The Development of an Open Architecture Control System for CBN High Speed Grinding

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The aim of this project is the development of an open architecture controlling (OAC) system to be applied in the high speed grinding process using CBN tools. Besides other features, the system will allow a new monitoring and controlling strategy, by the adoption of open architecture CNC combined with multi-sensors, a PC and third-party software. The OAC system will be implemented in a high speed CBN grinding machine, which is being developed in a partnership between the University of São Paulo (USP - Manufacturing Processes Optimizing Group (OPF) – NUMA – EESC; and a traditional Brazilian grinding machine manufacturer. This new CNC generation allows the implementation of new monitoring and controlling strategies due to the two-way CNC and PC communication using a High Speed Serial Bus (HSSB). As a result, third-party software routines, such as LabVIEW VIs (Virtual Instruments), can be used to act in the CNC, interacting with HMI software, via Active X. As a result, the performance of high speed grinding can be increased by the adoption of the open architecture controlling solution combined with high performance monitoring systems.

***Keywords**: Open architecture, monitoring, grinding, high speed, CBN*

Introduction

The Partnership and Its Objectives

The development of a new open architecture controlling (OAC) system was motivated by the necessity of performing grinding researches in high speed grinding with CBN wheels. Due to their high initial costs, the wheel wear must be reduced during grinding and their benefits must be fully explored in production. The best thermal and mechanical proprieties of the CBN grains when compared to the conventional ones have pushed forward the use of CBN wheels, mainly in heavy duty grinding, super alloys grinding for aerospace industry (Hitchiner, 1999), vehicle valves grinding, crankshafts and camshafts grinding, among others. The CBN wheels allow the reduction of the grinding energy and generate, in most cases, compressive residual stresses in the ground components surface and subsurface, increasing their fatigue life.

The possibility of the cost-effective use of CBN wheels is contributing to the development of the necessary technology to its correct implementation in the production lines. A higher cutting speed reduces the equivalent chip thickness and, combined with the best mechanical and thermal proprieties of the CBN grains, permit higher stock removal rates without thermal or mechanical damages making the process cost-effective. The design of a CBN wheel, in which superabrasive segments are bonded in a metallic core, permits higher cutting speeds, greater than 100 m/s. On the other hand, conventional grinding wheels have a safety cutting speed limited to 60 m/s due to mechanical strength limitations.

Besides the development of the superabrasives grinding wheels, the monitoring systems have become, nowadays, a reality, with a high number of new developments in this area. The increased flexibility of new controllers, labeled as “open architecture”, allows exploring the PC openness combined with the reliability of numerical controllers. It has been created a two-way communication between the CNC – PC, where new controlling and monitoring systems can be implemented. These PC-based monitoring and controlling systems have, as the most important feature, the fully integrated possibilities of communication with the controller, getting and sending information from and to the NC, acting on its up and low level routines. It allows the execution of corrective actions during the grinding and dressing cycles, monitoring and adjusting the core grinding parameters, permitting the operation and the monitoring of the process through Ethernet/Internet. A new conception of HMI (Human Machine Interface) can be developed. The process information can be easily gathered in a reliable manner. This collected information can be analyzed and shared. Based on these data, corrective actions can be taken by the CNC or by the grinding operator or the information can be spread to the high levels of supervisory systems.

There are special requirements to the implementation of new high speed grinding machines. Reliable monitoring and controlling systems are sought in order to reduce grinding collisions, ineffective grinding and dressing cycles. More effective cutting fluid application systems are needed, allowing a successful cutting fluid action (Webster, 1995, 1999).

This paper describes the open architecture controlling (OAC) system to be developed in partnership between the University of São Paulo (USP - Manufacturing Processes Optimizing Group (OPF) – NUMA – EESC) and a traditional Brazilian grinding machine manufacturer. The major characteristics of the system will be presented, focusing in the benefits that can be obtained by its application in the grinding process.

Why Grinding With CBN Wheels at High Speed?

When compared to conventional grinding, important benefits can be observed when grinding with CBN at high speed as reported by Tso (1995). Figure 1 presents these aspects.

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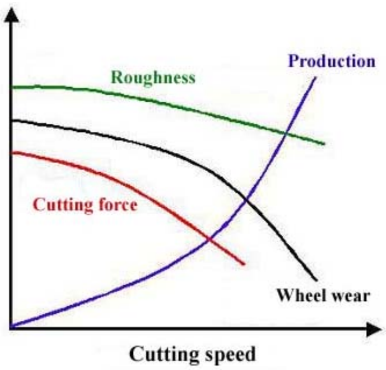

Figure 1. High speed CBN grinding characteristics.

The CBN wheel life is almost 500 times greater than the conventional ones, as reported by Hitchiner (1999). The G ratio values range from 1,000 to 5,000 in some cases using electroplated CBN wheels, depending on the cutting fluid type used.

Nowadays, there are a high number of CBN applications in the industry, and most commons are in the automotive industry, in engine valves and crank-camshafts grinding, and in the aerospace industry, in super alloys grinding. Even though the CBN wheel has a higher initial cost when compared to the conventional one, its application is still cost-effective since the total operational costs, the cutting fluid filtering costs, the machine downtime, among other costs can be reduced. According to English (1991), when comparing the performance of CBN and conventional grinding wheels in the Inconel 718 grinding, the CBN wheel leaded to a cost reduction superior to US$300 per wheel.

The Benefits of CNC – PC Integration

The term Open Architecture Controller (OAC) is a well-known term in the machine-controlling environment. Since the 90's, many efforts are being taken in order to allow that NC builders and vendors, machine builders and users could use the benefits given by the adoption of more agile and flexible products. The main purpose was the easier integration and implementation of user-defined controllers, adopting open interfaces and configuration methods, which were developed in a standardized and vendor-neutral environment (Jovane, 1998 and Binder, 1996).

The availability and the wide acceptance of such systems resulted in a cost reduction and increased flexibility. Programs can be readapted and user-defined algorithmic or application can be put together. The users can design their own controller according to a desired configuration.

There are many benefits for the vendors and for the users in the adoption of open-controller systems (Proctor, 1998). The CNC designers are favored by the high openness degree, which also includes the internal CNC interfaces. For the CNC users, the external openness is much more important (Pritschow et al, 2001). This feature makes available new methods and facilitates the inclusion of user-defined applications in existing controllers and adapts them to their necessities. New user-defined interfaces can be implemented combined with more effective data collection about the process.

The new HMI interface, with openness to act and interact with CNC functions, allows the fully interaction between the monitoring and controlling software with the CNC and their core parameters. It is possible to execute corrective actions during the machining cycle, monitor and adjust the essential machining parameters and the remote machine diagnostic and operation through Ethernet/Internet. A new concept of HMI interface can be developed in which the process data is collected and spread in a faster and in a more reliable way. This data can be analyzed and available so that corrective action can be performed by the operator and by the CNC or can be send to the high levels of information management systems.

The Most Important Features of the Open Architecture Controlling (OAC) System for High Speed Grinding

The OAC system will allow new monitoring and controlling operation in the grinding process, locally or remotely. In addition, it will be possible to collect the grinding data and make it available to the high management levels through Ethernet/Internet. An overview of the OAC system is presented in Fig. 2, in which the three scenarios of the OAC system are presented. The machine scenario is divided in other two scenarios. The first one presents the integration between sensors and server PC. The second one comprises the inter-relationships between the open CNC and the server PC. In the remote scenario, clients PCs can perform monitoring and controlling actions and/or collect information sharing it with the management systems.

The machine scenario 1 represents the connections between the PC server and the sensors installed in the grinding machine. The sensors were used to monitor and control the grinding process. This scenario is presented in the Fig. 3.

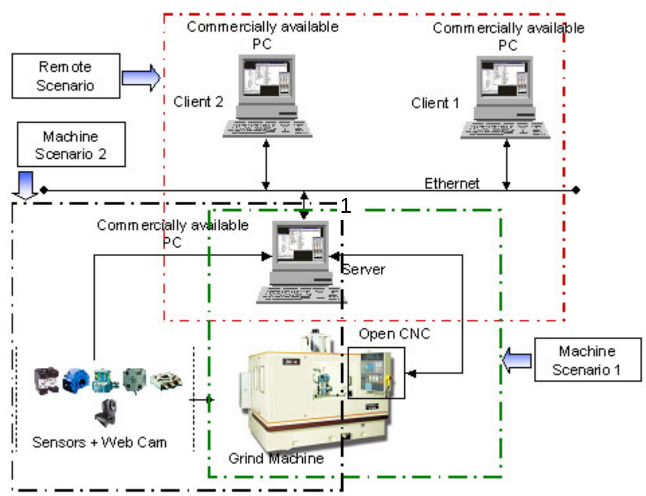

Figure 2. OAC system overview: open architecture environments.

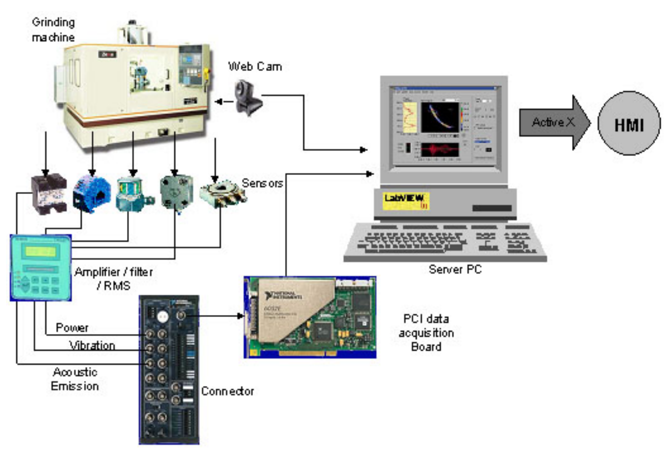

Figure 3. Machine scenario 1 – Connections between sensors and server PC via data acquisition board and software LabVIEW (National Instruments).

Different types of sensors, collecting core information about the grinding process, send data via acquisition board to the PC server. This one is installed in the grinding machine control panel. The signal processing, the monitoring and the execution of controlling routines are performed by the software LabVIEW (National Instruments).

The connections between the server PC and the CNC (machine scenario 2) are presented in Fig. 4. The PC - CNC communication is performed installing a PCI communication board in the PC main board (HSSB - High Speed Serial Bus) and using an optical fiber cable to connect PC to the CNC, with baud rate equal to 25MBps. All HMI interface is developed using the software Cimplicity HMI. All the monitoring and controlling sensor actions are performed in the PC environment and the core tasks are still performed in the CNC ladder logic.

Using the software Cimplcity HMI (GE-FANUC) it is possible to exchange data with the CNC, reading and modifying system variables, bits and bytes, ladder logic variables without the necessity of physical reading of a specific I/O. Consequently, important CNC information can be accessed and modified depending on the monitoring and controlling strategies. This data can be collected and logged into databases for trend analyzes. New alarms routines and corrective in-process actions can be performed during machine operation.

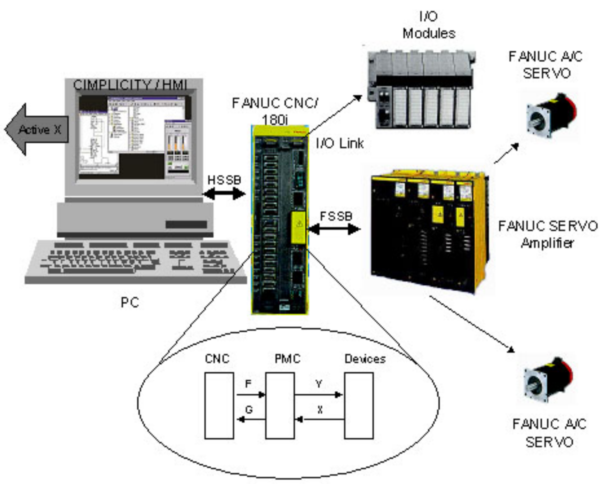

Figure 4. Machine scenario 2 – PC – CNC - devices communication.

The communication between the LabVIEW and Cimplicity HMI is made via Active X, in which monitoring and controlling LabVIEW Active-X objects are created and are embedded into the Cimplicity HMI environment. As a result all the actions (HMI, monitor and control) are performed in a unique environment and are PC-based.

Intelligent Grinding Routines (IGR) developed in OPF - NUMA based on PC platform can be easily integrated in the presented CNC environment. Some of these Intelligent Grinding Routines are presented in Fig. 5. An advanced and unique monitoring routing is shown as an example. It is the Intelligent Grinding Routine that allows the acoustic mapping of the grinding wheel surface by the processing of high-speed RMS acoustic signals (Oliveira et al, 2000). In the Figure 5, in order to verify the system sensitivity, an "L" shape groove was intentionally made in the grinding wheel surface. The obtained result map is shown on the left (right box – Fig. 5). This innovate mapping system is being used in grinding process to detect inefficient dressing cycles, unbalancing and vibrations detection, non-uniform interaction between wheel and workpiece, wheel wear mechanisms and other researches fields.

The last scenario is presented in Fig. 6. The client computers are connected via Ethernet with the server PC. Two basic actions can be performed. Acting on the databases, the grinding process and CNC information can be logged and transmitted to the upper levels of the business system. View and/or control can also be performed, in which machine setup, diagnostic and operation will be performed remotely. Analyzing the collected data it will be possible to improve grinding operation and reduces machine down time.

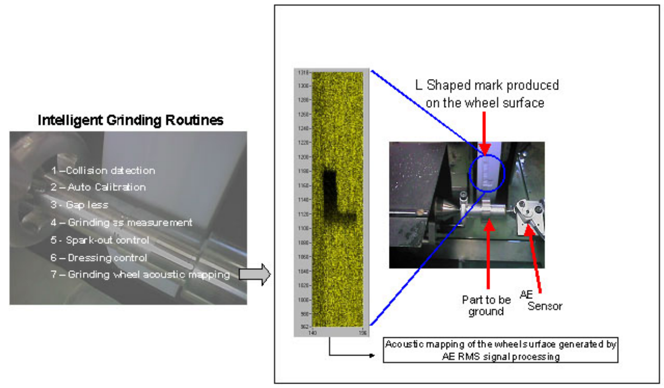

Figure 5. Intelligent Grinding Routines – Acoustic mapping of the wheel surface.

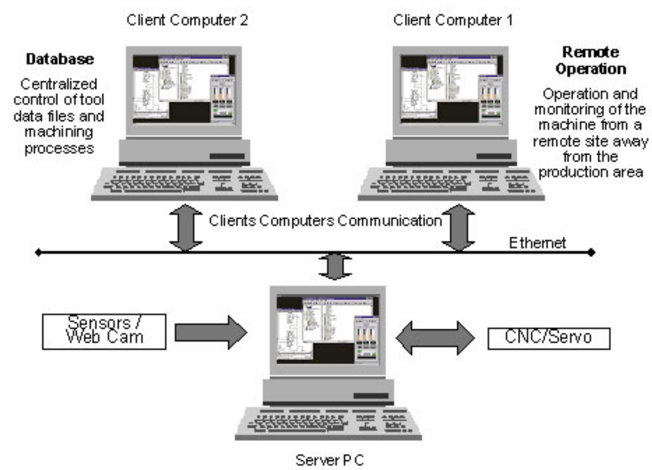

Figure 6. Remote Scenario – Integration between server PC and clients PC.

The Application of Open Architecture Controlling (OAC) System in Production Grinding

The implement OAC system is now being tested in order to develop new grinding strategies for crankshaft and engine valves using high speed. New monitoring systems, based on the developed IGR, will permit the most effective and reliable data collection and analyze. Two of these are presented bellow:

Grinding Wheel Automatic-Calibration

In this application the grinding machine can be used as a measuring machine using the grinding wheel and Acoustic Emission (AE) contact detection as a probe. For this, it is necessary to have a system able to automatically calibrate the grinding wheel. The automatic calibration of the grinding wheel is made based on a contact detection with a calibration diamond. Figure 7 shows this idea for a diamond fixed at the machine tailstock. The diamond can also be attached to the headstock. The distance between the tip of the diamond and the workpiece center (x=zero) is measured and stored in a CNC parameter. This distance is called diamond offset. Every time is necessary to compensate for the thermal deviation or wheel wear, a cycle is run where the grinding wheel touches the calibration diamond with a very low infeed speed using a contact detection instruction. That means, the grinding wheel will infeed against the dressing tool until an acoustic emission signal is measured from the contact between diamonds and grinding wheel. At this point, the wheel head stops and moves back some microns and the position of the grinding wheel surface value is replaced by that stored diamond offset value.

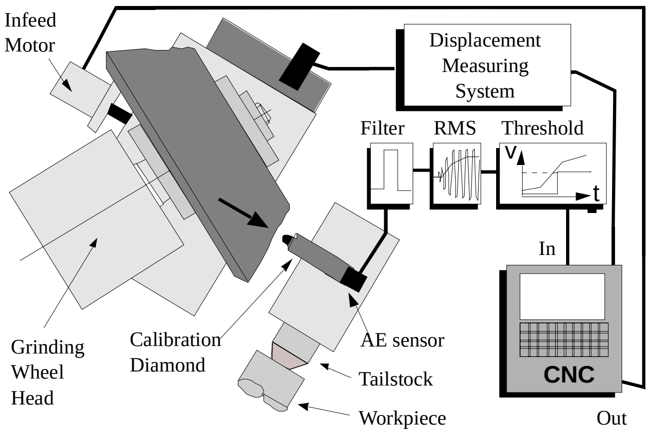

Figure 7. Calibration system attached to the tail stock.

The calibration diamond has a prismatic shape done by laser machining. The contact area with the grinding wheel is very high in order to generate a high acoustic emission level in the first contact. Due to the fact that the calibration diamond is used only in contact detection (depth of interaction of about 1 micron) and its position is very close to the workpiece center, the diamond offset does not change significantly along the production period.

Figure 8 shows a graph of the size of workpieces produced in the machine comparing a normal production with a production with the automatic calibration made every 5 pieces. The resolution and repeatability of the system depends obviously on the resolution and repeatability of the machine, once the measurement systems and controls of the machine are being used.

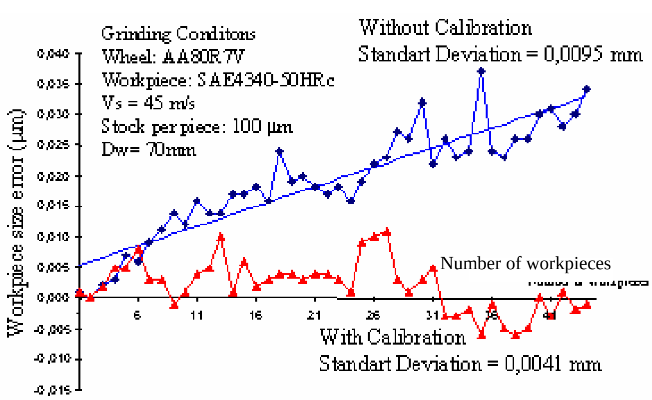

Figure 8. Grinding with and without using the automatic machine calibration .

Wheel Mapping System

Imagine that you could see an image of the grinding wheel surface on the CNC screen. This is possible now with the new system and the proposed OAC system. The image, already presented in Figure 5, is built up by representing the AE level of each acquired sample with a color scale in a three dimensional graph. During the dressing operation the image is constructed in real time by adding columns in the array as the dresser travels along the wheel surface. Figure 9 shows this procedure. The routines require very high performance hardware (such as sampling rates of 500k samples/second or screen resolution of 1024X768 pixels) and only possible with the proposed architecture.

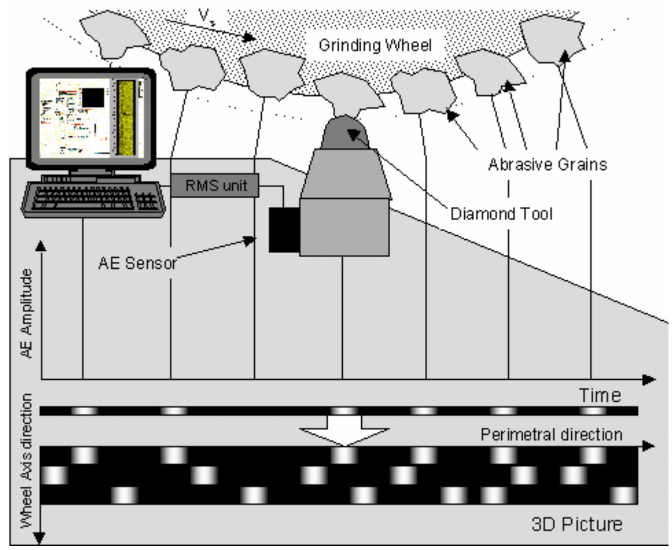

Figure 9. Acoustic map construction procedure.

The system can be used for three different evaluation procedures:

- Dressing evaluation: during the dressing operation the interaction between dresser and grinding wheel can be acoustically mapped. Lack of contact between dressing tool and grinding wheel will appear as dark areas in the map.
- Topographic mapping: in this case the map is similar to that obtained for the dressing operation but using the dressing depth of cut nearly zero or with a value close to the undeformed chip thickness for the operation. In this case the map shows the active surface of the grinding wheel, which means the surface that will actually be in contact with the workpiece during grinding.
- Grinding evaluation: during a plunge grinding operation the interaction between the grinding wheel and the workpiece can be evaluated. In this case a different map is obtained where one axis is the grinding time and the other shows the average acoustic energy in the whole wheel length along its perimeter. Figure 10 shows an example of this application for two wheel wear modes. As can be seen in the maps, topographic changes along the time indicate grain release (on the right side – second experiment) and constant patterns indicate sharpness loss (on the left side - first experiment).

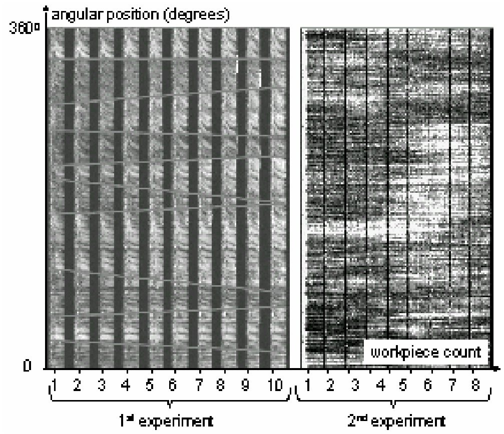

Figure 10. An example of grinding evaluation for two wheel wear modes.

The final step is the automatic diagnosis routines implementation on this new high speed grinding machine, performing valves and crankshaft grinding operations.

Conclusions

The development of the OAC controlling system will create a new automation level in the grinding process. It will also be possible to perform researches in high speed grinding with CBN wheels, for many materials and products. The grinding process and the collected data can be transmitted to the upper levels of the business system. New monitoring strategies will be implemented combined with the possibility of remote machine diagnostic and operation. There will be a technological improvement in the area monitoring and controlling systems, improving the machine automation level, reducing grinding costs.

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