# Experimental High Speed Milling of the Selected Thin-Walled Component

Jozef Zajac [1], Michal Hatala [1], Ján Duplák [1], Darina Dupláková [1], Jozef Steranka [1]

[1]*Technical University of Kosice, Faculty of Manufacturing Technologies with a seat in Presov, Štúrova 31, 080 01 Prešov, Slovakia*

***Abstract* – In a technical practice, it is possible to meet thin-walled parts more and more often. These parts are most commonly used in the automotive industry or aircraft industry to reduce the weight of different design part of cars or aircraft. Presented article is focused on experimental high speed milling of selected thin-walled component. The introduction of this article presents description of high speed machining and specification of thin – walled parts. The experiments were carried out using a CNC machine Pinnacle VMC 650S and C45 material - plain carbon steel for automotive components and mechanical engineering. In the last part of the article, described are the arrangements to reduction of deformation of thin-walled component during the experimental high speed milling.**

***Keywords* – High speed milling, Thin-walled component, deformation, C45 material.**

DOI: 10.18421/TEM64-05
https://dx.doi.org/10.18421/TEM64-05

**Corresponding author:** Darina Dupláková,
*Technical University of Kosice, Faculty of Manufacturing Technologies with a seat in Presov, Prešov, Slovakia*
**Email:** darina.duplakova@tuke.sk

*Received: 01 August 2017*
*Revised: 04 September 2017*
*Accepted: 15 September 2017*
*Published: 27 November 2017*



## 1. Introduction

High speed machining (HSM) is defined as progressive technology where the high cutting speeds are used. This machining process can be used in productions where there is necessary to meet the requirements of machining quality and high productivity. In the following table, presented is a comparison of HSM method and convention machining method. [1]

*Table 1. Comparison of HSM and Convection machining method*

| Conventional | High speed machining |
|---|---|
| **maximum speed 600 m/min** | speed starts at 600 m/min |
| **maximum feed 40 ipm** | feed starts at 100 ipm |
| **require high levels coolant** | no feed for coolant for low feed rate;<br>feed rate can go more than 2000 ipm |
| **cutting fluid is required** | cutting fluid is not required |
| **low surface finish** | high surface finish |
| **cutting force is large** | cutting force is small |

For the first time, the term high speed machining was used during the realization of experiments of aluminum, bronze and copper machining using the helical milling cutter in the year 1931. During the machining of materials by way of HSM technology and using the hard and heat-resistant tools, the temperature of the machined chips is approaching the melting temperature of the workpiece [1].

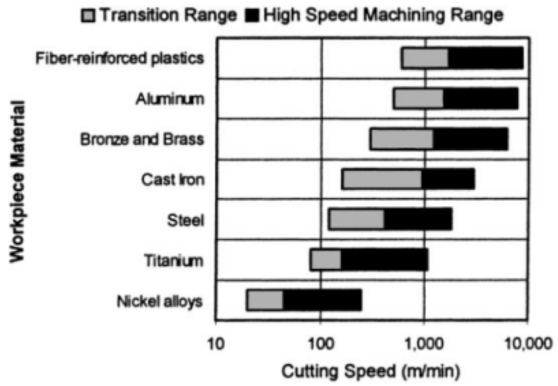


*Figure 1. High speed machining ranges of various materials [1]*

HSM technology is categorized in terms of machining method. The basic subgroups of HSM progressive machining technology include [2]:

- High Feed Milling (HFM)
  - most commonly used for milling that is characterized by the material having a low section thickness ($a_p$ = 2 mm) and a high feed rate on the milling tooth (up to $f_z$ = 3 mm);
  - the use of special tools for the reduction of production time;
  - the tools have replicable cutting plates that are dimensionally robust and have a small blade angle;
  - during the NC programming, it is necessary to follow the amount of working speed and the basis of programming is monitoring of the maximum feed;
- High Performance Cutting (HPC)
  - most commonly used for roughing operations or machining of hard machined materials;
  - large reduction of chip in the one step;
  - environmental and economic advantages in the assembly-line production;
  - machining tools should be made from tungsten carbide;
  - machining tools should have coating that is resistant to high temperatures;
  - machining tools – special milling cutters and milling heads with replaceable cutting plates;
- High Speed Precision Cutting (HSPC)
  - realised by micro-milling machining devices;
  - typical machining of very small surfaces;
  - emphasis on the precision of machining;
  - used for production of workpieces with the emphasis on quality and high precision of small machined surfaces;

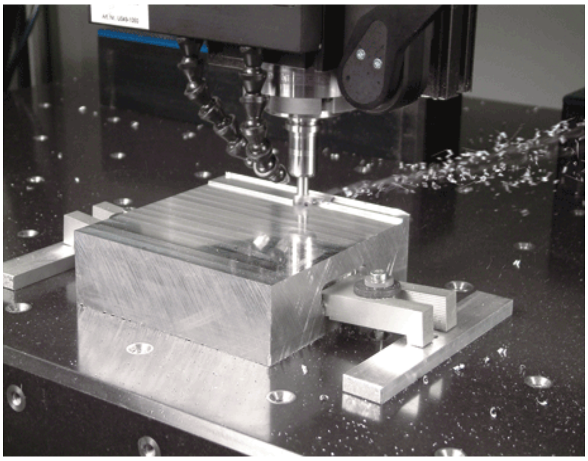

*Figure 2. Example of high speed machining*

HSM technology has the advantages and disadvantages which are presented in the following table. [3]

*Table 2. Advantages and disadvantages of HSC technology*

| Advantages | Disadvantages |
|---|---|
| high material removal rate | it is not sufficiently tested for every kind of material |
| high surface finishing | low surface finishing |
| reduction in lead times | financial costs (from the reason of safety provision of workers) |
| low cutting force | |
| reduction of production process | |

The use of HSM technology requires the demands for machines which are used during the machining via this technology. The basic demands are presented in the following table.

*Table 3. HSM technology - machine demands*

| Demands | Values |
|---|---|
| Spindle speed range | 40 000 rpm |
| Spindle power | 22kW |
| Programmable feed rate | 40 – 60 m/min |
| Rapid travels | 90 m/min |
| Block processing speed | 1-20 ms |

The high speed machining can also be used during the machining of thin-walled parts. The thin-walled is composed of small wall thickness in comparison to other sizes. This part is possible to describe by two parameters – thickness (h) and height (h). The wall thickness of a part (up to 5 mm) is smaller than height (cutting depth more than 30 mm).

The thin-walled parts can be divided into several groups [4]:

Frame parts

- double or triple fixing of component wall
- application - aircraft industry (reduction of total weight of the airplane)
- made of titanium alloys or aluminum alloys

Rib parts

- once fixing of component wall
- application - car industry or refrigeration industry (various sorts of coolers)
- made of copper alloys

Shape – complexity parts

- once fixing of component wall
- application: aircraft industry or power industry (various sorts of turbine blades)
- produced by milling (3, 4 and 5 axes)

Small - sized parts

- characterized by small sizes
- produced by micro-milling technology or progressive methods
- all of previous parts provided that they have small sizes

In practice, the thin-walled parts are usable in the car industry or aircraft industry. In these industries they are mainly applied due to the reduction of the weight of the components of cars and aircrafts. [5]

The basic advantages of thin-walled parts are:

- precision, strength, lightness and safety
- weight reduction of produced parts
- reduced number of components
- reduced total time of assembly
- reduction of delivery assembly time
- ensuring the faster machining time and lower costs (by application of HSM technology).

## 2. Material and Method

The experiments were realized by CNC machine Pinnacle VMC 650S (Figure 3.) which is designated for precise and fast machining of shape surface, drilling, milling, etc. Automatic exchange of tools provides the work in the cycles. The basic technical specification is presented in the following table.


*Figure 3. Pinnacle VMC 650S*

*Table 4. CNC Pinnacle VMC 650S – technical specification*

| Technical parameter | Value |
|---|---|
| Travel range – x [mm] | 650 |
| Travel range – y [mm] | 560 |
| Travel range – z [mm] | 560 |
| Spindle taper [DIN 69871] | ISO 40 |
| Tool storage capacity [pcs] | 20 |
| Maximum table load [kg] | 600 |
| Clamping surface of table [mm] | 800x510 |
| Air requirement [kg/cm$^2$] | 6 |

During the realization of the experiments, two cutting tools were used– milling cutter Feed King and monolith milling cutter. The basic specification of these milling cutters is presented in the following table.

*Table 5. Cutting tools – technical specification*

| Tools | Diameter of milling cutter [mm] | No. of teeth [mm] | Maximal cutting depth [mm] |
|---|---|---|---|
| Milling cutter Feed king | 20 | 4 | 1.15 |
| Monolith milling cutter | 12 | 4 | 10D |

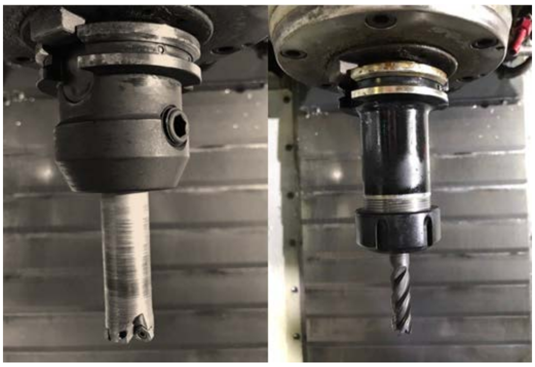

*Figure 4. Cutting tools*

It was used the C45 material – plain carbon steel for automotive components and mechanical engineering to the realization of experiments. [6] This material is used in the manufacturing companies around the world. The basic chemical composition and mechanical properties are presented in Table 6. and Table 7.

*Table 6. C45 – chemical composition*

| Chemical structure of C45 [%] | | | |
|---|---|---|---|
| **C** | **Mn** | **Si** | **Cr** |
| **0.42-0.50** | 0.50-0.80 | 0.17-0.37 | max. 0.25 |
| **Ni** | **Cu** | **P** | **S** |
| **max. 0.30** | max. 0.30 | max. 0.040 | max. 0.040 |

*Table 7. C45- mechanical properties*

| Mechanical properties of C45 | | | | | | |
|---|---|---|---|---|---|---|
| **Re [MPa]** | **Rm [MPa]** | **HB** | **HRC** | **A5 [%]** | **E [GPa]** | **ρ [kg/m$^3$]** |
| min. 305 | min. 530 | max. 225 | min. 55 | 16 | 221 | 7850 |

## 3. Description of experiments and results

Three basic experiments were realized for the analysis and evaluation of deformation of thin-walled part. The different maximum cutting depths were defined:

a) Experiment No. 1 – cutting depth 0.3 mm
b) Experiment No. 2 – cutting depth 0.5 mm
c) Experiment No. 3 – cutting depth 0.7 mm

The above mentioned experiments were carried out on selected thin – walled component (Fig. 5.). Every experiment consists in production of 80 pieces of semi-finished products (sizes 120 x 100 x 100 mm).

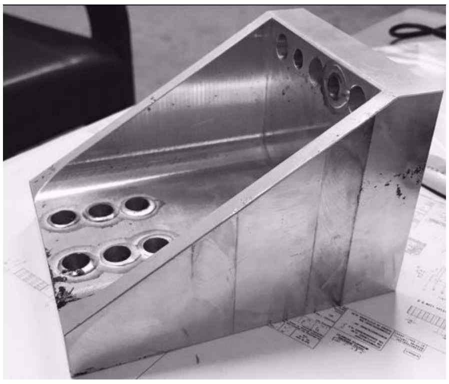

*Figure 5. Component*

In all three experiments, the basic cutting conditions were calculated in respect to the machined material and the used tools. The cutting conditions are given in the following table.

*Table 8. Cutting conditions*

| Specification | Value |
|---|---|
| Cutting speed $v_c$ [m/min] | 150 |
| Diameter of the cutter D [mm] | 20 |
| Feed $f_z$ [mm] | 0.7 |
| Number of cutter teeth z [mm] | 3 |
| Operating speed n [min$^{-1}$] | 2400 |
| Feed rate $v_f$ [mm/min] | 5000 |

After carrying out of the experiments, the deformation of the thin-walled parts after roughing was evaluated. The evaluation consists in determination of time efficiency of the production process and the total productivity of the production process (determination of percentage of suitable components). In the following table there are presented the quantity of suitable components and the percentage of suitable components.

*Table 9. Evaluation table*

| No. of experiment | Quantity of produced components | Quantity of suitable components | Percentage of suitable components [%] |
|---|---|---|---|
| Experiment No. 1 | 80 | 72 | 90 |
| Experiment No. 2 | 80 | 52 | 65 |
| Experiment No. 3 | 80 | 32 | 40 |

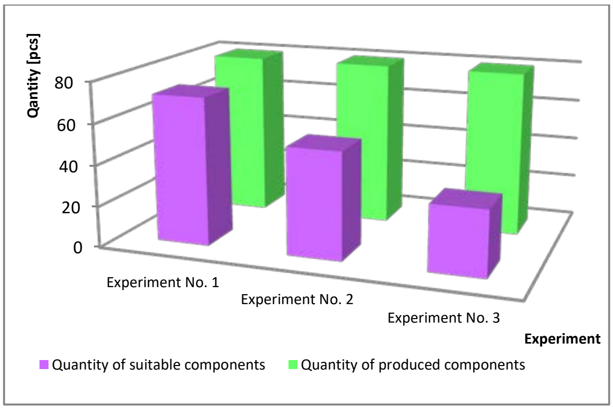


*Figure 6. Comparison diagram of produced and suitable components*

The second evaluation was the evaluation of total production time. This time consists in side and machining time. The side time includes the time for clamping of workpiece, tool change or loosening workpiece. In the following table presented is the total production time of the experiments.

*Table 10. Total production time*

| | Total production time [min] |
|---|---|
| **Experiment No. 1** | 3.23 |
| **Experiment No. 2** | 2.74 |
| **Experiment No. 3** | 2.53 |

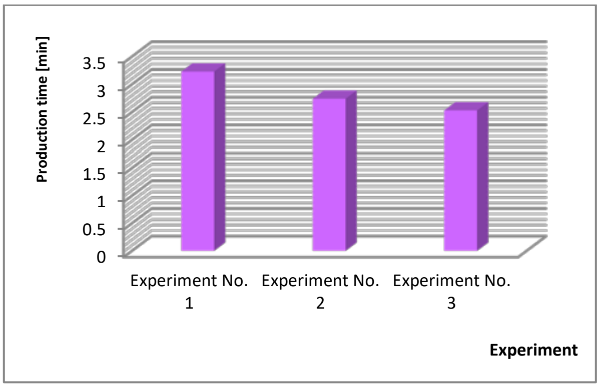


*Figure 7. Diagram of total production time*

The above mentioned diagram (Fig. 7.) presents the total production time. This time has decreasing trends due to the increase of the cutting depth in the experiments.

*Table 11. Summary table*

| | Experiment No. 1 | Experiment No. 2 | Experiment No. 3 |
|---|---|---|---|
| **Cutting depth [mm]** | 0.3 | 0.5 | 0.7 |
| **Total production time [min]** | 3.23 | 2.74 | 2.53 |
| **Percentage of suitable components [%]** | 90 | 65 | 40 |

The results show that the most suitable alternative is experiment No. 1, during which the cutting depth was 0.3 mm. However, during this experiment, the highest production time was achieved. Smaller production times were achieved during the second and the third experiment, but deformations occurred on a larger number of components. This phenomenon arises as a result of pushing of the material due to the resulting vibrations of the milling cutter.

## 4. Conclusion

The issue of machining of thin-walled parts is solved at a global level from the reason of their usability in the important sectors such as the aviation or the automotive industry. [6 -7] This article was aimed at solving the deformation problem of the selected thin-walled components in high-speed milling. From the above results, it is necessary to propose the following arrangements to reduce the deformation of the selected thin-walled component:

1. Enlargement in allowances for larger removal of material

2. Reduction of cutting parameters

However, in the first case, it is necessary to take into consideration the fact that– after the enlargement in allowances for larger removal of material the life of the tool will be reduced - namely the monolith milling cutter. In the second case, it is necessary to take into consideration the reduction of the total production due to the smaller percentage of suitable finished components. It is also possible that the reduction of cutting parameters will no longer apply high speed milling technology. These facts are subject of further research.

**Acknowledgements**

*This work has been supported by research grant VEGA 1//0492/16.*

## References

[1]. Fallböhmer, P., Rodríguez, C.A, Özel, T., Altan, T. (2002). High-speed machining of cast iron and alloy steels for die and mold manufacturing. *Journal of Materials Processing Technology, 98 (1),* 104-115.

[2]. Abukhshim, N.A., Mativenga, P.T., Sheikh, M.A. (2005). Heat generation and temperature prediction in metal cutting: A review and implications for high speed machining. *International Journal of Machine Tools & Manufacture, 46 (2006*), 782-800.

[3]. Sutter, G. et al. (2003). An experimental technique for the measurement of temperature fields for the orthogonal cutting in high speed machining. *International Journal of Machine Tools & Manufacture, 43 (2003),* 671-678.

[4]. Mitaľová, Z., Mitaľ, D., Botko, F.: Measuring of roughness and roundness parameters after turning of composite material with natural reinforcement. Science report : Project CIII - PL-0007 : Research on modern systems for manufacture and measurement of components of machines and devices. - Kielce : Wydawnictwo Politechniki Świętokrzyskiej, pp. 49-58 (2016).

[5]. Lia, L., Lia, C., Tangb, Y., Yia, Q.: Influence factors and operational strategies for energy efficiency improvement of CNC machining. Journal of Cleaner Production. Vol. 161, pp. 220–238 (2017).

[6]. Čep, R., Janásek, A., Čepová, L., Procházdka, J. (2010). Sandvik Ceramic Cutting Tool Tests with an Interrupted Cut Simulator. *Proceedings of World Academy of Science, Engineering and Technology, World Academy of Science Engineering and Technology*, 728-732.

[7]. Knapčíková, L. et al.(2016). Material recycling of some automobile plastics waste. Przemysl chemiczny,Vol.95,No.9 (2016). p. 1716-1720.