DATA ACQUISITION STRATEGY FOR OPEN CNC MONITORING IN HSM PROCESS

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Abstract. *The necessity of monitoring systems in High Speed Machining process (HSM) has increased with the high level of performance and security required. The cutting process parameters of a CNC machine are traditionally based on handbooks, or on user's practical experience, this approach results in a conservative cutting process parameters. In order to optimize these parameters, a monitoring system is developed and applied. The Open CNC concept is widely used to provide the integration of user's functions and communication capabilities with CNC data over the network, but a few machine controllers provide data access at all levels of communication. The objective of this work is the implementation of a monitoring data acquisition strategy applied in a commercial CNC with open architecture that eliminates the network transmission delay, increases the sample frequency and provide better accuracy of a monitored variable. A new data acquisition strategy was developed and analyzed by experiments considering different feedrates values. The open CNC communication interface was evaluated by the monitored variable resolution showing the limits of open CNC sample frequency when a variable of servo loop level is accessed.*

Keywords: *Monitoring System, Open CNC, High Speed Machining*

1. INTRODUCTION

The HSM (High Speed Machining) process is widely used in the machining of sculptured surfaces due the competitive machining time and high level of geometrical quality obtained. The machine motion is calculated by the CAM (Computer Aided Manufacturing) system and controlled by the CNC (Computer Numerical Control) and motor drivers. As a result, the performance of machining process is linked to the performance of CAM parameters and CNC control (Lartigue *et al.*, 2004).

The technologies involved in HSM process vary from the tool path interpolate methods to tool holder, motion control with high dynamic motors, security devices, process monitoring and others technologies that provide specific results in high speed machining process (Schützer and Schulz, 2003). Figure 1 shows the technologies related to the HSM process (Schulz, 1999).

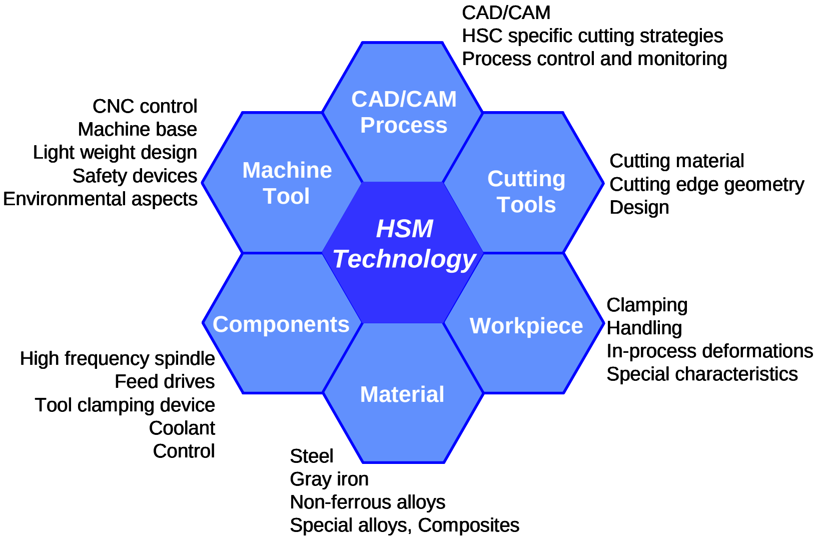

Figure 1. Technologies related to the HSM process (Schulz, 1999)

Machining parameters are usually based on people's experiences or according to handbooks, this approach results in a conservative cutting process, where the machining performance is not totally used to avoid the machine failure (Cus *et al.,* 2006).

Monitoring systems in HSM process have increasing importance with the demand of high performance of complicated operations and for process security. It obliges CNC manufacturers to include monitoring and protection functions of motors, drives, peripheral devices as well as to provide the integration of speed optimization (Haber *et al.*, 2005).

The infrastructure to integrate the all levels of factory automation and link the equipment in an e-manufacturing environment is still missing. It is necessary the development of new technologies for the implementation of monitoring and control capabilities of traditional CNC machine tools, without this infrastructure, the advanced factory automation can hardly become practical in the distributed manufacturing shop floor environments (Wang *et al*., 2004).

Haber *et al.* (2003) classifies the openness of CNC in two levels: Man/Machine Communication (MMC) and Numerical Control Kernel (NCK) levels. The first level is characterized by the interaction with the user and applications developed using DDE (Dynamic Data Exchange) protocol and a bus that enables low-level data communication. The NCK level is considered the more important level of opening from control-system viewpoint, where real-time events are performed.

The open architecture provided by a few modern numerical controllers allows the user to implement specific functions at higher levels and this is usually sufficient for many tasks, like process control and machine monitoring. In lower levels, including speed and current control loops, the implementation of customized functions is not possible (Pritschow and Kramer, 2005).

The influence of the network delay in open CNC data acquisition is showed by previous related work where the commercial communication module was used to develop a monitoring system in HSM process.

Del Conte *et al.* (2007) shows the influence of feedrate programmed value in monitored variable resolution, where the sampled data frequency provided by the open CNC network communication is not sufficient to the monitoring of control loop variables (e. g., position control, velocity control, current control).

The purpose of this work is the implementation of a new monitoring data acquisition strategy applied in a commercial open CNC controller that eliminates the network transmission delay, increases the sample frequency and provides better accuracy of a monitored variable. This new strategy uses an internal data acquisition procedure in an open CNC that stores the monitored data in a buffer and in the next step, this data is transmitted to a PC (Personal Computer), where the monitoring system is executed.

The concept of monitoring system is presented in Fig. 2 below.

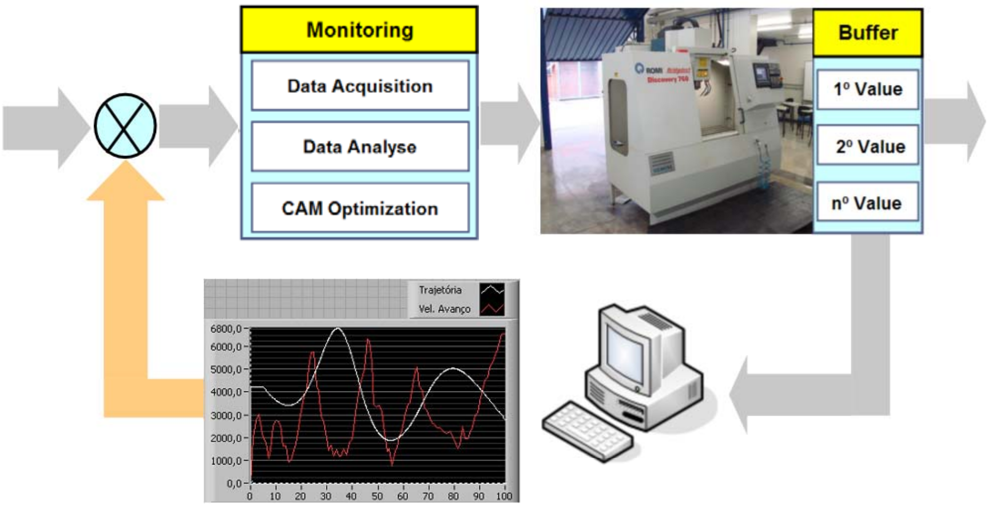

Figure 2. Monitoring system concept

Figure 2 shows the association with a feed forward control system, where the monitoring system is responsible to feed forward the loop. This concept is based on how the cutting strategies and cut parameters affect the machine behavior. By the correlation with cutting strategies and feedrate signal signature, it is possible to identify the cutting strategies that results in an optimized machining process.

1.1 Monitoring systems in HSM process

Norman *et al*. (2006) shows that typical challenges of monitoring in HSM process include the following facts:

- High-speed machining bears a high risk for tool failure and product damage.
- Complex structural parts with thin walls bear a high risk for product damage.
- Characterizing the dynamics of the combination system-process-product is difficult.
- Obtaining real-time feedback of the machining process is difficult.
- Developing a generally applicable closed loop control is difficult.

Therefore, in this paper our attention focuses on open CNC variable monitoring, including the monitoring of feedrate value.

The cutting accuracy of HSM process is affected when a curve with a corner is machined in high feedrate value, in this case the over-cutting is much more common than in traditional CNC. This is the most serious problem that a current HSM servo control faces (Wang and Li, 2003).

Table 1 summarizes the action of various categories of parameters on the HSM system performances (Bearee *et al.*, 2004).

Table 1. CNC parameters dominating effects on system performances (Bearee *et al.*, 2004)

CNC parameters	Productivity	Contouring accuracy	Machine vibrations decrease
Increase loop gains, feed forwards, decrease post-filtering	Good	Fair	Poor
Decrease speed limitations, increase pre-filtering	Poor	Good	Good
Geometrical filtering	Good	Fair	Good

The linear interpolation tool method is an example of critical CAM parameter in the context of HSM. The limitation of NC (Numerical Control) unit to execute a movement in a straight line between two successive positions with high speed causes significant decreases in feedrate that increases machining time and affects the geometric quality of the machined surface. The use of native polynomial formats offers the possibility to optimize tool paths (Lartigue *et al.*, 2004).

The necessity to known the influences of process parameters in machine behavior and performance has increased the importance of monitoring systems in HSM process and the open CNC has a purpose to provide the required integration to implement monitoring applications in this field.

1.2 Open CNC system

The Open CNC architecture requirements are different for the users and for the manufacturer's point of view. The openness for user's is the possibility to implement and access specific functions in all levels of communication, using a standard interface, and for manufacturer's the possibility to implement customized HMI (Human Machine Interface) and the proprietary way to implement specific functions in limited levels is considered openness (Erol *et al.*, 2000).

The IEEE (Institute of Electrical and Electronics Engineers, Inc.) technical committee of open systems defines a open system as: "An open system provides capabilities that enable properly implemented applications to run on a variety of platforms from multiple vendors, interoperate with other system applications and present a consistent style of interaction with the user." (IEEE, 1998).

Pritschow *et al.* (2001) divide the openness of control systems in following categories:

- Open HMI: This level of openness is restricted to the non-real-time control system part.
- Kernel with restricted openness: Offers interfaces to insert user-specific filters even for real-time functions, but has a fixed topology.
- Open Control System: The control kernel topology depends on the process and offers interchangeability, scalability, portability and interoperability.

The previous open control architecture such as OMAC (Open Modular Architecture Controllers), OSACA (Open System Architecture for Controls within Automation Systems) and OSEC (Open System Environment for Controller) have the same integration purposes, but are logically incompatible among them, and in order to avoid this incompatible situation, Park *et al.* (2006) proposes a middleware that makes the CNC control portable, interoperable and compatible with other controllers.

Pritschow and Kramer (2005) had introduced a comprehensive concept for an open drive architecture, which enabled the users to access all desired signals and, it can substitute the existing drive controller where the standard drive control is not enough in terms of speed and flexibility.

A few commercially available open architecture systems include Delta Tau PMAC-NC, IBH PA 8000, Galil DMC 1000, Creonics MCC VME, Adept Series A, Aerotech Unidex 31, CIMplus, and Typ3 osa. Although these controllers are excellent systems for research and development, the standardization have remained unresolved and their widespread application in industry is not obtained (Liang *et al.*, 2004).

This shortly open CNC overview shows the difficulty to obtain a non-proprietary standard interface that is operable in all levels of hardware and software communication. The flexibility required for the implementation of optimized functions is even today not provided for the most commercial open CNC systems applied in industry.

2. DATA ACQUISITION STRATEGY

The standard open CNC interface used in this research becomes possible the data acquisition over the network communication. This HMI open level does not provide the corresponding sample frequency to acquire data in servo level with satisfactory accuracy (Del Conte *et al.*, 2007).

The accuracy specified for monitored variable resolution is the acquisition of one monitored variable value per one millimeter traveled by the associated axis. This specification becomes possible the analyses of tool path interpolate methods and CAM tolerance in feedrate behavior (Helleno, 2004).

To attend the specification above, a new acquisition method divided in buffer and transmission module is proposed.

2.1 Buffer module

The main idea is to avoid the data collection trough the network with the creation of a buffer in CNC that can store the desired servo level data to be monitored.

The implementation of this strategy is possible by the usage of a function provided by the open CNC used, called synchronized actions. As defined in Siemens manual "These Motion–synchronous actions are instructions programmed by the user, which are evaluated in the interpolation cycle of the NCK in synchronism with part of the program in execution. If the condition programmed in the synchronized action is fulfilled or if none is specified, then actions assigned to the instruction are activated in synchronism with the remainder of the part program run". The Fig. 3 shows how synchronized actions work (Siemens, 2005).

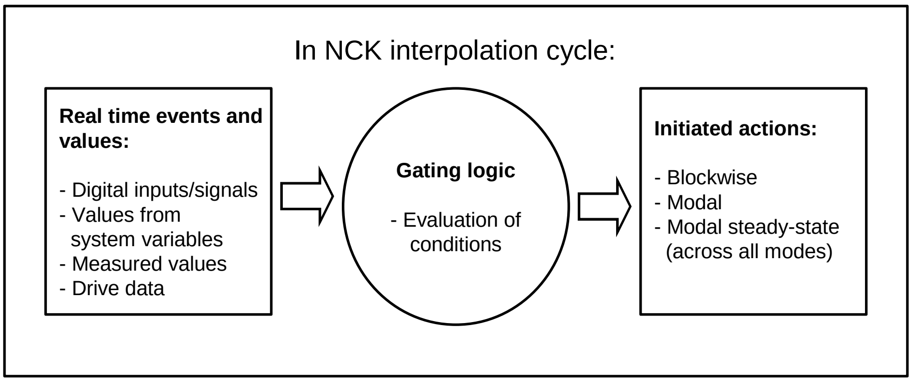

Figure 3. Schematic diagram of synchronized actions (Siemens, 2005)

The synchronized actions are programmed in CNC program and executed in parallel to the machining process execution. The condition is checked in the interpolation cycle and the associate action is executed when the condition is fulfilled. In this approach are used the variables called R -parameters to build the buffer, where the real-time variables are saved according to the condition programmed in synchronized action, in section 3 is demonstrated the CNC program with synchronized action developed.

2.2 Transmission module

The open HMI interface is used to transmit the acquired buffer data to the PC (Personal Computer), where the signals are analyzed.

The communication between CNC and PC monitoring system is through the MPI (Mult Point Interface) network with a transmission rate of 187.5 Kbps, an interface card CP5611 with MPI/PROFIBUS protocol installed in the PCI (Peripheral Component Interconnect) bus of personal computer makes possible the communication with CNC and PC.

A NCDDE server (Dynamic Data Exchange with the NC kernel) included in the OEM (Original Equipment Manufacturer) package enables the monitoring system developed in LabVIEW to collect the desired data using the DDE (Dynamic Data Exchange) functions (Siemens, 1997).

The transmission module was developed with LabVIEW software that provides the necessary DDE functions for establish a communication with the NCDDE server.

Figure 4 shows how the transmission module acquires the data storaged in CNC buffer. The communication is established by the DDE open function and the function DDE requests calls of the desired variable to access, and in this case is requesting the address of R-parameters that actuate as buffer.

The behavior of acquired signal is showed in a graphic and the correspondent value is storaged in a file. The LabVIEW block diagram developed is showed in Fig. 4.

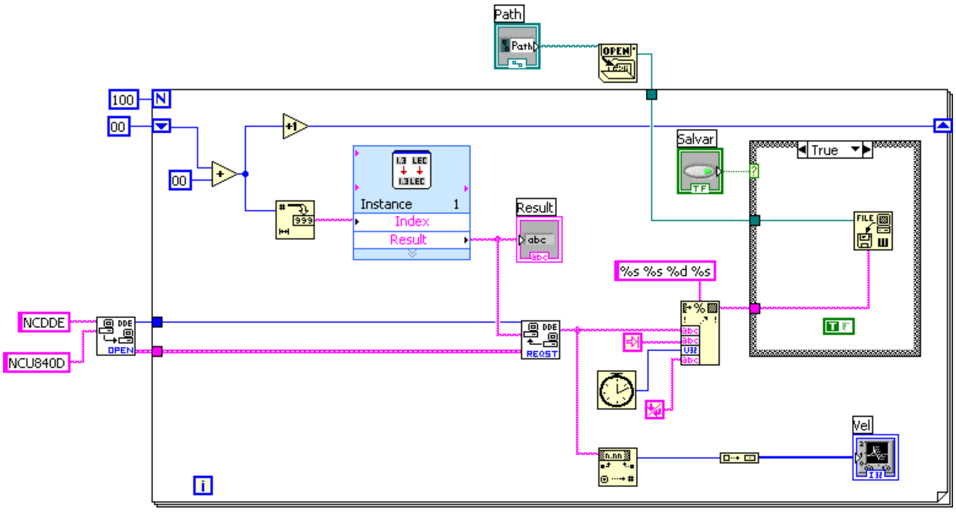

Figure 4. LabVIEW block diagram of transmission module

3. EXPERIMENTAL PROCEDURE

The experiments were conducted in the milling machine center with CNC SIEMENS 810D. The sampled variable data is a current position value of a X axis provided by an internal CNC system variable with the name $aa_iw[x1]. The buffer module was executed in two different conditions. In the first condition, the feedrate programmed value was 1000 mm/min and in the second condition 6000 mm/min. The CNC program below was used during the data acquisition buffer module.

```
G54
G1 X0 F1000
$ac_marker[1]=0
$ac_param[1]=0
$ac_param[2]=1
ID=1 whenever ($aa_iw[x1]>$ac_param[1]) and ($aa_iw[x1]<$ac_param[2]) DO R[$ac_marker[1]]=$aa_iw[x1]
        $ac_marker[1]=$ac_marker[1]+1 $ac_param[1]=$ac_param[1]+1 $ac_param[2]=$ac_param[2]+1
X100
M30
```

The CNC program executes a linear movement in X axis from 0 to 100 mm of distance and whenever the condition described of the synchronized action (called ID=1) is fulfilled, the X axis position data is stored in the variables called R -parameters of the CNC. The condition assures that one value of X axis position data is stored among one millimeter traveled by the X axis.

After the CNC program execution, the transmission module of the monitoring system is executed and the data storaged in R-parameters are transmitted to the PC.

4. RESULTS ANALYSIS

The interval distance of sampled data with synchronous actions is showed at the Tab. 2 below in both feedrate conditions.

Table 2. Experimental results for sampled data

Feedrate programmed value	Interval distance (mm)
F 1000 mm/min	1
F 6000 mm/min	1

Table 1 shows that the acquisition data strategy assures the specified variable resolution without data variability, this represents that the synchronized actions stores the data cyclically in the buffer.

The most way used to measure the CNC performance is block processing time. The block processing time is the time necessary to CNC translates moves from G-code, feed to the servo algorithms and execute in the servo loop. In the actual open CNC architecture this time corresponds to the least possible sample frequency to monitoring a variable.

Equation (1) can be performed to identify the influence of programmed feedrate in monitored variable resolution (Arnone, 1998).

$$Vamax = \frac{\Delta x}{BPT/60} \tag{1}$$

where:

Vamax	Maximum programmed feedrate
Δx	Distance between measures
BPT	Block Processing Time

Accordingly to the Eq. (1), the maximum feedrate programmed to assure a condition for acquisition of one measure variable value per one millimeter traveled is 6000 mm/min in a CNC with 0.010 s of block processing time.

Figure 5 shows the feedrate influencing in monitored variable resolution for three CNC different block processing times.

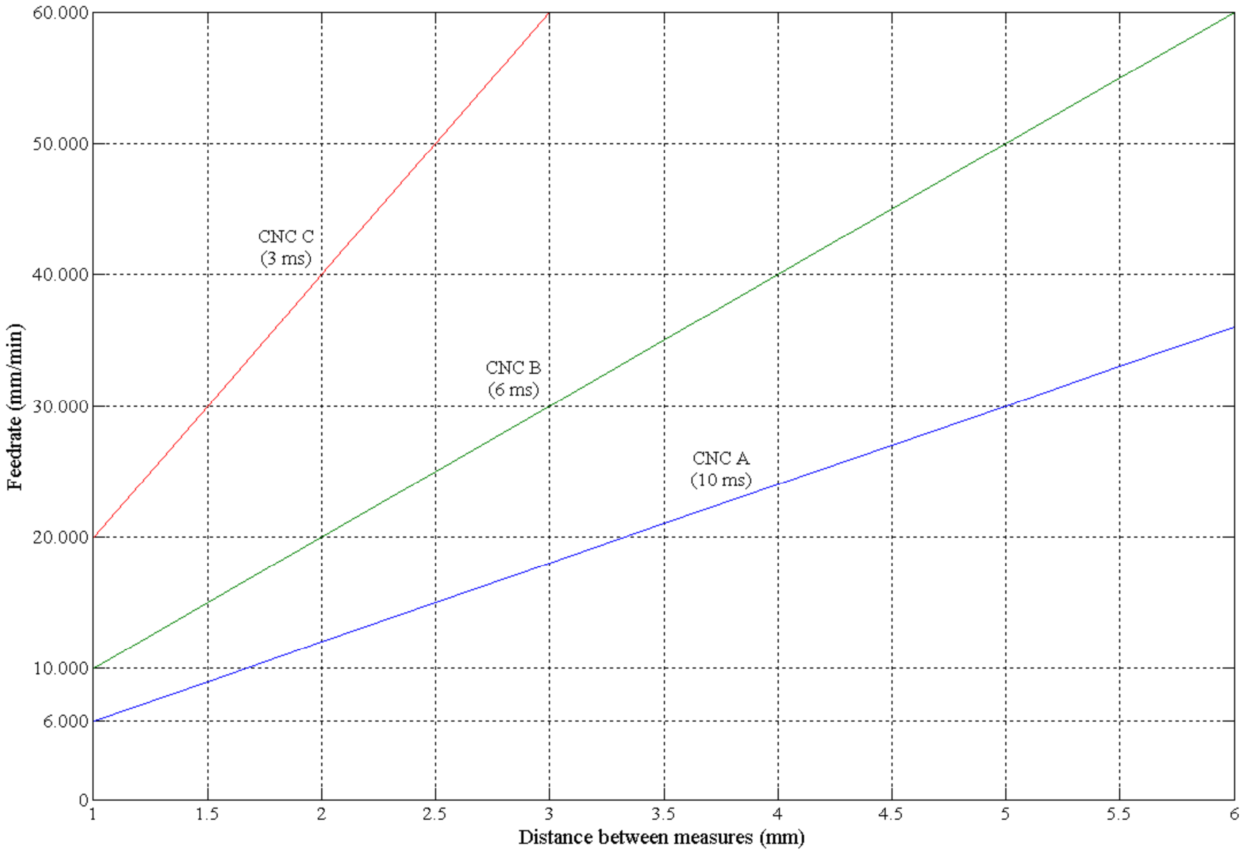

Figure 5. Feedrate influencing in monitored variable resolution

The shorter block processing times results in a higher sample frequency, and a monitored variable resolution decreasing proportionally to the feedrate increasing. In Fig. 5 one example is in CNC B, for a feedrate value of 10000 mm/min the system attends the acquisition specification and when the feedrate grows to 20000 mm/min the resolution is affected proportionally in 2 mm among measures.

5. CONCLUSIONS

The data acquisition strategy developed results in the elimination of network delay influence and increase the sample frequency, resulting in better monitored data accuracy. The variable resolution specification of one monitored variable value per one millimeter traveled is assured until the feedrate value exceeds the open CNC sample frequency.

However the influencing of feedrate in monitored variable resolution is still high when the feedrate value exceeds the maximum sample frequency. In this work, the maximum sample frequency is 0.010 s and the correspondent feedrate value is 6000 mm/min. The integrity of sampled data analysis is assured until this limit of frequency and affected proportionally to the feedrate increasing.

The level of openness in most actual open CNC architectures is the main reason for the situation found in this work. The sample frequency of implemented data strategy depends only to the CNC block processing time, and without a standard method to access data in servo loop level frequency, this limitation in monitored variable resolution will be continue in determinates conditions of feedrate value.

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