Experimental Validation of Cumulative Surface Location Error for Turning Processes

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Introduction

In the industry for production and manufacturing, turning is a widely used method. During this process, the manufactured surface differs from the desired one due to the so-called Surface Location Error (*SLE*), generated by the cutting force. Due to the fact, that *SLE* is relevant at finishing operations, its effect is usually neglected in the model of roughing operations, but despite this, it can has significant impact on the surface quality in case of consecutive immersions. We introduce a new type of surface error calculation which considers the effect of the series of *SLE*s during several consecutive immersion in roughing operations while the oversize of a workpiece is removed.

At every immersion, the machined surface differs from the desired one due to the *SLE*. The actual offset error SLE_i modifies the immersion at the subsequent immersion. This modified immersion generates different cutting force which leads another, modified offset error SLE_{i+1}. During this process, the *SLE* can be accumulated and leads to a new surface quality parameter denoted by the Cumulative Surface Location Error (*CSLE*).

Calculation of the *CSLE*

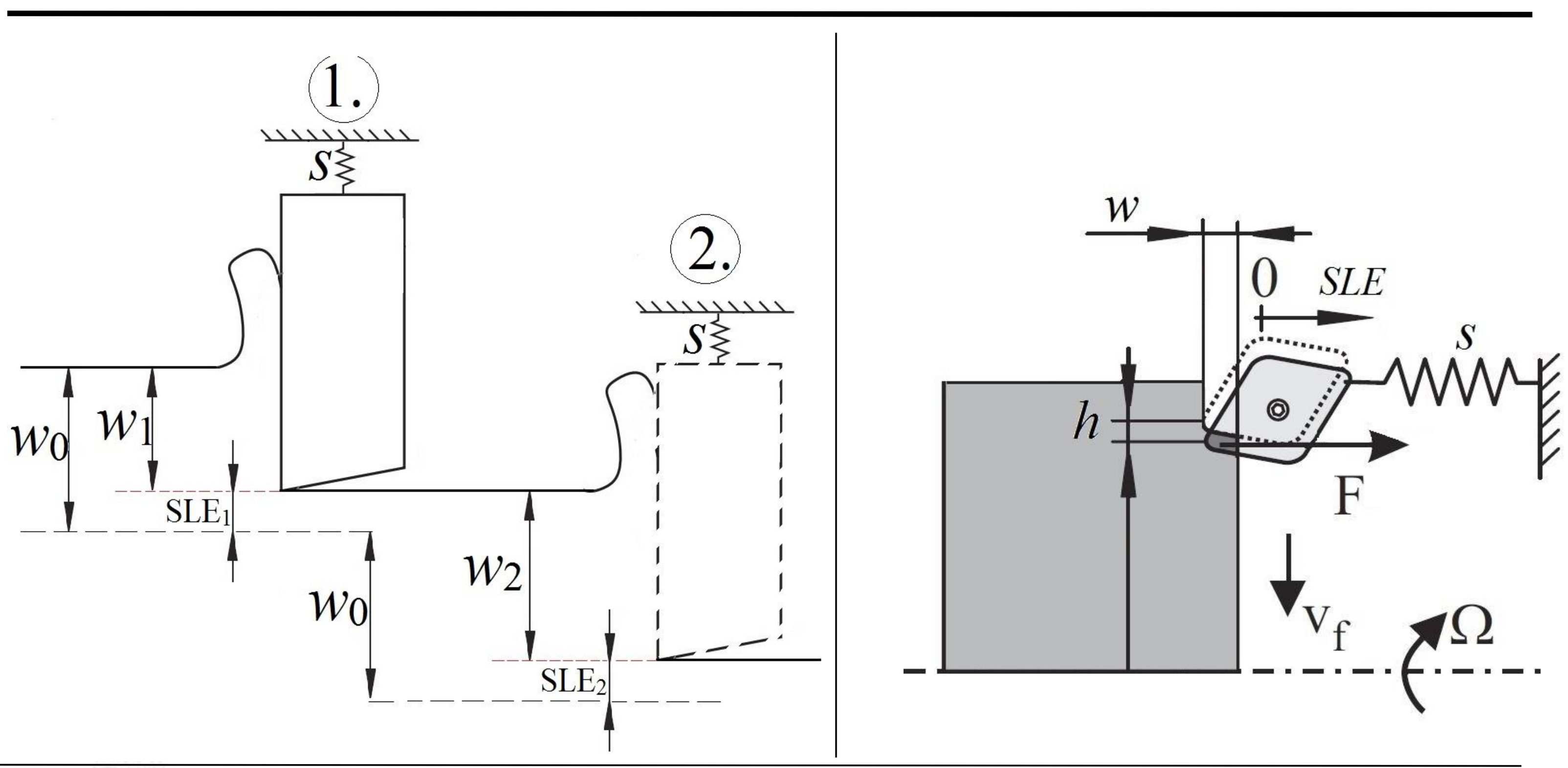
This phenomenon can be described as an implicit discrete map (Eq. 1) which describes how one *SLE* develops into another *SLE* over of a subsequent immersion. In the mechanical model, a Single-Degree-of-Freedom (S*DoF*) model is used, where the static displacement error – denoted by *SLE* – is generated by the *F* constant cutting force, presented in figure on the bottom.

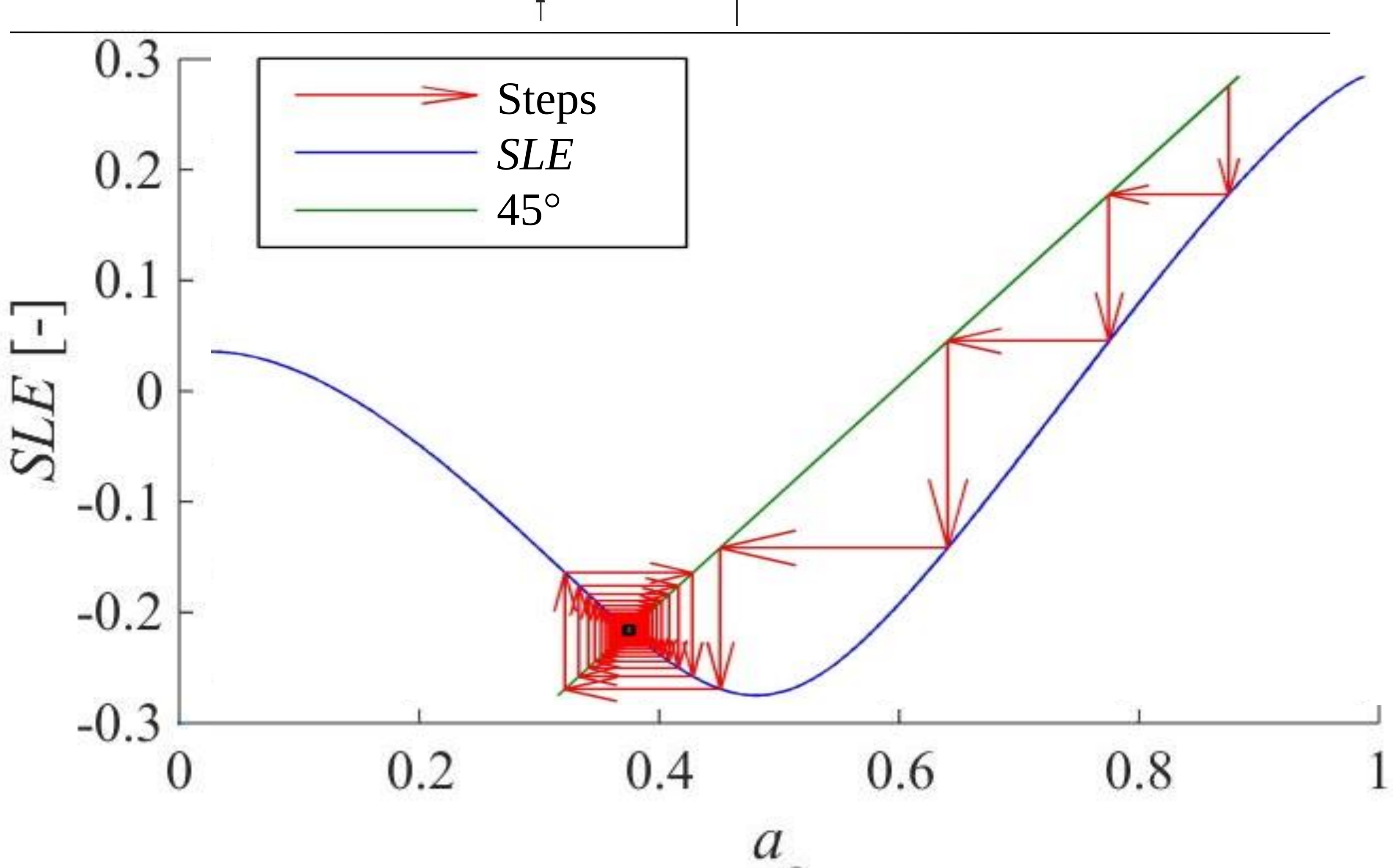
$$SLE_{i+1} = \frac{1}{s} F\left(w_{i+1}\left(SLE_i, SLE_{i+1}\right)\right), \qquad (1)$$

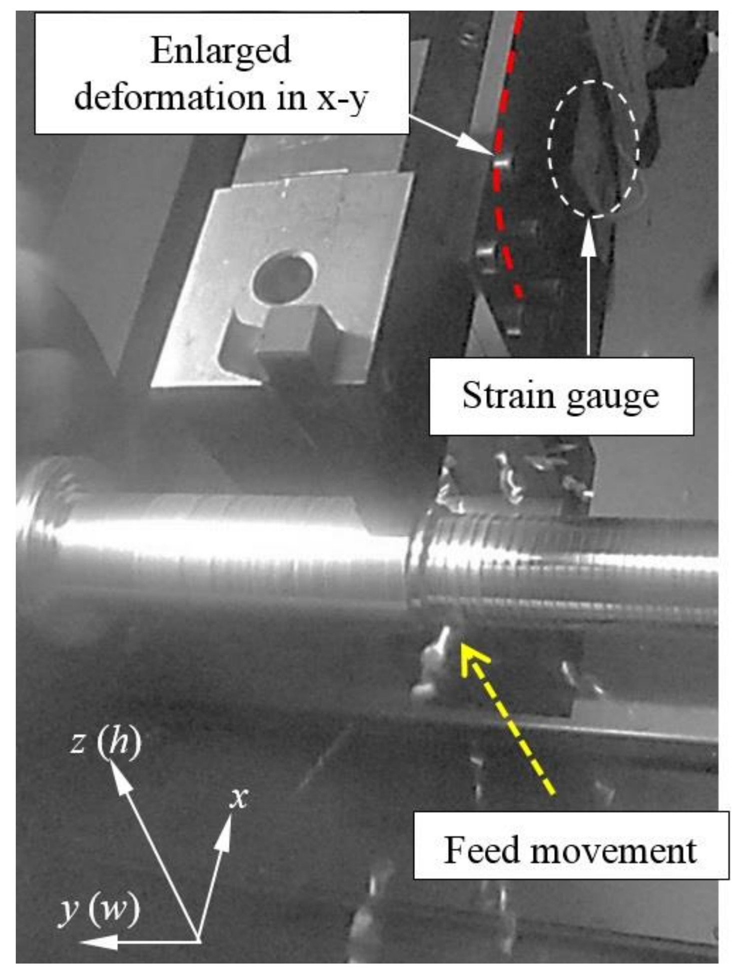
where, SLE_{i+1} and SLE_i represent the current and the previous generated *SLE*, *s* is the stiffness of the tool-holder, *F* is the applied force and the evolution of the width of the chip *w* is described as follows

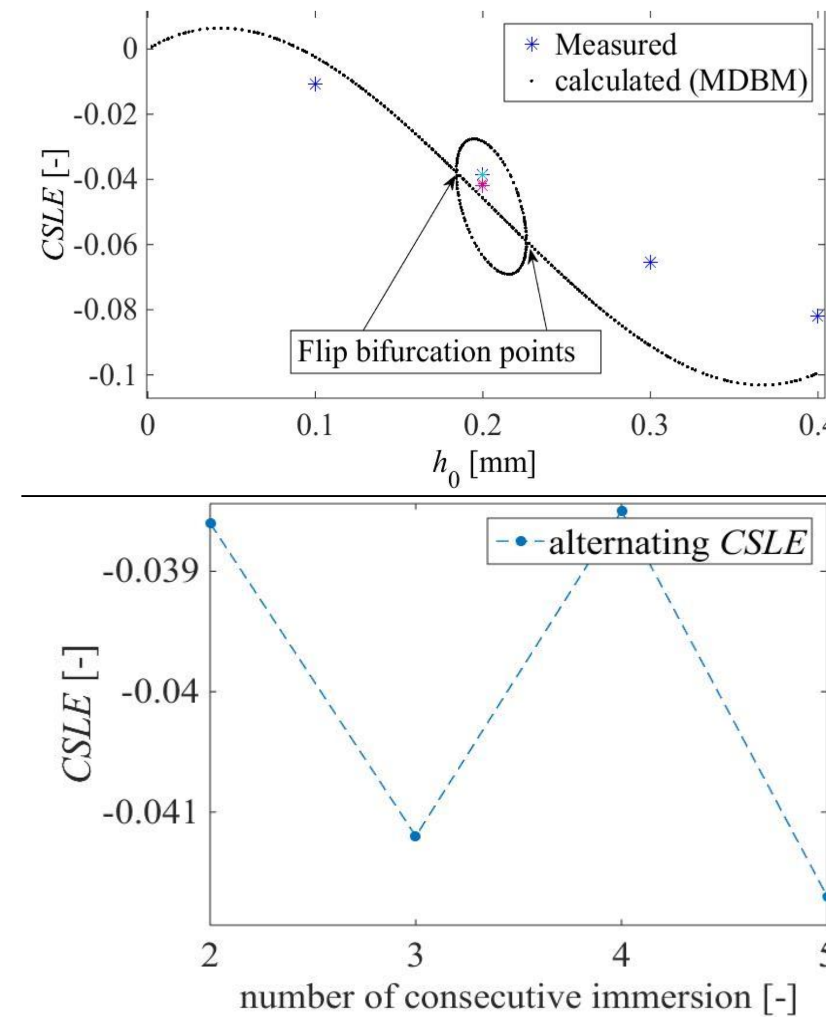
$$w_{i+1}\left(SLE_i, SLE_{i+1}\right) = w_0 + SLE_i - SLE_{i+1}, \qquad (2)$$

where w_0 is the pre-set width of cut, as shown in figure below.









The *CSLE* is defined by the fix points of the mapping (Eq(1)), detected by means of numeric iteration, as shown in figure on the bottom. For *CSLE*, Flip bifurcation is occurred at certain parameter points (for figure above: h_0 = 0.17 [mm], h_0 = 0.23 [mm]), where the stable solution becomes unstable and creates a periodic-2 solution. Between these parameter points, the series of *SLE* are not converged to a certain value, but it alternates around 2 values (see in figure above).

Measurement validation

For the validation of the theoretical results, a workpiece was machined in a 2 axes universal turning machine (GILDEMEISTER CTX – 420 linear) with a softened tool holder. The generated cutting force and the deformation along *z* direction were measured by means of strain gauges, as shown in figure on the top. The measuring instrument had to be calibrated for force and for deformation measurement. The stiffness of the softened tool holder (*s*) is determined by the measured forces and displacements values: $s \cong 600$ N/mm.

We carried out a series of test measurement at different turning process parameters. In a single test, 5 consecutive cuts were performed with fixed cutting parameters to investigate the development of *SLE*. A fitting method was applied based on the measured averaged cutting forces to determine the specific cutting coefficients of the widely used polynomial cutting force function.

The *CSLE* is calculated numerically from Eq. (1) for the fitted specific cutting coefficients and it is compared to the measured values.

Most of the cases, the series of deformations of one test are converged to certain value, which are in good correlation with the computed *CLSEs*. In the predicted parameter range of period-2 solutions, the series of the measured deformations shows alternating characteristic (figure on the top). We can state, that the predicted phenomenon is validated by measurements.

Conclusion

In the present study, we show a new type of stability problem, which can occur during roughing process. This *CSLE*-stability problem leads to an unpredictable final Surface Location Error, which can affect the finishing operation substantially. An experimental verification of the theoretical results was carried out in a softened machine tool environment, where correlation is found between the measured and the computed values.

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