METHODOLOGY OPTIMIZATION OF METAL CUTTING PROGRAMMING APPLIED TO AERONAUTICAL COMPONENTS

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Keywords: *metal cutting, Computer Aided Manufacturing, Virtual Manufacturing, post processor*

Abstract

An efficient CAM programming has to be considered a key aspect for a time and cost effective production in aeronautical field. In this paper, the authors describe a methodology to improve manufacturing process performances through the usage of computer aided instruments. Usually, a metal cutting operation is made by the following steps: definition of the toolpath, its output in APT language and subsequently the post processing phase in order to obtain an ISO format file for the specific machine, physical tryout, quality control of the obtained part on CMM, part program certification. The procedure does not allow to judge the process performances of the defined toolpath until the physical tryout is carried out such as the results of CMM are available.

The authors' aim is to propose an alternative approach to reduce the physical tryout requested time and relative costs through the employment of an Integrated Simulation Environment (ISE) that contains: CAM software, CAM integrated post-processors and virtual machining environment.

Moreover, the authors propose a new way to support the post processor programming through the usage of the simulation environment. This phase allows to perform a virtual validation of the post processor, speeding up its physical test.

The advantage arising from the usage of the proposed procedure can be more important if it is applied to the process start-up phase (new CNC machine tool that requires a new post processor).

1 Introduction

In metal cutting applications, the "*tape tryout*" (TTO), the first attempt part program execution upon CNC machine tool, is a very difficult and expensive phase in terms of: process time, raw material and human resources [1].

During real machining phase it is necessary to verify the part program's accuracy in terms of path and planned technological parameters and it is usually essential to perform a continuous inspection of the machined features having as result a quite frequent toolpath editing operations.

Most CAM software tools carry out a cutter location file (CLF) validation. CLF can be considered the toolpath definition before the post processing phase. This simulation offers a preliminary idea of the physical application, because it is totally disconnected from the machine tool and its numerical control. Any tool motion has to be cinematically checked during the first execution. In particular, the operator has to perform a step by step machining.

TTO needed time and relative costs can be reduced through the employment of virtual manufacturing. Virtual manufacturing is an emerging technology which allows to represent real manufacturing operations thanks to the usage of appropriate numerical models. The manufacturing activities and processes are modeled taking into account the real manufacturing operations. In any case, it is always necessary a numerical-experimental correlation in order to improve the numerical models effectiveness.

Virtual manufacturing is introduced into several CAM tools as an additional utility able to provide a kinematic inspection of machine tool motions. In particular, VERICUT® which is the application used in the present work, it is able to verify the tool motion generated by the post processor.

These computer aided techniques ensure a good tool path verification only in terms of proper path. In this virtual environment, after the post processing phase, machining issues and possible collisions (rapid motions that cause contacts between tool and physical part, collision among machine tool components, etc.) can be detected; no information is available about dynamic interactions (forces, residual stress, strain) among workpiece/tool/machine tool.

Authors' aim can be summarized in the proposal of a new methodology based on an Integrated Simulation Environment (ISE). A few material has been found in literature dealing with this topic. Lauwers et al. [2] worked on the generation of optimal tool paths using machine tool simulation. Lopez et al. [3] integrated in a CAM software the calculation of deflection forces acting on tool, in order to obtain a better surface finishing. Ratchev et al. [4] dealt with error compensation in thin wall machining operations, with a FEM based approach. Lee et al. [5,6] presented a Virtual Machining System for high precision turning, also working on some aspects related to post processing. Lin et al. [7] developed an Enhanced Virtual Machining Framework to integrate in tool path simulation a geometrical error model of the machine tool. Also five axis milling operations on axial compressors, blisks and turbine blades have been studied [8,9,10], sometime also with reference to post-processing or to machine tools.

In this work, the development of ISE will be presented with a more general and systematic

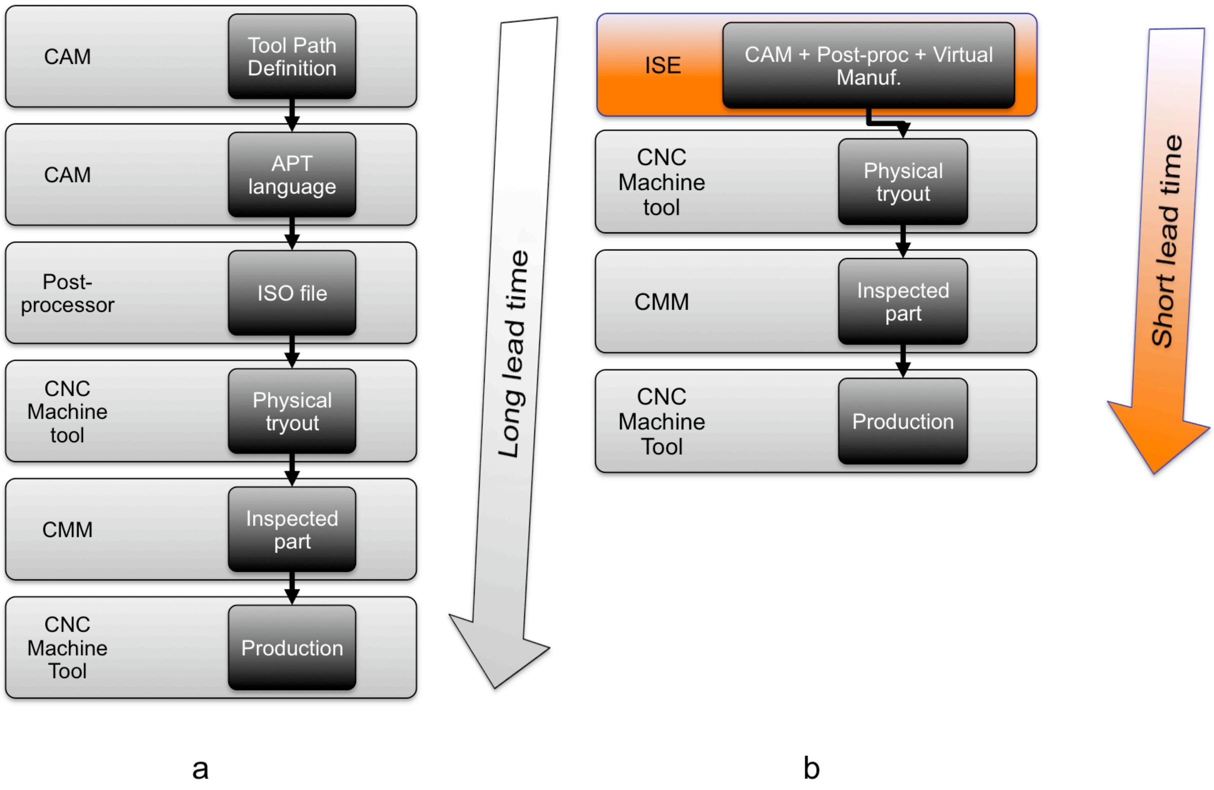


Fig. 1. (a) Traditional Approach, (b) Proposed Methodology

approach, trying to provide a global view on the critical issues typical of the aerospace industrial context.

2 Proposed Methodology: an Integrated Simulation Environment

The proposed methodology is based on the definition of an Integrated Simulation Environment (ISE), as illustrated in Figure 1b. The adoption of an Integrated Environment allows to uniform and to simplify the typically adopted internal procedures. Usually, it is the result of the stratification of different software and operative systems. The simplification of the computer structure enables the workflow re-design, in order to identify and to reduce criticalities.

The post-processing phase has been redefined inside the CAM programming environment, avoiding format conversion during the output to the CNC machine. The integration allows to transfer information from CAM software to post-processor (PP) at higher level, independent from the ASCII file.

After post-processing, the part-program has to be simulated with dedicated software. This phase can speed up the tape try-out (TTO) and avoid the high level of uncertainty during the physical execution on the machine tool. The simulation software has to take in account all the technological aspects of interest related to the machine tool and to the numerical control. With the adoption of simulation tools, risk of collisions, TTO time and part-program changes at the shop floor level can be significantly decreased.

As shown in Figure 1b, every step in the ISE methodology contributes to reduce the lead time and ensures technical and operative advantages as it will be demonstrated.

2.1 CAM Integrated Post-processing

The definition of an integrated PP can't be regardless of some functional requirements to obtain a correct ISO file for the CNC machine tool:

1. CAM tool path roto-translation has to comply with the reference system and the machine kinematics;
2. the ability to choose, in ambiguous situation, the best kinematic solution;
3. the definition of the machine mode usage;
4. the interpretation and execution of specific macros

Unigraphics® NX4 has been used as CAM tool in this activity. This software can manage the integrated post-processing via a proprietary PP definition tool The system can be widely configured by the programmer, developing customized procedures.

Every CAM operation corresponds to a set of "events" and variables, for example: a tool change, the first cutting move or the locking of an axis. The PP is made of event-related procedures, that can elaborate CAM environment variables and write on the output file proper ISO code. This event-based post-processing is much more flexible than the traditional one ASCII-based. It's possible to have a PP sensitive to particular tool path conditions that won't be recognized with simple text parsing.

The PP elaboration results in a more efficient process due to the fact that information don't need any intermediate processing. In fact, the CAM software defines a wide set of variables that the PP can use.

The main difference between an external PP (not integrated) and an internal (integrated) one lies in the way information is captured. An external PP has necessarily to parse a text file to define its own variables. Instead, an internal PP uses the same variables generated by the CAM software and so it can benefit from a richer amount of data with respect to a traditional APT based PP.

The analysis of these tools highlighted significant potentialities and enabled the development of the ISE methodology.

2.2 A CNC Machine Tool Simulation

The first point to focus on when considering the simulation of a CNC machine tool is that, inside a CAM software, the programmed tool path is independent from the real machine tool that will realize the part.

This condition, that ensures maximum generality to the definition process, brings some critical aspects. In the CAM environment the machined part is considered in steady state and the tool is free to follow the programmed path. On the other side, in the real working environment, the machine tool has a specific kinematic configuration. This means that, on the machine tool, movements are generally different and referred to a different coordinate system, with respect to various mechanical constraints. In other terms, by the usage of traditional CAM software, it's not possible to take into account any aspect concerning the real CNC machine tool.

Hence, a simulation tool has to create a "link" between CAM and the specific CNC machine tool, from a mechanical, kinematic and numerical control point of view.

The machine tool simulation introduces in the ISE:

1. tool path verification (collision check, machining time, axis override);
2. the analysis of the virtual machined part (gouges and stock material);
3. cutting parameters optimization.

3 ISE Development and Validation

The ISE development and validation has to guarantee the reliability and the robustness of every single tool that is part of the ISE.

The PP writing for CNC machine tools is a critical and time consuming activity.

Every PP is an application specific to the machine tool and to the related numerical control, and it's the key element to correctly manage and to fully exploit a machine tool.

The integration of the PP in the ISE leads to its development in accordance with the proposed methodology, as shown in Figure 2. In the start-up phase of a milling centre, when a new PP is needed, as far as during subsequent maintenance and improvement phases, the PP output can be verified thanks to a machine tool simulator.

Also the simulation requires resources to be correctly implemented and developed according to the CNC machine tool characteristics.

Hence, following the methodology, during the start-up phase, PP and simulation have to be developed together. When needed, can be useful to design a virtual test case *ad hoc*, to provide the largest possible envelope of working conditions.

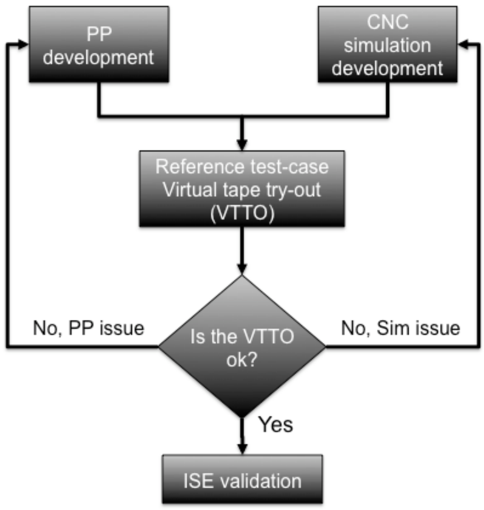


Fig. 2. ISE Validation Workflow

In this way, a further off-line feedback level has been introduced in the ISE. The PP and the simulation validation can be confidently done before the physical tests on the CNC machine tool, safeguarding the machine tool itself and the machined components, and cutting down the set-up time.

4 An Industrial Test Case

In order to validate the ISE methodology, the proposed workflow has been used to realize an aeronautical engine component in collaboration with Avio S.p.a.

The activity aimed to the realization of a milling operation on a low pression turbine (LPT) case. The activity in the ISE can be summarized as follows:

1. post-processor development;
2. virtual machine development;
3. PP and virtual machine validation;

4. milling operation programming and part-program generation;
5. virtual tape try-out (VTTO);
6. physical tape try-out (TTO);

The usage of this workflow allowed to identify various issues related to the tool path in an early stage. It has been possible to directly correct the tool path during the programming

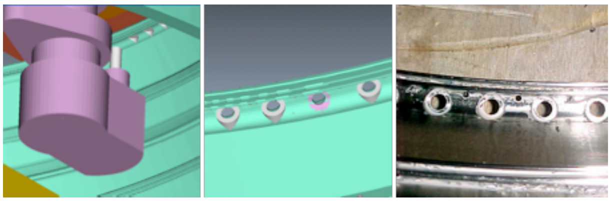
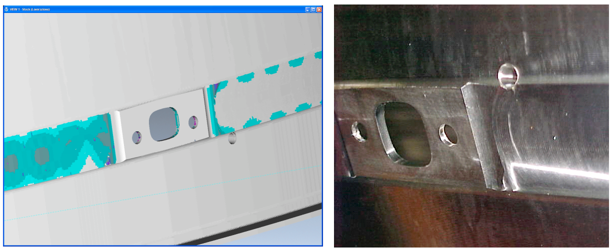


Fig. 3. An example of a complex drilling operation

phase, avoiding errors on the real LPT test case. An example is given in Figure 3. In particular, the simulation enabled to evaluate with high precision the stock material left by tools over the most complex parts of the component (Figure 4).

The ISE adoptions made possible an easier and faster PP development, underlining from the early stage critical issues and supporting the



choose of the most proper processing methods.

The obtained results can be summarized as follows:

- A collision free machining of the LPT case.

Fig. 4. Stock material analysis on the component

- A validation of ISE for the considered test case.
- The real TTO was carried out without any significant intervention neither on the post-processor nor on the part-program.
- TTO required about 47% less time with respect to similar components realized with the old methodology.

Conclusions

Metal cutting complex phases, like it is tape tryout (TTO), can be sped up thanks to the proper usage of specific computer aided tools. This has been obtained through definition of an integrated simulation environment (ISE). The present work has proposed, in accordance with experimental validation on an aeronautical engine component, a methodology based on the ISE for the virtual tape tryout (VTTO) of the designed tool path for very complex cutting operative conditions. The obtained results have confirmed the approach validity. In particular, they have showed its utility in order to reduce execution time and possible dangerous collisions during the physical tryout.

Moreover, the advantage arising from the usage of the proposed procedure has been demonstrated applying it to the process start-up phase of a milling center, developing a new post-processor and a new virtual machine tool for the simulation software.

Acknowledgements

This research has been supported by Avio Group, in particular the authors express their thanks to Periale P. and Giglioli M. for their support on the developed activities.

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