Advantages of Automatic CAM Programming in Industrial Practice – A Case Study

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Abstract. The paper presents the implementation of automatic CAM programming for the manufacture of special production tooling. The programming procedure, called ACPUT (Automatic CAM Programming Using Machining Templates), includes the development of special machining templates in the CAM program, supported by the acquisition of technological knowledge in a specially prepared database. These templates are dedicated to a given group of parts, characterized by the similarity of their geometric features. ACPUT makes it possible to shorten the time required to develop a machining program, thereby having a positive impact on the total cost of tooling production. The aim of the work was to present the advantages of the use of automatic CAM programming compared to the traditional approach used by technicians/programmers with different levels of experience (expert and beginner). The tests were carried out on CAM programming process for welding tooling.

Keywords: CAM programming automation · KBE - Knowledge-Based Engineering · Machining templates

1 Introduction

To meet the expectations of the mass personalization of products, it is not enough to simply invest in modern machinery. It is necessary to develop digital systems that allow for the comprehensive use of various data gathered in product designs and its production technologies [1–4]. The implementation of such systems requires the appropriate organization of departments responsible for the preparation of technical documentation (construction and technological). The use of CAx systems in technical departments has been a standard for many years. Thanks to this, designers and technicians can use tools that make it possible to use the knowledge gained in previously implemented projects (like KBE - Knowledge-Based Engineering). Such smart solutions are used primarily in companies dealing in the mass production of technologically similar, multi-variant products [5, 6]. An example of this can be found in the automotive sector, where similar components having the same purpose may differ on account of different vehicle variants. The same is true in other industries, such as in the manufacture of household appliances, sanitary or electronic products.

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It should be emphasized that the plan of the technological process, next to the engineering design, is undoubtedly the most important part of the technical preparation of the production process. It concerns the planning of elementary activities related to the production of semi-finished products, final products, and tools necessary for their production. In other words, it is about "how to realize what the designers have designed". An important step of the technological process in modern production systems is the stage of programming of CNC machines, which is performed in CAM software. The process of machine programming in the CAM program determines the basic parameters of the machine, such as the number of controlled axes, dimensions of the machining table, movements along individual axes, etc. Moreover, the programming process involves determining the geometry of the stock and of the workpiece. In individual machining operations, the CAM programmer determines the specific geometric elements of the CAD model for processing (planes, edges, points), the machining tool type and features, the machining strategy (the machining tool path), and the specific parameters of the operation (speeds and the input/output paths of the machining tool relative to the workpiece).

Basis on that the CAM programming process is characterized by its repeatability. This means that certain activities are performed in every case, no matter what the specific project is. Since the process is repeatable, it is possible to automate it - at least in theory, because although there are various ways of automating work in CAM, the use of such solutions is not very popular in practice. Based on own observations and experience, the authors conclude that there are two main reasons for such a state of affairs. The first is caused by the level of education and experience of CAM programmers, and the second is related to the characteristics of the enterprise, the products themselves, and their manufacturing processes (high diversity and variability).

High efficiency of CAM programming or rather the quality of programs prepared in the CAM system (according to the principle – "do it right at the first time") requires high skills of using CAM software and knowledge about manufacturing process (e.g. milling, turning, etc.). Engineers at the basic level of skills are not able to prepare advanced, dedicated tools, because is not easy. Additionally, some of these tools require computer programming skills in the particular programming languages to operate. The preparation of dedicated solutions to aided engineering work in CAM software often requires the involvement of interdisciplinary teams.

The second reason for limiting automation in CAM is the characteristics of the processes carried out in the enterprise, or rather the level of variability of the manufactured products. Automation of CAM programming will be reasonable only in selected cases, where there is high variability in production and relatively its high similarity. In the case of single, unique work, CAM automation tools seem completely unnecessary. Each project is different, it should be analyzed separately and unique solutions should be selected for it. Moreover, such a program will probably be used only once (although the knowledge from such a project should be gathered despite this). Tool for automation of CAM programming will be used wherever many products are produced similar to each other (multi-variants), regardless of the scale of this production (i.e. small, medium, or large series).

To meet these needs, the authors developed their own methodology for preparing an automatic system of CAM programming, called ACPUT (Automatic CAM Programming Using Machining Templates). Its basic assumptions and some tools were described in detail in earlier works [7–10]. The main aim of this paper is to present the advantages of using ACPUT in industrial practice, presenting the results of automation of CAM programming on a selected example of special production tooling – matrix used in the welding process.

2 Research Methodology

2.1 Feature Recognition

The most popular tools for automating routine, repetitive tasks in a CAM system are based on recognizing the characteristic features of a CAD model (so-called FR – feature recognition technology). FR allows the assignment of appropriate machining cycles to specific recognized geometry shapes [11]. In practice, these tools can actually speed up the work on program preparation but are only effective for models with relatively simple shapes. In the case of advanced surface models (such as the dies or matrixes with shaping cavities described in this article), the proportion of automatic recognition of geometric features decreases, and the "manual" work of the technicians increases to a large extent. These tools are therefore a hybrid solution that works well in a single case. Therefore, for a group of families of similar products (several - several dozen items), their use does not significantly affect the effectiveness of the CAM programming process.

Although the FR technology have been known for three decades, they are still the subject of various works [12]. The authors focus on the development of various algorithms that can more accurately analyze 3D models and more effectively indicate possible technological operations [13, 14]. In turn, Zhou et al. [15] presented the FR method (supported by deep learning) for the selection of cutting tools, increasing the effectiveness and efficiency of this task. Another example is the use of FR for spot welding recognition. In turn, Chee Fai Tan et al. [16] described the methodology for recognizing the features of the CAD model, based on which appropriate operations in the CAM program are selected. Similar considerations were described in papers [17, 18], presenting different approaches to the data exchange between the CAD and CAM programs, as well as to recognition of the features of the objects processed, using universal STEP files format.

It should be noted that these works do not deal with the issue of the automation of CAM programming in a general perspective, which can actually improve the efficiency of this process, but only develops algorithms for searching for specific geometric features of 3D models.

2.2 ACPUT Procedure

Based on KBE approach a procedure for creating machining templates in the CAM system was developed. ACPUT in conjunction with a machining knowledge base, makes it possible to automate the operations in developing machining program for CNC machine [9, 10]. The ACPUT method is pointed to a specified product group (family of multi-variants products), and the rules it creates are effective and efficient in the whole group. The templates can be developed using any integrated CAD/CAM class software that allows the parametric construction of CAD models and programming in a scripting language (e.g. VBA – Visual Basic for Applications). Since machine programming in CAM systems is a time-consuming and high-cost process (it requires the involvement of highly qualified engineering staff), the aim of the ACPUT was to reduce time and minimize human participation in the programming of CNC machines (in the manufacture of special production equipment).

ACPUT assumes to develop a special machining template that represents all the technological operations possible for a given group of products. Data and information needed to prepare such a template are stored in the special knowledge base. Knowledge acquired mainly from specialists in a given field is accumulated and written formally, and in a way understood by the computer program. To ensure the correct operation of the machining template, and thus the automation of the preparation process in the CAM environment, firstly3D models for the tooling must be properly described in the CAD program (i.e. categorization of features and their assignation to the model). Based on this description, the template later automatically selects the appropriate features for the given part.

It is possible to look at ACPUT as a procedure, that includes the following steps (Fig. 1):

1) Analysis of 3D CAD models of a given group of tooling parts.
2) Preparation of the technological knowledge base.
3) Defining the geometry necessary to build the machining template and publishing it.
4) Preparation of machining template.
5) Preparation of machining program for each part of the given group of tooling parts (with simulation in CAM program).
6) Preparation of NC program.

Execution of the ACPUT procedure requires different skills in the field of manufacturing knowledge and CAx systems operation. It is therefore assumed that Step 1 and 2 are realized by technicians with large of experience. Step 3 can be carried out even by novice CAM programmer; however, Step 4 requires skills at expert CAM programmer level. Last two steps can be realized also by novice CAM programmer.

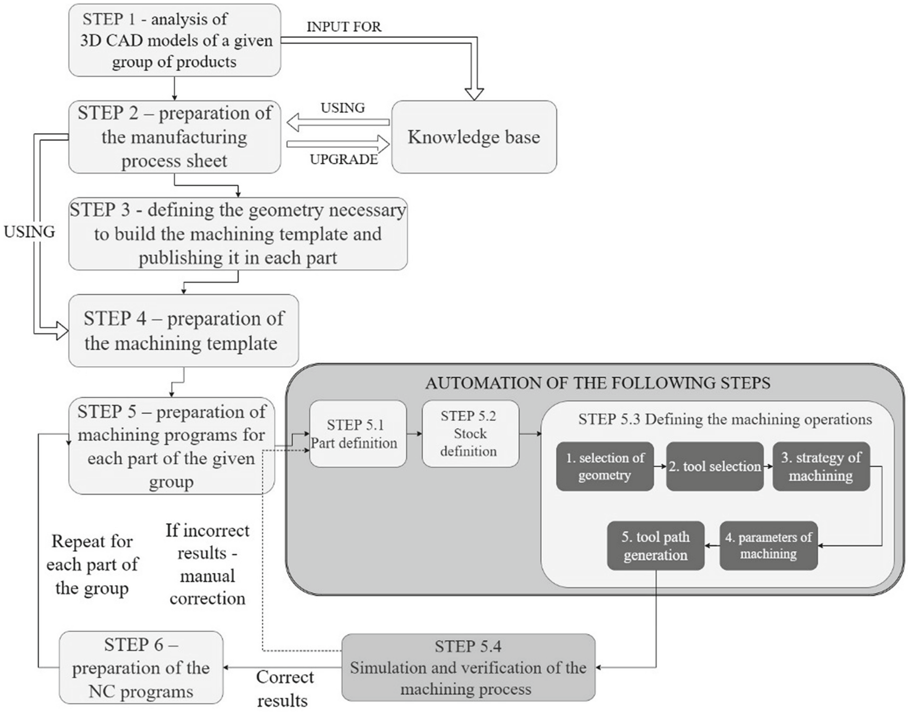

Fig. 1. The ACPUT procedure [10]

3 Case Study – CAM Programming for Welding Tooling Machining

The example, considered in this paper, is related to the machining of tooling elements for welding processes. Special production tooling in this case consists of 10 separate parts (Fig. 2) and manufactured by milling on a CNC machine. Acting in accordance with the assumptions of ETO (the tooling model was provided by the customer), it was assumed that in preparing programs it was not possible to interfere with the geometry of the 3D models of the tools, and the files were saved in the universal “stp” format.

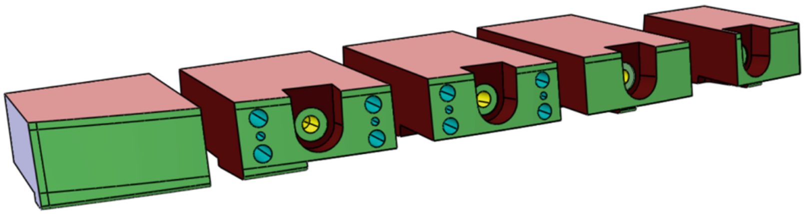

Fig. 2. Part of group of special tooling for welding

In accordance with the ACPUT procedure, ten different operations were identified and described, for which the detailed course of the machining process was recorded in the knowledge base. It consisted of (Fig. 3):

– machining of an oval pocket (here for the so-called suction cup),
– circular milling of the surface for the suction cup,
– drilling holes (various types), and
– roughing and finishing of the working surface of the tool (green in Fig. 2 and 3).

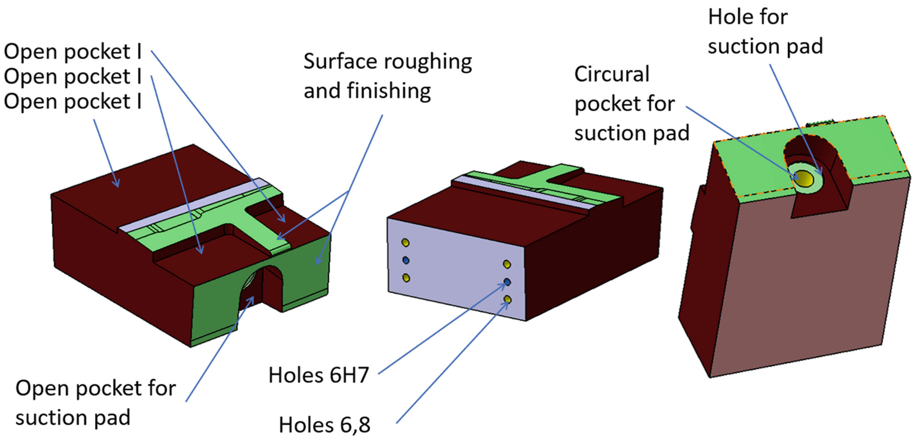

Fig. 3. Recognized geometric features of single welding tool

In the described case, this type of tooling is ordered by the customer who is responsible for its design. However, it has no influence on the method of its production in detail, as this is the subject of the manufacturer. The die group consists of 10 similar parts, so the manufacturer is interested in as efficient a process as possible (short time, less resource). One of the ways is to optimize it is to modernize the traditional approach in the CAM programming process, and for such need, the ACPUT procedure was developed.

4 Experiment and Results

To check the usability of the ACPUT procedure a comparing test to the traditional CAM programming method was proposed. For given group of welding tooling CAM programs were developed:

a) with the ACPUT procedure;
b) in the standard procedure by

   – a beginner programmer/technician,
   – an expert programmer/technician.

It should be emphasized that ACPUT (Fig. 4) is the procedure of implementation of CAM programming automation, not a specific IT tool, so the essence of the tests was to compare it with the traditional approach to programming (realized by technicians/CAM programmers), who can use any tools and methods in their work, even FR (Feature Recognition) or well-known GT assumptions (Group Technology).

The knowledge base, developed for the purposes of the ACPUT was also made available to the programmers (beginner and expert), so that the data for the machining process were the same in all cases.

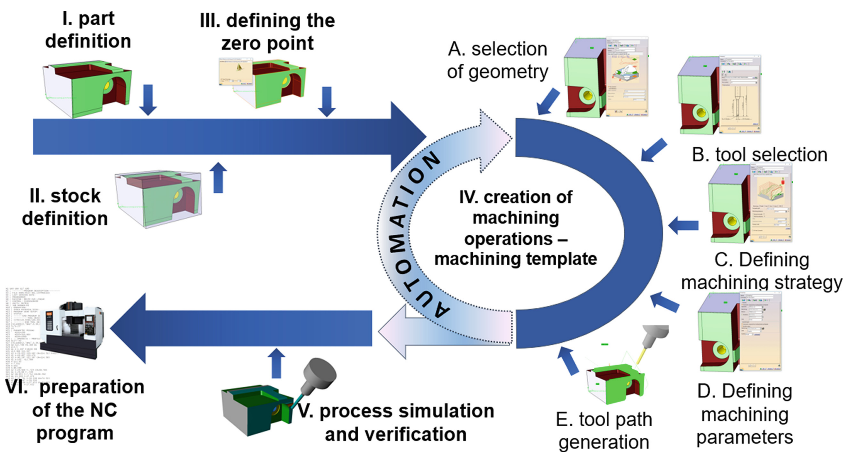

Fig. 4. Process of CAM programming for welding group of tooling using ACPUT procedure

The preparation times (cumulative) of the machining programs for all three cases are presented in Table 1. The automatic solution considered the time needed to develop the template (step 4 in Fig. 1 - it was added to the time for the first part), therefore the preparation time for the first part was much longer than the preparation times for the subsequent parts. A similar difference can also be seen in the work of the programmers programming in the traditional way. The differences between the expert and the beginner programmers' working times were related to their proficiency in using the CAM program.

The total preparation time (Tpt) for the machining programs for all the ten parts turned out to be the shortest in the ACPUT procedure and amounted to 193 min. This result was used as a reference to evaluate the other results. The working time of the beginner programmer was 478 min (representing 247% of the working time of the automatic solution), while the expert programmer had a working time of 298 min (154%of the working time of the automatic solution). The results presented in Table 1 are also shown in Fig. 4. This shows that the ACPUT procedure is already justified when the group of parts is greater than two (Fig. 5).

After execution and verification of the prepared machining programs, a simulation of the machining in the CAM system was performed, which made it possible to determine the machining times for the individual parts.

Table 1. Cumulative preparation time for machining programs

CAM preparation time [min] - cumulative			
After part no	ACPUT procedure	Standard procedure by beginner	Standard procedure by expert
1	66	143	48
2	82	208	80
3	97	256	105
4	114	288	135
5	122	315	157
6	140	353	191
7	147	379	211
8	166	420	243
9	180	447	270
10	**193**	**478**	**298**

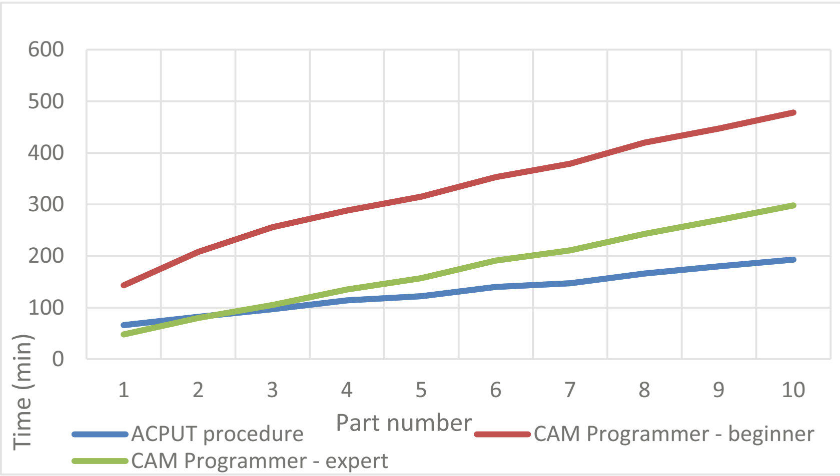

Fig. 5. CAM preparation time [min] - cumulative

Firstly, the obtained machining quality was checked. The measurements showed that in each of the three cases, the geometric accuracy, roughness, and surface and edge appearance on all the machined parts met the specified requirements. The cumulative summary of the time results from the simulation for each part separately is shown in Table 2.

Due to the fact that the parameters and the method of processing were specified in the technological knowledge base, and each of the programmer operated using the same data, the differences in the machining times for individual parts were insignificant. The difference between the ACPUT procedure and the expert programmer was only 0.6%,

Table 2. Cumulative machining time on CNC machine based on CAM simulation

Machining time [min] - cumulative			
After part no	ACPUT procedure	Standard procedure by beginner	Standard procedure by expert
1	131	146	125
2	327	326	335
3	492	504	493
4	713	730	724
5	959	984	964
6	1099	1146	1117
7	1307	1370	1313
8	1571	1625	1583
9	1763	1822	1769
10	**1883**	**1956**	**1895**

while between the ACPUT procedure and the beginner programmer it amounted to 3.9%. This mainly resulted from the selection of other speeds and the tool's path of movement during its approach and departure from the workpiece. It should be emphasized here that these parameters were not specified in the technological knowledge base.

The total time (cumulative) needed for the preparation of the machining program and the machining of individual parts is presented in Table 3.

Table 3. Cumulative time for manufacturing of tested parts

Machining time [min] – cumulative			
After part no	ACPUT procedure	Standard procedure by beginner	Standard procedure by expert
1	197	289	173
2	409	534	415
3	589	760	598
4	827	1018	859
5	1081	1299	1121
6	1239	1499	1308
7	1454	1749	1524
8	1737	2045	1826
9	1943	2269	2039
10	**2076**	**2434**	**2193**

The total time for the preparation of the machining programs and the machining for all ten pieces was 2076 min in the case of the programming using ACPUT procedure, 2434 min (representing 117.2% of the working time of the ACPUT procedure) for the beginner programmer and 2193 min (105.6% of the working time of the automatic solution) for the expert programmer.

5 Summary

Testing under industrial conditions showed that the ACPUT procedure makes it possible to reduce the time needed to develop a machining program. This has a positive effect on the total cost of tooling production.

The effectiveness of ACPUT was tested on the basis of the analysis of the time needed to prepare the CNC program and the machining operation time itself (based on the simulation in CAM). The preparation time of the program is a direct (next to the quality conditions) indicator of the effectiveness of ACPUT. Analyzing Table 1 and Fig. 4, it can be seen that the time benefits of using an automatic solution are significant, especially when compared to a less experienced programmer.

It should be emphasized that the effectiveness of the ACPUT procedure depends on the experience of those who prepare the templates. For the tests carried out two technicians were invited to participate: one with several years' experience and one with limited experience (working in this position for only a few months). The first was considered an expert and the second a beginner. The aim of the study was not to indicate the predictable differences between them, but to evaluate ACPUT which constituted a reference. Separating the programmers into more experienced and less experienced had one more purpose - to assess whether, after preparing the machining templates according to ACPUT, someone with less experience would be able to use the automatic solution successfully. The study revealed that it was possible: the results obtained using the automatic solution were even better than the work produced by expert.

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