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Research on the rolling moment in the symmetrical and asymmetrical rolling process

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Abstract. Research distribution the rolling moments symmetrical and asymmetrical report presents great importance both in theory and to introduce clarifications to the calculation of rolling resistance line assemblies. Clarifying individuals of metallic material deformation between the rolls single cylinder diameters act of any difference of work and analysis of advance and delay phenomena. Torque drive value for each of the rolling cylinders was done by reducing the thickness of the laminate samples, an experimental facility located in the laboratory of plastic deformation of the Faculty of Engineering Hunedoara. The analysis of research results show that in terms of power consumption for deformation and safety equipment in operation is rational for mills which require such a difference between the work rolls to execute about one cylinder operated.

1. Introduction

The methods for measuring the rolling forces are classified according to the type of equipment and the possibility to determine them for a particular type of rolling mill, as follows [1]:

- direct measurement of the forces occurring during the rolling process, using resistive transducers placed in the point in which these forces are acting:
- measurement of deformations or strains that develop in a certain part of the working stand, with subsequent recalculation of these deformations based on the values of the rolling forces.

In addition to the forces, the rolling moments represent one of the most important parameters, whose knowledge is necessary for the design and operation of the rolling lines. The electric motor torque, developed during the metal material deformation, determines the loading level of the machine, as well as the resistance of some parts and assemblies.

The assessment of motor workload by taking into account the power consumption for deformation is not complete, because this parameter does not characterise the electrical and mechanical capacity of the equipment.

To solve the usability and to increase the level of exploitation and driving of the equipment, the next three parameters must be analysed [1]:

1. *the rolling forces* – which determine the strains in the major subassemblies of the working stand (rolls, frame, bearings);
2. *the moment developed during the rolling process* - which determines the motor strain and the resistance of its parts, so that the maximum torque is limited by the motor capacity and the resistance of its parts;

3. *the quadratic mean of the motor current* – which determines the level of motor warming.

2. Experimental research. Equipment and procedures

The load level of the motor, according to the moment value, is determined by comparing the value of the reduced moment acting at the motor shaft ($M_{mot.}$) with the value of the rated moment $M_{nom.}$.

The maximum moment for reciprocating motors equals to (2.5 - 3.0) M_{nom}, and for the non-reciprocating motors, (1.5 - 2.0) M_{nom}.

The ultimate goal being the determination of the moments that are developing during the deformation process, we used two methods for analysis, i.e. [1], [2]:

1. *Determination of the electric motor torque;*
2. *Measurement of the deformations of universal bars that convey the moment to the rolls.*

2.1. Determination of the electric motor torque

Knowing the value of the motor moment, we can calculate the rolling moment, because:

$$M_{mot.} = M_{lam.} + M_{mg.} + M_{fr.} \pm M_{din.} \quad [kN \cdot m] \tag{1}$$

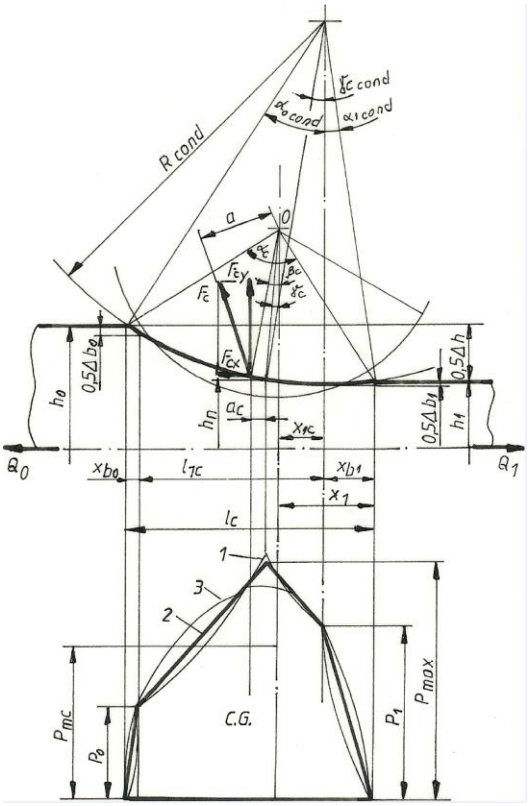

Figure 1. Diagram used to determine the neutral angle, material movement and rolling moment

To calculate the rolling moment, we used the balance equation, where the total moment at the roll barrel M_c, required for carrying out the plastic deformation at symmetric rolling (Figure 1), is determined by the tensile forces Q_0 and Q_1:

$$M_c = 2F_c \cdot a = 2F_{cy} + 2F_{cx}R \tag{2}$$

or if:

$$F_{cy} \cong F_c \tag{3}$$

$$M_c = 2F_c \cdot \psi_c \cdot l_c + R(Q_0 + Q_1) \tag{4}$$

Where:

- F_c, F_{cx}, F_{cy}, - represent the rolling force, its horizontal and vertical component;
- l_c - the contact arc length, calculated by considering the elongation and elastic deformations of the roll barrels;
- R – radius of the non-deformed rolls;
- Q_0, Q_1 – total anterior and posterior elongation of the strap;
- a, a_c – arms of the forces F_c, F_{cy};
- Ψ_c – coefficient that characterises the position of the resultant force application point on the contact arc, which is a complex function that depends on:
  - level and variation character of the normal and tangential strains;
  - reduction and hardening of the strap material;
  - coefficient of friction;
  - neutral angle and material elongation;
  - dimensions and elastic properties of the roll barrel material.

This coefficient is theoretically determined by considering the elastic deformation of the rolls and the strap, the uneven distribution of the contact normal strains and elongations, using the equation:

$$\Psi_c = \frac{M_{stn}}{p_{mc} \cdot l_c} \tag{5}$$

where:
- M_{stn} – static moment of the contact normal stress diagram in relation to the rotation centre of the rolls;
- p_{mc} – the contact average normal stress, calculated by considering the elastic deformations of the rolls (i.e. roll barrel mounted on the rolls);

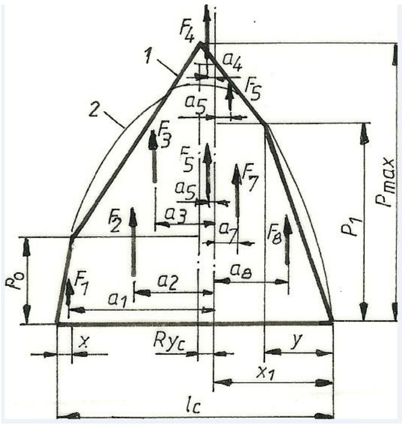

Figure 2. Diagram used to determine the Ψ_c coefficient

We determine this coefficient by two types of curves [3]:

a. *The normal contact stress diagram* is described by a continuous function consisting of linear segments (*curve 1,* Figure 2); assuming that the diagram area is divided into 8 simple geometric shapes, we use the Varignon's theorem:

$$M_{stn} = \sum_{i=1}^{8} M_i \tag{6}$$

The result of jointly solving the equation is:

$$\Psi_c = \frac{1}{6}\left[\frac{p_0}{p_{mc}}\left(1-\frac{\gamma_c}{\alpha_c}-\frac{x_1}{l_c}\right)\left(1-\frac{x_{1b}}{l_c}\right)-\frac{p_1}{p_{mc}}\left(\frac{\gamma_c}{\alpha_c}+\frac{x_1}{l_c}\right)\left(1-\frac{x_{0b}}{l_c}\right)+2\left(1+\frac{\gamma_c}{\alpha_c}+\frac{x_{1b}}{l_c}-2\frac{x_1}{l_c}-\frac{x_{0b}}{l_c}\right)\right] \tag{7}$$

b. *If the normal stress diagram is described by the curve 2* (Figure 2), then the static moment is determined by:

$$M_{stn} = \int_{R\gamma_c}^{l_c - x_1} p_{max}\left[1-\left(\frac{x-R\gamma_c}{l_c - x_1 - R\gamma_c}\right)^2\right]xdx + \int_{l_c}^{R\gamma_c} p_{max}\left[1-\left(\frac{x-R\gamma_c}{x_1 + R\gamma_c}\right)^2\right]xdx \tag{8}$$

Considering that $p_{max} = 1.5p_{m.c}$, by jointly solving the equation we obtain:

$$\Psi_c = 0{,}125\left(3+2\frac{\gamma_c}{\alpha_c}-6\frac{x_1}{l_c}\right) \tag{9}$$

These relationships are mostly used to theoretically determine the Ψ_c coefficient at rolling. The research regarding the accuracy of determination showed that, at cold rolling with great reductions ($\varepsilon > 20\%$), the values obtained for Ψ_c are close, but these values have large errors in case of small reductions. Therefore, the relationship x is the preferred one, because it provides a much higher accuracy thanks to the use of continuous linear segments function.

2.1. Measurement of the deformations of universal bars that convey the moment to the rolls

The second method based on the measurement of universal bars deformation, bars that convey the moment of the rolls, is based on the use of electrotensometric resistive transducers for the purpose of measuring the main strains [4].

The bearing holders of the inferior roller were modified for recording the lateral efforts so that the respective captors could be installed incorporated perpendicularity on the bearing's axis.

On the surface of captors were stuck tensometric stamps bound in deck, stamps that modify their dimension under the action of the effort to be measured.

These dimensional modifications of tensiometer stamps are generating variations of their electric resistance, that are proportional to the deformation efforts and the measuring of the forces is limited to the measuring of these resistance variations. The transducers are resistive, of grid type, have an electrical resistance of 203.2 Ω and the base width of 16 mm.

They were sticked using BF2-type glue, and their connection was made in bridge to enable us to apply the parallel resistance method, Figure 3, [1].

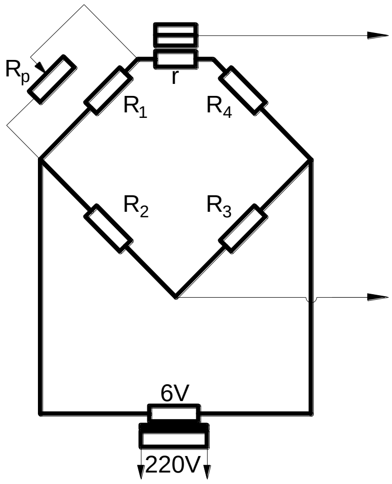

Figure 3. Tensometric bridge for measurements

Through the additional resistance *r*, connected in series with one of the inactive arms, the following condition is met:

$$(R_1 + r) \cdot R_3 > R_2 \cdot R_4 \qquad (10)$$

so that the bridge is heavily unbalanced.

For balancing the tensometric bridge, we connect in parallel with R_1+r the resistance R=100KΩ, which in turn it is connected in series with the potentiometer R_p = 100 kΩ:

$$R_{ech1} = \frac{R_1(R + R_p)}{R + R_p + R_1} \qquad (11)$$

This value is higher than R_1, so the bridge is unbalanced in this direction. For the extreme situation (potentiometer shorted):

$$R_{ech2} = \frac{R_1 \cdot R}{R + R_1} < R_1$$

This value is higher than R_1, so the bridge is unbalanced in this direction. For the extreme situation (potentiometer shorted):

$$R_{ech2} = \frac{R_1 \cdot R}{R + R_1} < R_1 \qquad (12)$$

the bridge being unbalanced in the opposite direction.

In this situation, the equilibrium is found between R and R+R_p. Change in resistance in these extreme situations:

$$\Delta R = R_{ech1} - R_{ech2} = \frac{R_1(R + R_p)}{R + R_p + R_1} - \frac{R_1 \cdot R}{R + R_1} \qquad (13)$$

Assuming that the rolling forces are F=1000 kN, in the active arms occur variations in resistance transducers ΔR=2.44 kΩ. Imposing the equilibrium condition to the bridge, the value of the resistance R+R_p connected in parallel, can be determined at equilibrium, resulting the value of 114 kΩ, which was confirmed during the balancing process.

The research for this theme purpose have been made on a 170 mm reversing two-high rolling mill, created and installed in the no conventional technologies and plastic deformation laboratory of the Engineering Faculty from Hunedoara [3].

An experimental installation formed of: special construction rollers, bearings, punctiform captors for lamination pressure, lamination forces captors and lateral pressure captors it was created for research in condition of technological similitude symmetrical and asymmetrical process.

In Figure 4 it is presented in overview the mentioned installation, with the way force captors are assembled in order to determine the lateral efforts in the longitudinal asymmetrical lamination but also to show the author's contribution regarding method of experimentation [1].

The symmetric and asymmetric rolling process was carried out by equipping the work rolls with segments adjusted with various radii, which have led to the following ratios between the diameters of the upper D_s and lower D_i rolls: $\frac{D_s}{D_i} = \frac{170}{170}; \frac{160}{180}; \frac{150}{190}; \frac{140}{200}$ mm

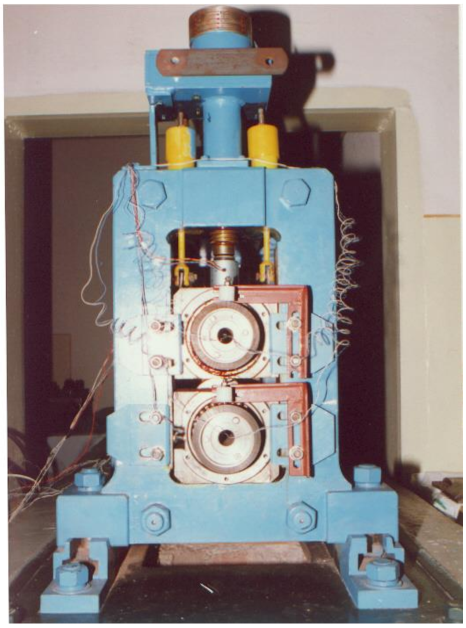

Figure 4. Montages punctifom captors for recording the pressure of contact

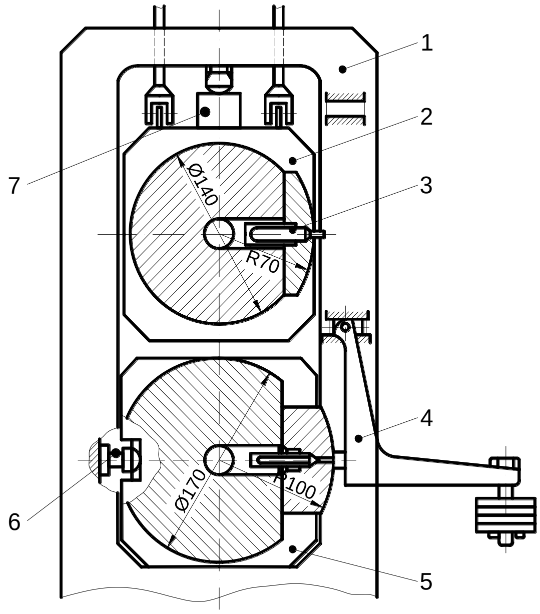

Figure 5. Diagram for measuring the deformations

1- the rolling mill stand; 2 - higher bearing; 3 - punctiform sensor; 4 - calibration device; 5 - lower bearing; 6 - sensor for the measurement of lateral forces; 7- sensor for the measurement of the rolling forces.

Usually, the tensiometer stamps of a forces captor are bound in deck. The deck has on a diagonal it is measured a electrical signal – proportional of the applied effort – and for recording of the measured values this signal is recorded by an oscillograph. The oscillograph is a the type N-700, having 14 channels, the impulses on recorded are a scale of 120 mm width, heaving 4 cm/s moving speed of the paper band.

3. Results and conclusions

When rolling thick samples (h_0 = 6; 12 mm), with the increasing degree of reduction ε, the resultant point of application is moving away from the plane through the centres of the rolls.

When rolling thin samples (h_0 = 1; 2 mm), with the increasing degree of reduction ε, the resultant point of application is approaching that plane.

These phenomena can be explained as follows:

- when rolling thick samples with low degree of deformation, the pressure along the deformation zone is distributed almost uniformly;
- when rolling thin samples, as a result of increasing degree of deformation, the influence of the stress and strain hardening state is intensified, leading to the movement of the resultant force point of application towards the exit plane of the metal material from the rolls.

For the symmetrical process, when rolling aluminium, this dependence is given as total moment M = f(ϵ), because in the ideal case of symmetry of all deformation conditions, the moments developed by the upper and lower rolls should have the same value. In practical cases, there is a difference between the moments of the upper and lower rolls, which is explained by a complicated dependence of the moment distribution on many factors of the deformation process.

Thus, experiments were carried out with the upper roll not driven, measuring the moment at the lower roll which characterises in this case the total moment required for rolling. A comparative assessment of the results obtained at symmetric rolling with both rolls driven and the case when the upper roll is not driven is shown in Figure 6.

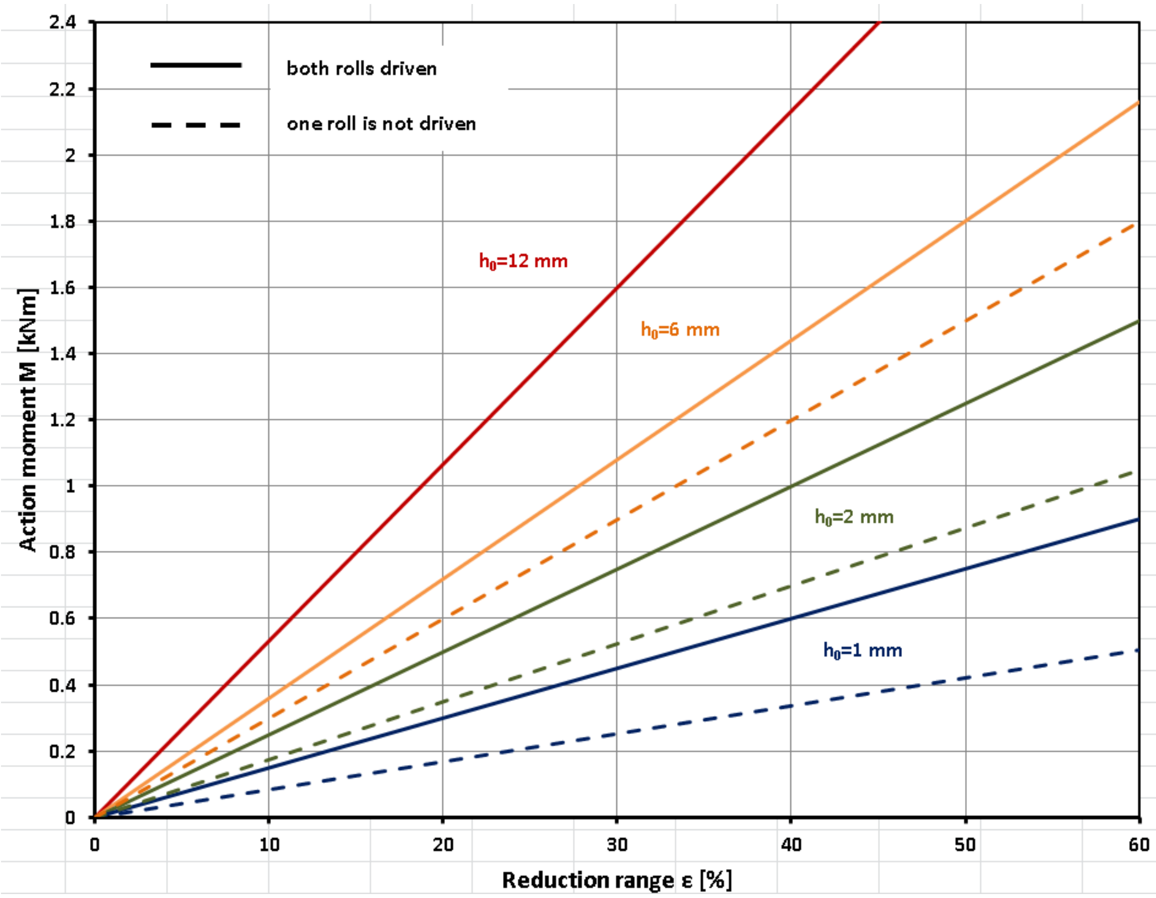

Figure 6. Moments versus reduction at the symmetric rolling ($\frac{D_s}{D_i} = \frac{170}{170}$ mm) of Al samples, with both rolls driven and when one roll is not driven

From the comparative analysis of the last two dependences, the same behaviour is resulting in terms of the distribution of moments, without any influence of the metal material nature, but in both cases when the upper roll is not driven, the moment required for deformation is much lower than when both rolls are driven.

For example, for a reduction ϵ = 40% and h_0 = 1 mm, the difference is 23%, and for the same reduction and h_0 = 6 mm, the difference is 14%.

This difference indicated above is taken as a percentage in relation to the moment consumed for the deformation of the same volume of metal material when both rolls are driven, with the result that the deformation of the metal material by symmetric rolling when one of the rolls is not driven is much more economical, because the moment required for deformation is lower.

For the asymmetric process, the moments are presented as separate functions for the upper and lower rolls, depending on reduction: $M_s = f(\epsilon)$ and $M_i = f(\epsilon)$. Figure 7 shows the dependences obtained by processing the data from asymmetric rolling of the aluminium samples, when the rolls ratio is $\frac{D_s}{D_i} = \frac{160}{180}$ mm.

This analysis shows that, within the reduction range 0 – 35%, the smaller diameter roll acts as a brake, because the developed moment has a negative value.

For samples of different thicknesses, at different reductions, the moments between rolls become equal and, with decreasing the thickness of samples, the intersection point between the moments of upper roll (whose diameter is smaller) and lower roll (whose diameter is greater) moves to the right, where the reductions are larger.

By increasing the difference between the working diameters of the rolls$\left(\frac{D_s}{D_i} = \frac{140}{200}\ \mathrm{mm}\right)$, we note that the moment at the smaller-diameter roll is almost always zero at small reductions, and if we remove the friction moment value, it becomes negative.

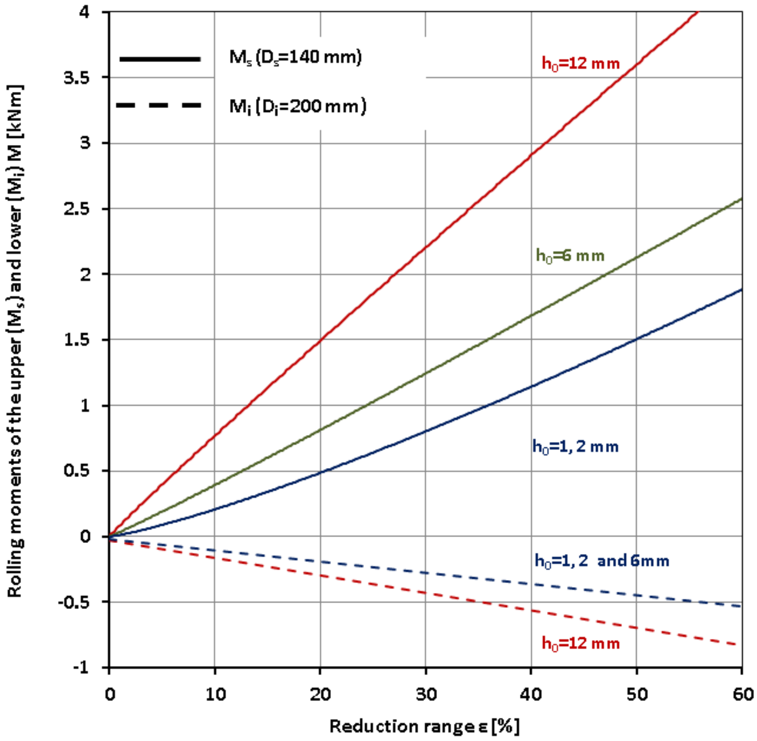

Figure 7. Rolling moments of the upper (M_s) and lower (M_i) driven rolls versus the reduction, at asymmetric rolling $\left(\frac{D_s}{D_i} = \frac{160}{180}\ \mathrm{mm}\right)$

When both rolls used for rolling are driven, for $\frac{D_s}{D_i} = \frac{140}{200}$ mm we noted the followings:

- the curves of the moments corresponding to the two rolls do not intersect;
- by increasing the reduction grade within this range, the roll with a smaller diameter opposes a growing resistance against the movement of the larger-diameter roll;
- the moment developed by the larger-diameter roll increases considerably because, in addition to the moment required for the metallic material deformation, it must overcome the braking action of the smaller-diameter roll – with the result that the practical use of two driven rolls, with greater difference between the working diameters, is not rational;

Figure 8 shows the comparison of moments for $\frac{D_s}{D_i} = \frac{140}{200}$ mm, in two cases:

(1) both rolls driven, and (2) upper roll not driven, obtaining the following results:

- the required moment for deformation when the smaller-diameter roll is not driven is much more reduced, as follows: if $\epsilon = 40\%$, the difference is 29.4% for $h_0 = 1$ mm and 25% for $h_0 = 6$ mm. This is related to the moment required for the deformation of the same volume of metallic material when both rolls are driven;

- either from the point of view of energy consumption for deformation or operational safety, it is rational to use rolling equipment with such difference between the working diameters of the rolls only when a single roll is driven.

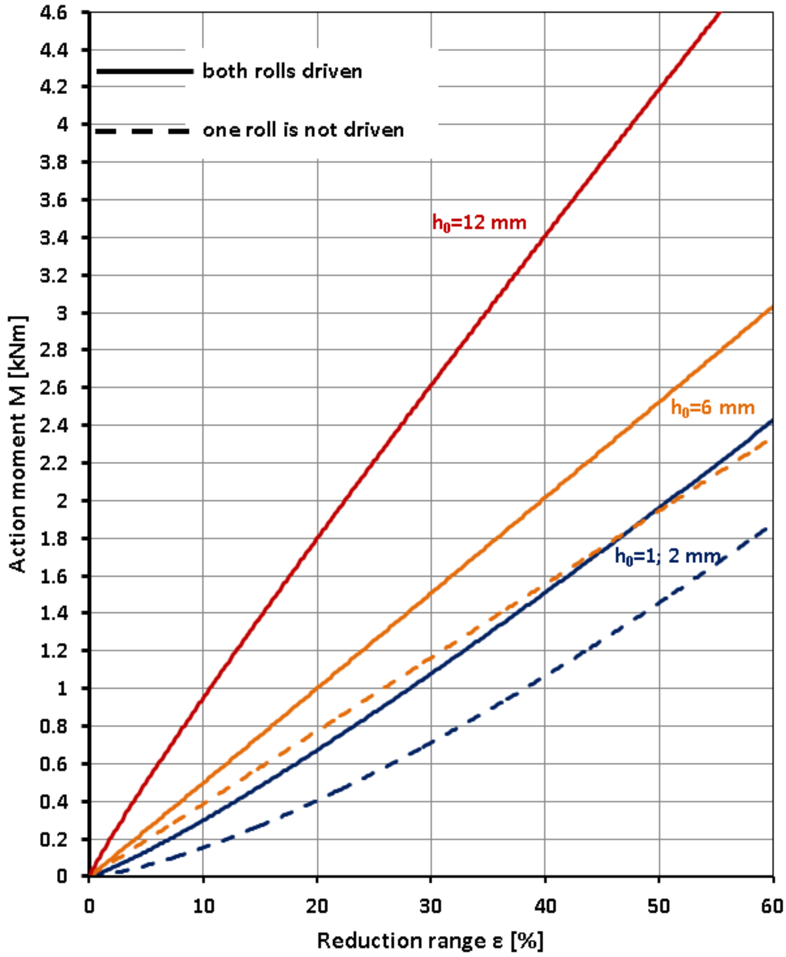

Figure 8. Driven moments M_s and M_i versus reduction, at asymmetric rolling $\left(\frac{D_S}{D_i} = \frac{140}{200}\ \text{mm}\right)$

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