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EXPERIMENTAL DETERMINATION OF MILLING MODEL FOR THIN-WALLED PARTS

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ABSTRACT: An article deals with the experimental determination of milling model for thin-walled parts. The determination of milling model is one of basic characteristics for calculating cutting forces and chip thickness. The calculation of milling model is analytically and numerically by finite element method. Experiment is performed with modal hammer. With modal hammer is determined dynamic elasticity for work-piece and tool. In the first section is summarized the basic knowledge of thin-walled parts. Inn experimental part is described Frequency Response Function and application of this technique. The last part of this work is to evaluate the experiment, which compared different techniques to determinate milling model during machining thin-walled parts.
KEYWORDS: thin walled parts, milling, milling model, frequency response function, rigidity

INTRODUCTION

The thin-walled parts are widely used in the aviation, aeronautics, automotive and energetic industry. Due to its shapes and low rigidity thin-walled parts easily deform during the milling process. The thin-walled structures are very easy to deform under the cutting force, which will influence to surface quality and accuracy. In finishing milling process, the thickness of the parts is reducing progressively, which makes it even more difficult to control the accuracy of machining. A lot of significant work was done in the predicting the deformation of thin-walled parts. Most researchers reflect that elastic deformation caused by the cutting force is the main factor of part deflection. The main topic of these scholars is to establish cutting forces, use finite element method for simulate the milling process or predict the deformation of the thin-walled parts.The thin-walled plates are that the thickness h is smaller than the minimal dimension of middle plane b, i.e. (1/80~1/100)b<<h<<(1/8~1/5)b [1]. Very flexible components are considered to have a wall thickness thinner than 5 mm and an axial depth of cut larger than 30 mm [2]. Budak and Altintas [2] view the tool and part as elastic figures and they investigated the error of peripheral milling process. The deformations in milling operations have been done several researches [3],[4]. Ratchev [4] investigate the compensation strategy specifically focused on force induced errors in milling. The finite element method for calculation of the deformation thin-walled parts and NC compensation method was done by Ning [5]. Liu [6] studied milling model especially rigid work-piece and flexible tool. Flexible work-piece a rigid tool of the milling process was done and describe by Seguy [7]. Dynamic milling model, flexible work-piece and flexible tool, was described in [8].In this paper, the milling model for thin-walled part is analyzed and set. Rigidity of tool and thin-walled part in bending is solved by analytically and numerically.

RIGIDITY OF TOOL AND THIN-WALED PART BENDING

Technological set rigidity is concerned with resistance to elastic deformations. Its influence in machining especially appears in the issue of accuracy in machining due to the occurrence of vibration [9]. According to various authors, rigidity in bending can be defined as follows: according to [10] the solid rigidity means it is resistant to elastic deformation. With respect to the theory of elasticity and rigidity, in the rigidity k we usually determine: solid rigidity k as a relation of Fy force and y deflection. Where y deflection is in the direction of Fy force action. The rigidity of parts and construction is evaluated via a k rigidity coefficient, which is defined as the ratio of the part load value and deformation. We can speak about specific rigidities like, rake rigidity, bending rigidity, torsion stiffness and joint rigidity. In machining we are chiefly interested in bending rigidity, which can be expressed as follows:

$$k = \frac{F_y}{y} \qquad (1)$$

where k [$N.m^{-1}$] is coefficient of bending rigidity, F [N] is loading force, y [m] is size of deflection.

RIGIDITY OF THIN-WALED PART IN BENDING

Technological set rigidity refers to resistance to elastic deformations and its influence on machining. It is especially found in the work of [9]: machining accuracy, vibration origin. In general, there is the principle that the increased rigidity of a tool and work-piece set prevents vibration from occurring in machining. The rigidity and mass of the tool and work-piece determine the vibration frequency. Thin-walled part rigidity cause changes in the cutting *process because of material takeoff in the form of a chip. To determine rigidity, it is necessary to locate the thin-walled part bending. The bending can be determined analytically or numerically via finite element method. However, the analytical determination of a thin-walled part deflection is quite demanding. Therefore, y deflection of the thin-walled par was determined by finite element method. The thin-walled part was exposed to the load of F solitary force. The wall deflection was measured at the point of the loading force. According to [1] the smallest deflection is in the point (position one) of the load force F (Figure 1) and the greatest deflection is in the point (position two) of the load force F (Figure 2). After the determination of static rigidity via finite element method, the part dimensions were as follows: height x width x thickness, 80x80x10 to 1 mm. The grey color depicts the wall restrain. The load force F acted on the point 75 mm, 40 mm (in the middle of the part) and in the other case, it acted on the point 75 mm, 100 (on the edge of a part).*

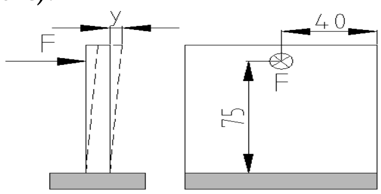

Figure 1. Load force activity in the middle of wall

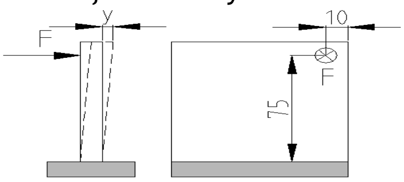

Figure 2. Load force activity on the edge of a wall

The simulation of plate bending was carried out in the environment of the Inventor Pro 2010 software. The load force F was 1 N. For material was chose EN AW 6082 aluminum alloy. The material density was 2.710.10^3 kg.m^{-3}. Its Young's modulus of elasticity was 68,9 GPA and its Poisson's ratio was 0,33. The simulations results for a plate with 1 mm thickness are shown in Figure 3 and 4. Subsequently, the rigidity was calculated as follows (1).

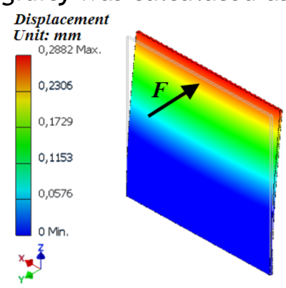

Figure 3. Plate bending by load force acting in the midle of a plate

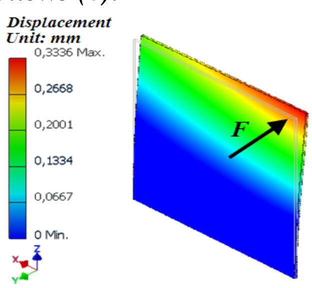

Figure 4. Plate bending by load force acting on the edge of a plate

The graph (Figure 5) shows that the thicker the wall, the greater the rigidity. Comparing the graphs (Figure 5 and 6), we can state there is a different rigidity value in the same wall thickness. This is the result of the F load force position.

If the tool has a higher rigidity than the part, then the chosen work-piece will be the vibrating element in the tool – work-piece set. Therefore, it is essential to investigate the tool rigidity so as to confirm that tool rigidity is greater than work-piece rigidity and it will as consequence not deform in experiments.

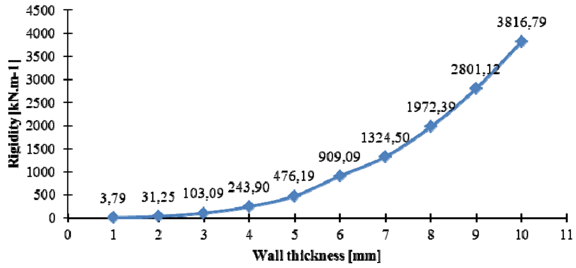

Figure 5. Dependence of wall static rigidity on wall thickness - force in the middle of the wall

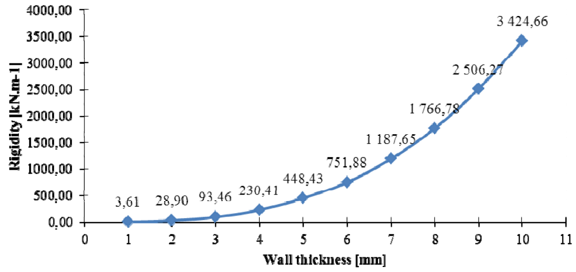

Figure 5. Dependence of wall static rigidity on wall thickness - force on the edge of the wall

RIGIDITY OF THE TOOL IN BENDING

Tool rigidity can be dealt with both analytically and numerically. In terms of an analytical calculation we need to be able to calculate tool deflection, which is defined by the relation (2), and the following: attaching of shank as a solid restrain, consistent section upon the whole length, joined load is replaced by a solitary force, force has its load point in the tool axis. Tool deflection calculates:

$$y = \frac{Fl^3}{aEJ} \qquad (2)$$

where y[mm] is tool deflection, a is coefficient, whose value depends on the conditions of support load (solitary force, joined load) and on the way of support position, for inclusion a = 3. F [N] is solitary load, l [m] is length of tool overhang, E is Young's modulus of elasticity, J [m^4] is quadratic moment for the circular section and is calculated as follows:

$$J = \frac{\pi D^4}{64} \qquad (3)$$

then the rigidity of toll can be expressed as follows:

$$k = \frac{F}{y} = 3\frac{EJ}{l^3} \qquad (4)$$

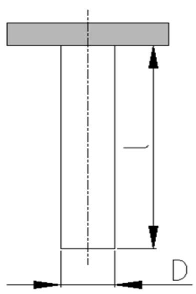

Figure 6. Diameter if D tool and tool overhang l

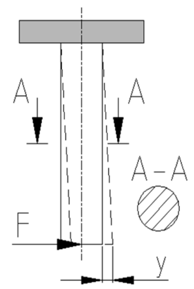

Figure 7. Tool bending y [mm] and load by solitary force F [N]

Tool bending y and tool load by a solitary force F is illustrated in (Figure 6). The grey colour depicts the *tool restrain. Tool diameter is D = 20 mm. Tool ovehang is l = 60 mm (Figure 6 and 7) and force is F = 1 N. The tool bending is calculated according to relation (2) and tool rigidity in bending is analytically calculated according to relation (4).*

The simulation result of the tool bending developed in the Inventor Pro 2010 program is shown in Figure 8. Tool rigidity is obtained analytically and numerically in Table 1.

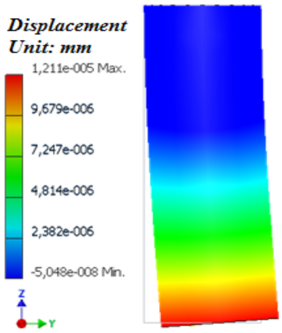

Figure 8. Tool bending in Invertor Pro 2010

Table 1. Tool rigidity

	Analytically	Numerically
Rigidity	65449.84 kN/m	82576.38 kN/m

The work-piece rigidity of 10 mm thickness part's is 3816.79 kN/m and for 1 mm thickness is rigidity 3.79 kN/m. The tool rigidity is numerically 82576.38 kN/m. With respect to the comparison of tool and work-piece rigidity, we can see than tool rigidity is twice as great as work-piece rigidity. Therefore, we can state that the tool has a higher resistance to elastic deformation.

EXPERIMENTAL DETERMINATION OF MILLING MODEL USING FRF

The assessment of stability for machine tool, tool and work-piece is possible use vibration test. Modal hammer is one of possibilities how to get vibration to the system. With modal hammer is obtaining Frequency Response Function (FRF). With this parameter we set natural frequency, damping ratio, stability diagram, milling model etc. For measurement of FRF is needed to determine place on work-piece and tool. In this place is a piezoelectric sensor. Hit with modal hammer have to be against piezoelectric sensor. The scheme of work-piece with piezoelectric sensor and modal hammer is pictured in Figure 9. The grey colour depicts the workpiece restrain.

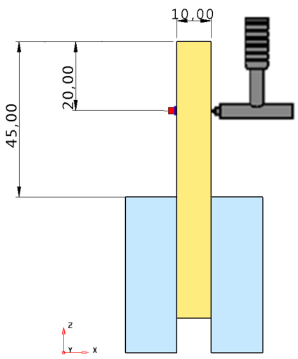

Figure 9. Scheme of FRF measurment of work-piece

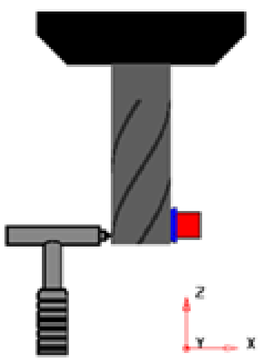

Figure 10. Scheme of FRF measurment of tool

Same measurement of FRF was use on the tool with diameter 20 mm and tool owerhang from tool holder 50 mm (Figure 10). Measurement was carried out in two directions X and Y of work-peiece and tool.

FRF MEASUREMENT CHARACTERICTICS

During milling process about stability of machining decides the spindle. However, in case of milling thin wall structures decides about stability of machining the work-piece. This fact is possible to identify the excitation of thin walled-structured by FRF characteristic (Figure 11). Those characteristics are depended on driver frequency and location of measurement. Vertical axis indicates dynamic elasticity of system (m/N). Horizontal axis is frequency (Hz). A visual inspection of the FRF shows different natural frequencies for tool and work-piece. For us is important first shape of natural frequency which determines the stability of milling process.

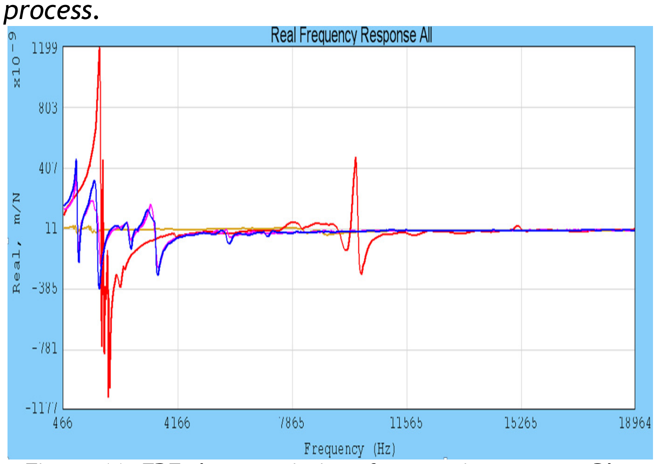

Figure 11. FRF characteristics of measuring system. Blue and purple line is corresponds to tool. Red line is work-piece in the X direction (10 mm thickness). Brown line is work-piece in the Y direction (80 mm length).

FRF characteristics of clamped tool in the spindle are shown blue and purple color. Both lines are almost identical, because the tool is geometrically symmetric component. Positive dynamic elasticity of tool is 433.10^{-9} m/N. FRF characteristics for clamped work-piece is very clear. Dynamic elasticity of thin walled part in Y direction is lower than tool. It means good rigidity in Y direction (80 mm length). Dynamic elasticity in X direction is huge (1199.10^{-9} m/N) as you can see on figure eleven. Rigidity in X direction of thin walled part is poor. The same conclusion was done with analytical and numerical methods. According to these claims is easy determine milling model. Milling model for thin walled parts is considered as single-degree-of-freedom spring-damper vibration system in one direction X.

SINGLE-DEGREE-OF-FREEDOM MILLING MODEL

An elastic work-piece and rigid tool represent a dynamic model of thin-walled part milling. The tool has a large diameter and good rigidity. The tool does not deform during the milling process or the deformation is very small and negligible in comparison to the work-piece.

In this model, the work-piece vibrates and this vibration results in waved machined surface. In this model of thin-walled part milling with single-degree-of-freedom is shown in Figure 12.

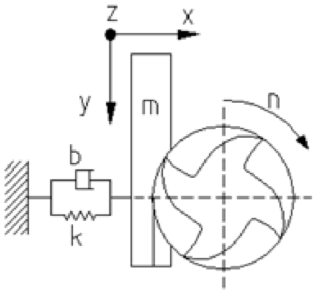

Figure 12. Single-degree-of freedom milling model

The structure is assumed to be flexible in the x direction, while the feed is parallel to the y direction. The dynamic model is defined by the following equation:

$$m\ddot{x}(t)+b\dot{x}(t)+kx(t)=Fx(t) \qquad (5)$$

where: x [mm] is deflection in x-axis, b is the damping, k is the stiffness, and Fx(t) [N] is the cutting force in the x direction. According to linear cutting law, the x component of the force is given by:

$$Fx(t)+ap\sum_{j=1}^{z}[(Kr\cos\varphi j - Kt\sin\varphi j)\, hj(t)] \qquad (6)$$

whereap[mm] is axial depth of cut, φj [°] is the angular position of the cutting edge, Kt and Kr [-] are thespecific tangential and radial cutting coefficient, and hj(t) [mm] is chip thickness.

CONCLUSIONS

The experimental determination of milling model for thin-walled parts is proposed. Milling model is given by numerical and finite element methods. For thin walled-part is characteristic different rigidity during milling process. Different deflection on work-piece is proposed and we can state there is a different rigidity value in the same wall thickness. With respect to the comparison of tool and work-piece rigidity, we can see than tool rigidity is twice as great as work-piece rigidity. Therefore, we can state that the tool has a higher resistance to elastic deformation. In x direction the work-piece rigidity is poor. Work-piece vibrates and this vibration results in waved machined surface. Thin-walled parts determine the stability of milling. Milling model for thin-walled parts is important to identify and calculate the cutting force or chip thickness.

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