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CONSIDERATION OF CIRCUMFERENTIAL WORK ROLL SURFACE DISPLACEMENTS IN A NON-CIRCULAR ARC TEMPER ROLLING MODEL

Klaus Zeman*, Konrad Krimpelstaetter*, Alexander Kainz*,
Gerhard Finstermann†, Gerwald Glanner‡ and Dieter Paesold‡

*Institute for Computer Aided Methods in Mechanical Engineering
Johannes Kepler University Linz, Altenbergerstr. 69, 4040 Linz, Austria
e-mail: klaus.zeman@jku.at, web page: http://came.mechatronik.uni-linz.ac.at

†VOEST-ALPINE Industrieanlagenbau GmbH & Co, Turmstr. 44, 4031 Linz, Austria

‡voestalpine Stahl GmbH, VOEST-ALPINE Str. 3, 4031 Linz, Austria

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1 INTRODUCTION AND SUMMARY

In the course of the production of cold rolled flat products, temper and skin-pass rolling represents the final rolling operation. Thereby a slight thickness reduction resulting in an elongation of app. 0.2 - 2% is applied to the cold rolled and annealed strip.

Usual mathematical models[1,2] for cold rolling of strip cannot be used in temper rolling conditions, as high work roll flattening, high macroscopic friction between work roll and strip due to textured work rolls, significant elasto-plastic strip behavior, relatively large no-slip-zones and the potential appearing of „contained plastic flow“[6,7] make the situation much more complicated.

A new temper rolling model is presented applying a non-circular arc theory for the calculation of the elastic work roll flattening. In addition to the radial displacements of the work roll surface, also its circumferential displacements, generated mainly by the shear stresses acting between work roll and strip, are taken into account. The underlying rate-dependent elasto-plastic model of the strip allows for the appearance of several subsequent elastic and plastic zones. The consequence is that the case of "contained plastic flow" will appear automatically without additional simplifying assumptions. Excellent agreement between measured and predicted rolling forces and rolling torques was achieved.

2 ELASTIC WORK ROLL DEFORMATION INCLUDING CIRCUMFERENTIAL WORK ROLL DISPLACEMENTS

Similar to the influence functions derived by Jortner[5] who merely considered the radial work roll displacements due to rectangular distributions of compressive stresses, Meindl[4] additionally took into account the circumferential work roll displacements caused by the applied compressive and shear stress distributions. Consequently, the formulae for the displacements were derived from the numerical superposition of analytical influence functions based on Meindl's investigations, which has the advantage to obtain not only the radial and circumferential displacements, but also their first and second derivatives without additional numerical complications.

As a result of the calculated first and second derivatives of both radial and circumferential work roll displacements (due to arbitrary distributions of compressive stresses and shear stresses), also the speed state (tangential speed) and the curvature of the deformed non-circular arc work roll contour can be calculated with "arbitrarily" high accuracy.

Investigations[4,6] showed that for small contact angles (typical for temper rolling), the qualitative behavior of the variation of the tangential speed of the deformed work roll contour is dominated by the behavior of the first derivative u'_Θ of the circumferential work roll surface displacements.

Hence, the circumferential work roll displacements, which are generated mainly by the shear stresses acting on the roll surface, heavily affect the relative speed between the surfaces of the deformed work roll and the strip. As this relative speed (slip speed) is a significant input parameter for every friction law, also the evolution of frictional forces in the roll gap is re-affected by the circumferential displacements.

The effect of circumferential displacements becomes more and more crucial with decreasing strip thickness and draft in combination with increasing "macroscopic" friction (between work roll and strip) and cannot be neglected in such cases. The formation of a neutral zone instead of a neutral point is a natural consequence of this approach leading to a much more realistic model of this process (cp. Figure 1).

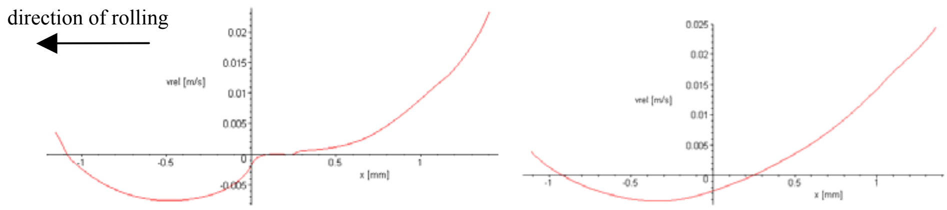

Figure 1: Relative speed (slip speed) inside the roll bite calculated by including (left) and by neglecting (right) the influence of circumferential work roll displacements

Figure 2 demonstrates the influence of circumferential work roll displacements on the resulting calculated rolling force for different strip thicknesses and different drafts for a constant "macroscopic" (sliding) friction $\mu_0 = 0.2$ (between work roll and strip). Hereby, the relative rolling force error caused by neglected circumferential displacements (compared to included circumferential displacements) increases significantly with decreasing strip thickness and draft.

Hence, the incorporation of circumferential work roll surface displacements ensures an improved modeling of temper rolling, as the circumferential displacements in combination with a modified Coulomb friction law allow for the existence of a slip- as well as no-slip zone inside the roll bite.

$$f = \frac{F_W^{negl.} - F_W^{\mathrm{incl.}}}{F_W^{\mathrm{incl.}}} \cdot 100\%$$

$F_W^{\mathrm{negl.}}$ … Calculated rolling force with neglected circumferential displacements

$F_W^{\mathrm{incl.}}$ … Calculated rolling force with included circumferential displacements

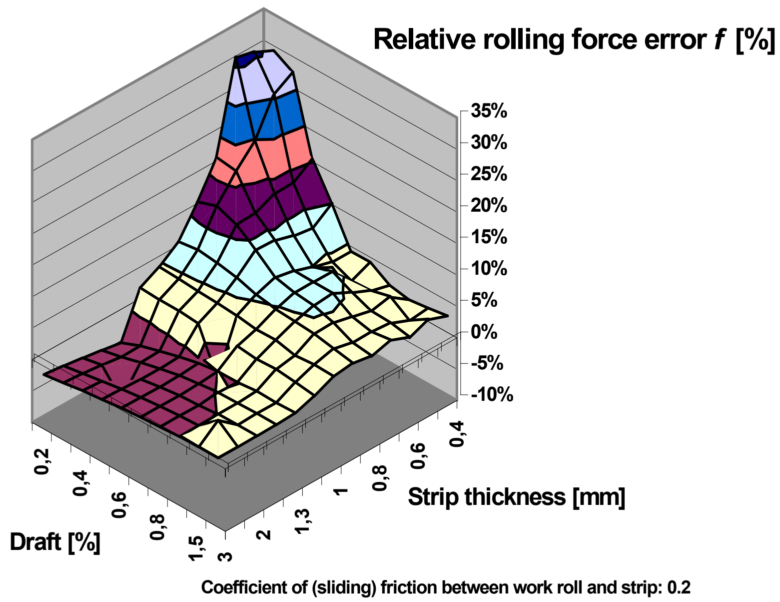

Figure 2: Influence of circumferential work roll surface displacements on rolling force

3 RATE-DEPENDENT ELASTO-PLASTIC MODEL OF THE STRIP

The underlying rate-dependent elasto-plastic model of the strip is based on von Karman's[1] theory with several extensions including additionally an elastic compression zone at roll gap entry, an elastic recovery zone at roll gap exit and possible plastic zones in between, whereby elastic regions (internal elastic zones) are also allowed to arise between plastic zones. As a consequence, the case of "contained plastic flow"[6,7] (= a region in which further plastic yielding is prohibited; i.e. vanishing plastic strain rate) will appear automatically without imposing additional simplifying assumptions (e.g. constant strip thickness[7]). The rate dependence of the strip's yield stress significantly affects the rolling forces.

4 COMPARISON WITH PRACTICAL DATA FROM AN EXISTING TEMPER ROLLING MILL

To compare and calibrate the model with practical data from an existing temper rolling mill, extensive temper rolling tests were carried out with the help of voestalpine Stahl. In addition to the standard process data as rolling force, rolling torque, tensions, elongation etc. also the roughness of work roll and strip (lasertopography and perthometer measurements) and the mechanical-technological data (tensile tests) were gathered and evaluated. Thus, 24 representative test coils with different strip thicknesses and different steel grades were analyzed very thoroughly.

Excellent agreement between measured and predicted rolling forces and rolling torques was achieved, which is demonstrated for the prediction of rolling forces by Figure 3 including all data sets from the temper rolling tests.

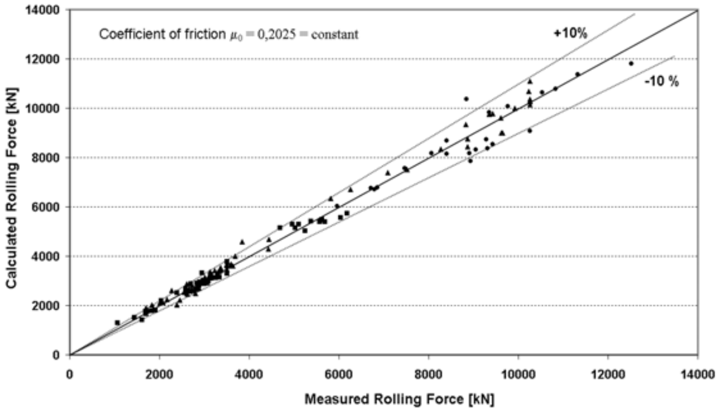

Figure 3: Comparison of predicted and measured rolling forces

5 CONCLUSIONS

A new temper rolling model was developed taking into account (non-circular arc) radial as well as circumferential displacements of the work roll contour. The approach ensures an improved modeling of temper rolling, as the circumferential work roll displacements in combination with a modified Coulomb friction law allow for the existence of slip- as well as no-slip-zones inside the roll bite and the formation of a neutral zone instead of a neutral point. The effect of circumferential displacements increases with decreasing strip thickness and draft in combination with higher friction (between work roll and strip) and cannot be neglected in such cases. The appearance of "contained plastic flow" is detected automatically by the model without imposing additional simplifying assumptions. Excellent agreement between measured and predicted rolling forces and rolling torques was achieved.

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