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STUDY UPON MILLING COMPLEX SURFACE

PART II: HIGH SPEED MACHINING AND MACHINING ERRORS

BY

BOGDAN-GABRIEL ANIŢĂ and CĂTĂLIN DUMITRAŞ*

“Gheorghe Asachi” Technical University of Iaşi,
Faculty of Machines Manufacturing and Industrial Management

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Abstract. Complex surface, called free-form used in industries engineering, aerospace industry dies / molds, plants high precision technical mechanisms aircraft / nuclear, robotics, etc. Complex surfaces is mainly produced by CNC center, in particular 3-5axe. Different methodologies application in the field of milling has been developed in the past to improve the efficiency of processing of complex surfaces milling process. This paper aims to provide a two-part study, recent research development on complex surfaces millings. In the second part of this study focuses mainly on two aspects: high speed machining and machining errors.

Key words: milling, surface complex, high speed, machining errors.

1. Introduction

Mechanical engineering and aerospace they find widening extension with complex geometric, made from various materials.

An important area of application for milling is high speed machining, focusing primarily on reducing of establishment time and processing time. High speed machining has long been an accepted technology for machining of various materials manufactured by using high speeds and feeds cutting and

* Corresponding author; *email:* dumitrascata@yahoo.com

secondly by reducing the number of operations related to execution of parts of complex surfaces.

For high speed milling tools are available in a variety of materials for tools, including tungsten carbide, metal-ceramic and PCBN conventional ceramics. With the appearance of super hard tools, ability of high speed machining has increased significantly. In terms of manufacturing tool, cutting tool developments are closely related to the tool geometry, material and treatment coverage. Due to the complex surface geometry, CNC milling centers are often used to achieve the required design quality while maintaining machining efficiency. In spite of progress in the process of cutting forces is causing run out and deflection of the tool resulting poor performance of surface quality. The rest of the paper aims to provide a survey of recent research development millings complex surfaces. This study focuses mainly on two aspects: high speed machining and processing errors.

2. Machining with High Speed

High-speed machining is a manufacturing technology with great potential in the future. Along with the processing of aluminum alloy parts, manufacture of molds / dies is an important field of application for high speed milling of cast iron (Fallböhmer *et al.,* 2000), steel / alloy steel (Toh *et al.,* 2006), magnesium alloys (Fang *et al.,* 2005), titanium alloy (Rahman *et al*., 2006), nickel alloys (Soo *et al.,* 2010), brass and fiber composite polymer (Kauppinen, 2004).

According to his survey (Fallbohmer *et al*., 2000), 50% of the common material is steel mold, P20, the hardness typically in the range of 29-33 HRC for the construction of injection molds, molds for casting of H13 to the hardness of 45-60 HRC and pressure molds the hardness of 46-50 HRC.

The problem with high speed milling of tool steels is insufficient strength and deficiency of knowledge of cutting parameters for hard materials. Development for tool materials and geometry tools made possible to conduct research in high speed milling on various steels, even high alloy tool steel hardened. The machining of titanium alloys are used extensively in aerospace and biomedical industries due of their ratio hardness / weight and superior corrosion resistance. (Rahman *et al.,* 2006) present an evaluation of joint material titanium alloy (Ti6Al4V) in high-speed machining which represents more than 50% of the production of titanium alloy. Recently they have developed some types of titanium alloys Ti555.3 (Arrazola *et al.,* 2009) and Ti56M (Armendia *et al*., 2010). Titanium alloys are generally difficult to machine at cutting speed of 30m/min with high-speed steel and over 60m/min with ceramic tools with tungsten carbide inserts resulting in low productivity.

Some of the toughest materials like diamond or cubic boron nitride (NCB), but both diamond and cubic boron nitride are very expensive at the moment on the market. In addition, there are also highly reactive with titanium alloys at high temperatures, as a result are not suitable for the treatment of titanium alloys. The use of materials with low specific gravity is a way to reduce the structural weight. Aluminum alloys are among light metal materials, the most commonly used in the aerospace industry (Heinz *et al.,* 2000) and in the automotive industry (Miller *et al.,* 2000) with different mechanical and thermal properties. They are relatively easy to modeling, and in particular the removal processes, such as machining. In fact, aluminum alloy, as a class, the family of materials are considered to offer the higher level of workability, comparing with the other family of light metals such as titanium and magnesium alloys.

Aluminum alloys (Kaufman, 2000) are classified into two categories: in castings and wrought. Wrought aluminum alloy parts have excellent machinability, while the aluminum alloy castings can cause some machining difficulties. Development of aluminum alloys is often subject to the requirements of the aerospace and automotive industry but aluminum alloys are interesting for several applications in other sectors. Over the years, high-speed machining has been recognized as one of the key processes in the manufacture of aluminum alloy parts, owing to the advantages of high speed processing of conventional machining.

The most common aluminum alloy is 7xxx series owing to the low density and high strengths (high ratio between strength and weight), high rigidity and high breaking strength, being investigated on cutting forces (Davim, 2011), the quality of the machined surface (Erdel, 2003) cutting speed of 1500 m / min and chip morphology. Progress of tools for high speed milling is available in a variety of materials including tungsten carbide, metal-ceramic and PCBN conventional ceramics.

The main material for tools most commonly used in high-speed machining are: a) high-speed steel (HSS), including new classes of sintered powder b) sintered carbides, usually known as hard metal, c) ceramic of aluminum (Al_2O_3) or silicon nitride (Si_3N_4), d) the super-hard material, for example, on the basis of polycrystalline diamond (PCD) and cubic boron nitride (PCBN).

High-speed steel tools coated with Ti (C, N) with a thin layer of less than 10μm in the PVD process (Mills, 1996), extends the life of the tool that provides a smooth finish and machining forces and temperatures are small.

Sintered carbide tools known as hard metal are made of a mixture of tungsten carbide with cobalt micrograms of the high temperature and pressure. Carbides of tantalum, titanium or vanadium may also be mixed in small proportions (Davim, 2011). Sintered carbide tools are manufactured in two forms: a) integrated tools being produced by adjustment rough rod. The main advantage of these tools is the perfect balance, but the main disadvantage is the high price, given that only a small area of the tool is used in the cutting machining; b) inserts: small plates with special geometry made of hard metal, but they are fixed on steel, offering the potential for more new lines of development in tool materials and geometry. In particular, the material of the surface plates may be selected for maximum resistance to wear under specific conditions, while the material of the plate body may be selected for resistance to stress. So far coatings were developed almost entirely by high speed cutting tests on cast iron and steel (Fallböhmer *et al.,* 2000), (Trent, 2000). Minimum temperature PVD deposition, resulting lower residual stress compared to CVD coatings. This can be the advantage, although residual stress and stress cracking in CVD coating not significantly affect performance cutting applications.

Ceramic tools are based primarily on alumina (Al_2O_3), silicon nitride (Si_3N_4). Alumina-based tools may contain additions of titanium, oxides of magnesium, chromium and zirconium homogeneously distributed in an alumina matrix to improve the hardness. The solubility of iron-alumina, is only one fifth of tungsten carbide, therefore, alumina-based ceramic is reduced diffusion wear and very high anti-oxidation.

However, ceramic based on alumina has a small capacity, breaking strength, thermal conductivity and thermal shock resistance resulting from a better productivity in cycles of short high-speed machining. Compared with ceramic based ob alumina, silicon nitride (Si3N4) has more power, toughness, thermal shock resistance and adhesion is not sensitive to iron, so it is mainly used in high-speed machining of cast iron (700m / min) and gray cast iron (800m/min). Improved performance and wear resistance of the tool include reinforcing ceramic silicon carbide (SiC) (Liu *et al.,* 2004), being very effective in high speed machining of composite materials and super alloys used in the aerospace industry, such as nickel alloys, but are not suitable for processing of iron and steel.

Tools super-hard materials (Davim, 2011), (Trent & Wright, 2000), (Liu *et al.,* 2004) are widely distributed than sintered carbides. In entering this category based polycrystalline diamond (PCD) and cubic boron nitride (PCBN). CBN grit and related phases affect processing performance PCBN.

PCBN with a low content of CBN (50-65%) is mainly used in finishing hardened (45-65 HRC) 45-60m/min speeds, while high CBN content (80-90%) is used machining with high speed roughing, semi-finishing of cast iron alloyed with nickel and chrome, hard metal, sintered metals and hard alloys, etc. The evolution of hard materials for tools such as PCD and PCBN will continue to grow and have an important role in machining speeds. Ceramic materials are the most promising and will be widely used. NBC combination will be promising ceramic materials for high speed machining. However, rapid steel will continue to take an important place. Given this economic reality (Trent, 2000), researchers suggest that the research community to re-evaluate some of their efforts.

3. Machining Errors

In precision machining of CNC machine tools is affected by a number of sources of error based on specific parameters, including forces and tensions, geometrical deviations of machine tool structure and thermal variations.

The cutting force is for the most part of the induced errors directly affecting machining accuracy. These geometrical errors can be working time machine tools due to wear and mechanical damage. Although they often face many obstacles, such as milling errors and adjacent imperfections. Therefore, these factors are not integrated into the software CAD / CAM, leading in models of compensating these errors (Depince, 2006). Number of studies has been performed in connection with the processing of complex surfaces, most of these studies focus on tool path generation, detection and compensation of machining errors.

Runout (deviation) tool (Desai *et al.,* 2009), (Yang *et al.,* 2011), classified as geometric caused by the eccentricity of tool axis and non-uniformity cutting edge and the dynamic deviation caused by vibration.

Modeling the effect of deviation the current assessment tool, chip thickness is important for reliable estimation of cutting forces. Deviation can be defined by two values: the transfer of cutter ρ, which is the distance of cutter and the center of rotation and the second value, is the angular position of the center of rotation λ measured from an arbitrary position of the cutting edge (Fig. 1).

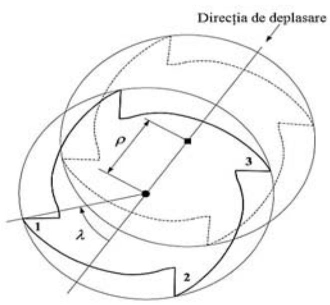

Fig. 1 − Tool geometry deviations.

Identification of tool deviation parameters being derived from the basic concept, only the value of each coefficient of cutting chip thickness irremovable data, regardless of the cutting conditions. Moreover, since the cutter the deviation leads to a redistribution of cutting forces in different periods being necessary to choose the cutting forces measured at different times of the tooth where ρ and λ solving.

Deflection tool (Fig.2) (Smaoui *et al.*2011), (Lopez *et al.,* 2007), (Ryu, 2012) being caused by cutting forces or distortion entire system machine tool / cutter holders under cutting forces, resulting machined surface errors.

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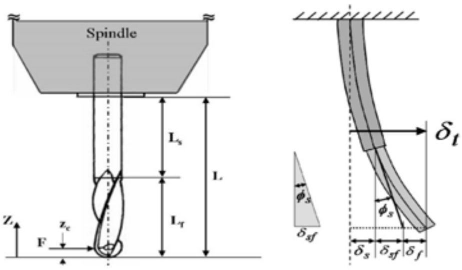

Fig. 2 − Deflection tool.

Deflection tool induces significant components machined surface errors and is one of the major obstacles to achieve higher productivity. The problem becomes more complicated deflection tool during machining curved surfaces. Quality and accuracy are both critical in industrial milling, however, milling errors and imperfections, mainly due to flexing tool, preventing the full realization of these objectives. Deflection tool can be determined by three factors: geometric modeling tool (tool diameter equivalent cylindrical model), modeling cutting forces (Lopez *et al.*, 2004) and the model for calculating bending, simple model such as cantilever (Smaoui *et al.,* 2011); (Kim *et al.,* 2003) or complete such as the finite element (Kivanc *et al*., 2003). In high speed machining, deflection tool gives birth to inaccuracy on the surface produced. Thus, minimizing the effect of various factors produced by dimensional errors for meeting the finishing (Lopez *et al*., 2004).

The variables tests considered where: cutting strategy, tool size, material hardness and surface slopes it is possible to determine the tool strategy used to minimize the error resulting from the deflection tool. The best strategy to minimize bending may have the negative side, inducing more problems dynamical and tool wear.

4. Conclusions

The conducted bibliographic study revealed a series of concerns related to the milling complex surfaces:

- high speed machining technology has long been accepted for machining a wide range of materials manufactured by using high cutting speeds and feeds and secondly by reducing the number of operations related to execution of parts with complex surfaces, the for example, those of the molds.

- for high speed milling tools are available in a variety of materials for tools, including tungsten carbide, metal-ceramic and PCBN conventional ceramics. Capital cost, availability and performance varies significantly between these types of tools.
- in modeling process geometry for curved geometries and in the presence of cutter run out, it is necessary to consider the interaction of current tooth trajectory with that of preceding teeth trajectories
- tolerance integrity and surface quality of machine parts are of prime importance in milling processes as well as productivity. Static and dynamic deformations of machine tool, tool holder and cutting tool play an important role in tolerance integrity and stability in a machining process affecting part quality and productivity. Excessive static deflection may cause tolerance violations whereas chatter vibrations result in poor surface finish.

REFERENCES

Arrazola P. J., Garay A., Iriarte L. M., Armendia M., *Machinability of Titanium Alloys (Ti6Al4V and Ti555.3).* J. of Mat. Proc. Technology , **209** 5, (2009).

Armendia M., Garay A., Iriarte L. M., Arrazola P. J *Comparison of the Machinability's of Ti6Al4V and TIMETAL 54M using Uncoated WC–Co Tools*. J. of Mat. Proc. Technology **210**, 197–203, (2010).

Davim J. P., *Machining of Hard Materials,* Department of Mechanical Engineering University of Aveiro 33-38, ISBN 978-1-84996-449-4, 2011.

Desai K.A., Piyush K. Agarwal,. Rao P.V.M *Process Geometry Modeling with Cutter Runout for Milling of Curved Surfaces*. Int, J, of Machine Tools & Manuf, **49,** 1015–1028, (2009)

Dépince P, Hascoët J.Y., *Active Integration of Tool Deflection Effects in End Milling. Part 2. Compensation of Tool Deflection.* Int J Mach Tools Manuf **46**, 945–956. (2006)

Fallböhmer P., Rodríguez CA., Özel T., Altan T.*, High-Speed Machining of Cast Iron and Alloy Steels for Die and Mold Manufacturing*, J. Mater. Process. Technol. **98**, 104-115 (2000).

Fang F. Z., Lee L. C., Liu X. D., *Mean Flank Temperature Measurement in High Speed Dry Cutting of Magnesium Alloy*. J. of Mat. Process. Technol., **167** 1, 119–123, (2005).

Heinz A., Haszler A., Keidel C., Moldenhauer S., Benedictus R., Miller W. S., *Recent Development in Aluminum Alloys for Aerospace Applications* Mat. Science and Eng.: A 102–107. (2000).

Kaufman J. G., *Introduction to Aluminum Alloys and Tempers*. ASM International Technical Books Committee (1999-2000).

Kauppinen V., *High-Speed Milling - A New Manufacturing Technology,* 4th International DAAAM Conference, Tallinn, Estonia, 2004.

Kim G. M., Kim B. H., Chu C. N., *Estimation of Cutter Deflection and Form Error in Ball-End Milling Processes*. Int. J. of Machine Tools & Manuf. **43,** 917–924. (2003).

Kivanc E. B., Budak E., *Development of Analytical End-Mill Deflection and Dynamic Models*. ASME Int. Mechanical Eng. Congress & Exposition, Washington, D.C., 16-21, (2003).

Liu Z. Q., Wan Y., Ai X., *Recent Developments in Tool Materials for High Speed Machining*, Materials Science Forum, **471-472**, 438-442, (2004).

Lopez de Lacalle L. N., Lamikiz A., Sanchez J. A., Salgado M. A., *Tool Path Selection Based on the Minimum Deflection Cutting Forces in the Programming of Complex surfaces Milling* Int. J. of Machine Tools & Manuf. **47**, 388–400, (2007).

Lopez de Lacalle L. N., Lamikiz A., Sanchez J. A., Salgado M. A., *Effects of Tool Deflection in the High-Speed Milling of Inclined Surfaces*. Int J Adv Manuf Technol., **24**, 621–631, (2004).

Mills B.*, Recent Developments in Cutting Tool Materials,* J. of Mat. Process. Technol., **56,** 16-23, (1996).

Miller W. S., Zhuang L., Bottema J., Wittebrood A. J., Smet P., Haszler, *A Recent Development in Aluminum Alloys for the Automotive Industry*. Mat. Science and Eng. **A280**, 37-49, (2000).

Rahman M., Wang Z. G., Wong Y. S., *A Review on High Speed Machining of Titanium Alloys*. JSME Int. Journal Series C, **49**, *1*, (2006).

Ryu S. H., *An Analytical Expression for End Milling Forces and Tool Deflection using Fourier Series*. Int. J. Adv. Manuf. Technol., **59**, 37-46, (2012).

Smaoui M., Bouazis Z., Zgahl A., *Simulation of the Deflected Cutting Tool Trajectory in Complex Surface Milling*. Int J Adv Manuf Technol **56**:463–474, (2011).

Soo S.L., Dewes R. C., Aspinwall D.K., *3D FE Modelling of High-Speed Ball Nose End Milling.* Int. J. of Adv. Manuf. Technol., **50**, *9-12*, 871-882, (2010).

Toh C. K., *Cutter Path Orientations when High-Speed Fnish Milling Inclined Hardened Steel,* Int J Adv Manuf Technol., **27**, 473–480, (2006).

Trent E., Wright P. *Metal Cutting* – 4th ed. Butterworth–Heinemann, 2000.

Yang Y., Zhang W. H., Wan M., *Effect of Cutter Runout on Process Geometry and Forces in Peripheral Milling of Curved Surfaces with Variable Curvature*. Int. J. of Machine Tools & Manuf., **51,** 420–427, (2011).

STUDIU ASUPRA FREZĂRII SUPRAFEȚELOR COMPLEXE

II. Prelucrarea cu viteze mari și erorile de prelucrare

(Rezumat)

Suprafețele complexe se întâlnesc în industria de automobile, industria aerospatiala (în special atunci când se utilizează matrițe), robotică, etc. Suprafetele complexe sunt obținute în principal pe mașini cu comandă numerică care au 3-5 axe. Au fost dezvoltate diferite metodologii de frezare care au scopul de a îmbunătăți eficiența procesului complex de prelucrare. Această lucrare își propune să prezinte un studiu privind dezvoltarea recenta a directiilor de cercetare în domeniul frezării suprafețelor complexe. În a doua parte a acestui studiu se concentrează în principal pe două aspecte: prelucrare cu viteze mari de prelucrare și erorile de prelucrare.