DETERMINATION OF PRESSURE DISTRIBUTIONS USING A GRADIENT BASED OPTIMIZATION METHOD AND APPLICATION AT FORMING TOOLS FOR HIGH GEARS

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1. Introduction

Gradient based optimization algorithms have found applications in many fields of science. In Mechanical Engineering it is common to identify unknown parameters of material models or to optimize the shape of structures. In this paper another application will be presented. Our research deals with the identification of the loads applied to a round rolling tool at a forming process basing on measured strains.

2. Round rolling of high gears

Round rolling is a favourable manufacturing process for helical gears (Fig. 1) if we compare it to cutting techniques. Very short processing time, no loss of material, no need for chip disposal and improved load capacity caused by contour-related fibre-orientation are only a few of its advantages.

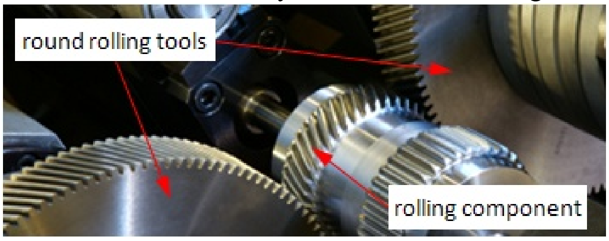


Fig. 1: Round rolling process

Within the research at Fraunhofer IWU the possibility to form helical gears with high teeth was found [1]. To increase the suitability of this rolling technique for commercial use, the process has to be stabilised. Questions like: "How do changes in feed rate, rotational speed or other machine-parameters affect the loads and the life cycle of the tool?" have to be answered.

3. Inverse strategy

The load identification we are presenting here is based on a fundamental assumption: We consider a linear elastic material behaviour of the forming tool. In this case the principle of superposition is valid.

Strain measurements $\boldsymbol{\varepsilon}_m$ are obtained from 20 strain gauges installed at a deformable measuring zone underneath the tool gearing (Fig. 2). Experimental setup and some experimental results are described in [2].

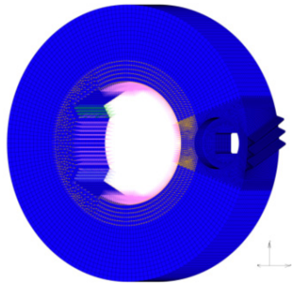
a)  b) 

Fig. 2: a) original round rolling tool, b) FE-Model

We designed a numerical Model with a regular element structure (Software: MSC.MarcMentat, number of nodes: 280000, number of elements: 290000). This model has to reflect the behaviour of the real tool with high accuracy. Using this model we perform a large number of FEM calculations to estimate the sensitivity between each measuring point and all potential discrete contact surfaces at the tool gearing (Fig. 3).

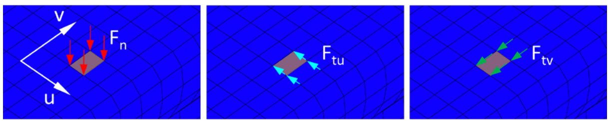


Fig. 3: potential contact surface with load F_n in normal direction and loads F_{tu} and F_{tv} in tangential directions

Thus we form matrices $\mathbf{C}_n$, $\mathbf{C}_{tu}$ and $\mathbf{C}_{tv}$ with calculated strains (in measuring direction) for each measuring point and three load directions (Fig. 3), where the rows indicate the u-location and the columns indicate the v-location of the potential discrete contact surface at the forming tool.

Another requirement represents an approach of the expected load distribution described as a function f($\mathbf{p}$) with free parameters $\mathbf{p} = (\mathbf{q},\mathbf{o})^T$. The load intensity is described with $\mathbf{q}$ and o is used to capture the load location. There will be more parameters if we consider the tangential loads too.

Having the matrices $\mathbf{C}_n$, $\mathbf{C}_{tu}$ and $\mathbf{C}_{tv}$ we can calculate strains $\boldsymbol{\varepsilon}_c$ corresponding to $\mathbf{p}$ at all measuring points (1).

$$\boldsymbol{\varepsilon}_c = f(\mathbf{p}, \mathbf{C}_n, \mathbf{C}_{tu}, \mathbf{C}_{tv}) \qquad (1)$$

To find the unknown parameters, we need to minimize the least square between calculated and measured strains (2).

$$\Phi(\mathbf{p}) = \| \boldsymbol{\varepsilon}_m - \boldsymbol{\varepsilon}_c(\mathbf{p}) \|^2 \rightarrow \min \qquad (2)$$

The in MATLAB implemented Levenberg-Marquardt algorithm is a convenient gradient based optimization tool to find a solution for this nonlinear inverse problem iteratively.

It's obvious that we have to solve an ill-posed inverse problem, if we consider the validity of the Principle of St. Venant. For this reason we need to stabilize the optimization by applying a suitable regularisation. We introduce a regularisation term to penalize to large load intensities (3).

$$\Phi(\mathbf{p}) = \| \boldsymbol{\varepsilon}_m - \boldsymbol{\varepsilon}_c(\mathbf{p}) \|^2 + \alpha \| \mathbf{q} \|^2 \rightarrow \min \qquad (3)$$

Fig. 3 shows the flow chart of the identification algorithm.

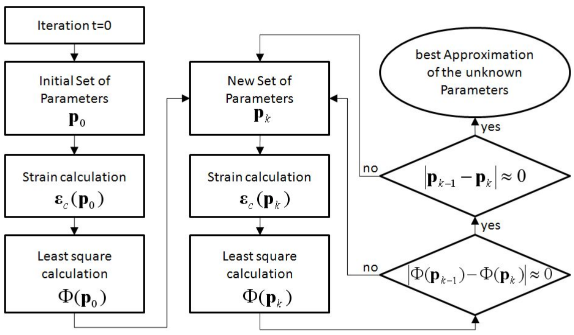


Fig. 3: Flow chart of the identification algorithm

4. Load identification

Let us illustrate the identification with a simple numerical example. We describe the expected load as shown in fig. 4 as piecewise linear function with three parameters for load intensity and two parameters for the u-location (v-location is constant). With this function we generate synthetic noisy measurements. Tangential loads are not considered. We start the identification with a chosen set of parameters. The first value of α is 1. To show the influence of α, we perform 30 single identifications and half the value of α after each identification. Fig. 5 shows the results of this procedure. The significant discontinuity in the average change of the unknown parameters after step 20 indicates the best solution with a value of $\alpha = 2 \cdot 10^{-6}$ at this step. The identified load matches very good with the applied load. If the influence of α is to big, the load distributes over a wide area of the tool gearing (Step 1). If α becomes to small (Step 25) we also can't find a proper solution.

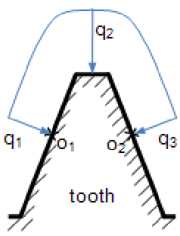


Fig. 4: Approach of the expected load distribution

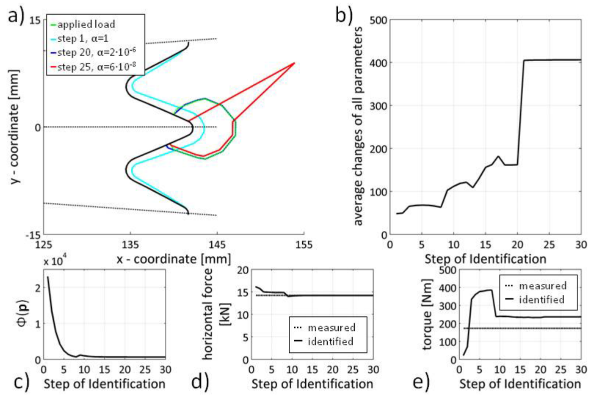


Fig. 5: Identification results a) load distribution for selected values of α, b) average changes of all parameters, c) Residual, d) horizontal force and e) torque for all values of α during the identification

It has to be pointed out, that the selection of the starting parameters has also influence to the found solution. A variation of the starting parameters and comparison of the calculated residuals leads to the best selection.

5. Conclusions

The independence of the actual load identification from time consuming FEM-forward calculations represents an advantage if we do parameter studies at a single tool with fix geometric properties. Once the sensitivity between surface and measuring points is estimated, the presented method is a very fast way for load identification concerning linear elastic components.

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References

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[2] Kretzschmar J., Experimental-Numerical Method to Determine the tool surface loads during the rolling process of gear wheels, 27th Symposium on Advances in Experimental Mechanics, Conference Proceedings, 2010