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STUDIES ON AUTOMATED NON-DESTRUCTIVE INSPECTION FOR ALUMINIUM CASTING PARTS MACHINED ON A MILLING CENTER

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Abstract: *In this paper some aspects concerning the influences of milling process over the surface quality for casting material are presented. A non-destructive technique was used to identify defects over the surface caused by cutting process conditions and different CAD-CAM techniques. The general goal of this paper is to present a way of automatic inspection of products quality in machining process.*
A general plan was made for a computer integrated manufacturing which could include a fully-automated liquid penetrant inspection line for increasing productivity. A case study was made for an inspection of milling a casting piece. The piece was casted in aluminium mould using a gravity die casting technique. On this piece a pocket was created by using a 3x milling centre and an advanced CAD-CAM software. Roughing and finishing machining operations were used in order to achieve better surface quality.

Key words: *milling, cutting process, CAD CAM, LP non-destructive inspection, optical inspection*.

1. INTRODUCTION

To become more competitive into a world with diversity of products, with continuous change, the companies must to modernize and increase the flexibility of their production systems. The most efficiently tool for a fast adaptation of the production at the strategical and operational options of the company is computer aided manufacturing [1].

Among the priorities of manufacturers, in their attempt to be more competitive and better serve their customers, there is the need to shorten delivery times. Manufacturers strive to do things faster at every stage of the process, attempting to decrease design, programming, machining and inspection times. Two machining methods, High Speed Milling (HSM) and High Performance Machining (HPM), have become increasingly popular because of their ability to drastically speed up machining, while achieving better results.

The general flow of a workpiece into a manufacturing process consists in machining, (that involves CAD-CAM-Postprocesing-Cutting process on a machine tool), assembly, inspection, and delivering. In Fig. 1 the general schema is presented for the flow of a workpiece into industrial process.

1.1. Milling process overview

Milling is the most common form of machining, a material removal process, which can create a variety of features on a part by cutting away the unwanted material. The milling process requires a milling machine, workpiece, fixture, and cutter. The workpiece is a piece of pre-shaped material that is secured to the fixture, which itself is attached to a table inside the milling machine. The cutter is a cutting tool with sharp teeth that is also secured in the milling machine and rotates at high speeds. By feeding the workpiece into the rotating cutter, material is cut away from this workpiece in the form of small chips to create the desired shape.

Milling is typically used to produce parts that are not axially symmetric and have many features, such as holes, slots, pockets, and even three dimensional surface contours. Parts that are fabricated completely through milling often include components that are used in limited quantities, perhaps for prototypes, such as custom designed fasteners or brackets. Another application of milling is the fabrication of tooling for other processes.

For example, three-dimensional molds are typically milled. Milling is also commonly used as a secondary process to add or refine features on parts that were manufactured using a different process.

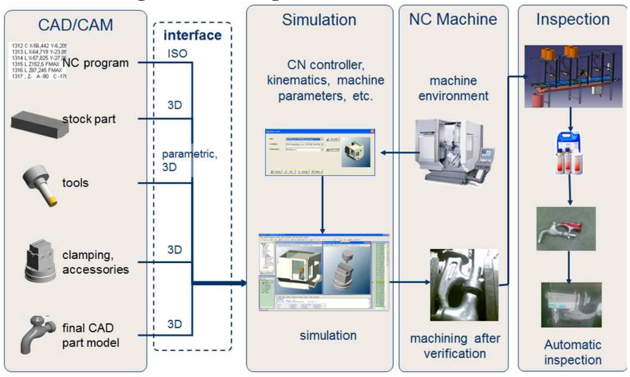

Fig. 1. General schema of general workpiece flow.

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Due to the high tolerances and surface finishes that milling can offer, it is ideal for adding precision features to a part whose basic shape has already been formed

Milling can be performed on workpieces in variety of materials, including most metals and plastics. Common materials that are used in milling include the following: aluminium, brass, magnesium, nickel, steel, thermoset plastics, titanium, zinc etc.

When selecting a material, several factors must be considered, including the cost, strength, resistance to wear, and machinability. The machinability of a material is difficult to quantify, but can be said to process the following characteristics: results in a good surface finish; promotes long tool life; requires low force and power to mill; provides easy collection of chips;

The quality of a milled product can be measured from point of view of surface quality and dimensional accuracy.

The inspection method depends of machined material and by the way of obtaining it.

1.2. The liquid penetrant inspection overview

Dye penetrant inspection (*DPI*), also called *liquid penetrant inspection* (*LPI*) or *penetrant testing* (*PT*), is a widely applied and low-cost inspection method used to locate surface-breaking defects in all non-porous materials (metals, plastics, or ceramics). The penetrant may be applied to all non-ferrous materials and ferrous materials, although for ferrous components magnetic-particle inspection is often used instead for its subsurface detection capability. LPI is used to detect casting, forging and welding surface defects such as hairline cracks, surface porosity, leaks in new products, and fatigue cracks on in-service components [4, 5 and 6].

The liquid penetrant inspection (LPI) is a non-destructive evaluation (NDE) method used for verifying the presence of open discontinuities at the surface of analysed parts submitted to inspection [6 and 7].

A typical in-line set-up for LPI consists in the following working stations: penetrant application; surface penetrant removal; drying penetrant liquid; developer application; inspection.

Currently, the evaluation is visually performed by an inspector, who gives a pass/fail grade for the inspected part depending on size, shape and orientation of the flaws, taking into consideration also the fact that the indications (visible in colour) are larger than the actual defect. Therefore the results are influenced by subjective issues such as the inspector experience, knowledge and motivation. The automation of the process eliminates these advantages, and leads to a decrease of the total inspection time, thus to important cost savings [7].

The difficulty to fully automate the LPI process relates not only to the evaluation process (which must be performed by automatically processing the images acquired using a digital camera and dedicated software), but also to determine and control process parameters such as dwell time, developer time, drying time, quantity of penetrant, developer and cleaning water, pressure for spraying solutions with penetrant, developer and cleaning water, transport speed, distance between stations etc [9 and 10].

2. MILLING OF CASTING TAP

In this study the goal was to verify if the automatic process of non-destructive inspection with penetrant liquid is possible for milling casting tap.

The tap is from aluminium made by using a gravity die casting techniques. Figure 2 shows the main parts constituting a classical mould for gravity die casting. Cores (inner parts of the mould) are generally made of bonded sand. In Fig. 3 is presented the mould used.

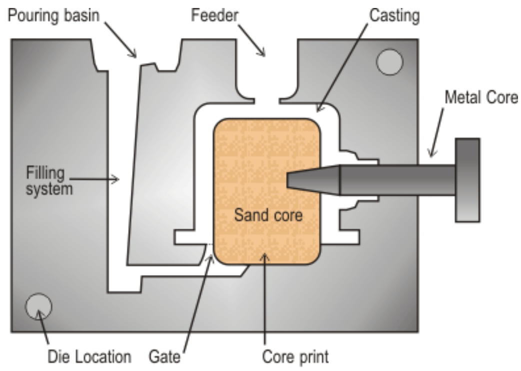


Fig. 2. Schematic view of a casting mould.

a

b

Fig. 3. Two parts of the mould.

Fig. 4. Aluminium casting tap.

This technique represents almost 20% from aluminium casting methods. Other methods are high pressure casting, low pressure casting, vacuum and squeeze casting.

The main disadvantage of gravity casting consists in possible air bubble which will be as porosity or inclusion.

These defects in material will influence the cutting process in finish milling.

The result of gravity casting of an aluminium tap made in our laboratory is presented in Fig. 4.

2.1. CAD-CAM of Aluminium casting tap

A milling process was made on this part.

A 3D cad model was made by using advanced CAD software and imported into CIMATRON E10 CAM software. (Fig. 5)

Cimatron E10 is an advanced software which allows to generate an NC file based on the simulation of the cutting process.

Cimatron E10 offers some important advantage in order to obtain an optimum NC program. It could operate with tools and tools library

A flexible administration of the programs, based on a simple and intuitive interface is also one of the main characteristics of it.

The most important features is that Cimatron allowed a powerful interaction between tool trajectory, verification and optimization.

Two ways of machining are right now implemented in this software: high performance machining (HPM) and high speed machining (HSM).

HPM fulfils its goal of faster material removal by working with either a large sidestep, a large downstep, or both simultaneously, and achieving as fast a feed as possible.

During HPM with a large sidestep, the tool will be cutting at sidesteps that are 60–80% of its radius, which means that a 50mm cutter will be working with a side step of 30–40mm.

Enabling this level of sidestep has a huge pay off for the material removal rate, but can only work if the tools, holders and machines are built to withstand strong machining forces, and if the CAM software can create special toolpaths that minimize the strain.

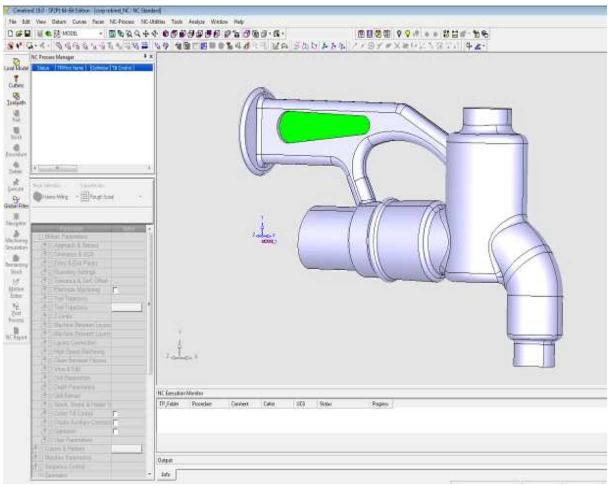


Fig. 5. Tap 3D Model in Cimatron E10.

HSM is the second of two high speed roughing methods. While HPM helps increase the material removal rate by facilitating larger downsteps and/or sidesteps, HSM provides a solution for faster machining when using a small sidestep and a small downstep, combined with very high spindle speed and feed rate.

Usually, a small sidestep and downstep become necessary in the second stage of the process, where the main goal is to achieve a uniform remaining stock across the entire surface of the part. However, there are situations in which a small sidestep and downstep are used for the entire roughing process, for example when working with small parts.

In our study we develop a NC file for the green pocket (Fig. 5) based on the principle from above.

It was used a 8 mm flat mill for roughing the green pocket in one single downstep. The depth of cut was 3 mm in zigzag tool path.

The process parameters were calculated based on standard formula for milling

The main spindle speed was calculated with

$$n = \frac{v_{as} \cdot 1000}{\pi \cdot D}, \qquad (1)$$

where v_{as} – surface cutting speed; D – tool diameter

The feed rate of the machine was calculated based on spindle speed, number of teeth and feed per tooth

$$v_f = z_n \cdot n \cdot f_z, \qquad (2)$$

where z_n – number of teeth; n – spindle speed, f_z – feed per tooth;

In Fig. 6 is presented the value for machining parameters used in Cimatron for milling the poket.

A roughing procedure was used for tool path generation.

Some parameters were modified in order to optimize the machining process (side step and direction angle for toolpath, Fig. 7).

In order to check the results some simulations were made based on tool path obtained.

Special simulation with material removal and virtual machine were made. Based on this result the CAM process was validated and a NC file was created.

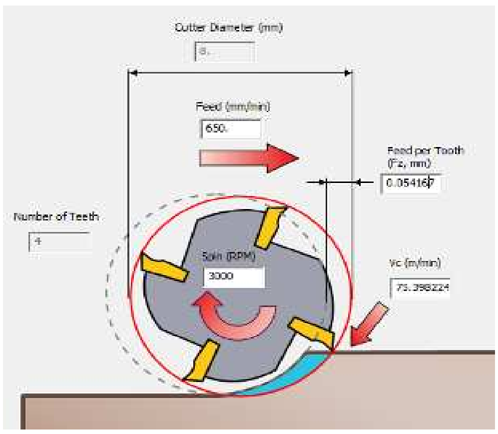


Fig. 6. Machining parameters.

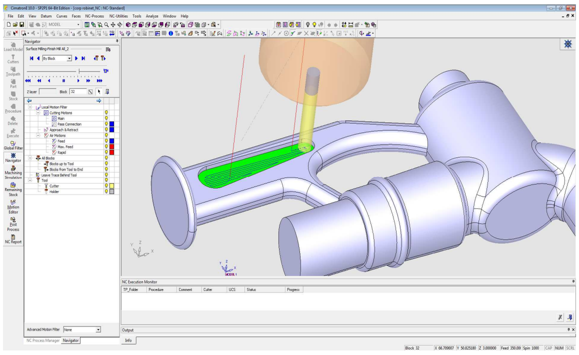


Fig. 7. Tool path for roughing.

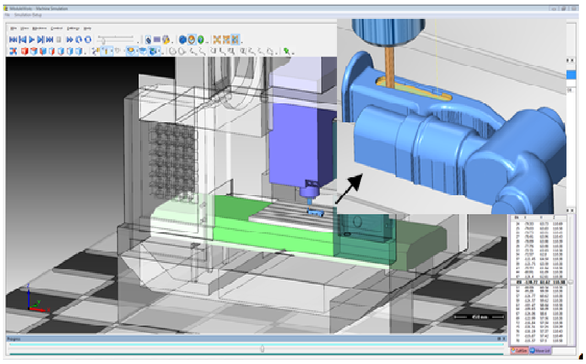


Fig. 8. Tool path for roughing.

The role of simulation was to identify possible problems like collisions between tool, shank, tool holder and machine parts. Also it was check that all trajectories are in the limit of machine axis.

In this way the NC file was optimized for a certain machine tool (Fig. 9).

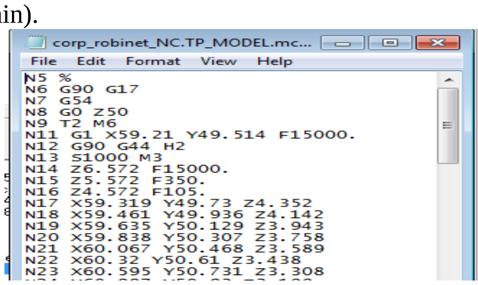
2.2. Machining the pocket

Based on NC file obtained by CAM techniques the pocket was milling on the MCV 300 milling centre. The main characteristics of this machine are: Machine Type : VERTICAL; Control :Fanuc; Number of Axes :3; *X* Axis Travel :610 mm; *Y* Axis Travel :305 mm; *Z* Axis Travel : 460 mm; Tool Stations : 24; Spindles :1; Motor Power: 7.5 to 11 kW; Spindle Speed: 8 000 rpm (Fig. 10).

The results of milling are presented in Fig. 11. It can be notice that there are some problems on the edge of the pocket.

At first look it seems that the quality of the surface at the bottom is ok.

In this case the quality of the surfaces was influenced by milling parameters and type of tool path. Very important is the way of entering the tool into material. It was used a ramp entering with different feed (v_f = 300 mm/min).



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N18 X59.461 Y49.936 Z4.142
N19 X59.635 Y50.129 Z3.943
N20 X59.838 Y50.307 Z3.758
N21 X60.067 Y50.468 Z3.589
N22 X60.32 Y50.61 Z3.438
N23 X60.595 Y50.731 Z3.308
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Fig. 9. Part of NC file.

Fig. 10. Machining on MCV300 vertical milling center.

Fig. 11. Results of machined part.

3. AUTOMATIC LP INSPECTION

In the next step an automatic non-destructive LP method will be applied over the pocket in order to identify defects resulted from machining and casting of aluminium.

The general schema of the automatic system is presented in Fig. 12

It was used a red double-check DP-50 penetrant from Sherwin and a white developer Sherwin D -100. The surface was clean up with a Sherwin DR-60 degreaser.

In the first step the surface was clean-up using air jet and then was degreased using DR-60 degreaser

DP-50 penetrant liquid was applied over the surfaces and a 15 minutes were waiting (Fig. 13).

In the next step the liquid excess was washed.

After drying the developer D-100 was spraying over surface and also a few minutes were necessary for drying (Fig. 14).

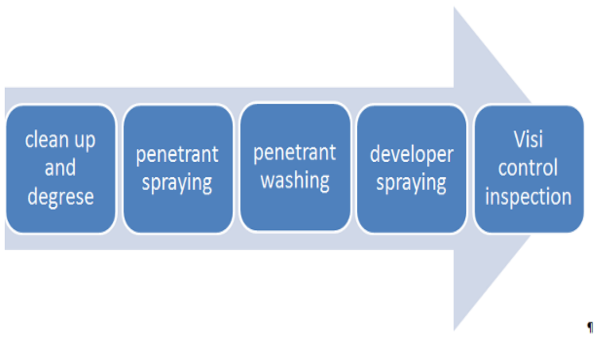

Fig. 12. General schema of the system.

Fig. 13. Penetrant liquid application.

Fig. 14. Developer application.

3.1. Inspection on an automatic system

The inspection and analyse of the results was made by using Visi control industrial system from a computer integrated manufacturing in one of the Politehnica laboratory.

The inspection post contain a Visi Control camera mounted vertically (1), an infrared light source (2), a control system (3) and an industrial computer (4) with specialized software for programing and analysing and a conveyor for pieces transfer (Fig. 15).

The software allows identifying difference between pixels function of their greyscale. Based on this different parameters can be measured like distance, length and angles, areas and perimeters (Fig. 16).

The programming techniques are based on an intuitive interface. The software can automatically calibrate the image, but also allow user to define a coordinate system as datum for measuring and positioning.

Once the programme made it can be used to verify an unlimited number of similar parts.

The pieces was positioning by using the conveyor (5) for image acquisition under the infrared camera.

The system was programmed (Fig. 17) to identify the area of the black spots with a certain value. What it is under this value is considering good.

This means that there is a surface defects underline by LP method.

The results can be used for different type of decision. If the defect can be repaired (also through milling) the piece will return to the milling centre. In our case the edge of the pocket can be remachined.

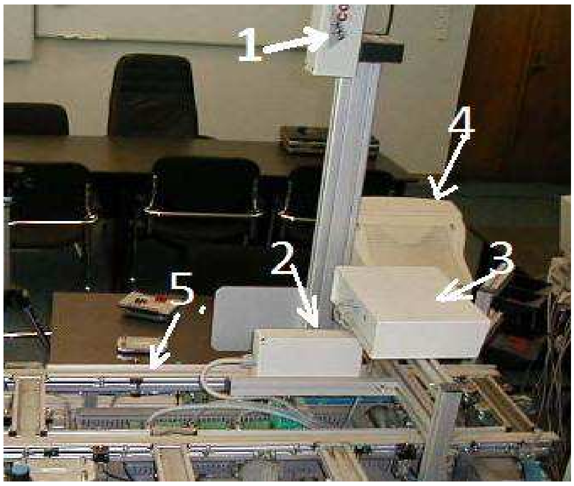

Fig. 15. Results of machined part.

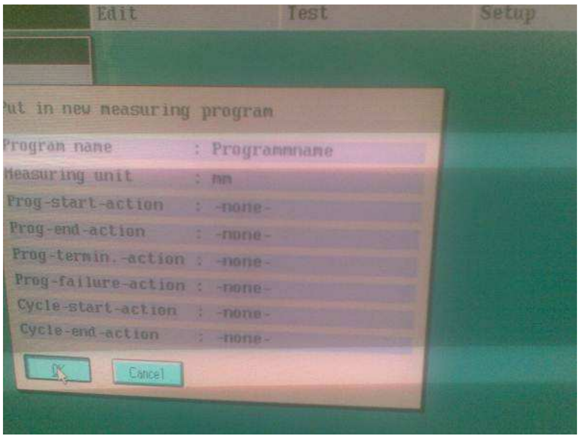

Fig. 16. Programming the inspection station.

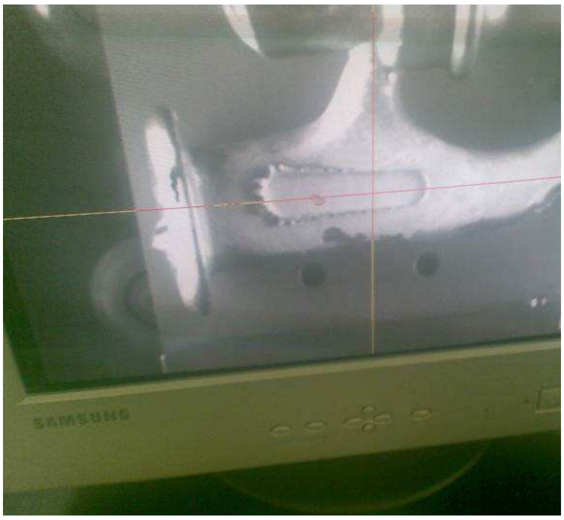

Fig. 17. Visualization at the inspection station.

The result from inspection of the part after the system was programmed is presented in Fig. 17. As it can be noticed in Fig. 17 a defect was identified and marked on the screen. The red cross represents the reference coordinate system

For this visual system in order to work the piece must be in the same position every time.

4. CONCLUSIONS

The study presented in this paper shows the link between different technologies in order to obtain quality products.

The results obtained from the verification made shall be used for developing a fully-automated inspection system with penetrant liquid which can be implemented in any computer integrated manufacturing.

From the point of view of machining in continuing attempts to shorten overall delivery times by reducing machining times, manufacturers have turned to High Speed and High Performance Machining.

High Speed Milling (HSM) and High Performance Machining (HPM have the potential to greatly speed up machining and to improve overall results, ultimately achieving a fast rough and an efficient finish with a superior surface quality.

For the CAM system to be effective, it has to go beyond superficial "compatibility" with High Speed Machining methods, empowering the manufacturer to create a process that is as fast as it can possibly be, and is also controlled enough to achieve a uniform remaining stock and ultimately a high quality finish.

Cimatron CAM software used in this study fulfils the requirements presented above, and optimizes the toolpath according with different strategies.

The results of machining are influenced by CAM strategies, performances of the machine and tool, but also by the state of the machined material.

The quality of the surfaces obtained through milling on casting aluminium is influenced by the inclusion in materials.

Our study was made on an aluminium tap made by casting in metal mould through gravity die casting techniques. In this case the risk of porosity and inclusion (air) is higher than other techniques like high pressure casting, low pressure casting, vacuum and squeeze casting.

When the tool reaches these defects in the milling process the cutting conditions are changed and the defect can be amplified. On the machined surfaces can occur traces, superficial cracks, and small holes.

Also the tool is affected and the tool life is decreased.

Automatically identifying these defects can validate very fast the quality of a product.

On aluminium parts the use of liquid penetrant technics and automatically visual control has the advantage to offer a good contrast between machined surfaces and surface defects (the penetrant liquid is red and developer is white).

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