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straightening
modelling with FEM

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PROCEDURE TO IMPROVE THE UNDERSTANDING OF THE ROTATING STRAIGHTENING PROCESS

In industry wire is used for great variety of applications, such as cables, springs or nails. For many applications straight wires are necessary, e.g. shopping trolleys, dishwasher baskets or construction steel. Besides straightness these products demand specific characteristics, such as the structure of the metal or the residual stress.After being produced, wire is normally coiled up for better handling. For the following production process the wire has to be straightened and cut into pieces. Therefore, different technical processes such as roll straightening, straightening by stretching or rotating straightening are possible.Rotating straightening with its special characteristics is one of the least known straightening processes in science. At the time being, skilled experienced workers are necessary to adjust and control the process. For a scientific description of rotating straightening, parameters have to be identified.After defining such parameters, they are then used to assess the different settings of a rotating straightening machine in order to explain the physics of the process. Another possibility to describe the physics of the process would be through a model. All of this should make it possible to predict the quality of wire after straightening, reduce waste wire and accelerate the ramp up.

1. INTRODUCTION

Steel is an important material for industry and production and it is important in our everyday life. In the year 2009 32.7 million tons of steel where produced in Germany and 1.33 billion tons worldwide [1]. Wanzl, the world leader in producing shopping carts, has produced 2 million carts a year [2]. For those straightened wire is used. Also for the production of cable wire is needed. Modern architecture using construction steel and concrete needs straightened steel to get its resistance.

One possibility to straighten wire for these applications is “rotating straightening”. Today, skilled experienced workers are needed in order to adjust the rotating straightening process and to evaluate the quality of the produced beams. In order to improve this process, an FEM model of the process is being built. In this paper the straightening is described and the special characteristics of rotating straightening, followed by a short introduction of how straightness can be described and how it is measured. The paper focuses especially on the difference in the rotating straightening process compared to other straightening processes. Finally the model and the evaluation of the model are being described.

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2. DIFFERENT STRAIGHTENING PROCESSES IN PRODUCTION

In literature straightening is seldom described. Most publications describe roll straightening [3],[4]. For roll straightening /coils with different displacements $z_{1 \dots} z_n$ are arranged after one another (Fig. 1). The displacement is reduced in the direction of the wire ($z_n<z_1$)andthus the residual stress is minimized. Normally, the rolls are arranged in one or two directions (z,y-plane) and only rarely in more than two directions.

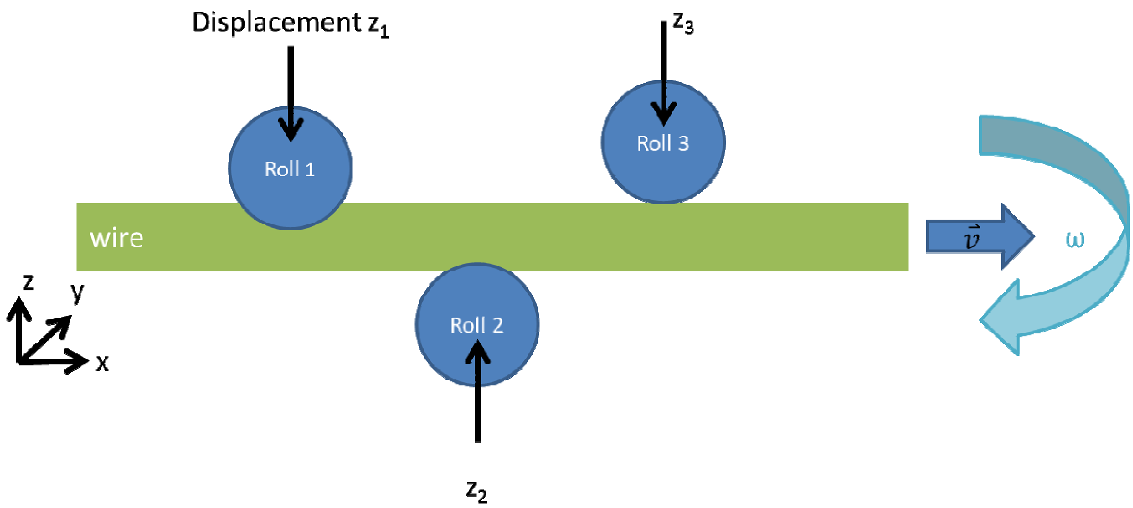

Fig. 1. Model process of straightening

This limitation of directions makes it harder to diminish the 3D residual stress condition. On possibility to reduce the 3D stress is to use rotating straightening. In this process the straightening tool rotates with ω around the wire, which has a speed in the axis of rotation of the tool. This makes it possible to diminish the 3D residual stress in the wire. It also causes a periodic geometry of the wire, which has to be taken into account, when deciding upon the measuring strategy for the wire.

3. METHODS TO MEASURE STRAIGHTNESS

In order to be able to define the wire and the quality of wire, straightness is the key characteristic. The current method is to rotate the wire with a one bearing and the hand on the other side and inspect the wire visually. This is used in order to inspect the large ripples. Another test is to touch the wire along its length and feel the short ripples. The third commonly used test is to roll the wire on a flat surface and inspect the smoothness of the motion.

In the GPS Standards there are different types of geometry definitions. The GPS Standards contain several standards on different geometries and how those are defined.

There is the raw and the fine geometry and under that there is gauge, shape, position, ripple and roughness (refer to Fig. 2). For straightness of wire, all the characteristics can be used.

Another possibility to characterize wire is given by [5].The standarddescribes the shape and position tolerances that can be specified in technical drawings. Some of these are straightness, circularity, cylindricity, profile of a line and concentricity. Some researchers in the area of straightening have also defined straightness. Behrens defined straightness in [3] as run-out in the boundary and middle of the sheet metal. Renz measured straightness in [4] by positioning the wire on two bearings and then measuring the maximum deviation from the ideal run-out by rotating the wire and measuring in the middle position of the wire with a dial gauge. He measured with different distances of the bearings. A similar method is used by Fangmeier [6].Menz [7] puts parts of sheet metal on a measurement table with a flat surface and measures the maximum height.

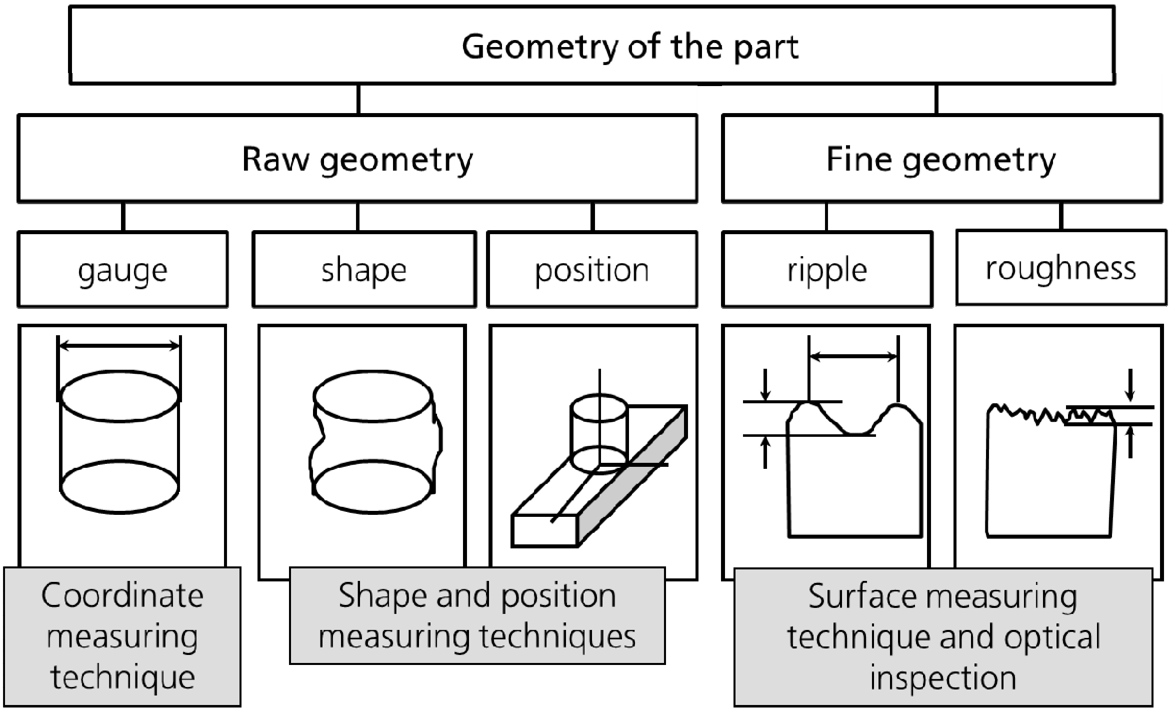

Fig. 2. GPS types of geometrydefinition

All these techniques only measure the maximum deviation from the ideal geometry of the wire or sheet metal. In order to be able to measure also the short ripples, a different approach will be used. There will be a characteristic number similar to the arithmetic average roughness Ra. Ra is defined as:

$$Ra = \frac{1}{lr}\int_{0}^{lr} |Z(x)|dx \tag{1}$$

lr is the length of the measured surface and Z(x) is the height of the surface features. For defining the wire, several measurement points along the length of the wire are set and the position difference to the ideal wire is measured. These measurement points are 1, 2, 3 …10, 20, 30…100,150,200,250, 300, 350. By the scaling of the measurement points and the increasing distance between points it is possible to detectperiodic events along the beam. With this characteristic number the wires will be characterized in short range ripple and long range ripple.

Fig. 3. Measurement device

This will be measured in a first step with a coordinate measuring machine and the device shown in Fig. 3. On the left hand side of the device the beams start in a given position and on the right hand side they end loosely. The coordinate measuring machine then starts with the first beam on the left side and works its way along the beam and then starts with the next one. The usage of an optical measuring technique makes it possible to measure the z, and y coordinate at the same time. After the measurements with the coordinate measuring machine, the possibilities of a faster measuring with optical methods and induction will be evaluated.

4. PROCESS DATA OF THE STRAIGHTENING PROCESS

In order to be able to predict the process there has to be an accurate model of the rotating straightening process. To describe a process the input parameters of the material going into the process and the parameters defining the processhave to be known.The results of the process are also given by various parameters; some of these concerning straightness have been mentioned previously.

The parameters on the input side of the rotating straightening process are the condition of the wire before straightening. The parameters describing the process could be the velocity of the wire or the rotational speed ω of the tool. And after the straightening, there are the output parameters e.g. straightness, stress or the surface of the wire.

In order to model the process correctly, it is necessary to validate the results from the following simulation with the results of experiments. For that reason, there are experiments taken out with a R23 rotating straightening machine from WAFIOS AG in Reutlingen. In a first step, there is a very rough experimental design, which will then be refined in the areas needed. For the rough experiments, many parameters concerning the settings of the machine will be used, with only a few settings. In order to minimize the experimental cost, design of experiments (DoE) is being used [8].

After the evaluation of these experiments it should be possible to decide upon the important parameters concerning the settings of the R23 and discard others. Also the rough experiments are carried out with a large sample size in order to be able to decide upon the needed sample size. For that the standard deviation σ can be calculated from the first tests. There after the confidence interval can be decided upon [9],[8]. Once these characteristics of the process are known, the needed sample size for a given confidence can be calculated.

After the parameters concerning the settings of the machine are defined, therelevant parameters defining the input and output of the process have to be identified. The input parameters cannot be taken into account. In daily use of the machines, it is not possible to monitor those parameters. The residual stress in the wire will change within a decoiler, as well as the ripple of the wire. The only parameter which can be taken into account for the input is the stress-strain curve, because it will not change with the decoiling of the wire. For the output the straightness and the changes in the stress-strain curve will be considered in a first step. The surface of the wire and the residual stress will not be monitored. The microstructure of the wire will be monitored for significant parameters, which lead to good straightening results.

5. RESULTS

The geometric model for the FEM modelling and simulation was built (Fig. 4). The tools have been implemented as rigid bodies and the wire with 3D continuum elements and reduced integration. The mesh was coarse compared to the measurement points of the coordinate measuring machine. A mesh evaluation will be taken out after more experimental results are available for comparison.

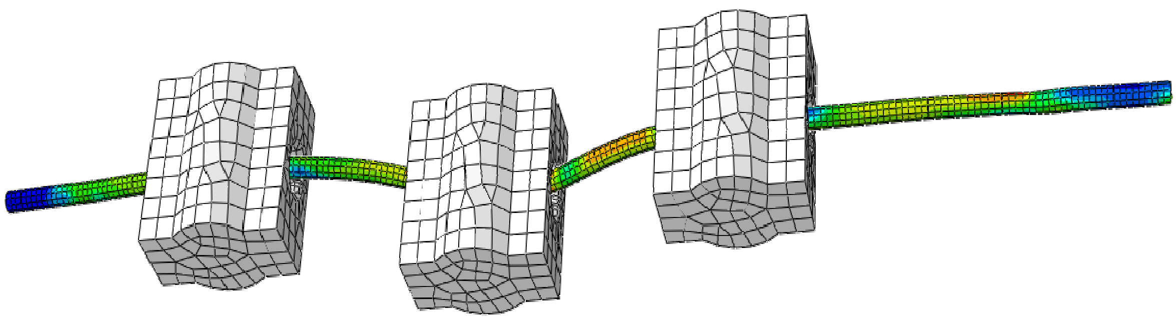

Fig. 4. First results from modelling

6. CONCLUSION

After the evaluation of the experiments, the model of the rotating straightening process can be compared to those results and adjusted. Parameters which will need adjustment are the stress-strain-curve and its change because of cold work hardening, the contact definitions and the mesh. For the mesh a mesh evaluation will take place in order to decide on the needed size of elements. An accurate model then makes it possible to simulate the different settings of the machine and predict the output parameters of the wire. In further developments this can be used to improve the adjustments in the rotating straightening machines and enable automation.

Also the data from simulation can be used for the processes adjacent to the rotating straightening.

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