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Optimization procedures for machining operations on CNC machine tools

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Abstract

This paper describes some advanced optimisation procedures for machining operations performed on CNC machine tools. The presented problems are divided into two sections. The first section gives practical solutions concerning tool path optimisation by using different genetic algorithm methods and creation of virtual machines. The second section provides some important commercial solutions, in particular commercially available optimisation systems. The most important optimisation areas of the cutting process signalized by the industrial users are considered.

Keywords: optimisation, CNC machine tools, Virtual Machining.

Procedury optymalizacji operacji obróbki skrawaniem dla obrabiarek CNC

Streszczenie

Artykuł przedstawia zaawansowane procedury optymalizacji procesów obróbki skrawaniem dedykowane dla obrabiarek sterowanych numerycznie CNC. Opisano praktyczne rozwiązania dotyczące między innymi problemów optymalizacji toru ruchu narzędzia, ich długości czy doboru racjonalnych parametrów technologicznych. Uwzględniono różne koncepcje sposobów prowadzenia kompleksowej symulacji procesu wytwarzania elementów maszyn na drodze obróbki ubytkowej. Zwrócono uwagę na konieczność globalnego podejścia do problemu optymalizacji procesu wytwarzania. Przejawia się to w konieczności uwzględniania procesu wytwarzania, kontroli jak również aspektu doboru obrabiarki i nie często także montażu wytworzonych części maszyn. Najciekawsze rozwiązania praktyczne wybranych obszarów optymalizacji przedstawiono w oparciu o funkcjonujące, reprezentatywne pakiety programów komercyjnych. Stwierdzono, że mimo wielu możliwych kryteriów optymalizacji procesu obróbki skrawaniem najczęściej wykorzystywanym jest podejście ekonomiczne, przy równoczesnym zachowaniu wysokich wymogów co do jakości funkcjonalnej wyrobu. Oczekiwaniem rynku jest stworzenie komercyjnych systemów ekspertowych ujmujących całościowo problem optymalizacji procesu wytwarzania części maszyn. Dąży się do tego poprzez zintegrowanie obszarów symulacji i optymalizacji procesu technologicznego z optymalizacją obrabiarek (VM), a kończąc na procesie optymalizacji produkcji (VP) na bazie łańcuchów programowania CAD-CAM-CNC.

Słowa kluczowe: optymalizacja, obrabiarki CNC, obróbka wirtualna.

1. Introduction

CNC machining is a key technology in production of complex parts and free-form surfaces with high productivity and accuracy. It has been observed that NC machining is utilized not only in small and medium-scale production but also in large-scale production. Much attention has been paid to CNC machining optimisation in order to obtain high quality products at low cost. All approaches to the optimisation of NC machining can be classified into two categories:
- adaptive control based optimisation (*on-line* optimisation),
- computer simulation based optimisation (*off-line* optimisation).

The on-line optimisation of CNC machining is generally realised by adjusting machining parameters, especially the feed rate [1]. In contrast to it, the off-line optimisation (computer simulation-based optimisation) is more flexible and multi-purpose, and no expensive devices are needed. Via computer simulation, the primary optimisation aspects of NC machining, such as reliable verification, cutting parameter optimisation and error compensation can be performed.

For the adaptive control based optimisation of a machining process, either the minimum production time or the maximum profit rate are used as the objective functions subjected to the practical constraints. Some of the methods that have been used to solve machining problems are predominantly limited to turning operations [2]. Very few researchers have concentrated on multi-tool operations. Different methods have been reported in the literature to optimise machining parameters of face milling operations [3].

However, other advanced optimisation methods like genetic algorithms [4, 5] and the hybrid algorithms [6] have been used to solve this problem. Recently, new methods of optimisation of machining parameters for milling operations by using non-conventional approaches based on the genetic algorithm, tabu search, and colony algorithm as well as particle swarm optimisation have been reported [7]. In addition, a scatter search approach for optimising the machining parameters of milling operations based on maximum profit is used [8].

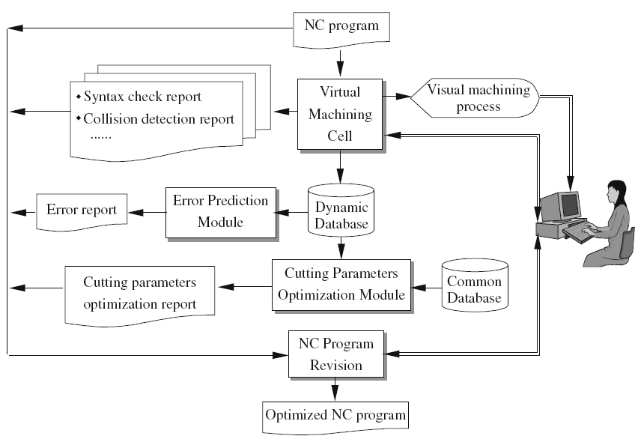

Fig. 1. Framework of NC program optimisation system based on virtual machining concept
Rys. 1. Struktura systemu optymalizacji programów NC bazującego na koncepcie wirtualnej obróbki skrawaniem

Off-line optimisation of CNC machining can be performed using virtual machining concept [9]. Virtual machining, which includes the entire model of a machining system, allows simulating, evaluating and optimising the actual machining process with high aspect of reality. It provides digital off-line optimisation tools for NC machining. Taking these advantages of virtual machining used in machining process simulation into consideration, one can build the framework of optimisation system on NC machining, so that the processes of reliable verification, cutting parameter optimisation and error compensation can be integrated into one system to improve machining processes comprehensively. Virtual machine concept can be a basic idea to create a commercial software for optimal modelling of manufacturing systems [10], termed Virtual Manufacturing (VM). As an example, the framework of a NC program optimisation system based on virtual machining is shown in Fig. 1.

VM is a computer-based technology [9], which can provide tools to optimise the production activities and improve the production efficiency via simulation prior to the actual production. Virtual machining is one of special applications of virtual manufacturing in the production process. It focuses on both geometrical and physical simulations. In case of geometrical simulation, virtual machining system is used to verify, in advance, the correctness and reliability of NC programs. On the other hand, physical simulation is employed to predict process parameters such as cutting forces, power, tool-life and surface roughness. As a result, the tool-path planning and the combination of cutting parameters can be evaluated and optimised prior to the actual production.

2. Machining simulation concept

One of the representative concepts of machining simulation developed by Spring Technologies is shown in Fig. 2.

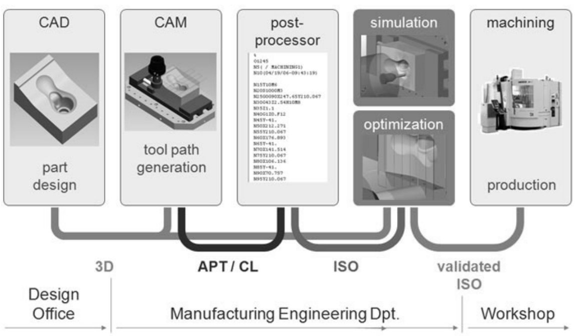

Fig. 2. The machining simulation concept proposed by Spring Technologies [11]
Rys. 2. Koncepcja symulacji obróbki skrawaniem zaproponowana przez Spring Technologies [11]

Elements that must be considered in simulation should be closest to real machining conditions. They include NC controller, set-up of machine characteristics and machine operator actions, as illustrated in Fig. 3.

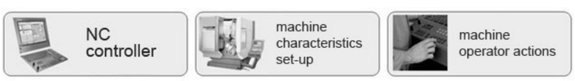

Fig. 3. Machine environment that must be considered in simulation [11]
Rys. 3. Elementy środowiska funkcjonowania obrabiarki konieczne do uwzględnienia podczas symulacji [11]

The NC program can be set up using at least four different steps. The first step concerns analysis of the NC program. It encloses supporting structured programs for decoding of ISO codes, variables, cycles, macro calls, etc., automatic detection of programming errors as well as precise and reliable estimations of cycle times.

The second step encloses machine simulation with material removal from the workpiece. This type of simulation is performed on a solid model for all types of machining, total simulation of the "machine-part pair" with detection of all collision types in a single process, detection of machining errors, 3D viewing operations (rotate, zoom, pan) independently of the program size, or the complexity of the part or program and probing.

Next, at the third step there was performed dimensional analysis of the part with quick and precise comparison between the machined part and the original CAD model which utilizes dynamic 3D cross-section. The last step was aimed at analysis and optimisation of cutting conditions. In it many procedures were carried out: analysis of cutting parameters for each section in a block, generation of alarm logs based on user-defined criteria, optimisation of approach and retract motion and cutting parameters according to the tool-material pair, and finally graphic comparison between the initial and optimised program with rewriting the ISO program based on optimal feeds and spindle rotations to be used during machining. Some examples of screenshots of NCSIMUL software which use this 4 steps-approach are presented in Fig. 4.

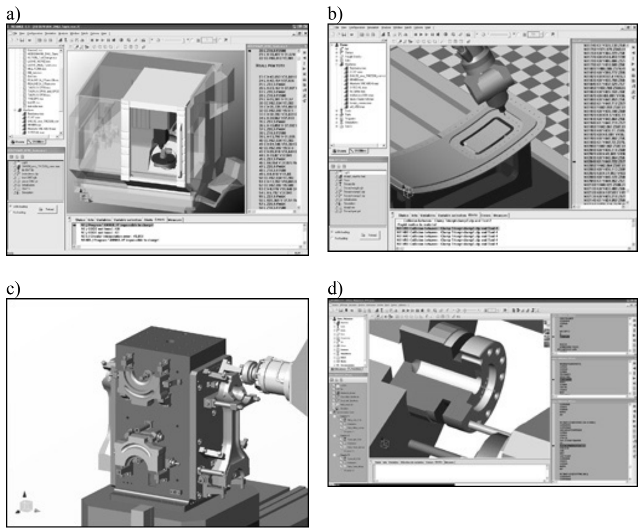

Fig. 4. Screenshot for NCSIMUL software for four procedures: a) analysis of the NC program, b) material removal and machine simulation, c) dimensional analysis, d) analysis and optimisation of cutting conditions [11]
Rys. 4. Zrzuty ekranów oprogramowania NCSIMUL dla czterech procedur: a) analizy programu NC, b) usuwania materiału naddatku i symulacji obróbki, c) analizy wymiarowej, d) analizy i optymalizacji warunków obróbki [11]

One of the optimisation and simulation procedures is based on Virtual Machine (VM) [12]. Virtual Machine seamlessly unites advanced post-processing solution with a comprehensive graphical machine tool simulator in one integrated platform. This software enables CNC programmers to graphically simulate and test programs, easily and automatically, against collisions during post-processing, and in this case is capable of avoiding and correcting possible programming errors.

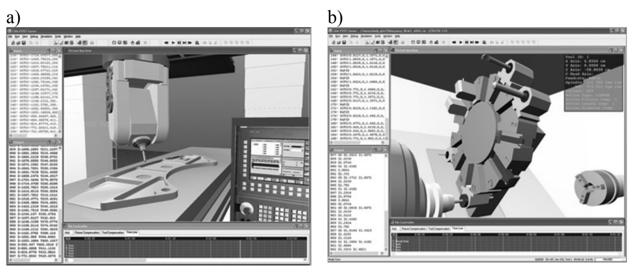

Fig. 5. Screenshots of graphic machine tool simulations by using a ICAM Virtual Machine [12]: a) mill centre, b) dual spindle turn centre
Rys. 5. Zrzuty ekranów graficznych symulacji pracy obrabiarek wygenerowanych w oparciu o oprogramowanie ICAM Virtual Machine [12]: a) centrum frezarskie, b) dwuwrzecionowe centrum tokarskie

The basic, useful functions of VM are:
- Support for Mill/Turn Centers (ability to synchronize dual turret merging lathes, environment to define a rotary axis as either a spindle or a lathe tool turret).
- Simulation of "timeline" control (full controlling of visualizations of machining cycles for the tested NC programs).
- Effective NC tape proofing (detection and correction of collisions between machine components in real time).

Some representative screenshots of graphic machine tool simulations using a ICAM Virtual Machine are shown in Fig. 5.

Also, Siemens [12] developed a simulation support which covers the entire life cycle of a machine. This simulation support encloses four phases. They are the following ones (Fig. 6): *Mechatronic Support* for simulation of machine development, *Machine Simulator* for supporting commissioning, *Virtual Production* for production optimisation and, finally, *Virtual NC Kernel (VNCK)* for testing the NC part programs at the end-users.

The most interesting part of the simulation support is the Virtual Production. Virtual Production enables the comprehensive simulation with respect to surface quality, part accuracy and machining speed. As a result, it is possible to identify optimisation potentials in the area of the CAD-CAM-CNC chain significantly faster and more cost-effectively than running tests on the actual machine. Virtual Production means the optimisation of all CNC machine tools employed and direct benefits through reduction of total or part of the machining time, increase in quality and saving of costs.

Virtual NC Kernel (VNCK) enables testing of NC part programs in the simulation system that is parameterized with the settings from the NC archive file taken from the real machine. With VNCK, it is also possible to predict exactly the machining times and therefore optimal utilization of the machine, and verify precisely the workpiece quality.

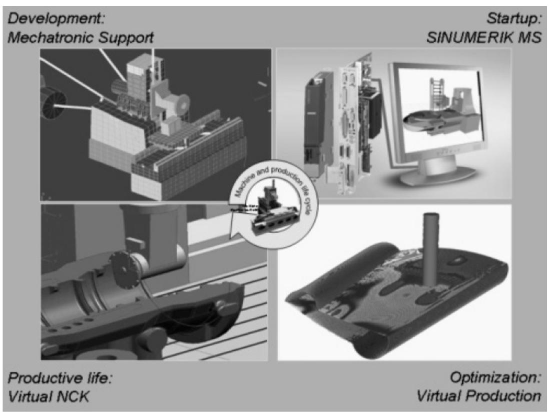

Fig. 6. Simulation activities for machine manufacturers and users by Siemens [12]
Rys. 6. Sugerowane przez Siemensa [12] obszary symulacji dedykowane dla producentów maszyn oraz końcowych ich użytkowników

3. Optimisation of cutting tool and machining parameters

The most of CNC simulation and optimisation software for manufacturing are driven by the same logic as the machine control. The software behaves exactly like the physical machines and is the most accurate collision-checking available. Using simulation and optimisation software one can:
- eliminate crashes and close calls,
- speed machine implementation time,
- check machine capabilities,
- improve process efficiency,
- reduce CNC cycle time,
- improve finish quality,
- reduce feed rate adjustment,
- minimise machine and cutter wear,
- increase productivity.

Most of the popular optimisation software is based on the optimisation of feed and cutting speeds, "air" cutting and tool length. Optimising the cutting speeds is an effective way to reduce cycle time, increase tool life and improve finish quality. Based on the cutting conditions (required machining depth and width, tool life, maximum feed rate, roughness, etc.) and tool capability, the CNC optimisation software automatically assigns the best feed rates for each cutting condition encountered. It works under a simple assumption, illustrated in Fig.7. The feed rates increase for lighter cuts or better machining conditions, and decrease as more material is removed from the workpiece. Without changing the tool trajectory, the updated feeds and speeds are put to a new NC program.

When a CNC machine is not cutting something, which is popularly defined as *air cutting*, the productivity decreases. In order to optimise air cutting problems, the optimisation software allows the programmer to define its own approach and retract motion parameters to maximise the use of rapid motion [11].

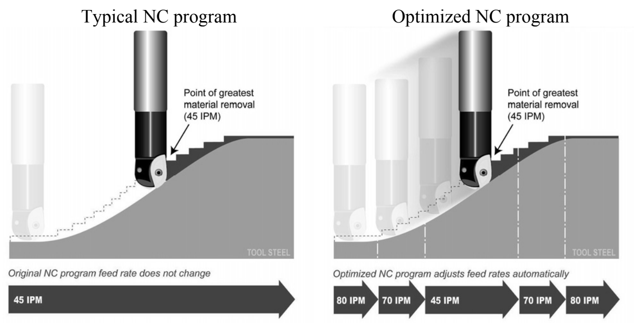

Fig. 7. Idea of NC program optimisation using a Vericut software [14]
Rys. 7. Idea optymalizacji programu NC przy użyciu oprogramowania Vericut [14]

Another problem arisen is the optimisation of the tool length. This problem is associated with a reduction of the bending phenomena as well as collision risk with the tool support. Minimisation of the tool length increases the tool stiffness and results in improving the quality of surface finish. Screenshots of tool length optimisation by using a VM simulator are shown in Fig. 8.

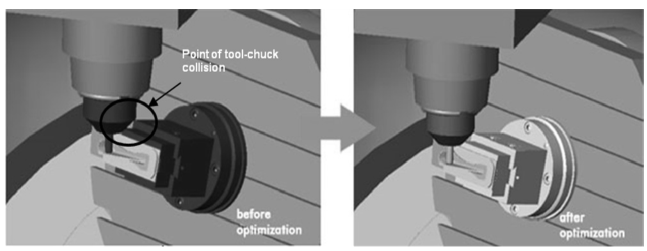

Fig. 8. Screenshots of tool length optimization using a NC SIMUL software [11]
Rys. 8. Zrzuty ekranów wizualizacji procedury optymalizacji długości narzędzia przy użyciu oprogramowania NC SIMUL [11]

4. Conclusions

In modern manufacturing industry the procedures of machining simulation support the technological process itself, its control and the assurance of part quality. In particular, CNC machining optimisation is developed in order to obtain high quality products at low cost. Optimisation of CNC programs can be performed at several levels using a number of dedicated programs. Most of the popular optimisation software is based on the optimisation of feed rates and cutting speeds, as well as "air" cutting and the tool length. Minimum cutting time can be achieved by optimisation of the tool path and machining parameters. Recently, Virtual

Production (VP) has been developed as a simulation tool covering the entire life cycle of a machine tool. Virtual Production enables the comprehensive simulation with respect to surface quality, part accuracy and machining speed. The virtual approach is more effective in optimisation of the CAD-CAM-CNC chain and significantly faster and more cost-effective than running tests on the actual machine.

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