HERZOG

Tool condition monitoring for precise evaluation of milling efficiacy

Abstract

Milling of the surface is an essential step in the preparation of QC samples for OES or XRF analysis. Wear of cutting tips can significantly impair the functionality of the milling process due to insufficient material removal and damages of the machined surface. This may have negative impact on the reliability and accuracy of analytical results. Based on thorough evaluation of the break-off edge of the cutting tips we show that the HERZOG TCM system efficiently monitors the functional state of the milling process.

Key words

• **Tool Condition Monitoring** • **Cutting tips** • **Milling** • **Optical Emission Spectroscopy**

Introduction

Surface machining is a critical step in the preparation of steel and iron samples for chemical analysis by means of optical emission (OES) or X-ray fluorescence (XRF) spectrometry. In many QC laboratories, milling is the preferred method of sample preparation and serves following purposes:

1. Removal of the outermost scale layer of the sample (thickness 10 µm): The oxidation layer forms after unpacking the sample from the sampler mold due to the direct contact of the hot sample surface with air (Figure 1).
2. Removal of the non-representative layer (thickness 0.3-0.6 mm) beneath the scale layer: This layer is characterized by segregation as a result of so called asymmetric solidification. During solidification of the liquid steel sample, decomposition of the elements occurs due to different solubility of the alloy elements in the solid and liquid phase. The element decomposition usually remains after complete solidification and represents permanent inhomogeneities in the chemical composition of the sample. In general, these inhomogeneities have major impact on the material properties and potentially lead to inconsistent and non-representative analysis results. Just below this layer a representative sample layer is available which is appropriate for chemical analysis.
3. Creation of a geometrically uniform analysis surface: This is of prime importance to provide consistent OES results from different spark

points on the same sample. Furthermore, the quality of the sample surface has to remain stable over time to allow interindividual comparison of analysis results.

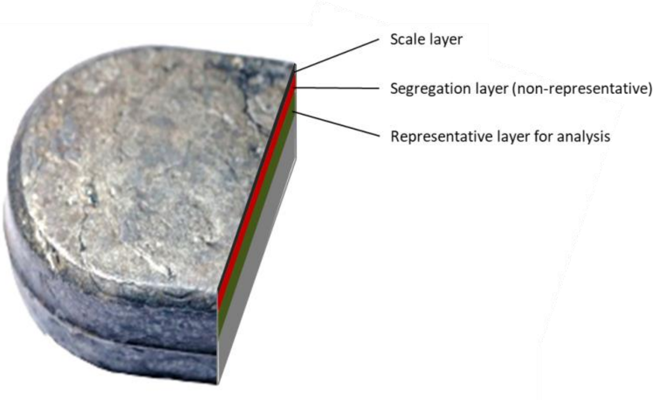

Figure 1: *Schematic layout of layers in a production sample used for QC. In order to receive reliable analysis results, the scale layer and the non-representative layer beneath have to be removed by milling.*

The impeccable functional state of the milling tool is a precondition to fulfill the abovementioned targets and create a surface suitable for analysis. The most important factor compromising functionality of the milling tool is wear of the cutting tips. Most commonly, wear results from abrasion of the cutting edge of the milling tip (so called flank wear) leading to damage of the machined surface and reduced dimensional accuracy. At worst, material removal becomes insufficient and eventually fails to uncover the representative sample layer. As a consequence, this may significantly jeopardize analytical accuracy and precision.

Usually, by using milling heads with several cutting inserts, more than one cutting tip contributes to material removal. With ongoing wear, it is fundamental that at least one cutting tip remains operable to guarantee sufficient material removal. In case of round cutting tips, full functional capability is only given if the maximum diameter at the friction point between tip and material is maintained (Figure 2 A).

The tool condition monitoring (TCM) system of the HS-F1000 milling machine uses vibration and torque of the spindle to supervise the wear of the milling tips (Application Note 14/2017). In this study, we investigated whether the parameters of our TCM system provide information sufficient enough to specifically evaluate the functionality of the milling process.

Methods

We used the HERZOG machine model HS-F1000 for milling of production samples from a German steel plant. The samples were of various hardness. We performed 9 milling cycles with an average of 150 milling operations (range from 30 to 438, total milling operations 1351). The life time of the cutting tips and consequently the number of milling operations in each cycle depended from the hardness of the samples. We used a milling head with four cutting items (Sandvik Coromant R200-068Q27- 12L). Milling parameters were kept constant with spindle speed of 1000/min, milling depth of 8/10 mm, and milling head advance of 800 mm/min.

The TCM module of the HERZOG PrepMaster Analytics software was applied to record vibration and torque. All data were automatically normalized to values between 0.0 and 1.2. Simultaneously, we assessed the frontal view of all four cutting tips by standard photographic procedure (Figure 2).

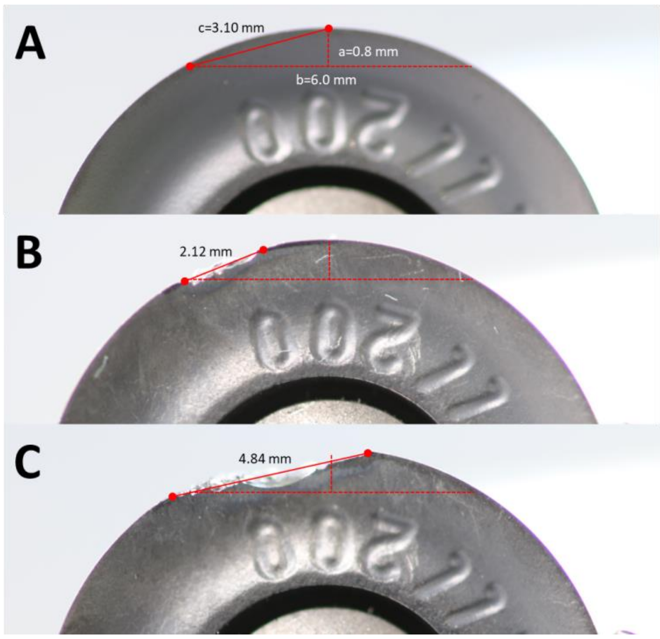

Figure 2: *Evaluation of the length of the break-off edge of cutting tips.*
A: *Line a: Cutting depth of 0.8 mm, line b: baseline of the sector of the cutting tip involved in milling, line c: length from baseline to maximum of sector circumference*
B: *Break-off edge not affecting maximum of sector*
C: *Break off edge exceeding maximum (insufficient cutting tip)*

In each photograph, we measured the length of the break-off edge of each cutting tip. In all cases, wear of the cutting tips started on the side turned towards the sample (i.e. left of line a, Figure 2 B). From here, wear propagated medially and laterally until the maximum of the cutting sector was reached (Figure 2 C). At this point, the length of the break-off edge usually exceeded 3.1 mm.

As a consequence, the cutting tip was regarded as insufficient because it did not contribute to the complete removal of the aimed cutting depth of 0.8 mm (Figure 3).

We correlated the total length of the break-off edges of all four cutting tips with the normalized vibration. Furthermore, we calculated the mean vibration value with respect to the number of insufficient cutting tips.

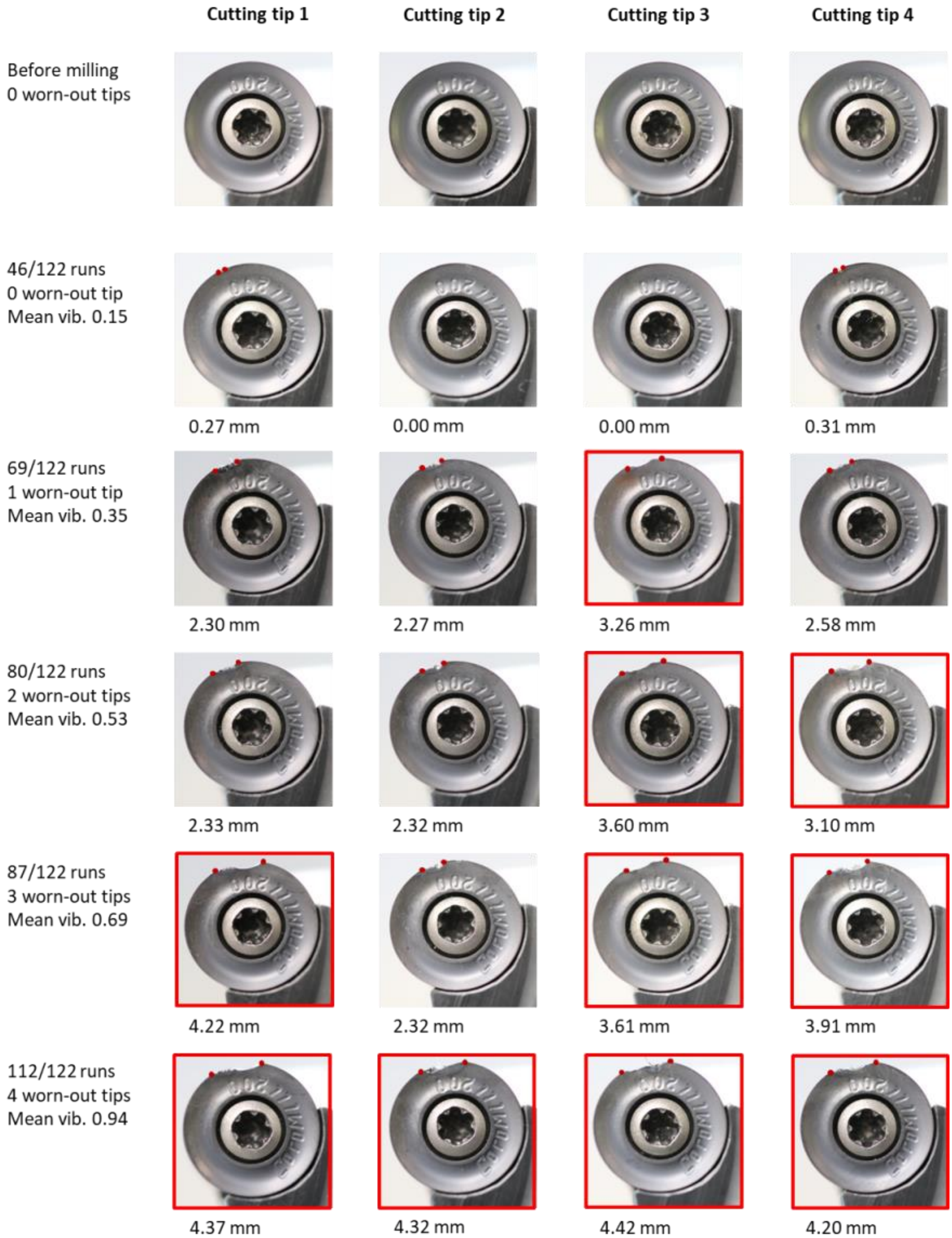

Figure 3: *Example for evaluation of functional state of cutting tips within one milling cycle. The cutting tip was regarded worn-out and insufficient as soon as the break-off edge was longer than 3.1 mm and exceeded the maximum point of the cutting sector (marked by red border). The mean vibration value was calculated for each stage with the respective number of insufficient and worn-out cutting tips.*

Results

We found a significant relation between vibration and torque measured in the TCM system and the total length of the break-off edge (shown exemplarily in Figure 4)

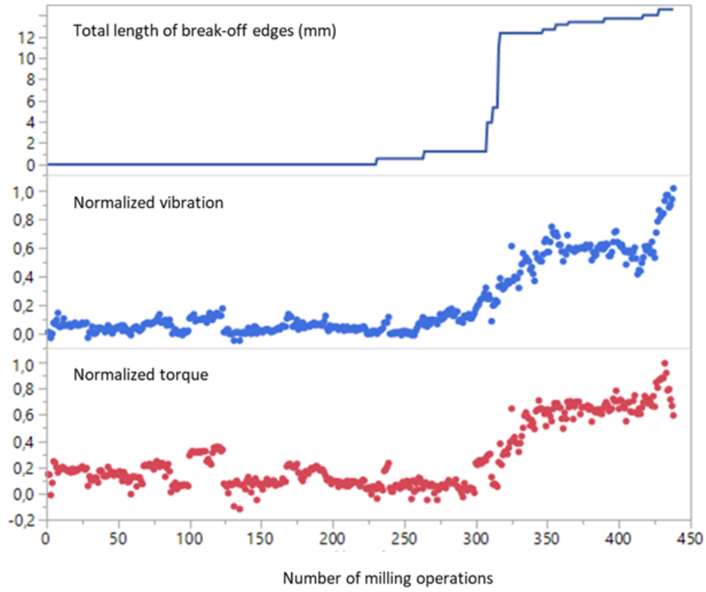

Figure 4: *Example of development of vibration and torque in relation to the length of break-off edges. Please note the significant increase of torque and vibration at the end of cycle which is due to functional impairment of the last cutting tip.*

Pearson analysis revealed a significant correlation between the total length of the break-off edges of all four cutting tips and the normalized vibration (r=0.817, P<0.0001, Figure 5).

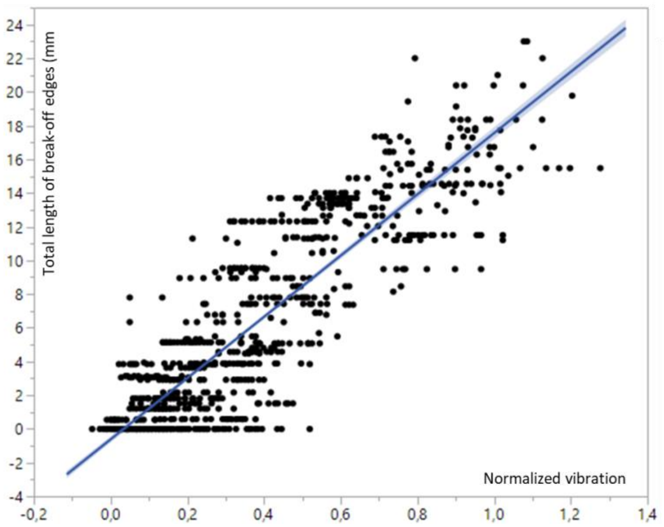

Figure 5: *Correlation between total length of break-off-edges of all four cutting tips and the normalized vibration*

Furthermore, we obtained a dependency of the vibration value from the number of insufficient cutting tips. The mean vibration value was 0.144 ± 0.005 (standard error) for nil insufficient tips, 0.307 ± 0.016 for one, 0.522 ± 0.021 for two, 0.644 ± 0.016 for three, and 0.896 ± 0.016 for four. All mean vibration values were significantly different from each other (one way ANOVA, P<0.0001, Figure 6).

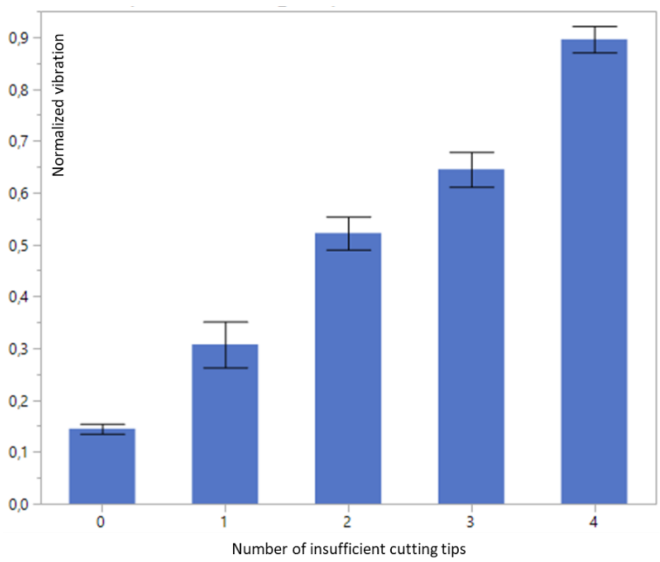

Figure 6: *Mean normalized vibration (± standard error) for milling operations with increasing number of insufficient cutting tips.*

Discussion

The results of this study show that measurement of vibration is a sufficient key performance indicator for monitoring the functional state of the milling process. The TCM system clearly indicates the End of Life (EoL) condition, i.e. when all cutting tips are in the state of insufficient functionality. This is also supported by the finding that in all milling cycles the EoL condition was associated with an insufficient material removal (i.e. decrease of cutting depth by at least 0.2 mm, data not shown). Moreover, the TCM system provides the operator with an easy and fast overview about progress of cutting tip wear for each milling head in the machine. For example, a steep ascent of vibration early in the course of a milling cycle strongly indicates a reduced life expectancy of the cutting tip set (data not shown).

As the TCM system is embedded in the PrepMaster (PM) software, recognition of an EoL condition can trigger a fully automatic change of the milling head without need of intervention by the operator. Furthermore, the PM Analytics allows an automatic evaluation of the tool life over a long period and optimization of milling parameters or equipment.

A high signal-to-noise-ratio is inevitable to detect subtle changes in vibration and torque. Therefore, interfering influences from vibration of the machine frame have to be avoided. The high predictive power of our TCM system is only made possible by the excellent damping features of the mineral cast frame of the HS-F1000. At the same time, the damping features significantly increases durability of the cutting tips (Application Note 13/2017).

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