# Tool condition monitoring of cutting tips used for milling on non-ferrous samples


## Abstract

The wear of cutting tips may have adverse effects on the preparation and analysis of non-ferrous quality control samples. Here, we describe a novel approach of tool condition monitoring (TCM) in the milling machine HN-FF using spindle torque and vibration as indicators of the wear of the cutting tips. In worn cutting tips, vibration increased from 8.72 ± 0.25 mm/s to 9.81 ± 0.21 mm/s while torque increased from 2.23 ± 0.06 Nm to 2.46 ± 0.05 Nm. Both changes were statistically significant ($P<0.001$, student's t-test). Data collection and evaluation was done automatically by the PrepMaster Analytics software package.



## Key words

• **Tool Condition Monitoring** • **Milling** • **Non-ferrous samples** • **Cutting tips** • **Inserts**


## Introduction

For chemical analysis of metal samples using optical emission (OES) or X-ray fluorescence (XRF) spectroscopy, it is necessary to prepare the sample surface by grinding or milling. During the milling cycle there is inevitably wear of the cutting tips on the milling head leading to degradation of their cutting edges. The integrity of the cutting tips is absolutely essential in order to achieve the targeted milling depth and to reach the representative layer within the sample. If all inserts of a milling head are worn the reliable processing of the sample material is no longer ensured. This may have a negative impact on the analytical procedure.

We have previously launched a novel approach for tool condition monitoring (TCM) of cutting tips in milling heads used for sample preparation of steel and iron samples. The technology is based on the recording and evaluation of vibration and torque of the milling spindle. Based on the combination of both parameters it is possible to continuously supervise the functional condition of the milling head and to exactly determine the point in time when cutting tips have to be changed.

In this application note we demonstrate that the same method is also capable of monitoring the functional state of cutting tips used for milling of non-ferrous samples. The TCM technology was set up in the newest model of the HN-FF, the automatic milling machine for non-ferrous samples. After adaption to the specifics of non-ferrous machining we assessed the effectiveness of the TCM approach in milling of aluminum samples.

## Methods

We used the Herzog milling machine model HN-FF newest version released in 2020 (Figure 1).

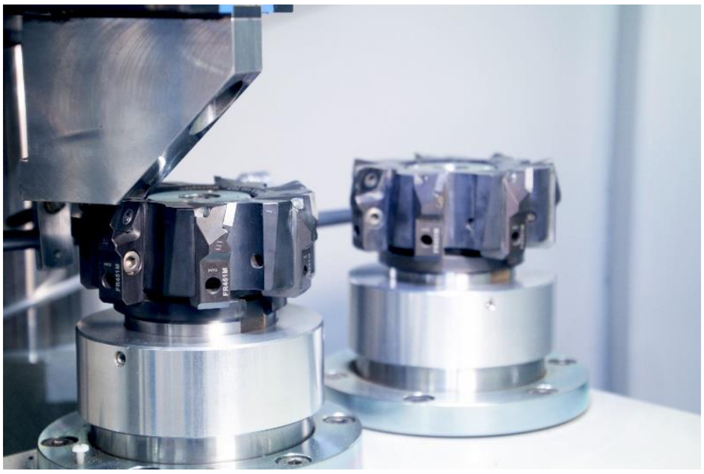

**Figure 1:** *Milling heads within the milling chamber of the HN-FF machine. The left spindle is used for coarse milling of the sample, the right for fine milling and finishing of the sample surface.*

The machine was equipped with the TCM package allowing the simultaneous recording of the vibration and torque of both milling spindles of the machine (Figure 2).

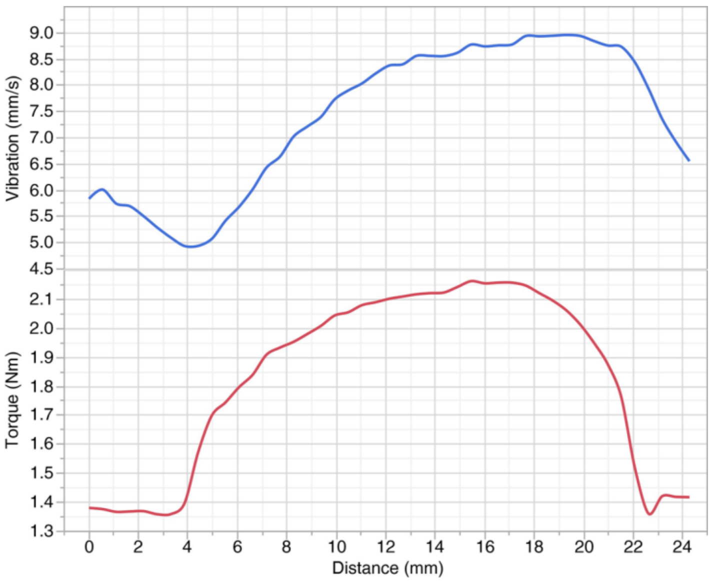


**Figure 2:** *Typical example of the course of vibration (upper graph, blue line) and torque (lower graph, red line) during one milling cycle. This example shows the grinding of an aluminum sample in the HN-FF.*

The machine was equipped with the TCM package allowing the simultaneous recording of the vibration and torque of both milling spindles of the machine (Figure 1). In this application note we only report the data recorded from the spindle used for fine milling of the sample surface. The data was collected, displayed and evaluated by the TCM module of the PrepMaster Analytics software.

For all milling cycles, we used the standard Herzog face milling cutter with seven teeth. We processed aluminum samples with a diameter of 50 mm using a rotation speed of 3000 rpm, a feed rate of 300 mm/min and a cutting depth of 1 mm. All milling parameters were kept constant during all subsequent trials. For this study we milled approximately 9.000 samples using the same set of cutting tips without changing or rotating one or more inserts.

At regular intervals we measured the roughness of the sample surface after milling. For this purpose we used a digital microscope (model VHX 950F, Keyence, Germany) allowing the automatic measurement of the area roughness value Sa. In each measured sample, the Sa value was determined at the three separate 1 mm2 square areas located at identical positions (Figure 3). Subsequently, the mean average of the three values was calculated.

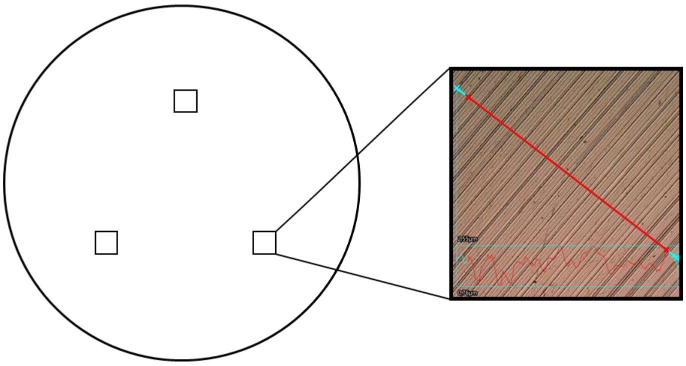

**Figure 3:** *The roughness of the sample surface after milling was measured at regular intervals. We assessed the roughness Sa values by using a digital microscope. The roughness was always determined in three identical positions by measuring an area of 1 mm$^2$. Subsequently, we calculated the mean of the three values.*

## Results

During milling of approx. 9.000 aluminum samples we found a continuous sigma-shaped increase of both the vibration and torque values. Using new cutting tips, the mean vibration value ± standard deviation of the first 100 milling trials was 8.72 ± 0.25 mm/s. The mean torque of the initial 100 milling trials was 2.23 ± 0.06 Nm (Figure 4, left). After approx. 9.000 milling trials an experienced user decided that the wear has progressed to the point where the cutting tips needed to be replaced. For the last 100 milling trials before change of the cutting tips, the mean vibration increased to 9.81 ± 0.21 mm/s. Simultaneously, the spindle torque went up to 2.46 ± 0.05 Nm (Figure 4, right). Both for vibration and torque, the differences between the initial and last trials were statistically significant (P<0.001, student's t-test).

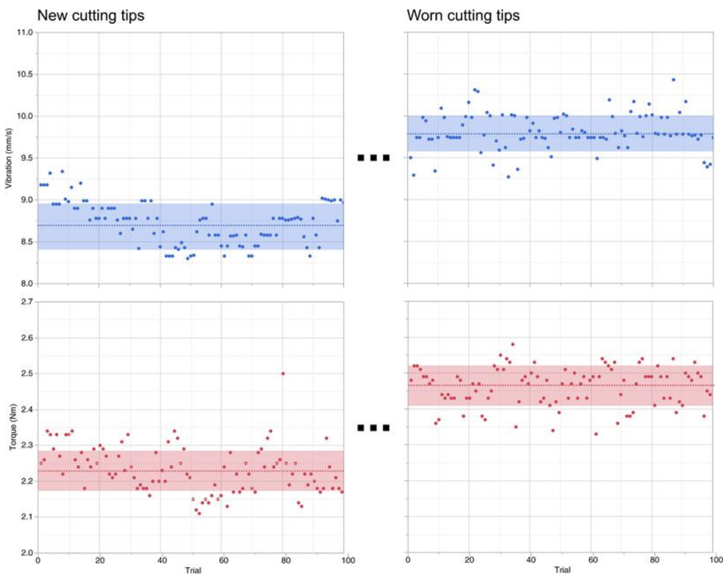


**Figure 4:** *The graph shows the vibration (blue) and torque values (red) during milling with new and worn-out cutting tips. The dotted line indicates the mean average of values while the shaded area indicates the standard deviation. The differences of vibration and torque with new and worn-out cutting tips were significant (P<0.001, t-test).*

The surface roughness as measured by the Sa value increased from 0.92 ± 0.02 µm to 1.27 ± 0.05 µm (Figure 5). This difference was significant (P< 0.001, student's t-test). More importantly, we observed a substantial build-up of burrs at the sample edge during the last milling trials (Figure 5, photographs). This burr formation was so prominent that it might have interfered with the analysis using a spectroscopic instrument.

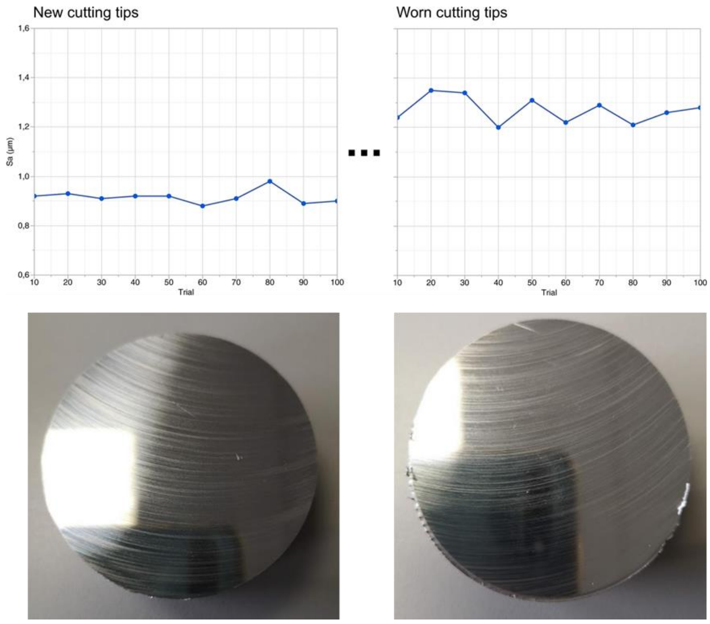


**Figure 5:** *The upper row shows Sa values of the sample surface after milling with new (left) and worn-out cutting tips (right). The lower row show typical photographs of samples after milling. The right sample shows marked burr formation due to the wear of inserts.*

## Discussion

The results of this study show that the wear of the cutting tips during milling of non-ferrous samples is clearly reflected by the increase of vibration and torque of the spindle. The difference between new and worn cutting tips is highly significant and enables an automatic supervision of the level of wear by a TCM algorithm.

As expected the increase of vibration and torque during milling of aluminum was not as pronounced as during milling of steel and iron samples. As shown in the steel milling machine HS-F 1000, the final stage of the cutting tip wear is associated with a 3fold increase of vibration and 30% increase of the torque. By contrast, in the recent study of aluminum samples, the outworn cutting tips led to an increase of the vibration by only 12 % and of the torque by 13 %. However, due to the small variability of the measurements, these differences were still highly significant and allowed a clear-cut distinction between usable and worn cutting tips.

The increase of the vibration and torque values was paralleled by a decline of the surface finishing as measured by the roughness. However, even with worn milling tips the increase of the Sa from 0.92 µm to 1.27 µm was only modest. Accordingly, the surface of the sample was still in the quality range of fine polishing being fully acceptable for OES or XRF analysis. The main problem arising from worn cutting tips is the formation of burrs impeding the appropriate sample handling within the analytical instruments. Therefore, close monitoring of the state of the cutting tips is absolutely necessary to guarantee a smooth and efficient analytical process.

The durability of the cutting tips used for aluminum is significantly longer than for steel or iron samples. The difference in lifetime is mainly attributable to the various hardness of ferrous and non-ferrous samples. This is also reflected by the difference in wear patterns during milling of steel and aluminum samples. In steel, the wear pattern is usually sigma-shaped. Already after the first milling cycles, vibration and torque slightly increase due to minor damages of the cutting edges of the milling plates. The initial increase is followed by a longer phase of constant vibration and torque values without a significant progress in the cutting edge damage. At the end of the lifetime of the cutting tips, vibration and torque values usually show a sudden and prominent incline. The final phase is initiated by a rapid break-off of one cutting tips which results in cascading damage to the other cutting tips of the milling head.

In comparison, the milling tips used for non-ferrous samples display a gradual degradation of the cutting edges without major outbreaks. Another damaging mechanism is the progressive formation of built-up edges interfering with the milling performance of the cutting tips. Correspondingly, vibration and torque increase continuously with the number of milling operations. If vibration and torque exceed their specified limits this is a clear indication that a tool change must take place. Using the PrepMaster Analytics, the operator can precisely monitor the degree of wear using vibration and torque as key performance indicators and plan appropriate maintenance work.


**Germany**

HERZOG Maschinenfabrik
GmbH & Co.KG
Auf dem Gehren 1
49086 Osnabrück
Germany
Phone +49 541 93320
info@herzog-maschinenfarbik.de
www.herzog-maschinenfabrik.de

**USA**

HERZOG Automation Corp.
16600 Sprague Road, Suite 400
Cleveland, Ohio 44130
USA
Phone +1 440 891 9777
info@herzogautomation.com
www.herzogautomation.com

**Japan**

HERZOG Japan Co., Ltd.
3-7, Komagome 2-chome
Toshima-ku
Tokio 170-0003
Japan
Phone +81 3 5907 1771
info@herzog.co.jp
www.herzog.co.jp

**China**

HERZOG (Shanghai) Automation
Equipment Co., Ltd.
Section A2, 2/F, Building 6
No. 473, West Fute 1st Road,
Waigaoqiao F.T.Z., Shagnhai,
200131
P.R.China
Phone +86 21 50375915
info@herzog-automation.com.cn
www.herzog-automation.com.cn