Experimental Validation of Cumulative Surface Location Error for Turning Processes

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Abstract.
The aim of this study is to create mechanical model which is suitable to investigate the surface quality in turning processes, based on the Cumulative Surface Location Error (*CSLE*) [1], which describes the series of the consecutive Surface Location Errors (*SLE*). The stationary surface location error and its bifurcations were analysed. Experimental verification of the theoretical results was carried out.

Keywords: *surface quality, Surface Location Error, implicit map, flip bifurcation*

Introduction

In the machining industry, the oversize of a workpiece is removed with several consecutive immersions in roughing machining operations. At every immersion, the machined surface differs from the desired surface due to the Surface Location Error (*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 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 (*DoF*) model is used, where the static displacement error – denoted by *SLE* – is generated by the *F* constant cutting force, presented in Fig. 1.a).

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

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

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

where w_0 is the pre-set width of cut, as shown in Fig 1.b).

The *CSLE* is defined by the fix points of the map, detected by means of numeric iteration, as shown in Fig. 1.c). For *CSLE*, Flip bifurcation is occurred at certain parameter points (for Fig 2.b): 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 Fig. 2.c).

Measurement validation

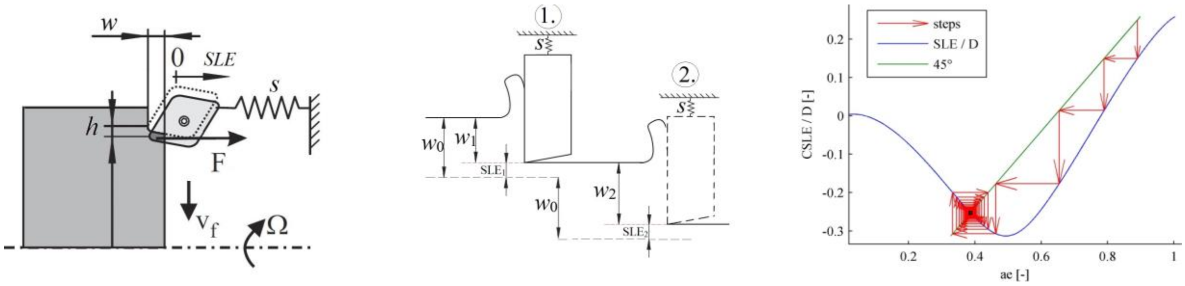
For the validation of the theoretical results, a workpiece was machined in a 2 axes universal turning machine (GILDEMEISTER CTX – 420 linear) with a softened tool holder. The generated cutting force and the deformation along *z* direction were measured by means of strain gauges, as shown in Fig. 2.a). 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 cut 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 [2].

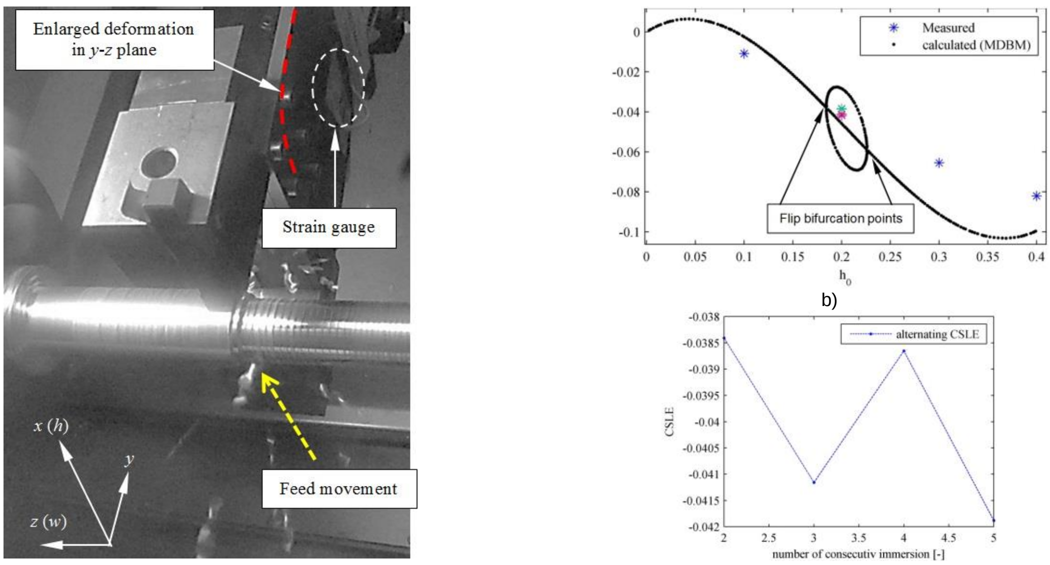
The *CSLE* is calculated numerically from Eq. 1. for the fitted specific cutting coefficients and it is compared to the measured values.

Most of the cases, the series 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 (Fig. 2.c). We can stat, that the predicted phenomenon is validated by measurements.



a) b) c)

Fig. 1 a) Single *DoF* turning dynamical model where, *h* is the chip thickness, v_f is the feed movement, Ω is the spindle speed, *F* is the thrust (passive) force; b) Evolution of the surface error in consecutive immersions; c) Detection of the fix point of the map (Eq.1.) by means of numeric iteration



a) c)

Fig. 2 a) Experimental setup; b) Calculated *CSLE* function and the measured displacements (blue stars denote the converged solutions; colored stars denote the period doubling characteristics); c) Measured period doubling characteristics; Parameters: w = 4 [mm], h_0 = 0.2 [mm]

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