A requirement that all cold-rolled strip materials should ideally satisfy is that they shall exhibit constancy and accuracy of dimensions in the longitudinal and axial directions, i.e., minimum thickness variation. One of the reasons for this is that automatic lines are often employed for the manufacture of parts from thin strip [1]. Apart from this, greater strip accuracy may lead to an appreciable saving of metal through an improvement in rolling mill design and a decrease, by half, of the tolerance limit, i.e., through a negative limit [2].

The diagram in Fig. 1a shows an ideal strip profile with a negative (to the left of the axis) and a positive (to the right) tolerance, as laid down by GOST standards and TU technical specifications. It is known [3], however, that the real strip profile differs from the ideal, the distribution of the true thickness over the width in the majority of cases being similar to that shown diagrammatically in Fig. 1b.

In the manufacture of cold-rolled strip of minimum thickness variation, considerable difficulties are experienced owing to the fact that a number of factors are involved, including the yield strength of the stock being rolled, the reduction conditions, the material, surface condition, size, and rigidity of the rolls, and the roll pass design. These bring about fluctuations in the total rolling force \( P \) and hence in the strip thickness. Thus, the quantity \( P \) may be written as a function of several parameters of the rolling process [1]:

\[
P = f(\sigma_s, R, \alpha, \mu, \ldots),
\]

where \( \sigma_s \) is the yield strength of the metal, \( R \) the roll radius, \( \alpha \) the gripping angle, and \( \mu \) the coefficient of friction between the metal being rolled and the rolls. Apart from this, the rolling force depends also on the elastic compression of the rolls and the strip, which alters the length of the arc of contact [4], and, in the rolling of porous materials, on the latter's relative density [5-7].

From what has been said above, it follows that what is needed is a single parameter which would make it possible to determine the effects of all the remaining parameters on dimensional accuracy. Such a parameter may be provided by the tolerance limit, i.e., the permissible thickness variation. Knowledge of the relationship between the permissible thickness variation and the rolling force would enable us to control the rolling process by means of the roll stand instruments.

In the rolling of porous sintered strip, as in the rolling of nonporous materials, bending of the rolls occurs (Fig. 2a, b), which increases the nonuniformity of thickness and density along the strip width (Fig. 1b, left-hand part). According to [8], the roll deflection (Fig. 2b) in any section at a distance \( x \) from a bearing (Fig. 2a) is equal to

\[
y_i = y_j + y_k,
\]

where \( y_j \) and \( y_k \) are the deflections due to the action bending moments and lateral forces.

To determine the possible thickness variation along the strip width, it is necessary to know not the total deflection \( y_i \) in the middle of the roll barrel but the difference between the total deflections in the middle
Fig. 1. Strip profiles, ideal (a) and true (b), as determined by thickness tolerance limit: a) to left of axis, minimum thickness \( h_{\text{imin}} \) with negative tolerance \(-\Delta_i\); to right of axis, maximum thickness \( h_{\text{imax}} \) with positive tolerance \(+\Delta_i\); \( h_{\text{nom}} \) is the nominal (calculated) thickness; b) to left and right of axis, respectively, strip thickness with greater compression of edges and strip center; \( \Delta y_i \) is the difference between total deflection in middle and total deflection at strip edge.

Fig. 2. Diagram of two-high mill (a) facilitating calculation of roll deflection \( y_i \) and \( \Delta y_i \) (b).

and at the strip edge (at a distance \( B/2 \) from the middle), i.e., \( \Delta y_i \) (Fig. 2b). For two-roll mills, this difference can be calculated with the equation [8]

\[
\Delta y_i = \Delta y_j + \Delta y_k = \frac{P_i B_i}{D^2} \left[ 1 + \frac{B_i}{8D^2} (12A - 7B_i) \right] \frac{1}{2\pi G},
\]

where \( \Delta y_j \) and \( \Delta y_k \) are the differences between the deflections in the middle and at the strip edge caused by the action of bending moments and lateral forces, respectively, \( P_i \) is the total rolling force, \( A \) is the distance between the axes of the housing screws, \( D \) is the roll diameter, \( B_i \) is the strip width, and \( E \) and \( G \) are, respectively, the elastic and shear moduli of the roll material. In practical calculations, it can be taken that \( E = 2.15 \times 10^5 \text{ N/mm}^2 \) (21,500 kg/mm²) and \( G = 0.82 \times 10^5 \text{ N/mm}^2 \) (8200 kg/mm²).

In the rolling of nonporous materials, the starting roll pass geometry allows for \( \Delta y_i \). However, on passing to another width at the same starting roll pass geometry, the roll deformation changes. This change may bring about transverse variation of strip thickness [3].

Let us establish the relationship between the permissible transverse thickness variation (tolerance limits) on the one hand and the roll deformation and rolling force on the other. From Fig. 1a and b, it will be seen that the limit of permissible thickness deviation is given by the difference

\[
h_{\text{max}} - h_{\text{min}} = (+\Delta) + (-\Delta) = \Delta_i
\]

If the strip thickness is to lie within the tolerance limits \( \Delta_i \), the following condition must be satisfied:

\[
\Delta_i \geq 2\Delta y_i.
\]

For nominal thicknesses \( h_{\text{nom}} \) (Fig. 1a), GOST standards and TU technical specifications stipulate