# INTERNAL SIGNAL FROM AN OPEN ARCHITECTURE CNC APPLIED TO CUTTING TOOL WEAR MONITORING: IMPLEMENTATION AND VALIDATION

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***Abstract.*** *The open architecture technology applied to CNC machine tools has been providing great improvements in the manufacturing environment, in various aspects: giving support to machine-tool builders; maintenance of equipment; monitoring of factories and monitoring of machining processes. However, very few applications can be found for the monitoring of machining processes. This paper presents an alternative on-line method to detect the cutting tool wear, during milling operation, using data available in an open architecture CNC. Only information and sources available in the CNC machine are required and any need of external sensors signals are dispensable. The proposed method represents an economical and simple approach to detect the cutting tool end-of-life during milling operation. It also opens other perspectives in applying the sources which this new technology offers, in order to optimize machining process in real time. Milling experiments using a high-end CNC machine center were accomplished to prove the method suitability. The final results of the experiments and the method used on the sensorless milling process monitoring are also presented in this paper.*

***Keywords:*** *open CNC; cutting tool wear; data acquisition and monitoring.*

## 1. Introduction

Process automation holds the promise of bridging the gap between product design and process planning, while reaching beyond the human operator´s capability. It can autonomously tune machine parameters (feed rate, speed, depth of cut, etc), or generate messages for operators, substantially increasing the machine tool's performance regarding to part tolerances, surface finish, operation cycle time, tool consuming, etc. The success of manufacturing process automation hinges primarily on the effectiveness of the process monitoring and control systems (Liang, 2005).

Regarding the process monitoring system, several sensors were developed for monitoring the tool wear and failure, part dimensions, surface roughness, surface burn, etc. Unfortunately, many of these sensors have negative points, such as high cost and intrusion in the process, low robustness, complexity to extract appropriate signals, and any standardization to integrate them on an existent system (Liang, 2005).

Additionally, in the past the CNC market was dominated by control systems with proprietary hardware and software components (Pritschow, 2001). Therefore, different solutions for the automation tasks were developed and implemented which led to very complex and inflexible systems, and not compatible with one another. The implementation, or the reuse, and the integration of customer-specific applications (e.g., human-machine interface, monitoring system) were extremely difficult, and many process data, that could be used for monitoring and supervising processes, were wasted because of these incompatibilities (Nacsa, 2001).

Nowadays, these difficulties have been solved with the open architecture control. This kind of control offers a vendor-neutral and standardized environment based in PC, which provides the methods and utilities for integrating of user-specific applications with existing controls and for adapting to user-specific requirements, e.g., monitoring systems (Pritschow, 2001) and (Ferraz and Coelho, 2004). It is possible to develop monitoring systems using only the resources (sensors, network, signal conditioners/amplifiers, etc) which already exist in the machine tools, which are resistant to chips, fluids, noise, and mechanical and electromagnetic vibration, without any additional costs and reduction of working space (Ferraz and Gomes de Oliveira, 2005) and (Nacsa, 2001).

According to Schmitt et al, 2005, there are mainly three different approaches to monitoring the cutting tool wear with accuracy. First: using statistical evaluation. Second: analyzing process signal, such as cutting forces or acoustic emission and thirdly, a direct measurement of the cutting edge. However, these approaches demand a number of requirements: equipments, sensors, time and money consumption and inconveniences for stopping the machine tool and install external appliances.

The present work analyzes an automatic system for data acquisition in real-time, which is also capable of monitoring the machining process, applied to machine tools using an open architecture CNC. The main target is to automatically estimate the cutting tool wear without any external sensor, without stopping the machine, and no user-interference.

A variable available on line by the CNC, which represents the spindle load during milling operation, was gathered. This variable was observed when different cutting conditions were carried out. Different levels of cutting tool wear were used in milling operations and the spindle load was observed in real-time. It was associated with the tool wear level and the spindle load. The profitable outcome of these experiments is shown in this paper.

### 1.1. The cutting tool wear

There are many types of cutting tools for milling operation available on the market. It differs in geometric aspects, surface, material and coatings. There are different mechanisms of tool wear and their influences depend on how they are applied. A worn out cutting tool can decrease surface quality which often occasions dimensional errors. For many applications the flank wear on the major cutting edge of a tool is the most significant parameter to determine the cutting tools end-of-life. According to the ISO 3685, Fig. 1 presents the main parameter for flank wear:

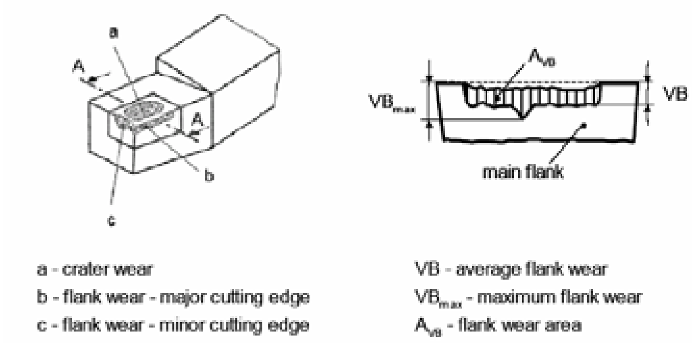



Figure 1. Cutting tool wear (Schmitt et al, 2005)

### 1.2. Data acquisition architecture

The data acquisition system was developed in LabView language, which carries out communication between machine tool and monitoring system. The machine tool was equipped with an open HMI CNC, the CNC SIEMENS Sinumerik 840D. As described in Fig. 2, the monitoring system was implemented in the external PC that uses a Profibus board SIEMENS CP5611 to the direct communication with the digital components of the machine control system. A standard physical media RS-485 was used with the OPI protocol (Operator Panel Interface), and the DDE protocol (Dynamic Data Exchange) for the integration with the monitoring system. As happens in the HMI PC of the machine tool, the external PC also carries out the DDE server (NC-DDE Server) that "encapsulates" the particularities of the OPI networking, allowing the communication through a standard protocol, the DDE. Therefore, the external PC became an additional point in the internal networking of the machine tool, as presented in Fig. 3.

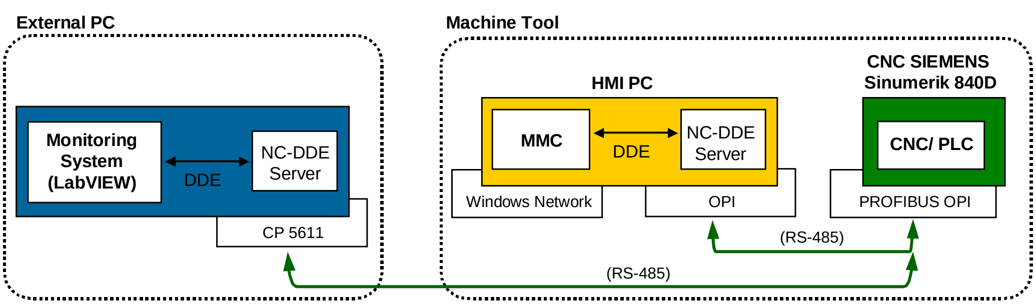



Figure 2. Hardware and software architecture – (Ferraz and Gomes de Oliveira, 2005) modified.

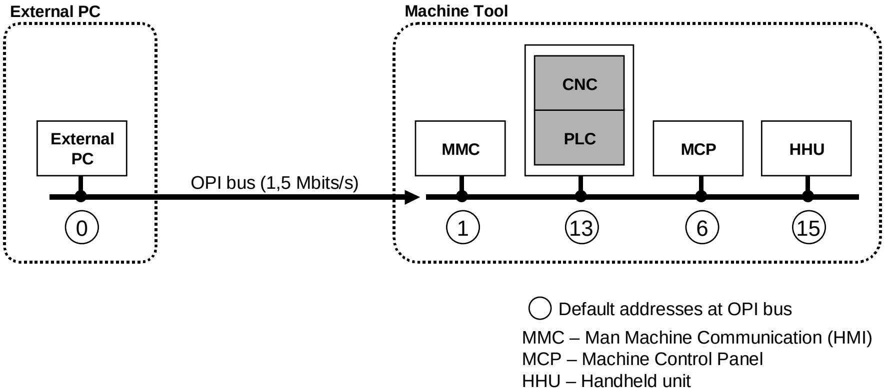



Figure 3. Default addresses at OPI bus between an external PC and a CNC SINUMERIK 840D – (Siemens, 2000) modified.

Through this networking among the components of the machine tool (HMI, CNC, PLC, drives and operation panel), it was possible to gather data and information from these components, as well as from the machine tool applications (Ferraz et al, 2005). This architecture allowed the implementation of the data acquisition system using only resources available in the machine tool, without external sensors. In another example of application, this data acquisition method was applied successfully to analyze the feed rate in each machine axis and the machine tool accuracy during interpolation movements (Souza, 2004; Ferraz and Gomes 2005).

## 3. Experimental procedure

For industrial applications, sensors should meet a series of requirements ensuring robustness, reliability, and non-intrusive behavior under normal working conditions. Many sensors and measurement systems have been tried out on adaptive controllers, tool wear detection, and machine status monitoring with promising results. They include dynamometers, accelerometers and acoustic emission sensors. However, almost every sensor has limits in its use in the metal-shaping industry. The main target of this paper is the sensorless tool wear detection. The CNC with open architecture, has some facilities that can contribute to sensorless monitoring. **The CNC open communication facilitating the reading and writing on internal variables is a step ahead towards a new level of automatization. This section describes the experiments using these characteristics of new CNC´s generation.

### 3.1 Experimental Environment

The experimental milling tasks were carried out on a vertical high speed machine center, Hermle – model C800. In order to verify the Cartesian components of the milling forces, a KISTLER piezoelectric dynamometer (model 9272) together with a multi-channel load amplifier (model 5019) were also used. To analyze the efficiency of the proposed methodology, a profibus interface was installed in an external PC, to capture the data from the CNC in real-time. A data acquisition routine was developed using the Labview software.

A two insert cutting tool 20 mm of diameter, provided by Sandvik (grade 4040 R08), was used. The workpiece was a rectangular block of H13 steel, hardened to 52 HRc, with the following dimensions: 300 mm large; 400 mm long and 50 mm depth.

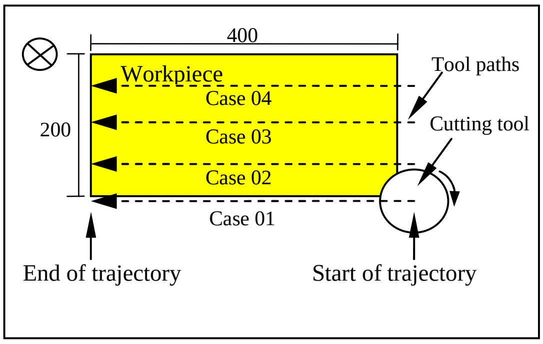
### 3.2 Procedure

As this paper has already detailed, the main aim of this work is to identify automatically, through data given by CNC, the cutting tool wear. To do so, tangential millings were carried out and the spindle load variable, supplied by CNC, was obtained with a frequency of 150 Hz, during milling experiments. At the same time, the Cartesian cutting forces were also observed. In these experiments the values of the maximum wear on the main flank of the cutting tool ($VB_{max}$) were verified, as illustrated in Fig. 1. The spindle load variable in four distinct values of $VB_{max}$, up to 0,7 mm were analyzed. These study cases are described in Tab. 1.

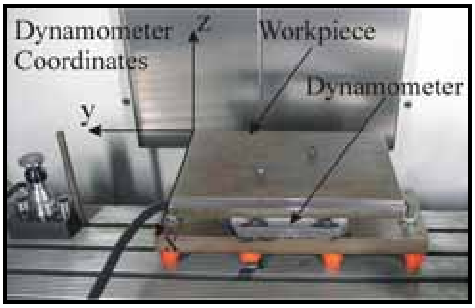
Table 1. Cases of study.

| Case | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Tool wear $VB_{max}$ [mm] | 0 (new inserts) | 0,25 | 0,4 | 0,7 |

The tool paths were paralleled to one another, in Y direction according to dynamometer coordinate system. The milling procedure and the dynamometer dispose are presented in Fig. 4.




a) Experimental sketch




b) Workpiece fix in the machine center

Figure 4. a) Milling experiments. b) Workpiece and dynamometer disposal.

Graphics of the spindle load variable against the samples acquired were plotted for these four conditions of tool wear. Each case analyzed corresponds to one horizontal tool-path Fig. 3-a. Table 2 presents the climb cutting parameters used in these experiments.

Table 2. Cutting parameters.

| ap | ae | fz | Vc |
|---|---|---|---|
| 2 mm | 2 mm | 0,07 mm | 160 m/min |

In order to save time and effort and reach results faster, the cutting tool wear was accelerated on purpose as to obtain the wear values presented in Tab. 1. This heavy cutting condition consists on the conventional milling process on another rough workpiece, using the cutting parameters presented in Tab. 3. These cutting parameters were obtained empirically in order to reach the desired value of $VB_{max}$ without breaking the cutting tool. This heavy cutting process propitiates obtaining the four cutting wear conditions in a very fast way.

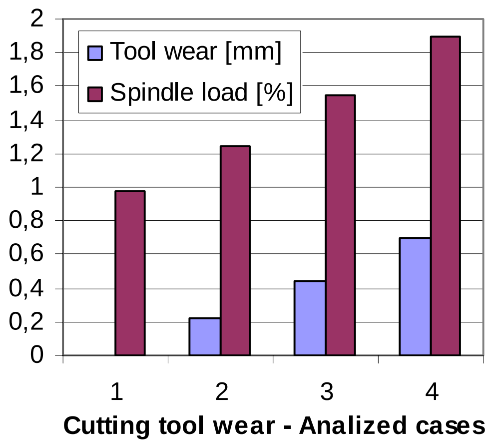
Table 3. Forced conventional milling parameters.

| ap | ae | fz | Vc |
|---|---|---|---|
| 0,5 mm | 1 mm | 0,1 mm | 100 m/min |

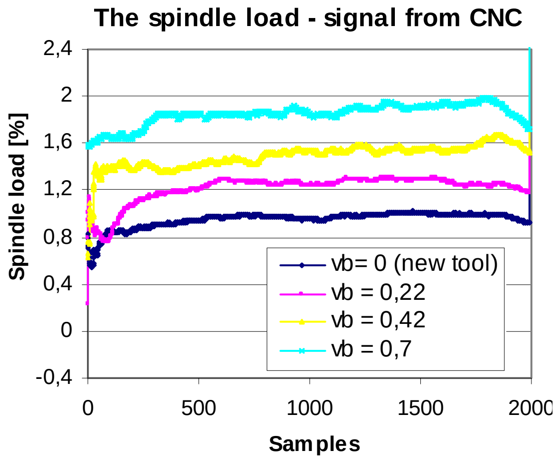
## 4. Results

The percentage signal of spindle load variable obtained form CNC in real-time is presented in Fig. 5-a. Figure 5-b show the RMS of the spindle load against the cutting tool wear. The RMS signals were obtained without taking into consideration neither the beginning nor the end of the milling path.

The results show that the spindle load varies significantly according to the tool wear. The variation of the spindle load among the cases analyzed is quite clear. The cutting tool wear and the spindle load rises proportionally.




a-) Spindle load. Signal acquired from open CNC.




b-) RMS of the spindle load and cutting tool wear

Figure 5. Behavior of spindle load and tool wear for the analyzed cases

It is possible to define a reasonable relationship between the tool wear and the spindle load variable obtained directly from an open architecture CNC. Using the RMS signal of the four analyzed cases and there respective flank wear results, it was possible to reach through using a graphical software a polynomial tendency curve to estimate the tool wear level of any intermediate case of tool wear, according to its spindle load. Therefore, in the range analyzed, it is possible to estimate the tool wear applying a specified spindle load, according to the Eq. (1):

$$VB = 0{,}0115L^2 + 0{,}7232L - 0{,}7127 \qquad R^2 = 0{,}9975 \tag{1}$$

L: Spindle Load
VB: Cutting tool flank wear

Figure 6 shows the cutting tool and its maximum wear on the main flank ($VB_{max}$) obtained from the experiments.

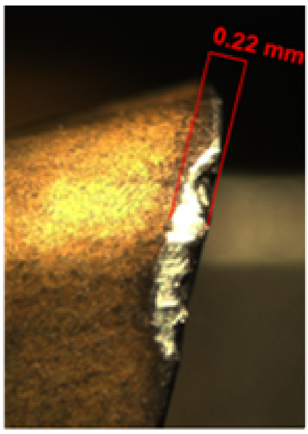



Fig. a. Case 2: $VB_{max}$= 0,22 mm
Spindle load RMS: 0,98%


Fig. b. Case 3: $VB_{max}$= 0,42 mm
Spindle load RMS: 01,24%

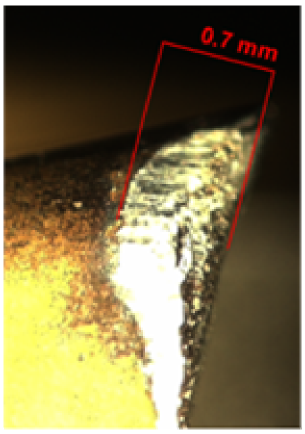



Fig. c. Case 4: $VB_{max}$= 0,7 mm
Spindle load RMS: 1,89%

Figure 6. Analyzed cutting tool wear.

Take note that the RMS signal for the case 1 (new cutting tool) was 0,82% of the spindle load.

## 5. Conclusions

High costs, time spending, and the inconveniences of using external sensors in order to get any information on machining process, motivates the work here presented which aims to help industrial application. Once more, the open architecture CNC shows how helpful it can be in improving manufacturing processes. During its implementation, a number of other possibilities for monitoring machining parameter in real time was noted, without using any external sensors.

Several experiments were made using different cutting conditions and cutting tool wear. This paper shows the great possibility in using a simple variable available by CNC to estimate the tool wear during operation.

During the experiments we noted that the spindle load variable can quite realistically show the tool wear stage. This method represents an effective manner in defining the cutting tool replacement, without any statistic approximation and no use of external sensor.

Theses experiments were accomplished using a specific cutting tool and work piece material. Be aware that the spindle load variable might change in accordance to the machining process characteristics. Therefore, for any application a first trial testing should be made as to reach the correspondent maximum spindle load acceptable for the related operation.

In addition, it is possible to program a routine in an open CNC that can automatically recognize the spindle load maximum limit, set by the user, and the machine carries out the cutting tool change without any external instruction.

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## 8. Responsibility notice