Integration of CNC Machines in Flexible Manufacturing Cell

Paulo J. Leitão *CCP*, Carlos Martins *CCP* and Rui Rocha *CCP*

***Abstract* - This paper is focused on CNC machines integration in the manufacturing cell. It describes the main auxiliary systems available in each machine, and the connection of CNC machines to a network via MAP/MMS cards, to establish the communication channel between these machines and the flexible cell manufacturing controller.**

1. Introduction

The machines integration in a flexible manufacturing cell is the way of making profitable the use of machines with numeric control. These machines are not profitable if they are used as isolated islands.

If they exist alone, the human users, that works on the cell, would be forced to make manually the download of machining programs, and to take decisions themselves, in real time. These decisions are related with the complex resources management, as machining time, machining tools and raw material. They would be forced also to make all the machining programs manually, which are in general very fastidious. Besides they must learn programming in several CNC languages, depending of the machine they want to program.

From these hints, we feel that the described manual process, based in the user's inspiration and, eventually, some human natural errors and his own locomotion limitations, would be really inconvenient. It would cause an extreme waste of time and of the potential equipment resources, and the process would become not profitable and a completely absurd. That's why it is so important to integrate the several machining resources.

The first step to follow the integration purpose was the development of several auxiliary systems as automatic workpiece measurement, "zero workpiece" determination, tool's information management and security systems. This systems will be explained in the next parts of the paper.

The second, and the biggest step for the need of integration was the machines connection to a communications network, which will be related in point 5. The network present in the manufacturing cell is based in the MMS protocol. It provides the communications between each of the machines and the external systems, and makes possible the remote machine controlling and the information exchanging. It makes also possible the automatic machining program generation, using a dedicated CAD system and post-processors. Using this network, we could develop dedicated software (the manufacturing cell controller) to control directly the machines and to make the interface between the machines and the shop floor control. This highest level software is dedicated to the integration of the several existent cells and their own low level controllers (as the manufacturing cell controller). The shop floor control takes care about the tasks scheduling and global resources management.

2. Description of Manufacturing Cell

The manufacturing cell is a group of resources like CNC machines, robot and transfer tables.

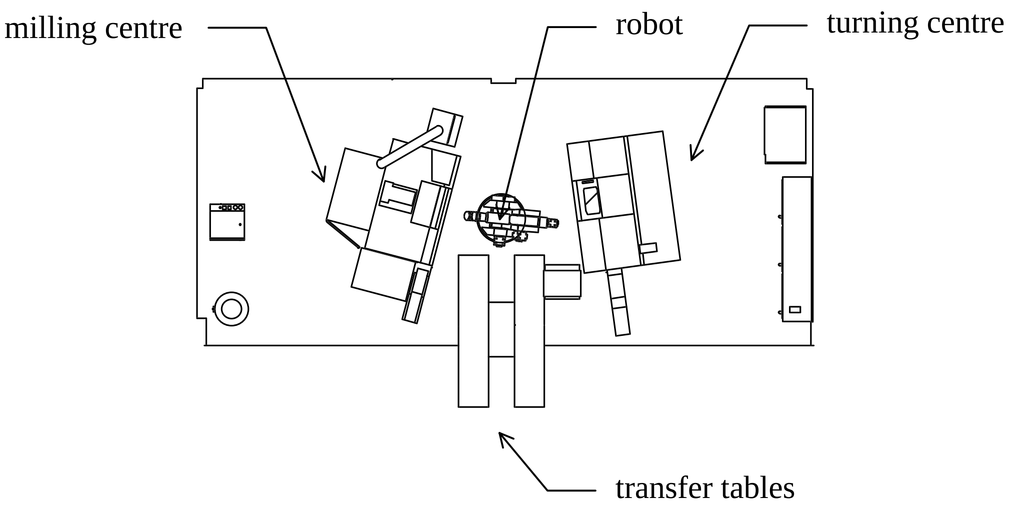


Fig. 1 - Layout of manufacturing cell

The CNC machines available in the cell are the turning center and the milling center.

3. Turning centre

The turning centre is a part of the manufacturing cell. The turning centre is Lealde, model TCN10, with numerical control Sinumerik 880T of Siemens and has with objective to turn cylindrical pieces.

This machine has a tool magazine with 12 tools of capacity.

The machine allows the movement in two axes X and Z, transversal and longitudinal axis. Additionally, allow a third axis (C), where it is executed a position control defined in degrees.

Physical characteristics :

* maximal rotation speed of spindle is 3000 rot/min;
* the physical limits are 438,64 e 384,03 mm for Z and X axis.

This machine has the follows auxiliaries systems :

* measurement of pieces system Renishaw;
* collision detection system Montronix;
* read/write of tool codes system Sandvik.

3.1. Workpieces Measuring System

The CNC of the turning centre has got a group of subroutines that use the Renishaw measuring system to measure the co-ordinates of some points on the workpiece's surface. These subroutines may be called by measuring cycles. With this system it's possible made a quality control inside of machine and determinate the workpiece zero.

3.1.1. Workpiece zero compensation

Cycle L973 may be used to measure the co-ordinates of a point P in X or Z. Those co-ordinates are related to the workpiece zero, W. However a few R parameters must be passed to this cycle. To answer this demand, those R parameters must be loaded before calling the cycle; when it ends the resultant values are available in another well known R parameters.

So, if robot Kuka isn't able to put the workpiece in the chuck with desired accuracy, it is possible to use this cycle to measure the difference, Δd, between the desired position of the workpiece's front surface and the real position. After that measurement, the workpiece zero will be translated of a value equal to that difference.

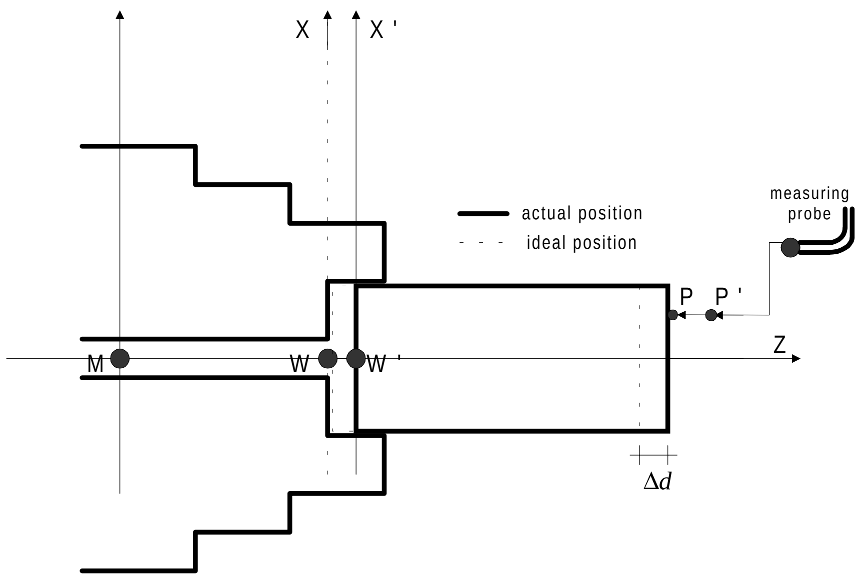


Figure 2 - Workpiece zero with Renishaw probe

To execute the workpiece zero compensation the following steps must be done :

1. Put the measuring probe in front of the workpice (position P'), so that the movement of the tool magazine may deflect the tool probe;
2. Activate the tool probe;
3. Load the R parameters that cycle L973 needs;
4. Calculate the co-ordinate in Z of the new workpiece zero, W'.

3.1.2. Tool Offset Compensation

After numerous machining processes, tool’s dimensions will be modified.

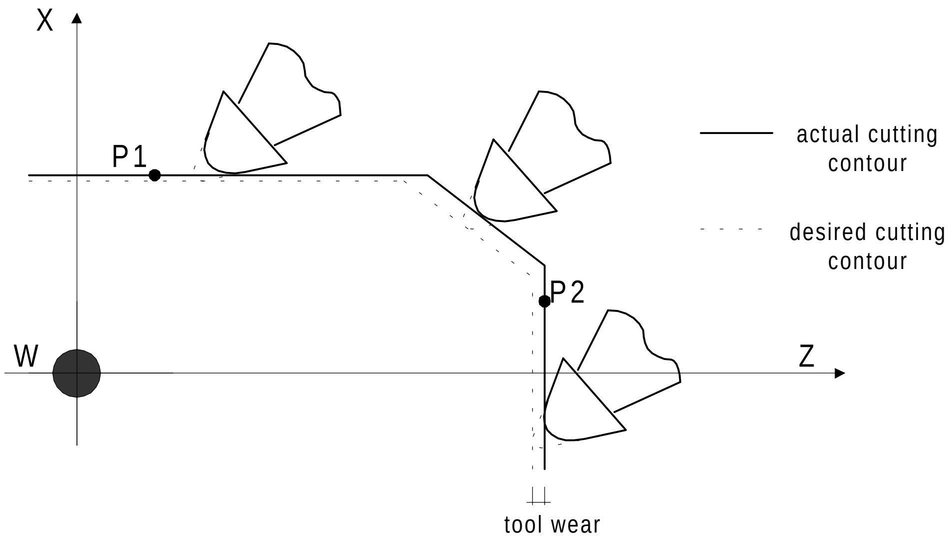


Figure 3 - Offset in the cutting contour caused by tool wear

Because of tool wear, the final piece surface dimensions will be offseted to the desired one.

In order to compensate the tool offset for further machining operations it is convenient to measure the just machined workpiece surface with some regularity, if possible along both two axes X and Z (points P1 and P2 respectively, in figure 3). Cycle L974 may be used to bring to an issue this request.

By measuring the workpiece along axe Z , in P2, the actual value of co-ordinate in Z will be obtained, and tool wear may be calculated, since the desired value of this co-ordinate is known (it must be in the machining part program). This tool wear, in Z, will be used to actualise parameter P6 in the structure of tool offset memory (figure 4).

If, thereafter, an analogous measure is taken along axe X, in P1, parameter P5 which correspond to the tool wear in X will be actualised.

So, if the tool wear values obtained fall into a limited boundary, the tool used for cutting that surface may be calibrate in the turning centre, avoiding all the work necessary to take the tool into the calibration cell which must always imply a "stop cell" order.

3.2. Collision Detection System

A major concern in the development of machining systems that rely on computer controllers is monitoring the performance of the machining process to protect the machine tool.

In order to sense tool wear and detect tool breakage, the Montronix TS200W system is incorporated at the turning centre.

3.2.1. Tool sensing capabilities of the TS200W

The TS200W provides tool monitoring protection with the following capabilities:

- **tool wear:** it may appear in a variety of ways such as chipping, flank, depth-of-cut notches, or crater wear. Tool wear is generally not a catastrophic condition; however, excessive wear may be catastrophic, so in that situation the CNC will receive a “machine stop” alarm;
- **breakage:** when tool chipping or breakage events occur the CNC must be advised with a “machine stop” alarm. The response time for breakage detection is about 8 milliseconds, about 2 milliseconds are required to send the alarm from the MONTRONIX to the CNC and an additional delay may be introduced by the CNC to stop the machine;
- **collision:** this feature is designed to protect the machine tool or tooling in the event of collision. The principle of collision detection is based on comparison between the three force components and a collision limit value. When this limit is reached by one of the force components a “machine stop” alarm signal will be generated in 3 milliseconds;
- **missing tool:** if the cutting forces fall bellow a low limit level and the tool is supposed to be “in-cut”, we can conclude that as a matter of a fact the tool isn’t really cutting the workpiece. This may be due to an incorrect part program, incorrect tool dimensions or offsets, wrong workpiece, or a missing tool. In all these cases the CNC will receive a “missing tool” alarm signal;

When one of the previous situations happens, the manufacturing cell controller must be advised of that event. The alarm occurrence will be notified to the cell controller by MMS service.

3.3. Read/Write of Tool Codes System

In the turning centre there is one or more tool offset number D for each tool. In the moment a tool is selected for cutting, it must be specified the associated D number. There are 100 different tool offset numbers D (D00 .. D99).

This number allows the identification of geometric parameters for the related tool, as length (in X and Z), wear, type, basis length, like shown in the next figure:

	Offset memory structure									
	T. No.	Type	Geometry			Wear			Basis (supp. TO)	
Dnn	P0	P1	P2	P3	P4	P5	P6	P7	P8	P9
	123..8	1..9	Length 1	Length 2	Radius	Length 1	Length 2	Radius	Length 1	Length 2

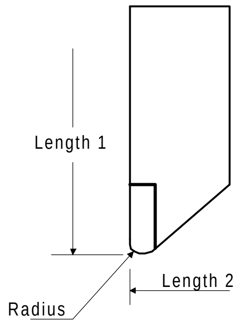


Figure 4 - Structure of tool offset memory

System Sandvik may be used to save in a magnetic disk (or read from it) the information related to a particular tool. That magnetic chip will be introduced in the tool, becoming integrate part of it.

It is possible to calibrate a tool in the cell calibration, save the resulting data in the magnetic chip and read it into the structure of tool offset memory in the turning centre; or read these data from this structure, write it in the magnetic chip and then read it in the cell calibration.

4. Milling Centre

The milling centre is Kondia, model B500 with a numerical control Fanuc 16MA, and has with objective to mill pieces with any kind of geometry.

This machine has a tool magazine, with 18 tools of capacity.

A machine allows the movement of the table in X and Y axis and the movement of spindle in Z axis. Additionally, allow a fourth axis (C), where is possible to execute position control with divisor plate.

Physical characteristics :

* maximal rotation speed of spindle is 3000 rot/min;
* maximal speed of table is 4000 mm/min (work speed);
* the physical limits of table are 560 e 380 mm for X and Y axis;
* the physical limit for Z axis is 380 mm.

This machine has the follows auxiliary's systems:

* measurement of pieces system Renishaw;
* read/write of tool codes system Sandvik;
* rupture detection and tools wear system Kondia.

4.1. Pieces Measurement System

Like as Lealde, one of the most important auxiliaries systems of Kondia is the Renishaw system.

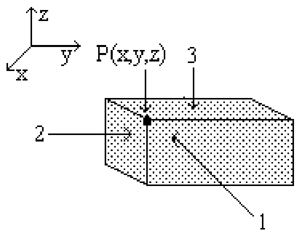
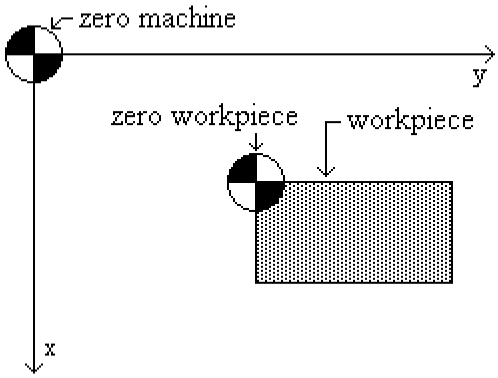


Figure 5 - Determination of a corner

The Renishaw system is based in a detector, which emits an optical signal, when it detects a contact with the workpiece. For instance, if we want to make the exact determination of one corner position, in a rectangular body (see figure 5), we make three approximations with the tool, across the three axis (X, Y and Z), until it detects each plan (YZ, XZ and XY). Each approximation gives us one of the co-ordinates that we want.

This system allows the automatic determination of "zero workpiece", the measurement of pieces and quality control. Because the Milling Centre is integrate part of a flexible manufacturing cell, it was necessary provide flexibility to the machining programs. When the Kuka robot loads a piece on Kondia, it may appear errors of some μm from the predicted placement position. So, if the machining programs were made, taking by reference a space fixed point, it would result in significant errors and loss of flexibility. Besides, the CAD post-processor, which generates automatically the machining programs, doesn't know what is the space point, in which the workpiece will be manufactured, therefore, the CAD demands a reference for its programs.



To resolve this problem, all the machining programs are made, taking by reference a point called “zero workpiece” (see figure 6). This point is known by the machine, taking the offset of this space point from the “zero machine”. If the “zero workpiece” is determined after each piece placement by the Kuka robot, the programs will be much more flexible and accurate. This is the biggest utility of the Renishaw system.

Figure 6 - The “zero workpiece”

Another interest of the Renishaw is the possibility of making quality control and tools offset measurement. With the Renishaw we can measure the manufactured workpiece, and detect the offsets from the workpiece drawn by the CAD. Therefore we can make quality control. These measures can be also done in order to determine the tools offsets, due to its ware, allowing the correction of those offsets. The Kondia has a set of attributes for each used tool as tool number, tool life, offsets, and so on. It can support a maximum of 99 different tools, which are called by “groups”. The tool life may be automatically actualised when a specific tool is used, if we put an instruction in the machining program, which indicates what is the tool’s group. When the tool life overlaps, an alarm is generated, and the machine cannot run any program, which uses a tool of that group.

4.2. Collision Detection System

The Kondia has a collision detection system, which is prepared to stop immediately the machine, and to generate a specific alarm for that situation, when any abnormal collision occurs.

4.3. Tool Codes Read/Write System

The read/write of tool codes system is based on the Sandvick system. This system can read from or write to a bulk information associated with a machining tool. Each tool can have a bulk associated, in which we can store relevant information, in a given format. This information may be as the table 1 shows.

Name	Size (bytes)	Variable type
Tool Number	2	integer
Tool Position	1	integer
Width (H)	4	real
Width Offset (H)	4	real
Radius (D)	4	real
Radius Offset (D)	4	real
Tool Life	2	integer
Tool Life Counter	2	integer
Group Number	2	integer
Corrector H	2	integer
Corrector D	2	integer
Type 1	1	integer
Type 2	2	integer

Table 1 - Information in tool chip

When a new tool is bought, we associate to it a bulk, in which we store all the tool attributes, after the initial measurements made in the palletising cell. This bulk will identify the tool along the cell, and distinguish it from the others using the "Tool Number" information. After each tool utilisation, we can measure again that tool in the palletising cell, and actualise the bulk information, about the offsets.

The system provides the communication with external systems, using the RS232C protocol. Besides, it has a specific protocol with a set of commands, in order to establish the external connection. The main commands are "Read" and "Write".

This system makes possible the automatic updating of tools information, providing an organised manner to store those information and to exchange them between the manufacturing cell and the palletising cell, providing also a not ambiguous identification, of each tool existent in the factory. The communication using MMS allows the actualisation of tool's information in the Kondia. If we compare the information stored in the tool's bulk, that is being used to machining, and the information stored in the Kondia's memory about the same tool, we can detect eventual tool placement errors, when the operator places new tool in the Kondia.

5. Machines Integration

In each machine there is one MAP/MMS card, which allows the integration of these machines in the same cell. The manufacturing cell controller runs on a workstation, which has a SISCO MMS stack. The integration of these machines in a network allows the downloading of NC programs faster than RS232. Besides, it allows the direct transfer of the NC programs created by CAD to the machine without any diskette or terminal.

5.1. Adaptation to Cell Controller and MMS

It was necessary to define several variables in each machine, so the cell controller knows, at each moment, the state of machine. Besides, the robot uses some of these variables to verify the state of the machine. For example, if the robot must load a machine, it verifies if the door is open, through the door sensor.

Variables	Designation
SEN_DOOR_KD	Sensor of Kondia´s door
SEN_VICE_KD	Sensor of Kondia´s vice
SEN_DOOR_LD	Sensor of Lealde´s door
SEN_CHUCK_LD	Sensor of Lealde´s chuck
SEN_CONT_KD	Sensor of Kondia´s NC
SEN_CONT_LD	Sensor of Lealde´s NC
SEN_CELL_DOOR	Sensor of cell´s door
ACT_DOOR_KD	Actuator of Kondia´s door
ACT_VICE_KD	Actuator of Kondia´s vice
ACT_DOOR_LD	Actuator of Lealde´s door
ACT_CHUCK_LD	Actuator of Lealde´s chuck

Table 2 - List of variables

There are two kinds of variables : physical signal and software events.

The robot uses the physical signals whenever it needs to verify the state of the door and the chuck in Lealde and the door and vice in Kondia. These physical signals (24 V) usually are sensors.

The software variables are used by MMS to know the machine´s or the cell´s state and to change the state of the machine´s devices.

The cell controller knows the value of these variables, through the MMS Read service and can change the state of devices using the MMS Write service. The MMS Write service of an specific variable, allows to open or close the door, open or close the vice and so on. For example, to close the Lealde´s chuck, it's necessary to execute the Write service with the follow parameters : ACT_CHUCK_LD and CLOSE_CHUCK.

One of the most important variables, related to the cell doors sensor is the SEN_CELL_DOOR. It´s used to detect if someone comes inside the cell and in that case, if the door is open the execution of all machines will stop.

To eliminate the collisions between robot and NC of each machine, there is a sensor in each machine NC to verify if the NC display is outside robot area. So, whenever the operator goes to the cell, he shall put the numerical control display in a SAFE pre-defined position. If don't, the cell controller detects this error and generates an alarm.

So, the definition of these variables has with objective the security of the machines and the people.

5.2. Adaptation of NC programs

The NC programs created by CAD must obey to a set of rules. The most important ones are:

- whenever the machine exchange the tool, the table with workpiece in the case of Kondia and the magazine in the case of Lealde, must go to Home position;
- when the program finishes, must go to the robot position; in case of Lealde, this position is equal to Home position; in case of Kondia, the table must be in front of door.

6. Conclusion

The architecture used for the flexible manufacturing cell permits the integration of machines of different manufacturers, with different protocols, in the same cell. Since all cell machines are connected into a network via manufacturing automation protocol (MAP/MMS), the communication between different machines is made possible because the information flux passes in the manufacturing cell controller.

The manufacturing cell controller plays a part analogous to a translator in a conference between people of different nationalities.

Particularly interesting is to use in an exhaustive way the resources already available in the machines. These resources may be upgraded for benefit of integration, since they constitute modular solutions which are out of errors by construction. An example in this application are systems Montronix, Sandvik and Renishaw.