THEORETICAL CONSIDERATIONS ABOUT ENERGETICAL PARAMETERS OF SHEET METAL BENDING ON MACHINES WITH ROLLERS.

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Abstract: *The paper presents a theoretical stress and deformation state analysis in plastically bending with cold-hardening sheet metal. With the relations established it have determined the inner deformation forces, moment with that it has established calculus relations of torque and drive roller power of bending on machines with rollers.*

Keywords: *stress, deformation, bending, moment, power, roller.*

1. Introduction.

The working by bending of work-pieces creates inner of this in deformed zone stresses in tangential and radial directions [1].

The metal strata placed to curving center are pressed in tangential directions, becoming shorter and in especially cases are stretching in transversal direction.

The metal strata placed to external piece are stretching in tangential direction and in especially cases are pressed in transversal direction, making the piece narrowing [2, 3].

Between the stretching and pressing strata is founded the neutral stratus M-N (fig.1).

The neutral status with the radius ρ_n is founding displaced to the curving center before the weight center, what is placed on the median arc with radius ρ_m. The radius value where the tangential direction stresses are null and is not produced the deformation in tangential direction is determined by the following relation [4]:

$$\rho_n = \sqrt{R\,r} \tag{1}$$

or

$$\rho_n = r + x\,s \tag{2}$$

where can be determined with the relation:

$$x = \sqrt{\left(\frac{r}{s}\right)^2 + \frac{r}{s}} - \frac{r}{s} \tag{3}$$

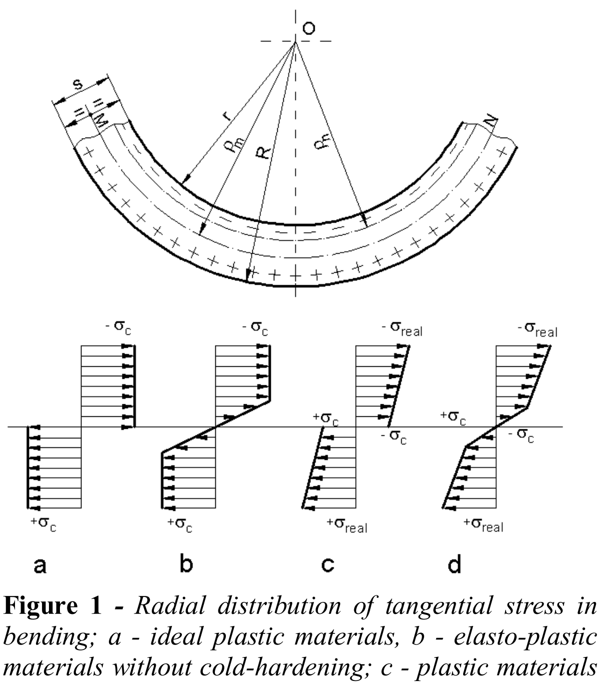

Figure 1 - *Radial distribution of tangential stress in bending; a - ideal plastic materials, b - elasto-plastic materials without cold-hardening; c - plastic materials with cold-hardening; d - elasto-plastic materials with cold-hardening.*

Practically, it is considered that the neutral stratus position coincides with the median stratus with ρ_n radius when the relative radius bending has the value $\frac{\rho_m}{s}>5$ [1]

The narrow work-pieces bending ($b<3s$) is realizing with the accented deformation of transversal section, while the broad work-pieces is take place with a very little breadth deformation, because the great work piece resistance deformation opposed (fig.2.)[3].

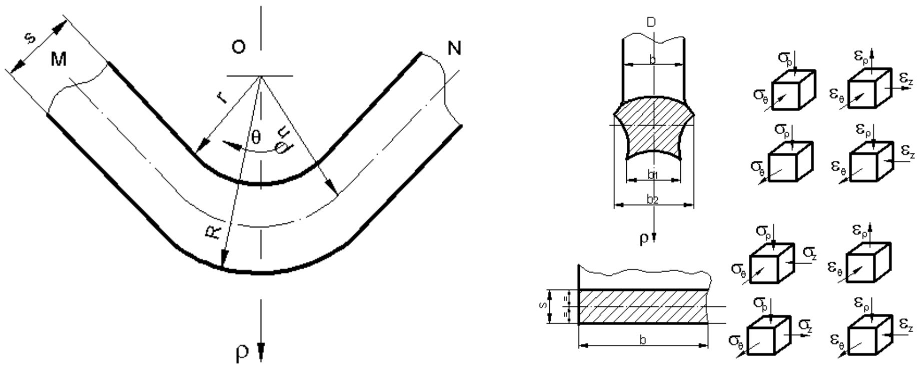

Figure 2 - *Mechanical scheme for processing*
a - sheets bending with b < 3s
b - sheets bending with b > 3s

2. Stresses in tangential direction and inner moment bending calculus

The real behavior sheet metal in bending is that which of elastic-plastic with cold-hardening (fig.1.d)

In bending energetically parameters calculus with $\frac{\rho_m}{s}\geq 200$ and even less, the influence exercised by elastic deformation of material near neutral stratus very little, thus can be considered that the plastic deformation zone are spreading until neutral stratus, corresponding by scheme at figure 1.*d*.

Barely, can be considered in neutral stratus is reached the material flowing stress, σ_c

The radial stresses by pressing σ_ρ not produce resistant moment in bending process.

This requests the work-piece material at radial direction compression in bending zone with maximum 10% of material flowing stress σ_c value.

Because the sheet metal bending on machines with rollers is making with relative radius $\frac{r}{s}$ much more than 5 value, it can consider that the neutral stratus coincides with the medial stratus ($\rho_n=\rho_m$).

If it is approximated the real cold hardening characteristic of material at requirement in tangential direction with a linear curve, correspondently figure 3, the real tangential stress $\sigma_{\theta real}$ can be determinate by relation:

$$\sigma_{\theta real}=\sigma_c+E_1\ \varepsilon_y \tag{4}$$

Or, if we consider the geometry of bending

$$\sigma_{\theta real}=\sigma_c+E_1\frac{y}{\rho_m} \tag{5}$$

where:

σ_c is flowing stress of material;

y- current stratus distance to neutral stratus;

ρ_m - bending radius of medial stratus;

E_1- plasticity modulus what is determined with real linear cold hardening approximated characteristic, and have the value [4]:

$$E_1=\frac{2{,}1\,\sigma_c}{\varepsilon_g} \tag{6}$$

where ε_g is the specifically elongation at narrowing of a section.

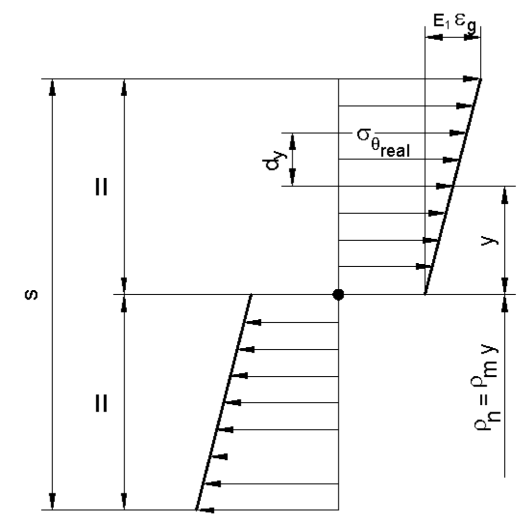

Figure 3 - *Plastic bending stress distribution with cold-hardening.*

If the bended work-piece has the section b x s and is bending on median stratus with ρ_m radius, the inner forces moment M, according in figure 3, can be definite by relation:

$$M = 2\sigma_c \int_0^{\frac{s}{2}} by\, dy + 2\frac{E_1}{\rho_m}\int_0^{\frac{s}{2}} by^2\, dy \qquad (7)$$

In relation (7), the double of first integral represent the transversal section statically moment S, and the double of second integral is the transversal section inertial moment I.

Thus, relation (7) can be written:

$$M = \sigma_c S + \frac{E_1}{\rho_m} I \qquad (8)$$

If it is multiplied and divided with the bended work-piece section resistance modulus W, is obtained:

$$M = \left(\frac{S}{W} + \frac{E_1 s}{2\sigma_c \rho_m}\right) W \sigma_c \qquad (9)$$

If it take account that $\frac{S}{W}$ from relation (9) is a section characteristic and is noted K_1, and $\frac{E_1}{2\sigma_c}$ is a physics and material characteristic and is noted K_2, the relation (9) become:

$$M = \left(K_1 + \frac{K_2 s}{\rho_m}\right) W \sigma_c \qquad (10)$$

The coefficient K_1, because depend only by geometrical transversal section form can be named the profile coefficient.

The coefficient K_2 express cold hardening intensity of plastic banded material, can be named
strengthening coefficient.

3. Torque and power bending on machines with rollers calculus.

A plan work-piece bended on a roller properly figure *4*, start from section *1-1* where the curvier radius of median stratus is null, and is finalized in section *2-2*, where the medial stratus curvier radius is ρ_m.

To calculate the torque M_t what to be applied on roller, it is considered a size L_s what must to bend on roller. The mechanical work of the inner forces must to be equal with the mechanical work of external forces.

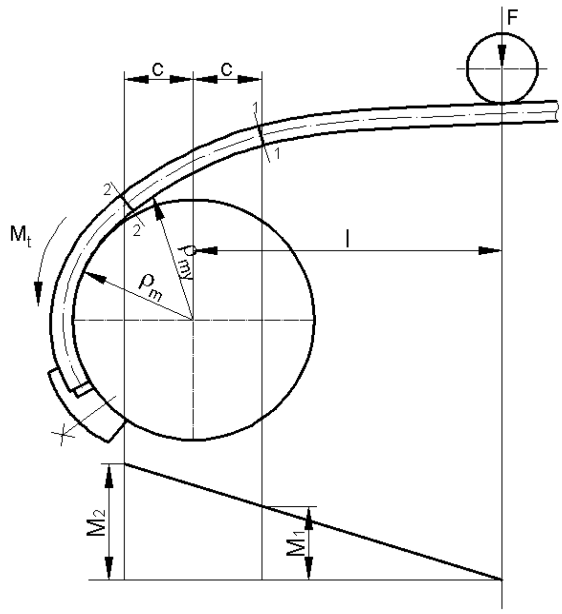

Figure 4. - *Bending scheme on bending roll*

Taking account figure 5, the mechanical work of inner forces L_i, for plastic bending of the work-piece size L_s can be determined by relation:

$$L_i = L_s \int_0^{\frac{1}{\rho_m}} M_y \, d\left(\frac{1}{\rho_{my}}\right) \qquad (11)$$

The inner moment value creates the curvier $\frac{1}{\rho_{my}}$ in a current section between section *1-1* and *2-2*, can be calculate wit relation (10), what become:

$$M_y = \left(K_1 + \frac{K_2 s}{\rho_{my}}\right) W \sigma_c \tag{12}$$

Replacing the M_y relation in relation (11) and making calculus, it is obtained:

$$L_i = \left(K_1 + \frac{K_2}{2}\frac{s}{\rho_m}\right)\frac{L_s}{\rho_m} W \sigma_c \tag{13}$$

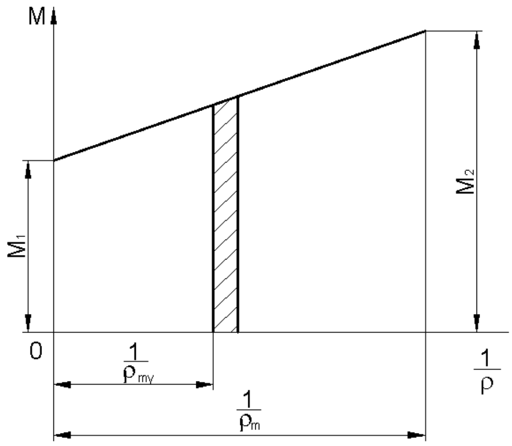

Figure 5. - *Bending moments at the plastic bending with cold-hardening.*

Taking account by the moment make at the bending on roller, relation (13) can be written thus:

$$L_i = \frac{M_1 + M_2}{2}\frac{L_s}{\rho_m} \tag{14}$$

The mechanical work of external forces L_e, is defined by relation:

$$L_e = M_t\,\alpha = M_t \frac{L_s}{\rho_m} \tag{15}$$

where α is angle which on the radius ρ_m has arc length L_s.

Equalizing L_i with L_e results:

$$M_t = \left(K_1 + \frac{K_2}{2}\frac{s}{\rho_m}\right) W \sigma_c \tag{16}$$

or

$$M_t = \frac{M_1 + M_2}{2} \tag{17}$$

The relation (17) shows that torque value of bending roller is arithmetical average of initial and final value of bending moment.

The power P consumed to drive the roll can be determined by relation:

$$P = \frac{M_t\, v}{\eta \rho_m} \text{ [W]} \tag{18}$$

in which M_t is the torque in *Nm*; *v*- peripheral linear bending speed in *m/s*; ρ_m-curvier of median stratus in *m;* η- transmission efficiency to roller.

Torque necessary to bend a work-piece between three rollers (fig.6), is obtained by the equalize between the work inner forces, defined by relation (14) , and work external forces.

The work external forces, relative to driver rollers diameter is:

$$L_e = \frac{2 M_t L_s}{D} \tag{19}$$

where D is the drive roller diameter in *m*.

Thus it is obtained:

$$M_t = (M_1 + M_2)\frac{D}{4\rho_m} \tag{20}$$

If it wants to change the radius of curvature from radius ρ_m to ρ_{m1} (case of bending in more operations, where $\rho_{m1} < \rho_m$) the torque is calculate by relation:

$$M_t = (M_1 + M_2)\left(\frac{1}{\rho_{m1}} - \frac{1}{\rho_m}\right)\frac{D}{4} \tag{21}$$

where M_1 is the bending moment suitable radius ρ_{m1}, and M_2 is the bending moment suitable radius ρ_m.

In this case, the power P consumed to drive the rollers of machine can be determined by relation:

$$P = \frac{2(M_t + M_f)v}{D\eta} \text{ [W]} \tag{22}$$

where M_t is defined by relation (21) in Nm; M_f –friction moment necessary for defeating rolling friction resistance between rollers and work-piece and rollers bearings in *Nm*; *v*-tangential peripheral speed of rollers, in *m/s*; η-transmission efficiency from electric motor to rollers.

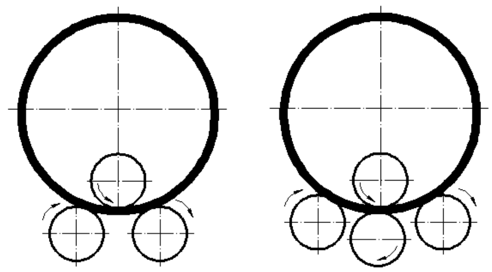

Figure 6 - *Scheme of positioning rollers with three and four symmetrical rollers.*

4. Conclusions

The stress an deformation state analysis of bending sheet metal allow stress and inner forces moment determination, in case of relative radius $\frac{\rho_m}{s}$>5.

The value of inner forces bending moment depend by transversal section form and dimension of this, the medial bending radius, physical and mechanical characteristics of the material.

With inner bending moment established for different bending scheme it was established calculus relations of drive torque roller of bending machines with rollers and the drive power of this.

5. References.

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