

NUMERICAL SIMULATION OF ECCENTRICITY CREATION IN THE PRODUCTION OF HOT ROLLED TUBES

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Abstract: The paper deals with the issue of eccentricity in the technological node of the piercing press, under selected conditions, which result from the possibilities of production in the conditions of ŽP a.s. These conditions were verified and adapted to the rolling process. This process consisting of individual technological nodes on the rolling mill, in which eccentricity is created on the piercing press and the following steps eliminate it in other technological nodes. For quality analysis of manufacturing tubes using numerical simulation, it is necessary to know the actual state of eccentricity creation on the rolling mill. A numerical simulation of piercing under different input conditions was used (software DEFORM-3D) and was performed for several different charge states before entering onto the piercing press. The eccentricity itself has a significant effect on the resulting geometric quality of the tubes.

1 Introduction

The dimensions of the tubes belong to the basic characteristics of the tubes. For the needs of industry and general use, tubes with diameters from tenths of a millimetre to tubes with a diameter of few tens of centimeters are produced. The dimensions of the tube must be given in such a way as to fully identify the tube in this respect. In addition to length, three main dimensions stand out for tubes with a circular cross-section: outer diameter, inner diameter and wall thickness.

1.1 Shape and Dimensional Defects of Tubes

When rolling tubes on rolling mills, defects on the surface of the tubes can occur at various stages of rolling for various reasons.

Rolled tube defects can be divided (classified) into 3 basic groups of errors:

- Shape and dimensional defects.
- External surface defects.
- Internal surface defects.

One of the problems in hot rolling (which the paper will also address) is the eccentricity on the piercing press. In essence, this is a specific form of tubes defects causing wall thickness unevenness.

Eccentricity is a measure (degree, volume, extent) of the difference between the centers of the outer and inner diameters. Eccentricity is allowed within the wall thickness tolerances and is calculated from the wall thicknesses in one cross section.

1.2 Causes of Eccentricity Creation

The main cause of eccentricity creation can be considered the non-concentrated piercing of the billet on the vertical piercing press, which can be caused by the following factors:

- Cutting process of batch preparation.
- Billet geometry.
- Uneven heating of the billets in the rotary hearth furnace.
- Incorrect calibration of the billet, which will cause poor chamfering quality of the billet's edges in calibration duo.
- Non-coaxial movement of the piercing mandrel with respect to the die axis.

The literature [1-10] deals with the issue of pipe eccentricity (from the point of view of analysis, prediction, monitoring, numerical modeling and measurement) at various technological nodes and materials.

2 Methodology

2.1 Eccentricity Calculation Method

The method for calculating the eccentricity dimension (1) in drawn-reduced tubes is as follows (Figure 1):

$$E = \frac{S_{max} - S_{min}}{S_{max} + S_{min}} * 100 \% \quad (1)$$

S_{min} - minimum value of tube wall thickness in one cross section (mm),

S_{max} - maximum value of tube wall thickness (mm) (opposite to minimum wall thickness).

2.2 Eccentricity Simulation in the Piercing Press

In the paper, the main attention is paid to the piercing press, where the primary reason for the occurrence of eccentricity is assumed by off-centering the mandrel of the piercing press when it is pressed into the material. Three presumed effects on eccentricity were selected and simulated, namely:

- the effect of poor cutting surface,
- uneven billet temperature distribution when heating in the rotary hearth furnace,
- off-centering of the billet in the die.

All previous operations were included in the models, in the case of uneven heat distribution in the billet also the course of heating in the furnace. The elastic model of the mandrel with predefined elastic properties of the material (Young's modulus, Poisson's constant) was used to monitor the mandrel deflection. In the analysis, the main deflection of the mandrel in the X axis was monitored (the Z axis was chosen as the mandrel axis).

This task also focused on the validation of the model of thermal quantities with experimental measurements directly on the mill.

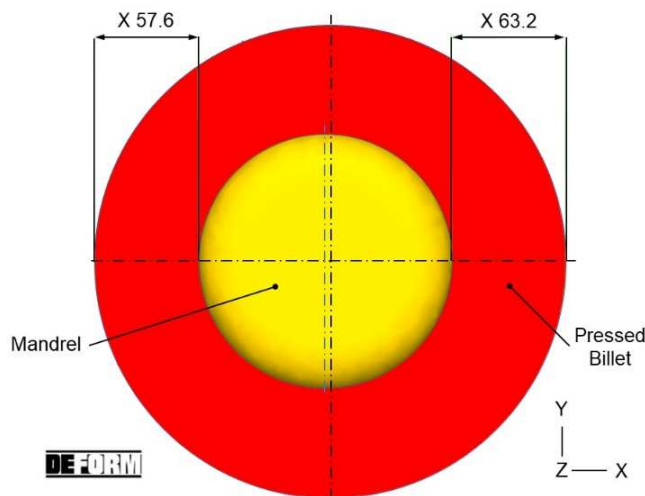


Figure 1 Eccentricity on pressed billet

2.3 Input Data for Simulation

Billet with diameter of Ø205 mm, fillet of R40 mm, length of 1020 mm and a number of 260 000 elements was used as an input model for all simulations (Figure 2). The size of the elements itself was set from 1 mm to 10 mm and the given refinement was used in places according to the necessity of the monitored quantities. An elastic mandrel having 60 000 elements with given elastic properties was used to analyze the eccentricity in the piercing simulation. Table 1 shows the main input data used for the simulation.

Table 1 Main input data for simulation

Number of billet elements	260 000
Billet material	E355
Number of mandrel elements	60 000
Poisson's constant of the mandrel	0.3
Young's modul of the mandrel	210 000 MPa
Thermal conductivity of the hearth	(Figure 3) W/mK
Heat capacity of the hearth	1.07 N/mm ² /K

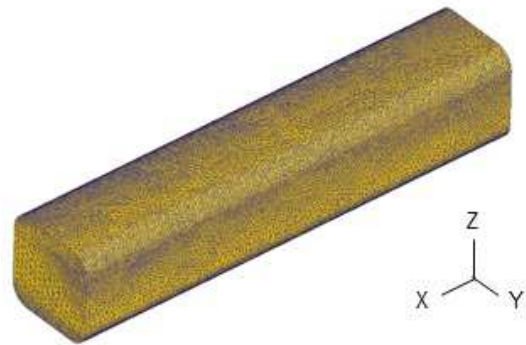


Figure 2 The used finite element model of the billet

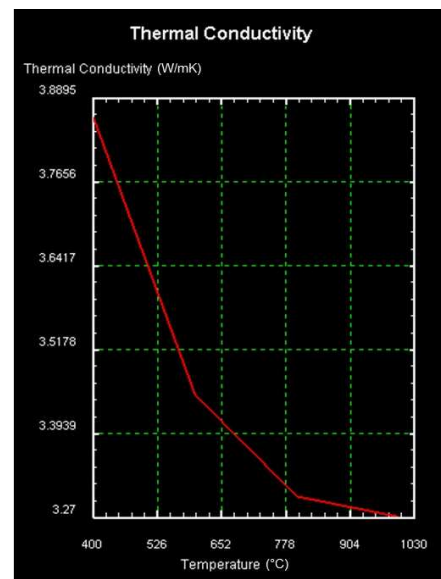


Figure 3 Thermal conductivity of the hearth

3 Results and Discussion

3.1 Uneven Heat Distribution

In this task, the billet was simulated for heating in a rotary hearth furnace. The main goal was to monitor the effect of the heat gradient along the height of the billet on the eccentricity of the piercing where the surface of the billet, which is in contact with the hearth of the furnace, has a lower temperature than the free surface on the opposite side (Figure 4). The temperature on the upper side (point 1) reached 1275 °C, on the middle of the billet (point 2) 1278 °C and on the hearth side (point 3) 1265 °C. The resulting difference between the temperatures on the sides of the charge is thus 10 °C.

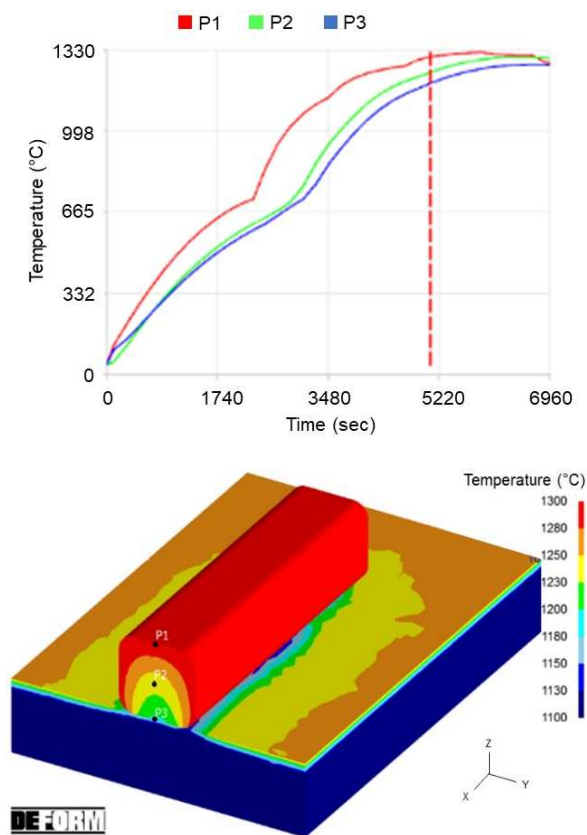


Figure 4 Heating of the billet in the rotary hearth furnace (approx. 1.5 hours)

The temperature difference before the piercing on the opposite sides of the charge was not significant (approx. 9 °C). This difference is similar to the output of the rotary hearth furnace (Figure 5). Also the temperature in the middle of the billet is the same (Figure 6).

The Figure 7 shows the course of the deflection of the axis of the mandrel along the length of the pressed billet. The selected point was on the surface in the center of the mandrel head. It can be stated that the mandrel was gradually pushed to the side with a higher temperature and reached a deviation from the axis by approx. 0.8 mm. For this reason, it can be stated that the uneven distribution

of heat across the cross section in this case does not have a significant effect on the resulting eccentricity.

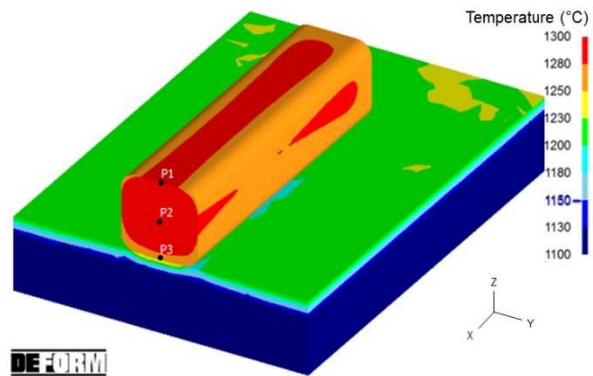
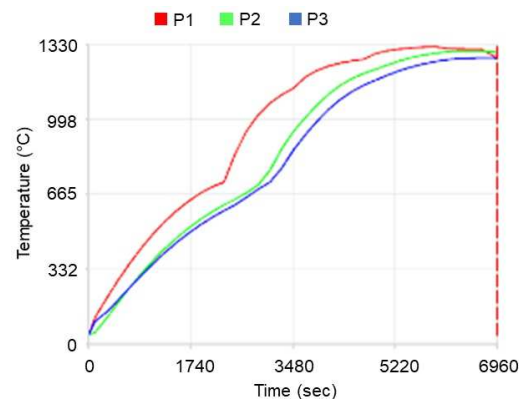


Figure 5 Heating of the billet in the rotary hearth furnace (output from the furnace)

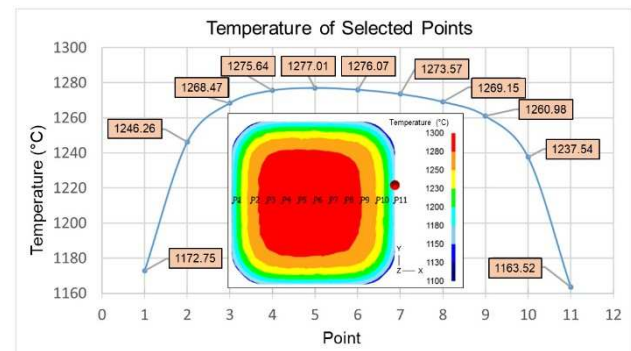


Figure 6 Temperatures in section before piercing

Heat dissipation to the conveyor rollers was not included in the models. For this reason, the border situation was also simulated, where directly before the piercing press the condition of difference approx. 50 °C on the sides of the billet was set (Figure 8).

The Figure 9 shows the entire piercing process of such a billet. A higher eccentricity is already visible here, where the deflection of the mandrel axis has reached a value of 3.9 mm.

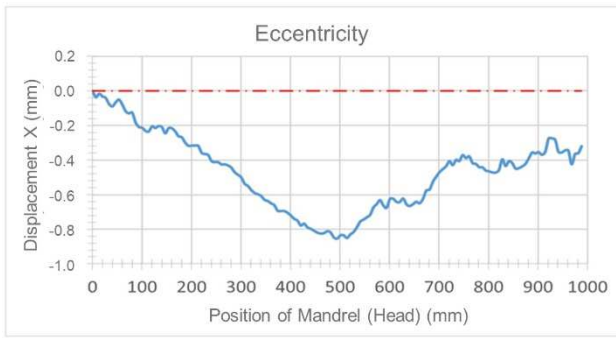


Figure 7 Eccentricity at the distance of the center of the mandrel head from the beginning of piercing (difference of 10 °C)

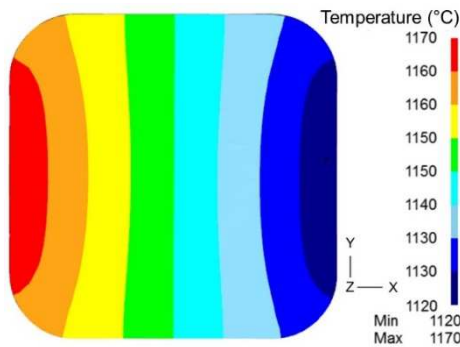


Figure 8 Temperatures in cross-section of the billet before piercing

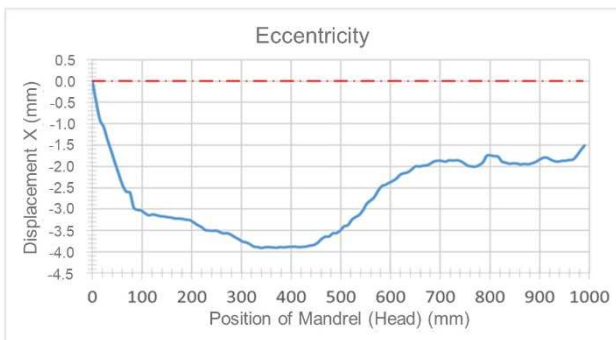


Figure 9 Eccentricity at the distance of the center of the mandrel head from the beginning of piercing (difference of 10 °C)

3.2 Off-Axis Centering

In this model, the charge was calibrated 10 mm more than the ideal calibration. This means that the diagonal of the billet was 10 mm less along its entire length, which allowed us to tilt the axis of the billet in the die by 0.7° relative to the axis of the mandrel (Figure 10). All previous operations before the piercing were included in the model. For the simulation, the charge had a constant temperature of 1260 °C before transport to the descaling. As can be seen from the course in Figure 11, the axis of the mandrel deviated to 5.3 mm at the beginning of the piercing. In the following course, the mandrel returned to its original value.

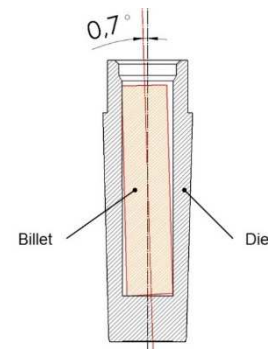


Figure 10 Informative example of charge (billet) tilt in the die

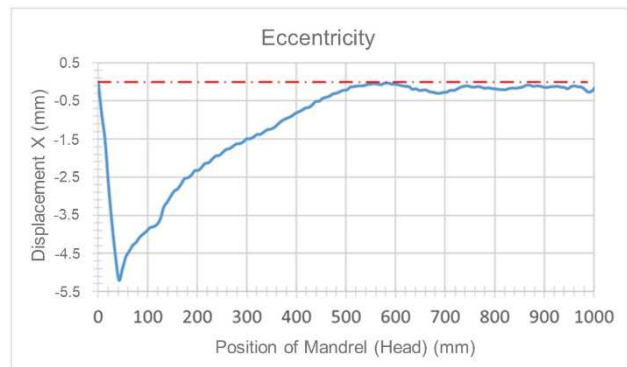


Figure 11 Eccentricity at the distance of the center of the mandrel head from the beginning of piercing (off-axis centering)

3.3 Cutting Surface

A billet model was created where one side of the billet was 10 mm longer, so a bevel was created on the top of the billet. For the simulation, the charge had a constant temperature of 1260 °C before transport to the descaling. As can be seen from the course in Figure 12 the axis of the mandrel deflected again to the value of 2.4 mm at the beginning of the piercing and in the following course the mandrel returned to its original value.

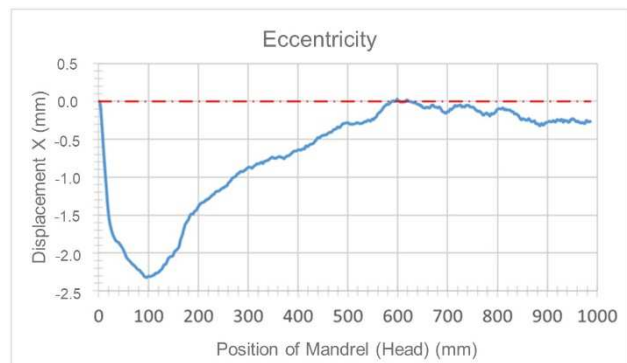


Figure 12 Eccentricity at the distance of the center of the mandrel head from the beginning of piercing (on cutting surface)

4 Conclusion

The simulations themselves were aimed at determining the individual effect of factors what (uneven heat distribution, off-axis centering, cutting surface) on the eccentricity creating. In real conditions, however, it is a combination of several factors on the resulting eccentricity.

Based on the achieved results, it is possible to state that the highest degree of off-centering of the mandrel (and thus the eccentricity creation) is mainly at the wrong centering of the billet in the die of the piercing press. Here, the feed of the mandrel compared to the piercing axis is up to 5.3 mm and the resulting eccentricity of the molding is at the level of 8.8% even in a small section of approx. 50 mm from the start of piercing. Also, the mandrel itself can partially eliminate this eccentricity in the upper part by further movement. Moreover, we cannot accurately assess this state of offset centering in real conditions.

The simulation of the uneven heat distribution at the cross-section of the billet did not show a significant effect on the eccentricity at difference of 10 °C between the lower and upper side after leaving the furnace. However, at a gradient of 1120 °C → 1170 °C (difference of 50 °C), the eccentricity on the molding reached 3.9 %. We assume that under operating conditions, this state can only occur if the billet is stayed on the conveyor for a longer period before piercing. The course between the simulations is similar, where the mandrel after the maximum deflection gradually returns approximately to the half position between the maximum deflection and the die axis.

In Table 2 are the results of the maximum eccentricity in the individual simulations.

Table 2 Eccentricity results for individual factors

Factor	Eccentricity
Uneven heat distribution	1.4 %
Uneven heat distribution at difference of 50 °C	3.9 %
Offset centering	8.8 %
Cutting surface	4.1 %

It is important to note that all piercing models in the simulation were set as the ideal state, i.e. ideal mandrel exactly in the middle of the axis without the possibility of tilting in the upper position and with regular running.

According to the obtained results and research findings presented in the paper, the installation of a measuring system for monitoring the off-centering the piercing mandrel in the piercing press would be appropriate to eliminate the eccentricity. Based on the measurement results, the piercing mandrel would be set up or replaced. A suitable solution for measurement could be the design of a non-contact measuring system for measure off-centering the piercing mandrel in the piercing press, what the authors of the article consider a reasonable future continuation of the work and research.

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