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Fast modelling of elastic work roll deformation in groove rolling

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For modelling of elastic work roll deformation in groove rolling, the finite element method offers a deep and detailed modeling approach. Nevertheless, FEM calculations require a great amount of computational power and time. For groove rolling, Schmidtchen et al. [1], [2] developed a pillar model derived from classic elementary theory to calculate the pressure distribution between groove contour and workpiece in width direction. A simplified model is available as a core model approach in the new simulation framework PyRolL developed at the institute of metal forming, Freiberg. In the current work, the framework is extended through a plugin focusing on the elastic deformation of the work roll. The implemented model calculates the elastic work roll deformation through bending and transverse contraction using matrix calculation and discretization of the work roll in width direction through disks. Besides, the grooved contour of the roll barrel also the roll journals are considered. This results in a bend line for the whole work roll which can further be used to adjust the rolling schedule or optimize the work rolls fatigue strength through more suitable material choice. To validate the model, the first calculations are made for simple groove shapes (Round, Oval, Diamond, Box) and results are first compared with FEM calculations witch shows good agreement.

KEYWORDS: ROLLING SIMULATION; GROOVE ROLLING; ROLL BENDING; SHAPE DEVIATION; ROLL PASS DESIGN

INTRODUCTION

In today's world, high energy and material prices are increasing pressure on companies to reduce their scrap rates to keep manufacturing costs as low as possible. Main sources of scrap are process-related losses and rejects due to non-compliance with tolerances. Regarding the latter, one major requirement in the field of groove rolling is the shape deviation of the profiles compared to the specified shape. The shape of the profiles is influenced by the actual groove contour, the degree of filling, and the elastic response of the plant to loads and torques caused by the rolling process. Modeling the elastic deformation of the work rolls therefore gives crucial process insights needed to avoid the production of scrap by shape deviations. In the field of flat rolling there are various solutions to model the elastic behaviour of work rolls (f.e. [3, 4, 5, 6, 7, 8, 9]). As far as the authors are aware, only basic analytical calculations with major simplifications are published for groove rolling (f.e. [10, 11, 12]). Therefore, the matrix method by Göldner et al. [13] was adapted to provide a flexible and fast solution to model the elastic work roll deformation.

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MODELLING OF ELASTIC WORK ROLL DEFORMATION

The core idea is to consider the roll as a prismatic rod with varying diameter and discretize its length into n disks with length $\mathrm{d}z$, which are subjected to a constant linear load q and have a locally constant I. Every disk has four state variables, which are the deflection v, the inclination α, the bending moment MB and the shear force FQ. These four variables unambiguously determine the deformation and stress state of a disc. The values of the state variables at entry and exit of each disk are denoted by the indizes 0 and 1 (see Figure 1).

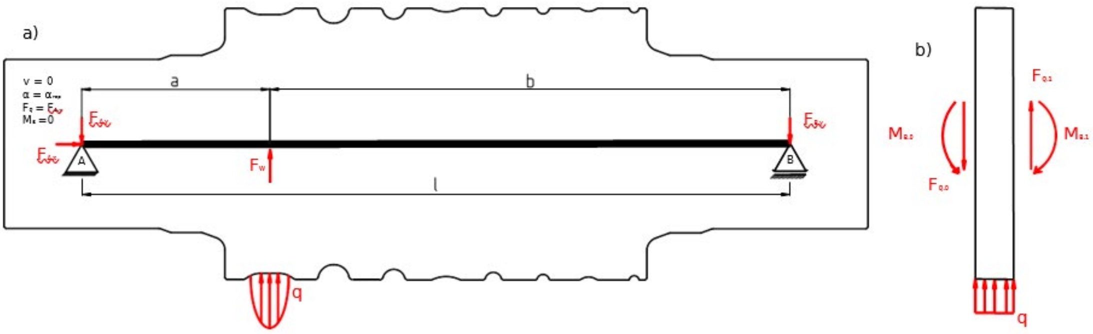

Fig.1 - a) Work roll for break down mill of the semi-continous roling plant at the institute of metal forming with exemplary load distribution and mechanical substitute system; b) disk element used for discretization.

Solving the 4th order differential equation for the deflection (see equation (1)) of a disk between its boundaries, under consideration of the above assumptions, allows the equations to be expressed as matrix. The resulting matrix is called transition matrix as it accomplishes the transition of the state variables in each disk. The entry state of the following disk can be calculated using the exit state of the previous disk through equation (2). As Becker et al. [12] and Kulbatschny [10] stated, the bearings of a roll are designed to be free of bending moments and have a very high bending rigidity. Göldner et al. [13] suggests, that bearings can therefore be modeled using spring constants resulting in a special transfer matrix for bearings. Since it was not possible to measure the necessary constants for the respective plant, the spring constant and the torsion spring constant were assumed to be ∞ and 0, respectively. Furthermore, the bearing of the roll was approximated to be located at the center of each roll joints. In order to better represent the load on the roll resulting from the process, it was assumed that the pressure distribution in the contact area between the rolled material and the roll is elliptical and has its maximum in the centre of the groove. The width of the ellipse is equal to the width in which the rolled stock experiences hindered spreading. This width was calculated according to the model from Lendl [14]. A similar assumption was made by Hitchcock et al. [15] for elastic flattening of the roll, but in rolling direction. The assumptions can bee seen in Figure 1.

$$EIv'''' = q \tag{1}$$

$$\begin{pmatrix} v \\ \alpha \\ M_\mathrm{B} \\ F_\mathrm{Q} \\ 1 \end{pmatrix}_1 = \begin{pmatrix} 1 & \mathrm{d}z & \frac{\mathrm{d}z^2}{2EI} & \frac{\mathrm{d}z^3}{6EI} & q\frac{\mathrm{d}z^4}{24EI} \\ 0 & 1 & \frac{\mathrm{d}z}{EI} & \frac{\mathrm{d}z^2}{2EI} & q\frac{\mathrm{d}z^3}{6EI} \\ 0 & 0 & 1 & \mathrm{d}z & q\frac{\mathrm{d}z^2}{2} \\ 0 & 0 & 0 & 1 & q\mathrm{d}z \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} v \\ \alpha \\ M_\mathrm{B} \\ F_\mathrm{Q} \\ 1 \end{pmatrix}_0 \tag{2}$$

For performing the calculation, the components of the vector in point A must be known. Deflection $v(\mathrm{A})$ and moment $MB(\mathrm{A})$ are equal zero due to the assumptions. The shear force $FQ(\mathrm{A})$ and inclination $\alpha(\mathrm{A})$ are unequal zero and must be determined numerically, so that the deflection $v(\mathrm{B})$ and moment $MB(\mathrm{B})$ are zero in point B.

$$\begin{pmatrix} v \\ \alpha \\ M_\mathrm{B} \\ F_\mathrm{Q} \\ 1 \end{pmatrix}_\mathrm{A} = \begin{pmatrix} 0 \\ \alpha(\mathrm{A}) \\ 0 \\ F_\mathrm{Q}(\mathrm{A}) \\ 1 \end{pmatrix} \tag{3}$$

To estimate initial values for the numerical solution, a substitute system is used, namely the bending of a constant cross-section rod by a point force, as shown in Figure 1. The force balance on this system leads to the expressions in Equation 4.

$$F_\mathrm{Q}(\mathrm{A}) = -F_\mathrm{A,y} = -F_\mathrm{W}\left(1 - \frac{a}{l}\right) \tag{4a}$$

$$\alpha(\mathrm{A}) = \frac{F_\mathrm{W} ab\,(l+b)}{6E\bar{I}l} \tag{4b}$$

Using the initial solution, the final solution is computed using the HYBRD algorithm by Powell [16] provided in Scipy [17]. To test the model, the deformation of a work roll used for break down passes in a semi-continuous rolling plant located at the instiute of metal forming in Freiberg shall be investigated. The material rolled is a low carbon steel used for rebars with an initial round profile with a diameter of 8 mm rolled to a final diameter of 80 mm in fourteen passes. The results calculated are compared to results from the analytical model from Becker et al. [12].

ELASTIC DEFORMATION OF WORK ROLLS IN BREAK DOWN PASSES

The considered work roll is shown in Figure 2b and is equiped with a swedish oval groove as well as round and oval grooves. The model was tightly integrated into the open source framework PyRolL [18] as a plu- gin, to be able to investigate the influence of roll bending on the groove rolling process. The used PyRolL configuration, input scripts as well as the pass schedule are provided as supplementary material on GitHub (https://github.com/pyroll-project/pyroll-rolling-12-benchmark). The results for four selected passes (eg. first, third, fifth and tenth) from the calculation can be seen in Figure 2. These passes where chosen be- cause the grooves used for the respective pass are different from one another.

The results for the deflection, inclination, bending moment and shear force match the load distribution shown in Figure 2a. As one can see, the maximum values for load corresponds to the zero crossing of the bending moment and shear force.

The maximum value for the deflection is 0.017 mm and is located near the center of the work roll at z = 175 mm (see Figure 2b). Through the high stiffness of the work roll, resulting from the used material and diameter of the roll, the total deflection is vanishingly small. Comparison of the the bending moment and shear force results calculated using the described method to the results generated by the analytical model can be seen in Figure 2d.

One can see that the average deviation lies within a few percent. The biggest difference between the two can be found in the shear stress which is caused by the different assumptions made for the pressure distribution. Becker et al. [12] applied the roll force as a point load at the center of the grooves contour. Therefore, the obtained results seem plausible and usage of the model is valid. For further usage of the model, it must be noted that the used groove contour as well as the shape of the initial profile have a considerable influence on the type of pressure distribution. The elliptical distribution used here represents a first approximation of the actual distribution, since the maximum rolling pressure is to be expected near the centre of the groove due to the material flow, which is influenced by the grooves contour. Furthermore, it should be noted that the model can only be used up to a maximum filling ratio i of 1.

SUMMARY AND OUTLOOK

The transition matrix approach offers a alternative to current simulations for simulation of the elastic work roll deformation for groove rolling. By using the matrix form for the calculation of the deflection, the inclination, the bending moment and the shear force. To investigate the influence of the assumption for the load distribution, the model shall be combined with the pillar model developed by [1, 2] to calculate the elastic work roll deformation for the production of more complex irregular profiles. However, these studies will be the subject of a separate publication planned for the end of this year.

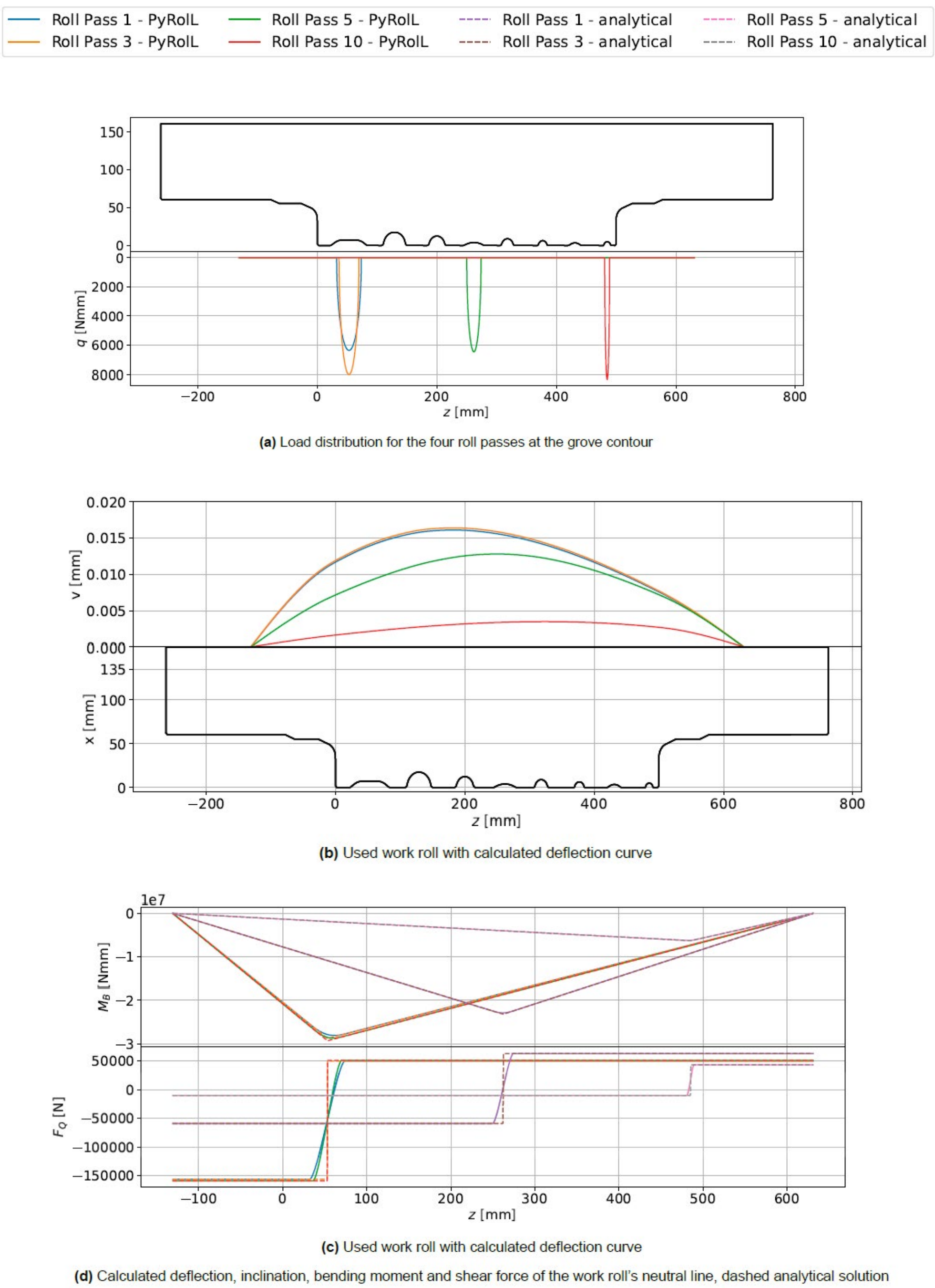

Fig.2 - Model results for deflection for four passes rolling of a 48 mm round profile to a final diameter of 8 mm

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