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Theory and practice of asymmetrical longitudinal rolling (Part 2)

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Abstract. This paper analyses the deforming aspects of the metallic materials in the asymmetric longitudinal rolling process, often encountered in the industrial practice when the process is asymmetrical, firstly because of the inequalities between the cylinders' work diameters, which complicated the entire picture of the tension state in the deforming area.
To include all the asymmetric rolling processes from the industrial practice, the author creates and achieves a unique equipment that allows the simultaneous research of the force parameters, needed for the technological calculus.
From these parameters, in the practical situations the attention is aimed in this paper at the distribution of the rolling moments on the work cylinders, based on the measuring of the deformations at the universal coupling bars.
The irregular allocation of the moments, leads to overcharge and to the breaking of the bars, especially in the case of asymmetric longitudinal rolling.

Keywords: asymmetric longitudinal rolling, duo rolling, trio rolling on profiles, volumetric tension, work parameters, force sensors, work cylinders, universal coupling bars.

1. Introduction

The development of the theory and practice of the asymmetric longitudinal rolling process is based on the general theory of the processing of metallic materials through pressure and on the rolling theory, to which many have added their contribution, mainly scientists.
It must me mentioned that the development of the theory and practice of rolling, and especially of asymmetric longitudinal rolling, still needs a careful analysis of the various phenomena, with the aim to clarify the essence of this complicated process [1, 2].

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With all the results until now, some aspects remain unclear regarding the metal deformation, the rolling process' kinematics and dynamics. As a result, in many cases are accepted important practical solutions that don't have enough scientific base.

Also, a series of theoretical phenomena need experimental confirmation, especially in the case of rolling, when the work cylinders have unequal diameters.

The literature regarding the theory of rolling from our country and from abroad analyses aspects that characterize the symmetric rolling process, although this process is only a distraction from the normal work conditions from the industrial practice, because practically, there exists a certain difference between work diameters of the cylinders, and sometimes after construction the rolling mill is equipped with cylinders of unequal diameters [3-5].

The research from past years concerning the trio profile rolling mills which function as reversible duos, the rolling mills for cold rolling, the trio rolling mills for slate and others show that the deforming process of the metallic material between the cylinders happens asymmetric. Firstly because of the inequalities between the cylinders' work diameters, issue that complicated the entire picture of the tensions state from the deformation area [6-11].

The few papers that analyse this technological aspects highlight the difficulties of this process, from which the conclusion that can be drawn is that research is needed regarding the special conditions of the volume tension, the allocation of the pressures and the reductions from every cylinder, the moving of the axis of symmetry of the laminated bars, depending on this allocation, the action moments for both of the work cylinders, as well as the features concerning the case when the moment needed for deformation is applied to only one cylinder.

In this situation, the research is difficult and must clarify through experiments the mentioned phenomena, keeping into consideration the influence of the kinematics of the deforming area and the force parameters which develop in the asymmetric longitudinal rolling [12,13].

In this way, the final aim in the research, of the force parameters in rolling, is finding out the moments which develop during the deformation process [14-16]. For this two methods are known. One based on determining the action engine torque with the relation (1).

$$M_{mot} = 9.55 \cdot \frac{P}{n} \quad [KN \cdot m] \tag{1}$$

where *P* represents the power that the action engine takes in *KN*, and *n* is the engine's speed in *rpm.*

Knowing the value of the action engine's moment, it can be calculated the rolling moment because

$$M_{mot} = M_{lam} + M_{m \cdot g} + M_{fr} \mp M_{din} \quad [KN \cdot m] \tag{2}$$

where M_{lam} - represents the rolling moment;

$M_{m \cdot g}$ - the backlash moment;

M_{fr} - the consumed moment to defeat the supplementary friction forces, which appear during rolling;

M_{din}- the dynamic moment at acceleration (+) or breaking (-).
The backlash moment will be:

$$M_{m\cdot g} = 9.55 \cdot \frac{P_0}{n} \quad [KN \cdot m] \tag{3}$$

where P_0 represents the consumed power during the backlash, in *KN*. The friction moment is determined by the relation (4):

$$M_{fr} = \frac{F \cdot d\mu}{i \cdot \eta} + \left(\frac{1}{\eta} - 1\right) \cdot \frac{M_{lam}}{i} \quad [KN \cdot m] \tag{4}$$

where *F* represents the rolling force, in *KN*;

d - the diameter of the friction circle, in *m*;

μ- the friction coefficient in the cylinders' bearings;

i - the transmission report of the entire kinematic chain from the engine to the work box;

η - the efficiency of the engine-work box transmission.

The dynamic moment is calculated with the relation (5):

$$M_{din} = \frac{J_r}{9549{,}3} \cdot \frac{dn}{dt} \quad [KN \cdot m] \tag{5}$$

where J_r represents the inertia moment reduced to the motor shaft.

The method of establishing the rolling moment through action parameters is difficult because it needs measurements and calculations which bring errors.
This is why a second method is preferred, based on the measurements of the universal bars' deformations that transmit the moment of the rolling cylinders [17,18].

2. The created equipment and the carried out experiments

The difficulties brought by the experimental study of the mentioned phenomena, specific to the asymmetric rolling, also caused by the modification of the volumetric tension scheme of the metallic material which undergoes the processing, were analysed in the paper [19]. The present paper represents a continuation of it, reason for which the mill of ϕ170mm is used. It is designed and created by the author in the laboratory of "Theory and technology of the process for plastic modelling" from the Faculty of Engineering from Hunedoara, presented in figure 1.
For the aim for the research and to include all the asymmetric rolling processes from the industrial practice, the author designed and created in the place of regular cylinders of ϕ170mm, the equipment from figure 2, which allows the simultaneous research of the force parameters of the symmetric and asymmetric process.
In this way, with the special constructed cylinders from this equipment it was analysed in rolling conditions the variation of the normal unitary pressure on the contact surface between the metallic material and the inferior cylinder (*pi*), as well on the contact surface with the superior cylinder (*ps*).
The variation of the normal compression pressure (*pi* and *ps*) on the contact surfaces of the metallic material with the cylinders, depending on the relative

reduction applied, it was researched with the help of point captures introduced in the work cylinders' bodies after the author's design and creation, presented in figure 3.

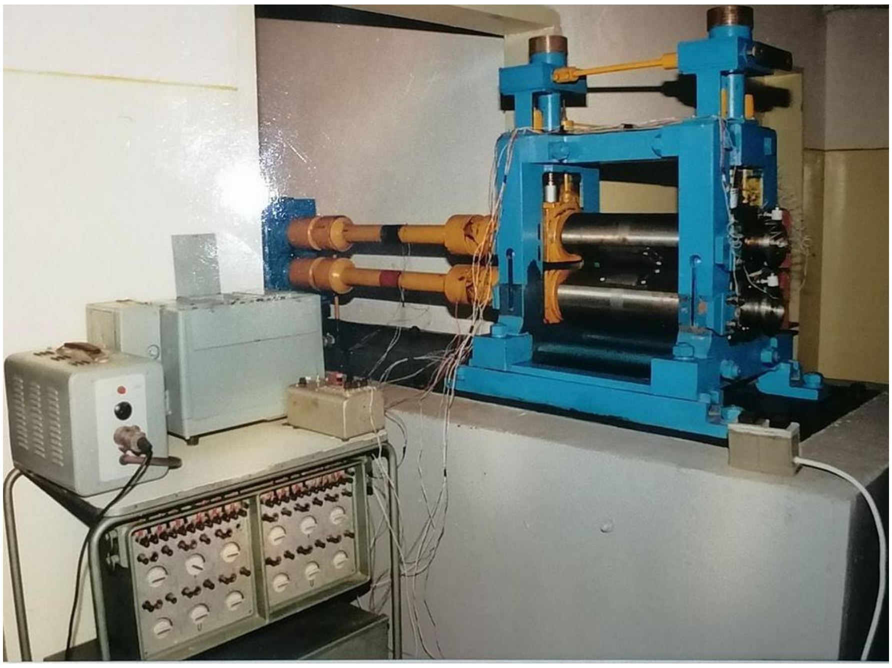

Fig. 1. Overview of the rolling mill with 170 mm diameter.

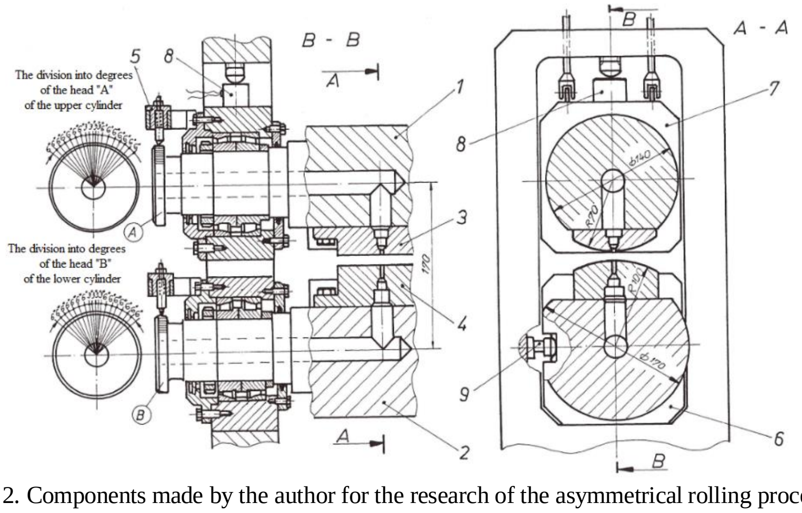

Fig. 2. Components made by the author for the research of the asymmetrical rolling process:
1 - superior cylinder Ds, 140mm diameter, with the head divided "A"; 2 - inferior cylinder Di, 170mm diameter, with the head divided "B"; 3 - R=70mm segment for the superior cylinder; 4 - R=100mm segment for the 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.

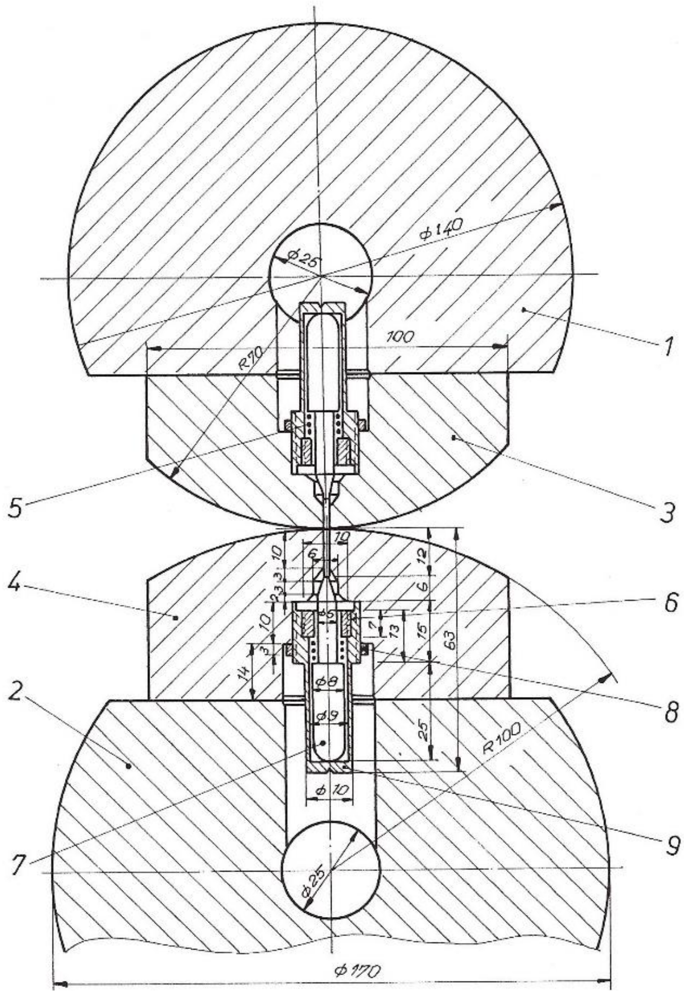

Fig.3. The installation of the captors for the contact pressure in the cylinders 'segments
1-superior cylinder; 2-inferior cylinder; 3-segment for the superior cylinder; 4- segment for the inferior cylinder; 5-spring; 6-cork; 7-steel pivot; 8-lock-nut; 9-the body of the pressure captor.

In the experimental facility, the sensitive elements are presented by the force captures and the universal coupling bars which transform adequately the pressure and the rolling moments in line and angle movements.

For practical situations it is important to determine not only the total value of the deforming moment, but also its distribution on cylinders, because uneven allocation leads to overcharge and to the breaking of the bars, especially in the case on asymmetric longitudinal rolling [20,21].

In the carried out researches, it was selected the measurement of the deformations with resistive electrotensiometric transducers applied on the universal bars in an angle of 45° opposed to the generators, in order to measure the main tensions.

The scheme of the facility for measuring the moments at the superior cylinder (M_s) and inferior (M_i), is given in figure 4, having as sensitive elements the coupling bars which transform correspondently the efforts in deformations. As first convertor are used load cells that transform the deformations into modification of the ohmic resistance.

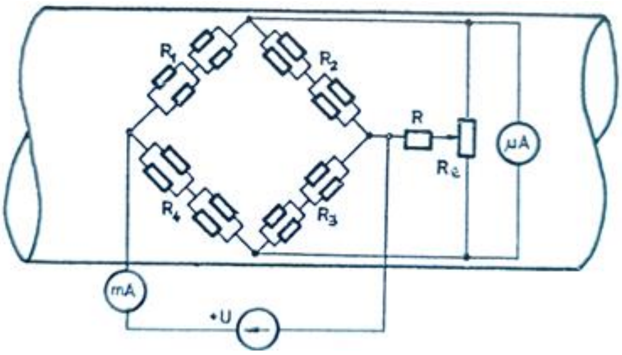

Fig. 4. Load cell bridge for measuring the rolling moments.

The second converting link is an electric bridge which transforms the changes of the ohmic resistance in electrical current.

The load cell bridge is balanced with the help of a variable resistance *Re*, which is chosen depending on the imbalance of the regular bridge, but being at least 10*Rb* (R_b - the arm's resistance).

The constant resistance *R* is introduced in the scheme to avoid the short circuit of the bridge's arms for balancing, as a result of this fact it may appear the obsolete state of the galvanometer - this also must be of at least 10Rb. The diagonals of the bridge are continuously powered from sources with adjusting possibilities in large limits of tension.

As indicators galvanometers of M001-1 type are used, with a sensitivity of 1400*mm/ma·m*.

For the symmetric process the dependence $M=f\ (\varepsilon_h)$ represents the summary moment (M_s+M_i), because in the ideal case when there exists total symmetry of all the conditions, the developed moments on the superior (M_s) and inferior (M_i) cylinder should be equal.

In figure 5 is presented a regular oscillogram from which it can be observed the distribution of the moments between the cylinders. The recorded oscillograms for different versions of symmetric rolling were written and presented in figure 6 under the form of the dependence $M_s+M_i = f(\varepsilon_h)$. However, even in real cases of the symmetric process, there exists a certain difference between moments at the inferior and superior cylinder. This points out the complex influence of the technological factors of rolling upon the distribution of moments between cylinders.

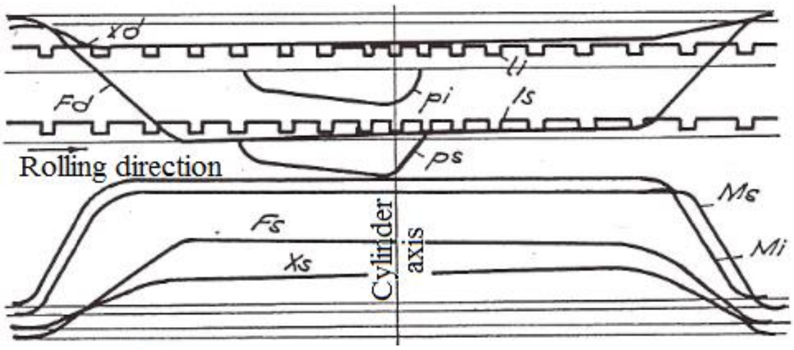

Fig. 5. Characteristic oscillogram for the symmetric process.

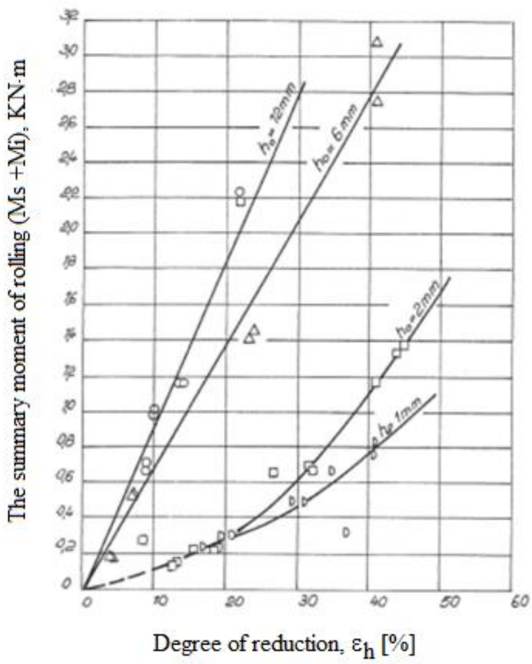

Fig.6. The dependence of the summary rolling moment $M_s+M_i = f(\varepsilon_h)$, in asymmetric rolling $\frac{Ds}{Di} = \frac{170}{170} mm$.

From the carried out researches it resulted that even an insignificant difference between the work diameters leads to an unequal distribution of the moments between the cylinders. The recorded oscillograms for different versions of the asymmetric rolling (fig.7), show that with the increase of the difference between the work diameters, the moments differ considerably. The processing of the obtained oscillograms for a difference of 20mm between the work diameters ($\frac{Ds}{Di} = \frac{160}{180} mm$) in a wide range of value of relative reduction εh which characterizes the distribution of the asymmetric rolling moments is given in figure 8.

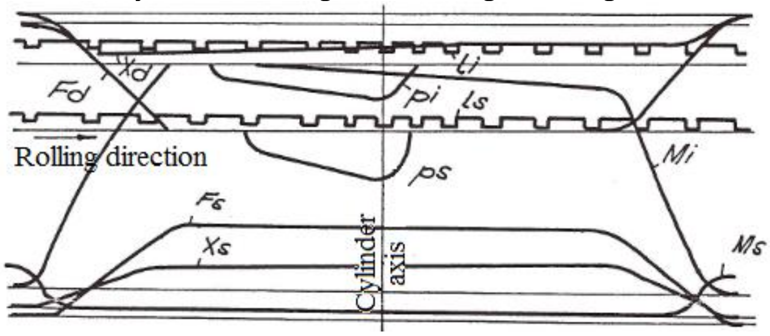

Fig. 7. Characteristic oscillogram for the asymmetric process.

From the curve's analysis it results that in the interval ε_h=0-30% the cylinder with the smaller diameter works as a break, because the developed moment has a negative value.

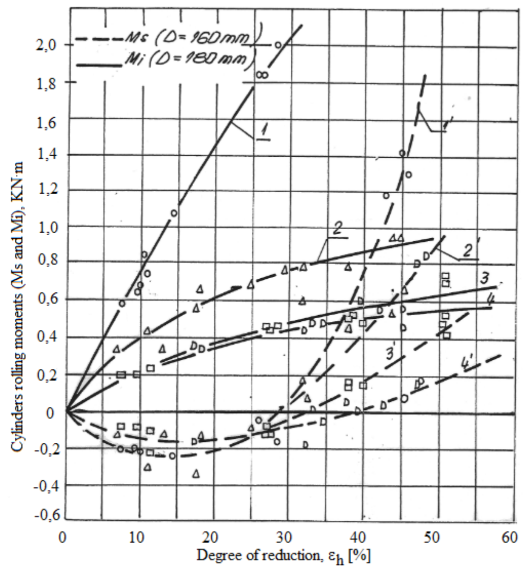

Fig. 8. The dependence of the rolling moment of the superior (Ms) and inferior (Mi) cylinder, reduction function at asymmetric rolling.

<u>Ms</u>	<u>Mi</u>
1'-h_o=12mm	1-h_o=12mm
2'-h_o=6mm	2-h_o=6mm
3'-h_o=2mm	3-h_o=2mm
4'-h_o=1mm	4-h_o=1mm

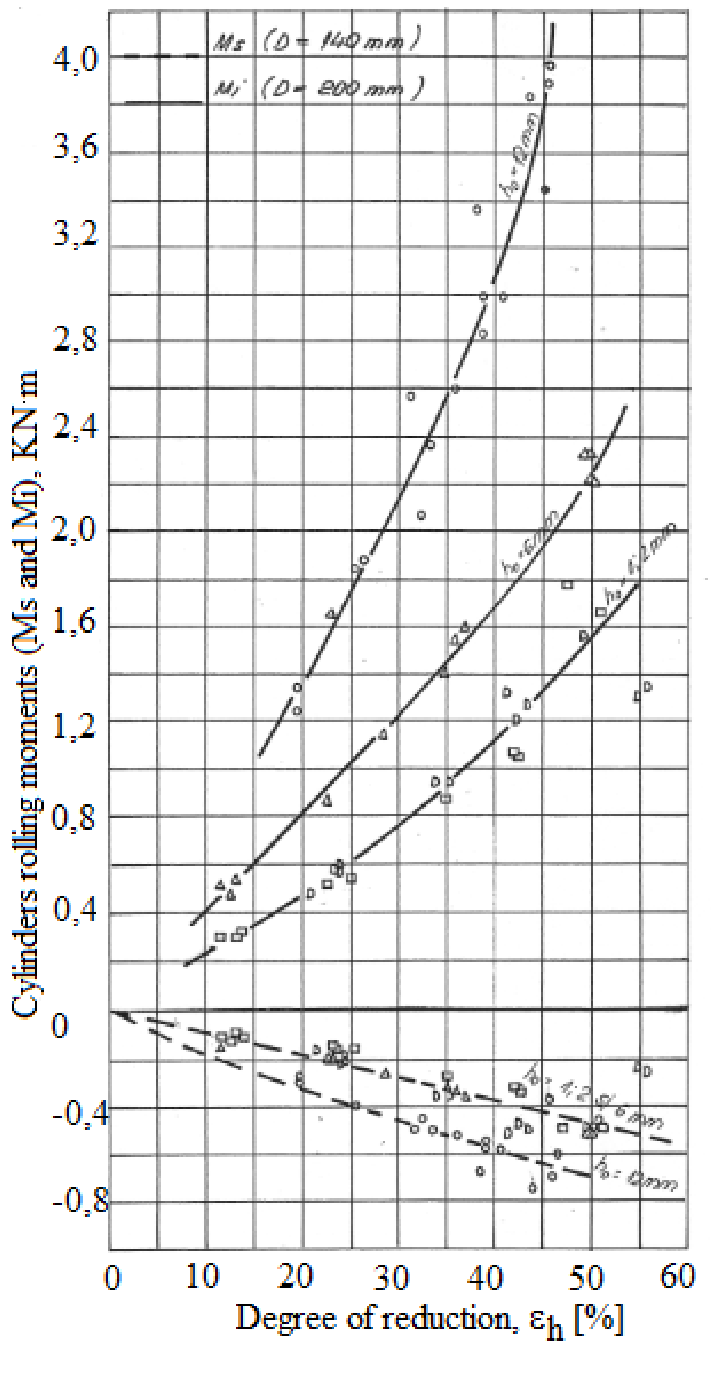

Fig. 9. The dependence of the rolling moments (Ms and Mi) at the asymmetric rolling, reduction function.

It is known the phenomenon that with the increasing of the degree of deformation and with the reducing of the thickness of the strip the influence of multilateral compression increases significantly [22-24].

This is why the moment at the cylinder with smaller diameter can obtain positive values and to increase considerably due to the moment from the cylinder with a bigger diameter, that is shown through a flat curve as compared to the zero axis. As it can be observed in figure 8 with the reduction of initial thickness h_0 of the laminated bars, the moments between the cylinders become equal in values of the reduction places towards the right in the area of bigger reductions.

The continuous increase of the difference between the work diameters ($\frac{Ds}{Di} = \frac{140}{200} mm$), leads to the enlargement of the reduction area in which the breaking action from the cylinder with the smaller diameter increases (fig. 9).

It is obvious that in this case it also has influence the elastic deformation of the cylinders, which increases the area of negative values in the cylinder with a smaller diameter.

3. Conclusions

It was created an experimental facility with its own construction subassembly for the research in technological similarity conditions of the force parameters for the symmetric and asymmetric longitudinal rolling process, consisting of:

- rolling cylinders with different work diameters;
- point captures inserted in the cylinders' bodies for the normal forces for compression with the metallic material in the deforming area;
- captures for the total and lateral rolling forces;
- load cells for the rolling moments.

The facility and the equipment created by the author will continue to be used for research purposes, to establish some correlations between the technological and force parameters of the rolling process, but also for exploitation purposes, for the determination of the degree of stress of the technologic machinery.

Concerning the moments of symmetric rolling, they are distributed equally among the cylinders.

For asymmetric rolling the increase of the difference between the work diameters leads to the appearance of some moments with negative value in the cylinder with a smaller diameter which applies a breaking action in the reduction area up to 30%.

In this way, the cylinder with a bigger diameters must develop, apart from the necessary rolling moment, an extra moment to defeat de breaking action made by the small cylinder.

These situations can be dangerous for the industrial practice and must be avoided.

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