Automated groove pass (pre-)design and optimisation of symmetrical and asymmetrical wires and profiles

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To understand the material flow and behaviour during the production of shaped wires different simulation approaches like the finite element method or the pillar theory [1-2] are available, the latter ones enables optimisation routines due to high accuracy and geometric flexibility at low computing speeds. Semi-automated optimisation programmes of the groove pass can only map the forward calculation process - the upstream backward design with an initial pass sequence is carried out using empirical manufacturing rules [3-5]. A numerical description of the groove contour is necessary and complicated due to the high number of degrees of freedom of the groove geometry. Within this work, model approaches for automated groove pass (pre-)design and optimisation are demonstrated. Based on rolling tests carried out in breakdown passes as well as selected asymmetrical shaped profiles, correlations have been investigated to obtain an automatic backward calculation and groove pass predesign. Mathematical design guidelines as well as different target intervals of relevant degrees of freedom, e.g. coefficient of elongation, their distributions and geometric values of the respective profiles, are derived which are used as boundary conditions for subsequent optimisation procedures. The challenges which arise due to the asymmetry of the profile contour are presented and considered for shape profiles. The methodology is shown by breakdown passes as well as for Z-profiles, whereby the approach can be transferred to other profiles.

KEYWORDS: ROD ROLLING, SIMULATION, GROOVE PASS DESIGN, COLD ROLLING, GEOMETRY MODEL, PYROLL

INTRODUCTION

The production of profile rod and wire is carried out by hot and cold groove rolling. In contrast to flat rolling there are additional challenges in the design of pass schedules for profile rolling due to the more complex geometric conditions in the roll gap which can only be solved at great expense without simulations. The classical process of groove pass design and pass schedule of irregular profiles is shown in figure 1. It can divide into two major phases: backward design (calculating from final shape to starting shape) and forward calculation (from starting shape to final shape). The steps of forward calculation are mainly addressed in common simulation approaches and programs (e.g. FEM-programs, PyRolL, MPC) and always presuppose an existing groove shape drawing which results from the previous backward design. Depending on the shape of the profile, there are various empirical rules and approaches for groove pass design to create the backward design mostly given as optimal parameter ran-

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ge. Examples for those approaches can be found for breakdown passes [7, 8, 9], angle profiles [10, 11], T-profiles [12, 13] or Z-profiles [14, 15]. Caused by the high individual effort needed to get the backward design (e.g. choice of initial values for degree of elongation, their distribution, groove types, geometric constrains) a direct integration of the backward design into the common simulation programs of groove rolling is challenging. Furthermore, due to numerical optimization calculations a complete numerical description of the shape contour is necessary which complements the design guidelines. Likewise, target intervals of relevant degrees of freedom, for example for the degree of elongation, their distributions as well as other geometric quantities of the respective profiles, are necessary for an optimization calculation. Although there are some efforts to semi-automated groove pass design and mapping of these steps with computer-aided systems, these are limited to restricted, rigid groove types [3, 4].

Within this paper, some aspects for an automated backward design are presented on the example of breakdown passes and irregular profiles. A fast, parametric geometry model is developed and the backward design is based on the degrees of elongation regarding information on their value and distribution.

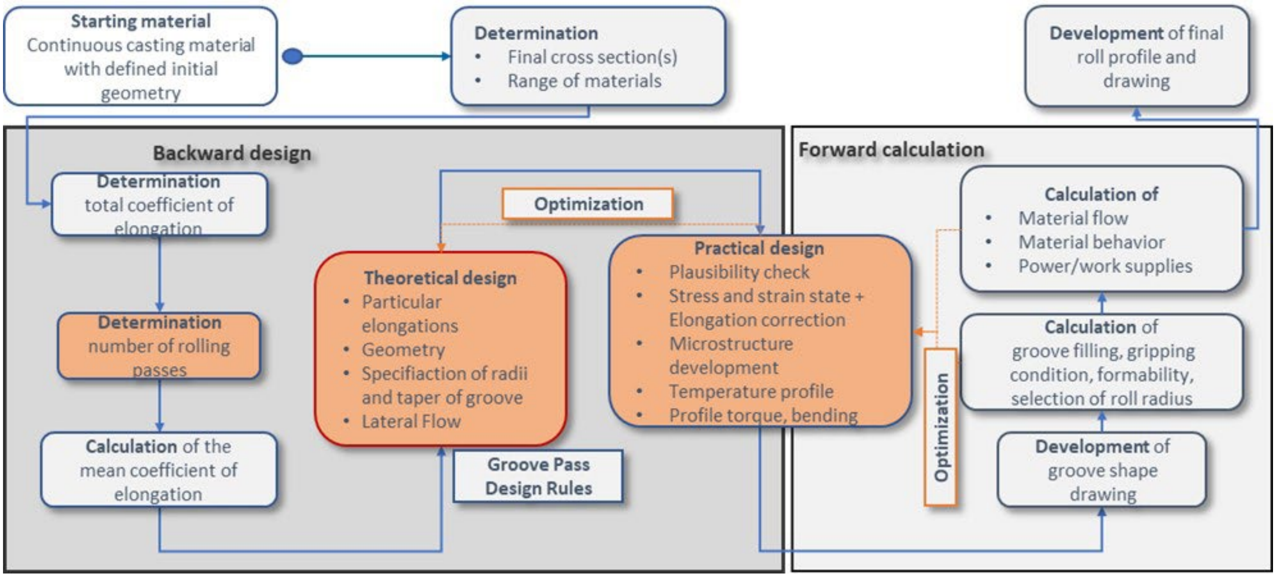

Fig.1 - Traditional process of groove pass design of irregular profiles, orange: steps with manual adjustment or decision by user, red: focus in this paper.

METHODOLOGY

In general, the backward design of groove rolling is characterized by some specifications noticed in figure 1. The final and starting geometry are crucial to know, moreover the material selection is needed as well as some basic information about the maximum possible degree of elongation λ, the distribution of λ over the rolling passes and the number of rolling passes. The backward design in general is strongly orientated on the degree of elongation, the total coefficient of elongation λ_{tot} is defined by the initial and final cross-sectional areas or by the partial coefficient of elongations of the individual rolling passes.

$$\lambda_{tot} = \frac{A_0}{A_n} = \lambda_0 \cdot \lambda_1 \cdot \ldots \cdot \lambda_n \tag{1}$$

With this information, the following basic steps can be down:

- Calculation of the end profile and their geometry, which is mostly given with its area and basic geometric sizes. A general profile contour with a parametrized geometry model is necessary.
- Calculation of the cross-sectional areas from the final profile back to the previous rolling passes due to knowledge of the λ_n and their distribution.
- Determination of the intermediate profile contours up to the initial profile on the basis of experimental data.

With the numerical depiction of these three steps an automated theoretical design is possible. Characteristic geometric parameters as well as requirements regarding the properties to be achieved are given as specifications for the profile to be produced. The results are an initial groove pass design and geometrical constraints due to the analysis of the experimental data. In addition, properties can already be specified here which, for example, are to be achieved by mandatory standard specifications. In the area of cold rolling this can be the strength, which is influenced by the material selection and the respective strain. These parameters can be used to calculate the strength.

APPLICATION ON BREAKDOWN PASSES

The design of breakdown passes has been addressed due to the use of regular and simple complicated groove forms and the symmetry that prevails with them by various authors [3, 4, 7, 12]. In addition to basic design guidelines, e.g. for the choice of individual groove geometries and the degrees of stretching as well as their distribution over the rolling passes, investigations are known. Furthermore, there are various simulation programs that allow an automated design of a backward calibration. The CARD program from Körmer [4] is worth mentioning. Moreover, several authors [15-17] developed parametrized geometry models for breakdown passes. The profile contour in this model is achieved by the interrelationships of the geometric sub-elements and is based on the free variables b_{kn}, b_d, b_d, d, i, α_1-α_4 and r_1 - r_4. Furthermore, various boundary conditions are given, which apply to these parameters as a result of achieving geometrically meaningful solutions. The advantage compared to a simple representation, e.g. by splines, is that individual limit values are clearly defined, which leads to variants that make sense from a rolling technology point of view.

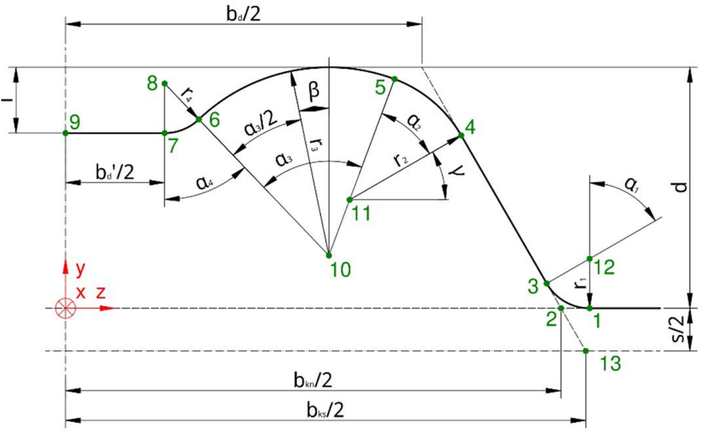

Fig.2 - Generalised model for breakdown passes [6].

APPLICATION ON Z-PROFILES

Z-profiles are complicated irregular profiles which are mainly used in rope production [18]. The rolling process is based on a round wire, which is cold formed into the final shape by groove rolling or drawing rolls. The groove pass design of Krautmacher [13] is generally used as a basis which allows production in four passes on the basis of empirical rolling tests. An industrial data set was generated in order to obtain a general geometry model for the profile contour and knowledge about the coefficient of elongation and its distribution over the rolling passes. The characteristic values of the head width K, the waist width N, the foot width F as well as the outer radius R_1 and the profile height H specified by DIN EN 10264 were examined. For the final profile contour, the centre of the coordinate system is determined by R_1, which marks the centre of the final rope. In addition, characteristic measures for the intermediate profiles with profile heights h_1 to h_6 were investigated which were used for backward calculation from the final contour to the previous rolling passes. The point of view for that former passes varies from the final profile. The profile height h is the sum of h_1 and h_6 and takes the maximum dimensions of the profile together with the profile breath b. Through nine arcs and three straight lines and their transition points a clear definition of the end profile can be made. Geometric constraints are to be defined at the transition points P01 to P13 in order to obtain geometrically reasonable solutions. Furthermore, boundary conditions result from the circle and straight line equations. These are used to create linear equation systems to get the x and y coordinates of the finale contour. This results in nonlinear systems of equations which are solved by applying appropriate optimization algorithm. Due to the circular equations there are multiple solutions when solving the systems of linear equations. In order to determine the correct solution in each case, the relative position of the coordinates to already known ones is considered. As an example, the value of the x-coordinate of P05 must be between the value of P03 and P01 (fig. 3). The y-coordinate has to be lower than the y-coordinate of P03 and greater than R_1-2·R_n. These boundary conditions are used by an algorithm to determine the right solution of the circular equations.

In order to be able to calculate back to the previous cross-sectional areas, the coefficient of elongation of the individual partial areas are required. The total coefficient of elongation is calculated with equation 1 and determined using the rolling trails. The largest average coefficient of elongation in the first rolling pass with $\frac{\lambda_1}{\lambda_{tot}}$ is 0.8, which is typical for shape profiles and reasonable due to the mass distribution with respect to the final shape to be achieved. These tendencies of distribution of coefficient of elongation can also be seen in other profile shapes. The extreme values can initially be seen as boundary conditions of the coefficient of elongation for an optimization procedure.

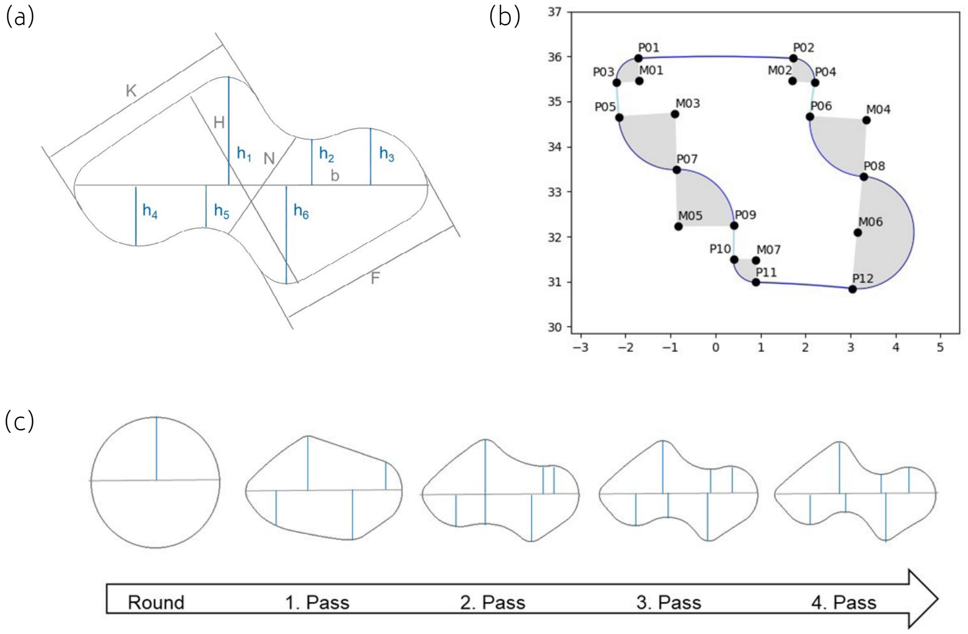

Fig.3 - a) generic geometric values of Z-Profiles for final and intermediate passes, b) contour of the final pass of Z-profile with geometric elements (dark blue: arcs, light blue: lines) and transition points (Pxx) and middle points of arcs (Mxx), c) pass schedule of Z-profiles oriented by Krautmacher [13].

To obtain equivalent initial values for the other passes, the geometric quantities h_1 to h_6 estimate as a function of the final cross sectional-area, so that an estimate of the geometric quantities can be made for the respective determined profile area on the basis of the coefficient of elongation. Correlations could be established with regard to the geometric description of the profile contours as a function of the profile sizes by measuring the data set. The initial round is described exclusively by the dimensions b and h, the first rolling pass requires only h_1 and h_6 as additional support points. h_2 to h_4 are mainly relevant for describing the construction at the tail which start to occur from the 2nd rolling pass. h_2 and h_5 become smaller with increasing number of passes since the web is formed out more and more. These correlation coefficients can be used to obtain a solution for backward design.

CONCLUSION AND OUTLOOK

Groove pass design of asymmetrical profile correlations with respect to the geometric design as well as the coefficient of elongation distributions are to be recognized for the necessary steps of the backward design. These can be made usable via sufficiently large test data sets and serve as a necessity to enable a complete numerical optimisation of existing groove passes with respect to material flow and material side criteria. For this purpose, a groove pass pre-design is requisite which is based on a parametric general geometry model for the respective profile shape as well as knowledge about the characteristics of the coefficient of elongation and their distribution over the rolling passes. A corresponding procedure for the design of the pass schedule has been carried out on the basis of the design of Z-profiles. A transfer to other profile shapes can be realized with corresponding data sets. The theoretical prediction can then be used as starting solutions for further forward calculation simulations in order to optimize various process- and material-related properties. An implementation of the geometric profile generation as well as the steps of the backward design is for example possible in the PyRolL project. This can further be used for optimization procedures which require fast models for different process and material criteria such as material flow, microstructure or mechanical properties. The further development of such models, specific solution algorithms and the extension of the methodology, presented here to other profile shapes, will be addressed by future work.

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