Multi-Axis Machine Tool Power Drives Exploitation

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Abstrakt
Článek je zaměřen na problematiku využití dispozic pohonů obráběcího stroje, zejména pro víceosé obrábění. Nejprve je zmíněna nutnost tvorby specifického postprocesoru pro každou kombinaci CAM systému – obráběcího stroje – řídicího systému. Dále jsou uvedeny funkce, využitelné při tvorbě NC programu pro ovlivnění chování stroje v závislosti na použitém řídicím systému stroje. V návaznosti na tuto problematiku je zdůrazněna nutnost dodržení posuvové rychlosti mezi nástrojem a obrobkem při víceosém obrábění. Prezentována je možnost využití postprocesoru jako prostředku pro úpravu NC kódu a modifikaci posuvové rychlosti vzhledem k vytíženosti pohonů stroje. Výsledky jsou ukázány na praktických aplikacích čtyřosých operací, včetně měření posuvové rychlosti.

Klíčová slova
víceosé obrábění, řídicí systém, postprocessor, posuvová rychlost

Abstract
This article is focused on the issue of the machine tool power drives exploitation method, especially for multi-axis machining. The need to create a specific post-processor for each combination of the CAM system - the machine tool - the control system is mentioned at first. The control system functions usable for machine tool behaviour influence by an NC program are noted consequently. The emphasis is put on the need of compliance of feed-rate specified in NC program with the actual feed-rate between a tool and a workpiece during multi-axis machining. The possibility of using a post-processor as a mean of adjusting the NC program and modifying the feed-rate due to the power drives exploitation is presented. The results are shown in practical applications of four-axis operations, including the measurement of the actual feed-rate.

Keywords
multi-axis machining, control system, postprocessor, feed-rate

1. Introduction

Realization of complex shape parts, especially the parts of various power generating equipment such as blades, impellers or turbines requires CAD/CAM systems usage to speed-up the technological preparation of manufacturing process. For the machining of such parts there is often necessary to use multi-axis machining operations that are feasible on four-axis or five-axis machine tools. Machine tools and their control systems must allow positioning (indexing), but also a continuous multi-axis machining using rotary axes. Any CAD/CAM system must be equipped with a specific postprocessor to convert the data format of the so-called CL-data (Cutter Location Data) to a specific NC program depending on the machine tool control system and rotary axes configuration. These are the important facts that must be programmed correctly during the specific postprocessor creation process, see lit. [5] and lit. [6]. The postprocessor should be able to use the most of machine tool and its control system functions. However, in the NC program automatic creation process it is very difficult to achieve this goal. It was found out that during an NC program execution process on a real machine tool the feed rate in multi-axis operations is much lower than the one specified, see lit. [7]. The reason is the use of rotary axes. In the CAD/CAM system there is no possibility of how to change the feed-rate in each block of the multi-axis toolpath. That is the reason why the power drives exploitation improvement method using a postprocessor algorithm have been proposed.

2. Current available solutions

The production engineer has many possibilities of how to influence the machine tool behaviour using NC program commands. Using these commands are dependent on applied CAD/CAM system and the real machine tool and its control system.

2.1 CAM systems and systems for NC program verification

A lot of CAD/CAM systems are able to compute optimized toolpaths for roughing operations. In the case of SurfCAM the production engineer can use the function TrueMill to create the toolpaths that are optimized to keep constant wrapping of the tool so the tool can move with higher velocities. If he should use e.g. the MasterCAM or the HSMworks he is able to apply an adaptive toolpaths. Adaptive toolpaths are alternative functions to the TrueMill but the calculation uses other principles. Another SW we can use is called Vericut. If we use this function the feed-rate in NC program is adjusted to the actual machined material volume in each tool step. None of CAD/CAM systems is able to adjust the feed-rate during multi-axis machining owing to an actual position of the tool against rotary axes.

2.2 Controll systems

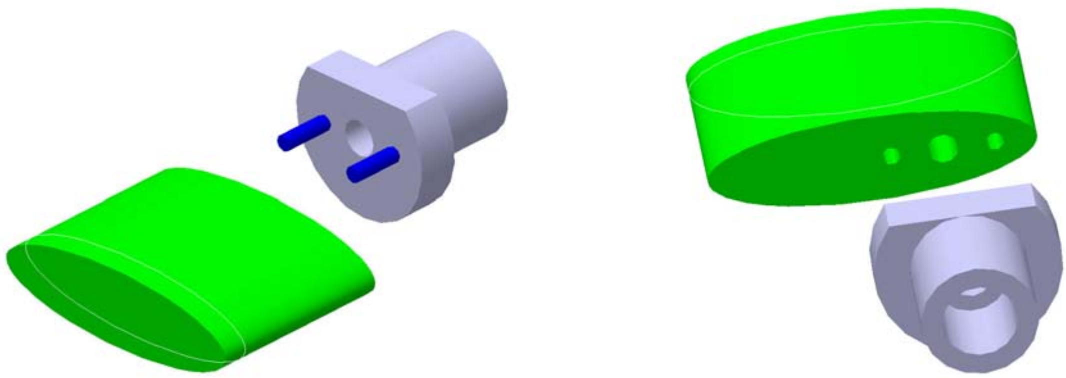
Control systems are equipped with a lot of auxiliary functions that are useful also for a multi-axis machining. Very often used function is cancelling exact stop of all axes in each NC program block during multi-axis machining (e.g. G64 by Haas). The move of the tool is then more fluent and also the quality of the machined surface is finer. Most new versions of control systems offer using a five-axis transformation (e.g. Tool Center Point). One NC program for multi-axis machining is then transferred to a machine tool with another nomenclature. Nevertheless the mentioned functions need not to be implemented in every version of the control system. Of course it depends on the control system price. Important fact is also that every control system has different solutions and different available auxiliary.

2.3 Solutions from the research

In the past, many attempts were made to optimize the feed-rate. The vast majority of solutions focused on generating the feed-rate with respect to the cutting depth (or currently removed volume of material). Different algorithms are used in calculating the feed-rate and mathematical models of cutting tools are also clarified to their continuous optimal cutting geometry development. This issue is the subject of the following texts in the literature [1], [2], [3], [4]. In these articles there can be found the principles on which the calculation method for calculating the feed-rate is based on.

3. Feed-rate analysis

At first it was necessary to design a suitable part that will supply a real part such as a blade. In the Fig. 1 there is shown the designed part with an oval cross-section surface (green part) for testing. This surface very well substitutes a blade surface and furthermore it is simple to machine this surface using two-axis flank milling operation. In the Fig. 1 there is also shown a grey part which is the fixture used for mounting the testing part on the rotary axis of a machine tool. The testing part is mounted to the fixture by a screw situated in a centre hole. The right position of the testing part against the fixture is ensured by two pegs (blue parts in Fig. 1).



a) *b)*

***Fig. 1** – Oval cross-section surface (green part) for testing and the fixture (grey part), a) front view, b) back view*

The created driving toolpath for feed-rate testing and measuring can be seen in Fig. 2. During the toolpath the tool is always perpendicular to the testing part surface. Due to this fact it is very simple to analyse the feed-rate between the tool and the workpiece and the postprocessor algorithm for feed-rate prediction can be applied.

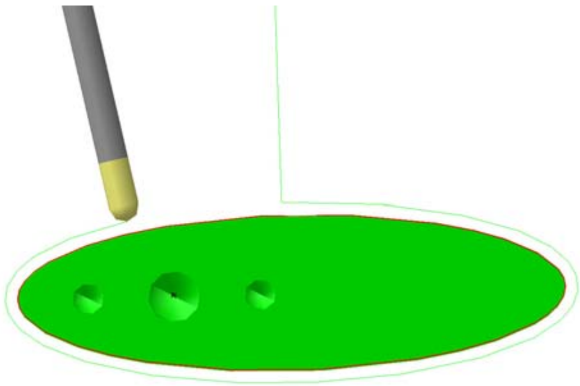


***Fig. 2** – Feed-rate measuring sensor driving toolpath (offset 1,4 mm from the surface)*

3.1 Feed-rate prediction

According to reasons and facts mentioned above a postprocessor algorithm for predicting the feed-rate in NC program has been proposed and tested. This algorithm is based on an important fact, that all of the machine tool axes must achieve their positions given in the next NC program block at the same time. During NC program generation the postprocessor also generates a text file with predicted feed-rates in each NC program block with four-axis interpolation. In this case of the toolpath the result of predicted feed-rate in NC program can be seen in Fig. 3. The specified feed-rate has been set on 800 mm/min. We can see that the actual feed rate is very different when compared to the programmed feed-rate. In two situations the feed-rate is dropped down to 50 mm/min. The tool feed-rate given in NC program is not kept and also machining time is being extremely prolonged.

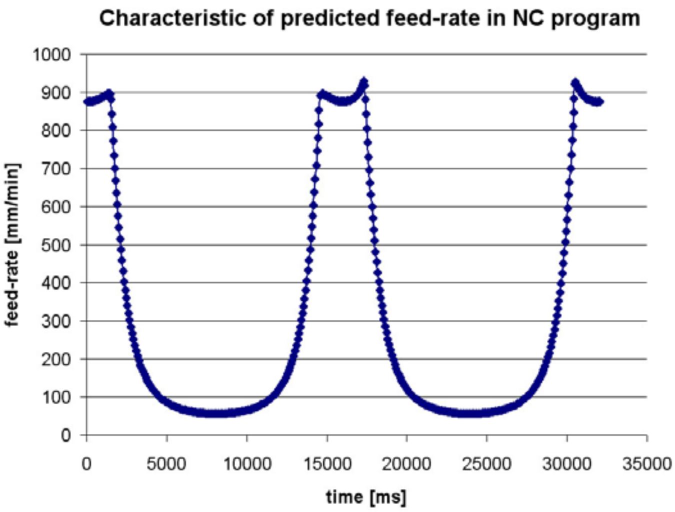


***Fig. 3** – Characteristic of predicted feed-rate in NC program when 800 mm/min have been programmed*

3.2 Feed-rate Measurement

Predicted characteristic of the feed-rate in NC program has been verified using an appropriate measurement. Feed-rate measurement method is based on contactless position sensor usage. For further testing it was necessary to use a real CNC machine tool. Haas ToolRoom Mill 1 is the machine tool that is in standard equipped only for three-axis milling. Nevertheless it can be upgraded using a rotary table for four-axis machining. In this case the rotary table HRT 160 has been used and the final nomenclature of the machine tool used for further testing can be seen in the Fig. 4.

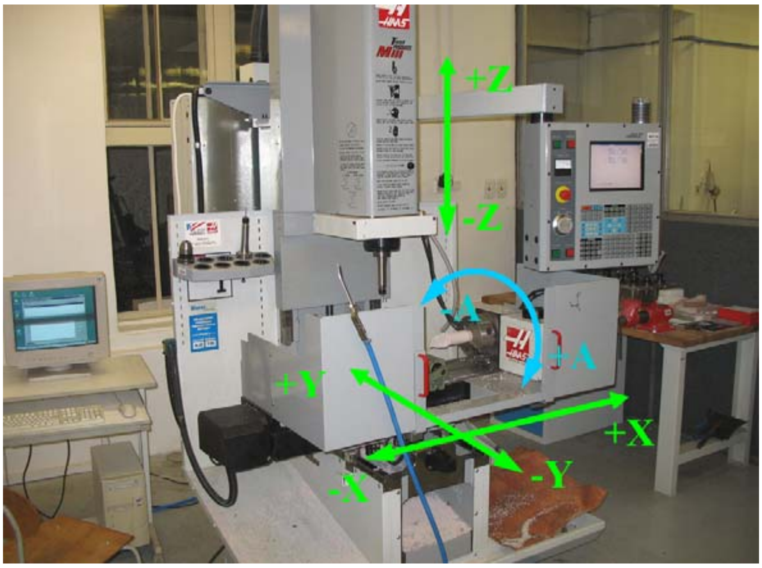


***Fig. 4** – Four-axis machine tool Haas ToolRoom Mill 1 nomenclature*

In the following figure (Fig. 5) can be seen the testing part mounted in machine tool rotary axis and also a contactless position sensor in its box during a measurement operation. In this figure is also clearly seen a gap between the testing part surface and the sensor box bottom. It is necessary to set up the right working gap for the position sensor currently used.

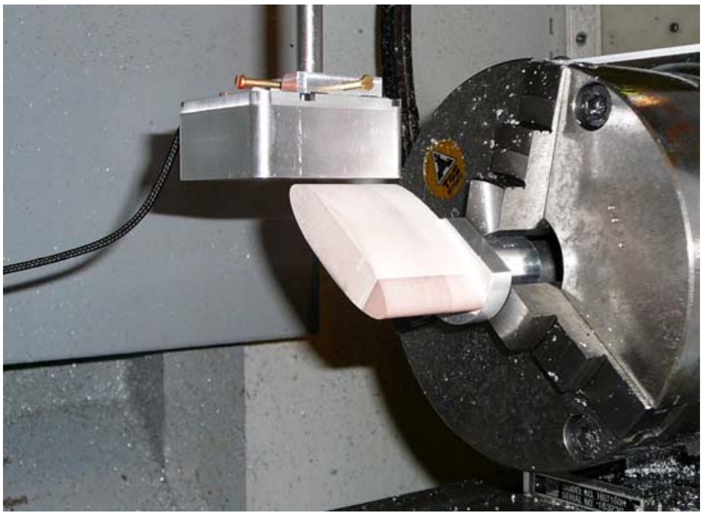


Fig. 5 – *Detailed view on the feed-rate measuring sensor and the testing part*

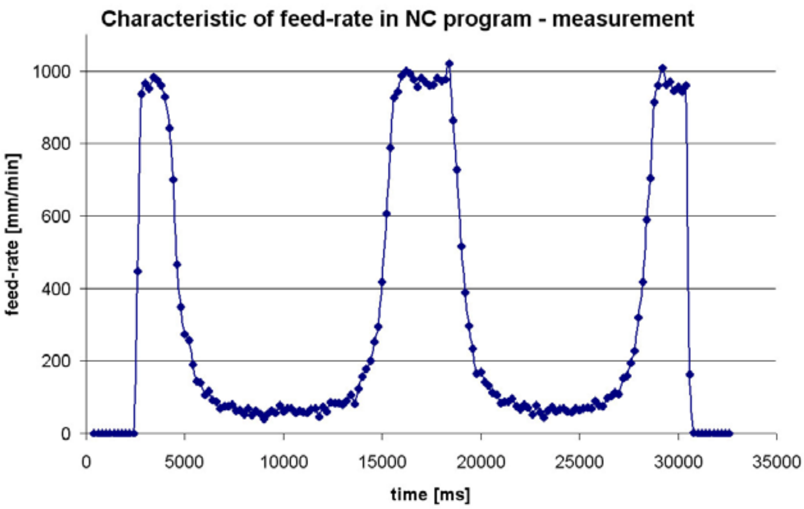
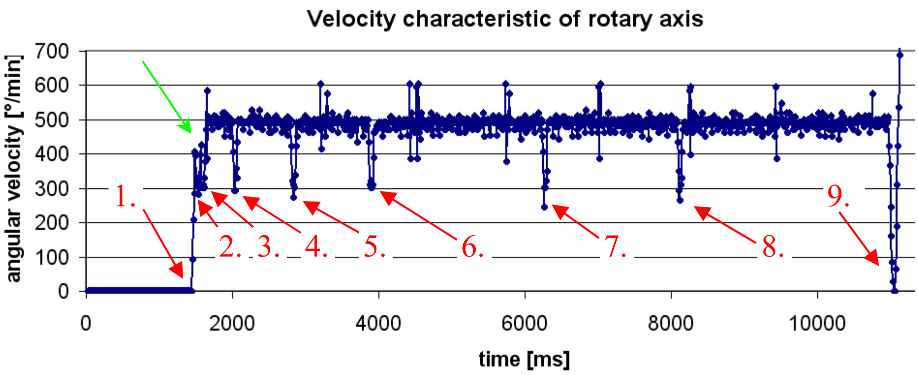


Fig. 6 - *Characteristic of measured feed-rate during NC program execution when 800 mm/min have been programmed*

In Fig. 6 there is finally shown the characteristic of measured feed-rate between the tool and the workpiece during a four-axis operation. This is the verification of the presumption mentioned above and it is clear that the specified feed-rate in NC program (800 mm/min) has not been achieved. By comparing the two figures (Fig. 3 and Fig. 6) it can be claimed that an almost 100% match has been achieved. This is not the main object of this article, but it is the instrument for introducing the reason why it is important to propose a method to improve machine tool power drives exploitation during four-axis continuous machining.

4. Power drives exploitation improvement method

It is clear that this detection can not be satisfactorily for a production engineer. That is the reason why it is important to propose a method to improve power drives exploitation. A simple way to do that is to prepare a postprocessor algorithm for correcting the feed-rate in each NC program block. The postprocessor algorithm for predicting feed-rate has been extended to predict also the rotary axis velocity and the velocity of the movement done by all linear axes. To achieve a constant feed-rate between a tool and a workpiece it is necessary to generate an NC program with corrected values of the feed-rate in each block. If we had a machine tool with a very quick rotary table we could achieve a constant feed-rate in NC program. In this case it means that the rotary axis must be able to achieve the speed of 11500 °/min very quickly. Due to possibilities of used machine tool and its rotary axis it is not possible to achieve this value of rotary axis velocity. Due to this fact it must also be considered the acceleration of rotary axis. The Acceleration of rotary axis can be measured using the same sensor mentioned above. In Fig. 7 a) there is shown the velocity characteristic of rotary axis an in Fig. 7 b) can be seen the NC program used for this measurement. It is clear that the rotary axis slows down when the angular position given in the NC program is achieved. These situations are marked using red arrows in Fig. 7 a) and corresponding NC program blocks are marked in Fig. 7 b). With a green arrow there are marked two situations when the rotary axis could not achieve the specified value of feed-rate given in NC program because of too small increments. From this measurement it is possible to calculate the real rotary axis acceleration value.



a)

G54 G64
1. G01 A1. F500.
2. A2.
3. A10.
4. A25.
5. A45.
6. A90.
7. A125.
8. A180.
9. G00 A0.

b)

***Fig. 7** – Velocity characteristic of rotary axis (a), NC program used for measuring (b)*

Calculated acceleration is then used to upgrade the postprocessor algorithm for feed-rate prediction. Obtained characteristic of predicted feed-rate in NC program using the upgraded postprocessor algorithm can be seen in Fig. 8.

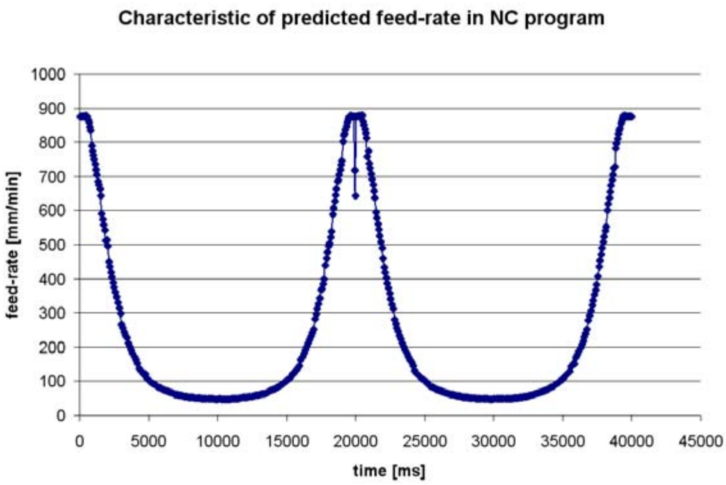


***Fig. 8** - Characteristic of predicted feed-rate in NC program when 800 mm/min have been programmed and the acceleration of rotary axis is considered*

In the last figure of this chapter (Fig. 9) there is given a characteristic of predicted feed-rate in NC program using the machine tool power drives exploitation improvement method. At first sight this characteristic appears to be the same as the previous characteristic of predicted feed-rate but it is not. It can be clearly seen that the NC program execution time in the previous standard NC program will be 40000 ms but in this case it is only 32500 ms. It can be claimed that very considerable NC program execution time savings have been achieved.

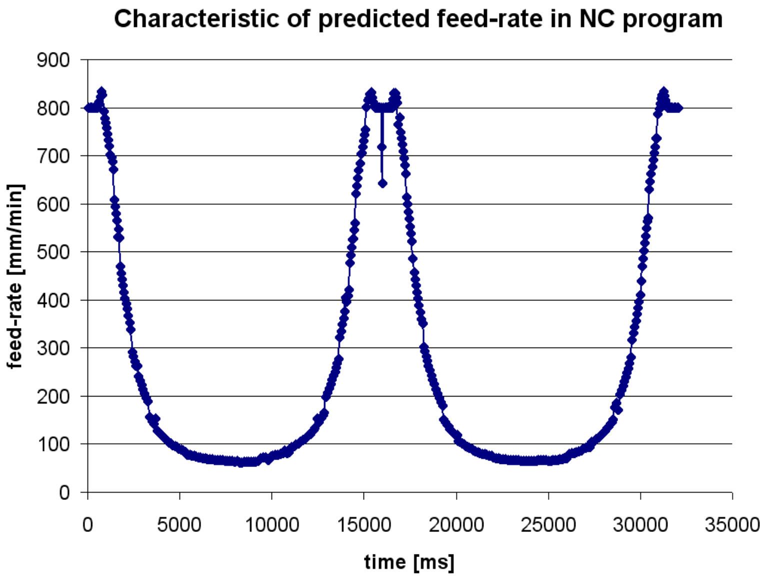


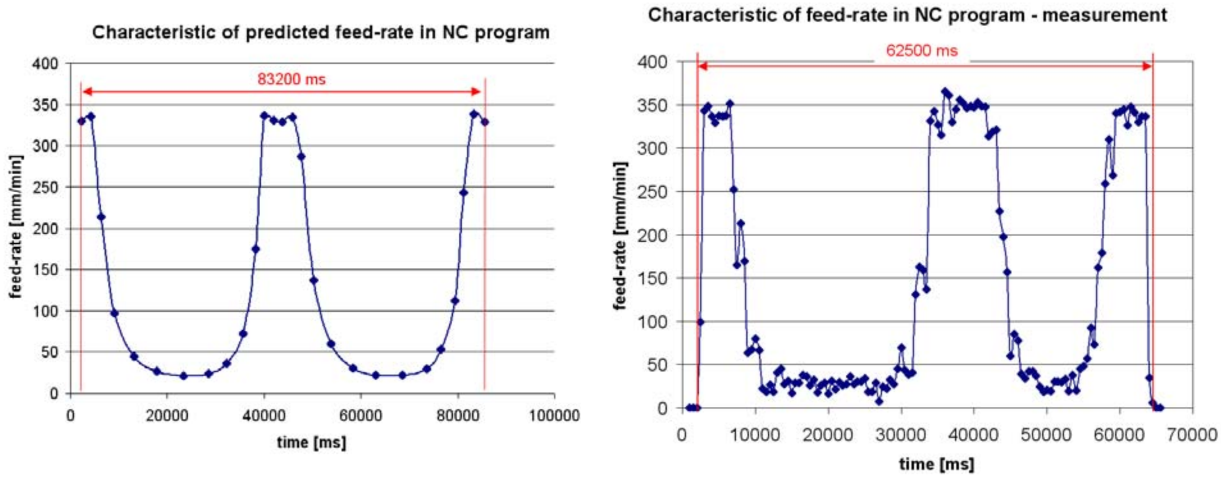
Fig. 9 - Characteristic of predicted feed-rate in NC program when 800 mm/min have been programmed using improvement method for NC program correction and the acceleration of rotary axis is considered

5. Machining time savings using the proposed method

In this chapter there is shown a relationship between the case of the standard NC program execution and the modified NC program execution on the four-axis machine tool. This will be presented on two cases of toolpath calculation tolerance settings.

5.1. NC program with toolpath calculation tolerance value equal to 0,2 mm

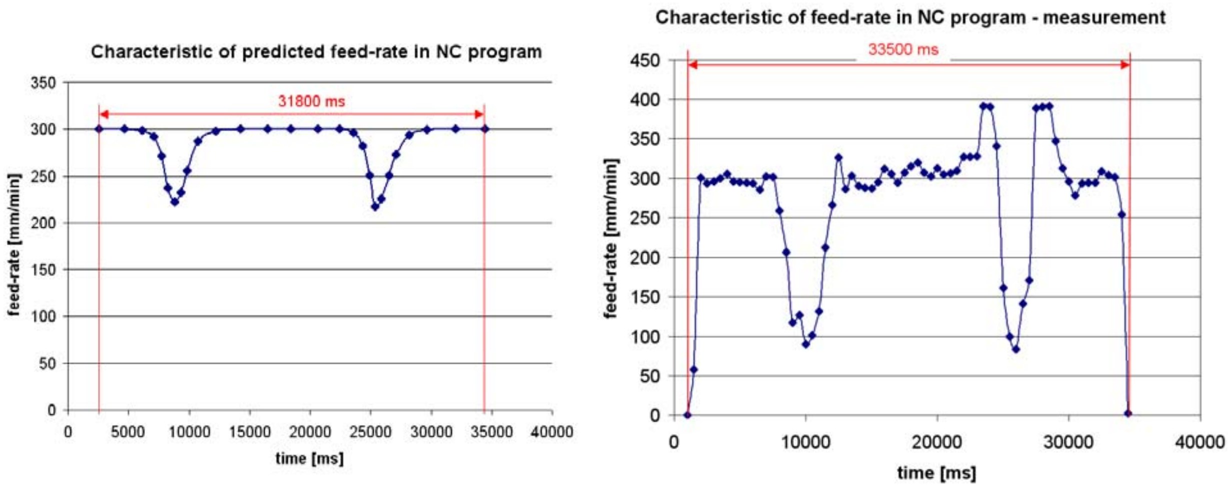
At first we will look at Fig. 10 a) where we can see the predicted feed-rate in NC program with toolpath calculation tolerance value of 0,2 mm. In this case the predicted NC program execution time is 83200 ms. If we look at Fig. 10 b) we can see the characteristic of measured feed-rate in the same NC program. In this case the measured NC program execution time is 62500 ms. The reason why the measured time is shorter than the predicted NC program execution time is because of the axis of rotation is positioned in an eccentric way with respect to the part's centre. By comparing these two figures it can be claimed that an almost 100% match in feed-rate values has been achieved.



a) *b)*

Fig. 10 - *Characteristics of feed-rate in NC program with toolpath calculation tolerance of 0,2 mm before the improvement method application, a) predicted, b) measured*

By means of the next two figures (Fig. 11a) and Fig. 1 b)) the comparison between the predicted characteristic of feed-rate in NC program and the characteristic of measured feed-rate in the same NC program can be seen, but after the power drives exploitation improvement method has been put to use. If we compare these figures with the previous two figures mentioned above we can see that the feed-rate specified valou of 300 mm/min is achieved in longer section of the NC program and the time savings are about 46% compared with the previous standard NC program.

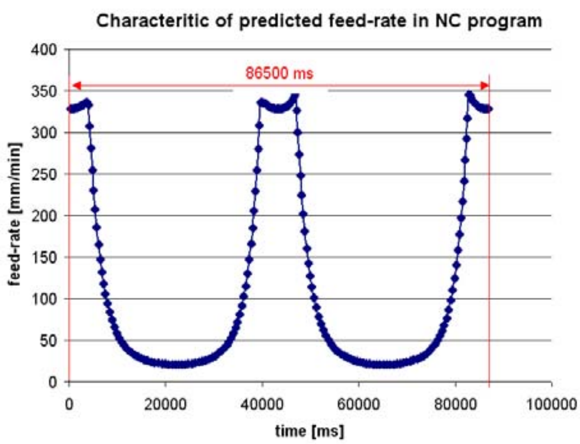


a) *b)*

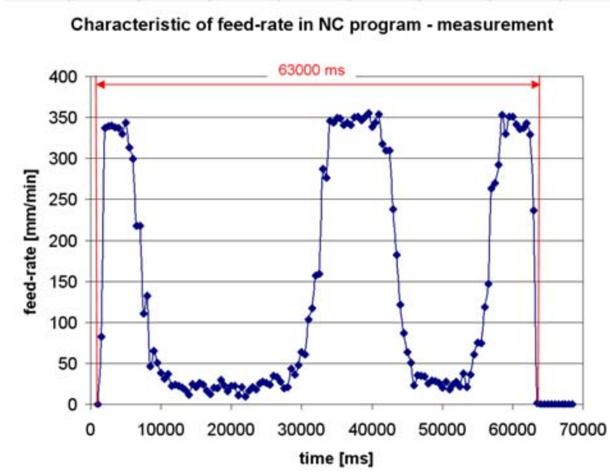
Fig. 11 - *Characteristics of feed-rate in NC program with toolpath calculation tolerance of 0,2 mm after the improvement method application, a) predicted, b) measured*

5.2 NC program with toolpath calculation tolerance value equal to 0,004 mm

As well as in the previous case of the toolpath calculation tolerance setting we can look at this case where the toolpath calculation tolerance has been set to 0,004 mm. If we look at Fig. 12 a) where we can see the predicted feed-rate in NC program with toolpath calculation tolerance value of 0,004 mm we can find out that the NC program execution time is 86500 ms. Let's have a look at Fig. 12 b) where we can see the characteristic of measured feed-rate in the same NC program. In this case the measured NC program execution time is 63000 ms. The reason why the measured time is shorter than the predicted NC program execution time has been explained above. By comparing these two figures it can be claimed that an almost 100% match in feed-rate values has again been achieved.

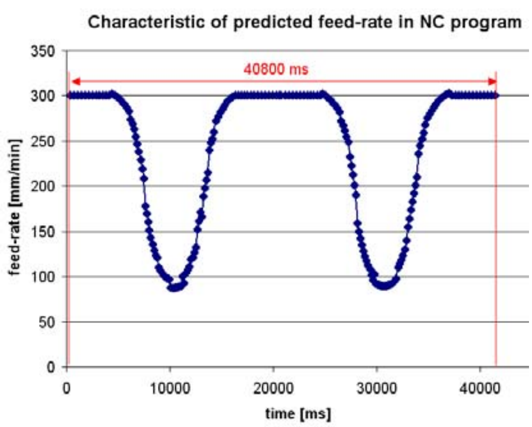


a)

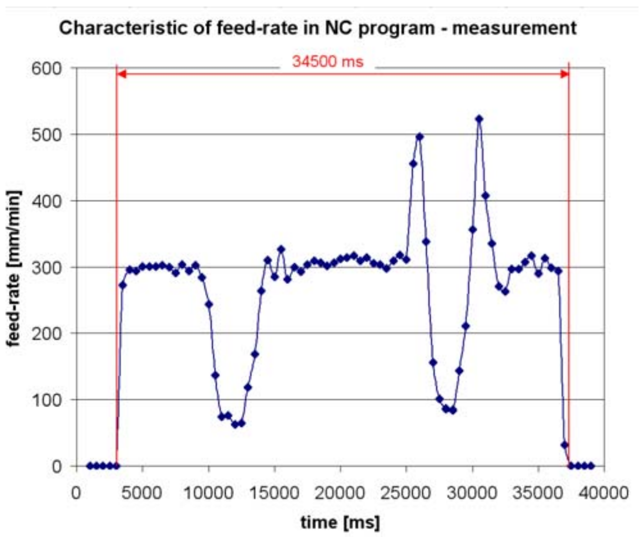


b)

Fig. 12 *- Characteristics of feed-rate in NC program with toolpath calculation tolerance of 0,004 mm before the improvement method application, a) predicted, b) measured*



a)



b)

Fig. 13 *– Characteristics of feed-rate in NC program with toolpath calculation tolerance of 0,004 mm after the improvement method application, a) predicted, b) measured*

If we look at the two figures Fig. 13 a) and Fig. 13 b) we can see the predicted characteristic of feed-rate in NC program and the characteristic of measured feed-rate in the same NC program but again after using the power drives exploitation improvement method. If we compare these figures with the previous two figures mentioned above we can see that the specified value of the feed-rate is achieved in longer section of the NC program again and the time savings are now about 38% compared with the previous standard NC program with the same toolpath calculation tolerance value setting. Time savings are now a little bit less because of shorter increments between two following positions given in NC program blocks. Therefore the rotary axis can not achieve such high velocities as in the case of toolpath calculation tolerance setting at the value of 0,2 mm.

5.3 NC programs with different toolpath calculation tolerance value setting

For convenience a summary of NC programs with different toolpath calculation tolerance value settings analysis has been assessed. In Tab. 1 can be seen that different NC program execution time savings for different toolpath calculation tolerance value setting has been achieved. The best effect of time savings is of course in the case when the toolpath calculation tolerance is set to 0,2 mm but the resulting quality of the machined surface is very bad. When the toolpath calculation tolerance is set to 0,01 mm we can achieve good results of NC program execution time savings too and this is the typical case used in "semifinishing" operations. It can be claimed that very good results in NC program execution time savings using the machine tool power drives exploitation improvement method has been achieved.

***Tab. 1** – NC programs analysis summary*

NC program	toolpath calculation tolerance [mm]	NC program execution time – prediction [ms]	NC program execution time – measurement [ms]	modificated NC program execution time – prediction [ms]	modificated NC program execution time – measurement [ms]	NC program execution time savings [%]
1	0,004	86500	63000	40800	39000	38,1
2	0,008	86000	62500	38800	37500	40
3	0,01	85800	62500	38000	37500	40
4	0,08	84500	63000	34000	34500	45,2
5	0,2	83200	62500	31800	33500	46,4

6. Conclusion

It can be said that the machine tool power drives exploitation improvement method has been proposed and verified. The main object of this article is not a description of postprocessor algorithm for predicting the feed-rate but it is used only as the instrument for introducing the need for machine tool power drives exploitation improvement for four-axis machining. The specific postprocessor algorithm has been proposed and applied when generating NC programs. Applying this new algorithm for NC program modification the time savings in four-axis machining have been achieved. These time savings are in relation with the toolpath calculation tolerance. Using the testing toolpath the 38% time savings for the toolpath calculation tolerance 0,004 mm and the 46% time savings for the toolpath calculation tolerance 0,2 mm have been achieved. The future work is to propose analogous postprocessor algorithm for a five-axis machining as well and test it in real applications.

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