling process between the cylinders with uneven diameters, when this equality is respected:

$$p_{ms} = p_{mi};$$
$$l_s = l_i$$

In this case, regardless of the existing difference between the work diameters, the ingot is straight.

The domain situated, in figure 11, above the curve corresponds to the big pressure and to the length of the small contact springs, from the cylinder with wide diameter, meaning:

$$p_{mi} > p_{ms};$$
$$l_i < l_s$$

In this case, the laminated at exiting the cylinders bends upwards, towards the cylinder with the smaller diameter.

The domain situated beneath this curve, corresponds to the big pressures and to the small contact lengths, from the cylinder with small diameter, meaning:

$$p_{ms} > p_{mi};$$

$$l_s < l_i$$

The bend of the laminate is produced, in this case, only downwards, meaning towards the cylinder with wider diameter.

As it is observed, as the difference between work diameters and cylinders grows and as the initial thickness of the metallic ingots is bigger, the domain is enlarged when:

$$p_{mi} > p_{ms}$$

The results of the research confirm the fact that the existing opinions, according to which in the asymmetric longitudinal rolling domain the unitary pressures from the cylinder with a smaller diameter are always bigger-they don't correspond to reality.

For the characterization of the rolling process, regarding the treated lawfulness, it was considered relevant to introduce a parameter to characterize the degree of asymmetry of the process, $K_a$, equal with the report:

$$K_a = \frac{l_s}{l_i} = \frac{p_{mi}}{p_{ms}}$$

In figure 12 it is given the variation of the proposed parameter, depending on the applied relative reduction. *As* its value differentiated more from the $K_a=1$, the bigger is the difference between the average pressures and the real lengths of the contact springs for the cylinders with unequal diameters and the degree of uneveness of deformation will be bigger.

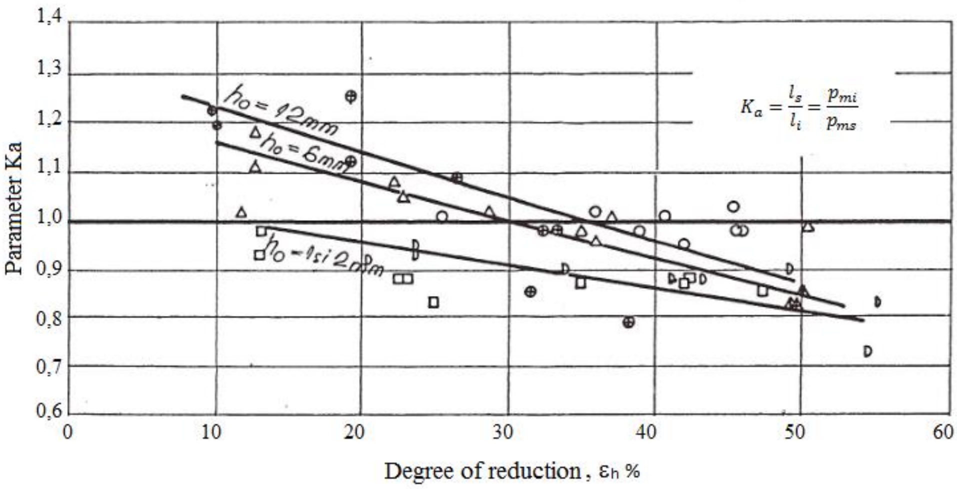



Fig. 12. The dependence of the *Ka* parameter, depending on the reduction at asymmetric rolling

$$\left(\frac{D_s}{D_i} = \frac{140}{200}\right)$$

## 4. Conclusions

-There were studied the variation lawfulnesses of the pressure and of the real length of the contact springs, depending on the relative reduction applied at the rolling between cylinders with unequal diameters, being established the dependence relation among these parameters;

-It was resulted that depending on the initial thickness of the laminate and relative reduction applied for the report given between the unequal work diameters of the cylinders, there is a critical value of the deformation degree, up to which the pressure is bigger on the part of the cylinder with wider diameter, and after this critical value the image changes inverse;

-The geometric place of the points that correspond to the critical reductions represent a parable which characterizes the parameters of the symmetric process at rolling between cylinders of unequal diameters;

-Also, it was proposed the parameter $K_a$ – "asymmetric coefficient of the deformation area"-, which represents the deformation's unevenness at rolling between cylinders with unequal diameters. With the increase of the value of this parameter, the pressure decreases considerably in comparison with the pressure obtained in the case of rolling between cylinders of equal diameters. The decrease of pressure in the case of rolling between cylinders with unequal diameters is due to the appearance of longitudinal high stretch tensions, which acts upon the metal from the deformation area.

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