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VERIFICATION OF FAST ALGORITHM FOR CROSS-ROLL STRAIGHTENING

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Abstract: *This paper describes a computational model to simulate cross-roll straightening of rods. This model is based on the Lagrangian approach to the description of the continuum. The implementation of the model was performed in the ANSYS software. In the other part of the work results are presented, which are then compared with the fast algorithm for cross-roll straightening based on the Euler approach.*

Keywords: Computational simulation, Cross-roll straightening, FEM, Hyperbolic rollers, Curvature, Rod bending, Residual stress.

1. Introduction

Rolled rods can be inappropriate deformed after a heat treatment and therefore they can wobble unacceptably during machining. For this purpose, cross-roll straightener is used, reducing the curvature and unacceptable wobble of the rod. In practice, there are different types of rods with different geometrical and material properties. Each type of rod requires particular settings of straightener's parameters, e.g. offset of upper deflection rollers, angle of roller. Values of these parameters can be estimated with experience or with virtual simulation of cross-roll straightening.

Despite the fact that the technology of cross-roll straightening is relatively old, virtual simulations of cross-roll straightening are only at the beginning. This confirms fact, that only few authors deal with this issue. One of them is Mutrux et al. (2008), where the collective of authors perform simulations of cross-roll straightening on a straightener with two rollers. The upper roller is concave and the lower roller is convex. The problem is solved in the LS-DYNA software. Authors use bilinear material model with kinematic hardening. The rod was 10 m long and its model is divided into two parts, the outer being modeled using beam elements and the middle one modeled using solid elements. During the simulation the beam elements never touch the rollers. Outputs are displacements in planes XY and XZ. Huang et al. (2011), another relevant team of authors focused on cross-roll straightening on a straightener with 10 rollers. This straightener has 5 upper and 5 lower rollers. Each upper roll is above the lower roll and there is no deflection roller. The simulation of straightening has been done in MSC.MARC software. The model of geometry is not the rod but it is a pipe. Outputs are Von Mises stress and strain and circularity. In Feng et al. (2013), team of authors simulated cross-roll straightening for a straightener with 7 rollers. The shape of the roller was created in software CATIA and MATLAB. Numerical simulation was solved in Abaqus.

Since the virtual simulation of cross-roll straightening is a very time consuming, a fast algorithm of cross-roll straightening has been developed by Petruška et al. (2016a). The final version of the fast algorithm should be used to adjust the position of hyperbolic rollers in real time. In order to make the predictions fast enough, it was necessary to use the Euler approach to description the continuum. Due to low computer time requirements, optimization of vertical offset of rollers could be made as shown in Petruška

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et al. (2016b). The fast algorithm can be used also for non-circular profile as presented in Návrat et al. (2014).

Many experiments are needed to be performed for the sufficient verification of the fast algorithm, which is too expensive. For these reasons, the main aim of the work was to create a standard Lagrangian FEM model to be used for the verification of the fast algorithm for cross-roll straightening.

The above-mentioned papers demonstrate that the simulation of cross-roll straightening has been solved in FEM software, such as LS-DYNA, MSC.MARC, Abaqus. Due to accessibility of ANSYS at the Institute of Solid Mechanics, Mechatronics and Biomechanics, the simulation will be solved in this software. As some results like the curvature per meter cannot be obtained directly from the FEM model, macros and m-scripts must be used to evaluate those. Then a curvature and residual stress from the fast algorithm can be verified by the curvature and residual stress from the standard FEM model.

2. Method

Based on the findings obtained from literature, an analysis model was created for the required straightener with nine rollers (Fig. 1). Rotation and translation of the rod was not driven by the rotation of rollers, but it was caused by the boundary conditions prescribed on the rod.

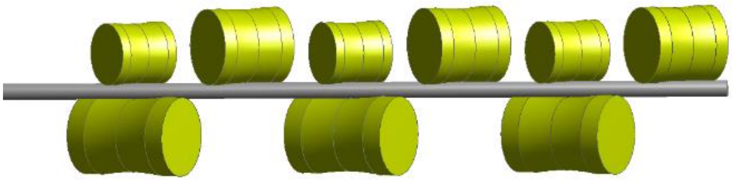

Fig. 1: Cross-roll straightener with nine rollers.

2.1. Model of material

Homogeneous, isotropic and ideally elastoplastic model of the steel material was used for the rod with the following parameters: Young's modulus 206 GPa, Poisson's ratio 0.3 and tensile yield strength 900 MPa.

2.2. Model of geometry

Model of geometry consists of two basic parts - hyperbolic rollers and the straightened rod.

Hyperbolic rollers: The cross-roll straightener with nine rollers has three types of rollers. There are lower rollers, upper pressure rollers and upper deflection roller (Fig. 1). The hyperboloid (work space of the roller) can be described by the length of the major semi-axis **r** and the minor semi-axis **c**. Other important parameters of the roller are the length of the work space $\mathbf{L_1}$ and the total length of the roller **L**. Values for the above-mentioned parameters of the three types of rollers are shown in Tab. 1.

Tab. 1: Parameters of the rollers.

Type of rollers	**r [mm]**	**c [mm]**	**L_1 [mm]**	**L [mm]**
lower	160	379	310	480
upper pressure	130	379	190	276
upper deflection	160	379	220	340

The rod: The diameter of the rod was determined to be 70 mm and the initial curvature per meter[1] was 4 mm/m.

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[1] The following relationship applies for the curvature per meter and radius of curvature: $k_m = r - \sqrt{r^2 - 10^6/4}$

2.3. Connections

In this standard FE model interaction can be only between the rod and rollers. The surface of rollers is rigid and the rod is modeled as a flexible body. The type of the contact was chosen “Frictionless” and the algorithm was chosen “Augmented Lagrangian” because the convergence is the best for this settings.

2.4. Mesh

Following elements were used for the mesh: BEAM188, CONTA175 and TARGE170. As the rod was meshed by BEAM188, it was not possible to prescribe the contact on the surface of the rod. The contact was prescribed in nodes that were placed on the midline of the rod. For this reason, the geometry of the rod penetrates the geometry of rollers as shown in Fig. 2.

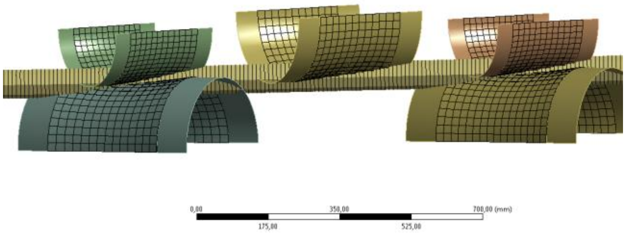

Fig. 2: Penetration.

2.5. Boundary conditions

The simulation was divided into two load steps. In the first step, the first part of the rod was loaded by the vertical displacement of upper deflection rollers as shown in Fig. 3. Displacements of other rollers remained zero in all directions. Due to convergence problems in the first load step, it was necessary to prescribe zero **x** and **z** displacements of the global coordinate system at the end of the rod. Boundary conditions that were applied on rollers in the first step stay unchanged in the second step with upper deflection rollers remaining in the same position as at the end of the first step. A new boundary condition is applied at the end of the rod in the second step. It is a displacement in the x direction and rotation around the x axis as shown Fig. 4. As the second part of the rod (the part for evaluation of results) must be affected by all the rollers and because the helix pitch is 110 mm, the displacement in the x direction must be 4800 mm and the rotation around the x axis 15709° (i.e., about 44 revolutions).

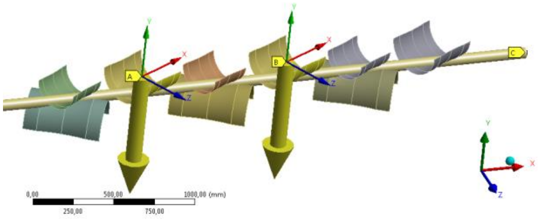

Fig. 3: The first load step.

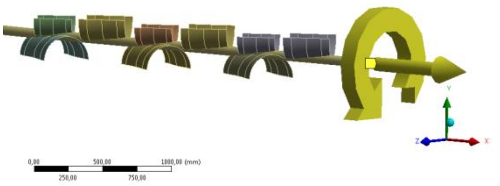

Fig. 4: The second load step.

3. Results

In this section, the fast straightening algorithm results are compared to standard Lagrangian FE analysis model.

Fig. 5 shows a graph in which the output curvature is dependent on the offset of upper deflection rollers. The blue curve represents results for the fast algorithm and a red curve represents results for the standard FE model. Both curves have the same trend and the minimum output curvatures are different by only a few percent. The offset of upper deflection rollers is different for the minimum output curvatures. It is 8 mm for the fast algorithm and 9 mm for the ANSYS model. Difference is about 11 %. ANSYS model has a greater stiffness.

Fig. 6 demonstrates a relationship between the residual stress and the offset of upper deflection rollers. Trends of both curves are similar again. The offset of upper deflection rollers are 7.4 mm for the fast

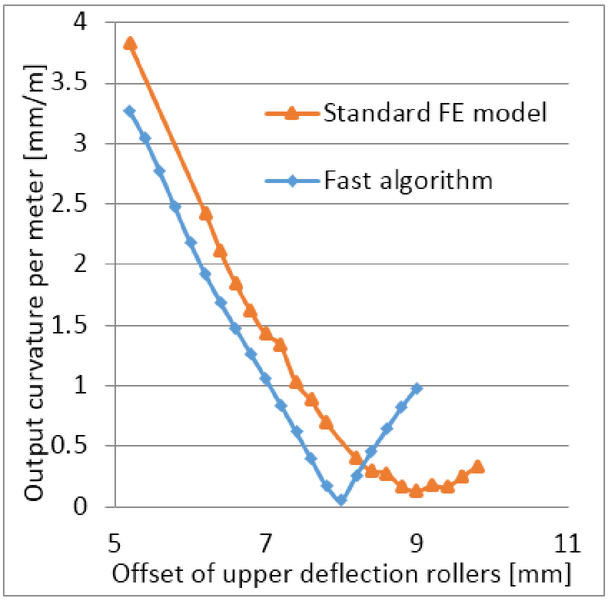

Fig. 5: Verification output curvature.

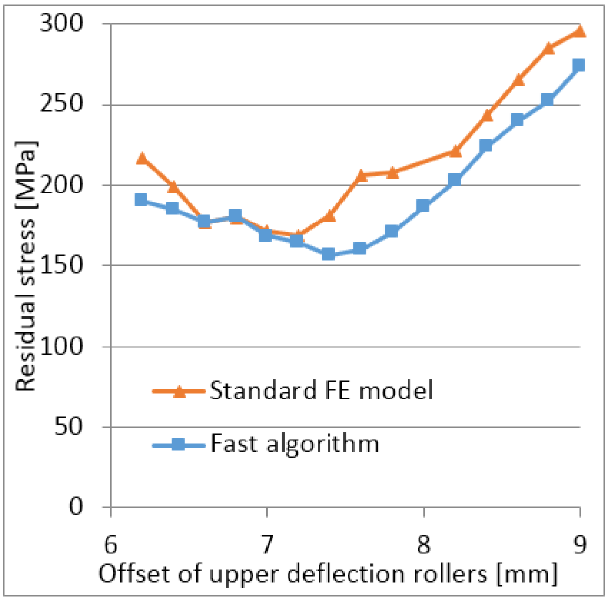

Fig. 6: Verification residual stress.

algorithm and 7.2 mm for the ANSYS model. Difference is less than 3 %. The value of residual stress for these offsets is 155 MPa for the fast algorithm and 170 MPa for the ANSYS model. Difference is less than 9 %.

The last important parameter is the calculation time. The calculation time of one standard FE model is about 10 hours. This simulation is a very time consuming because a real cross-roll straightening takes about 10 seconds. The calculation time of the fast algorithm is many times lower than the calculation time of the standard FE model. It is about 140 seconds for one simulation.

4. Conclusions

Although the fast algorithm is much faster than standard FE model, the application of fast algorithm for real-time control straightener will be probably not possible. This is caused by the fact, that we have to perform an optimization for each type of rod, which leads to a wide range of calculations. This problem could be solved with previously performed optimization and subsequent implementation of obtained parameters into the straightener control system.

In conclusion we can say that presented differences are (particularly in Figs. 5 and 6) greater than we expected. So the problem of the cross-roll straightening cannot be closed. Therefore, further research should be focused on creating a new FE model that will be based on solid elements.

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