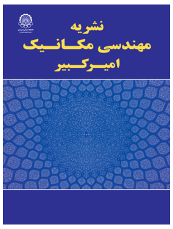

Amirkabir Journal of Mechanical Engineering

Amirkabir J. Mech. Eng., 53(Special Issue 4) (2021) 633-636
DOI: 10.22060/mej.2020.18159.6753

Mechanistic modeling of cutting forces in milling process by end milling with cutting edges with adjustment angle of 45 degree

G. R. Juzdani, S. E. Mirmohammadsadeghi*

Department of Mechanical Engineering, Khomeinishahr Branch, Islamic Azad University, Khomeinishahr, Iran

ABSTRACT: Determination of machining forces in order to calculate the required power and torque for cutting and select the right tools, equipment, and cutting parameters (feed rate, cutting depth, cutting speed) for machining the desired geometry and material prior to the process is significant. The analysis of machining forces is necessary to determine the forces to reduce the cost of performing multiple empirical experiments. In this study, the components of F_x, F_y, and F_z milling forces with two cutting edges with main adjustment angle $\kappa = 45^\circ$ were predicted by the mechanistic modeling method by calculating cutting and edge force coefficients. Also, for the first time, the cutting section of the workpiece was designed in order to eliminate the calculating error of the round corner of inserts. To avoid the interaction of the parameters, simultaneous change of cutting speed with feed rate was avoided and 8 experiments with different feed rates but with the same cutting speed were performed. A comparison of the modeled forces curve with the results obtained from the dynamometer shows acceptable agreement. As the feed rate increases, the difference between the predictive and experimental force decreases relative to the increase of force

Review History:

Received: Mar. 27, 2020
Revised: Jul. 10, 2020
Accepted: Nov. 14, 2020
Available Online: Nov. 25, 202

Keywords:

Machining forces
Cutting parameters
Milling
Mechanistic modeling
Cutting and edge force coefficients

1- Introduction

Predicting machining forces to determine the required power, torque and selecting the appropriate tools, equipment and cutting parameters (including feed rate, cutting depth and cutting speed) to achieve better chip removal conditions is of particular importance. Since one of the features of the milling process geometry is that the cross-sectional area of the chip is not fixed and is changed with the rotation period of the milling tool, so there is a need for a model that can be used to predict forces at any time. Various cutting models are commonly used for this purpose. One of the methods for calculating cutting forces is finite element analysis with related software [1]. Using the finite element method to analyze the machining process is very time-consuming and costly. There are other analytical methods for calculating cutting forces in the machining process, in which the exact calculation depends on the exact calculation of friction in the cutting process. Due to the complexity and non-linearity of friction, in the machining process and the formation of cutting edges with different wear rates [2], and geometric errors, elastic deformation of tools and workpieces or the phenomenon of chip thickness accumulation that occurs in each tool rotation period due to heating and elastic recovery of chips from previous tool cycles [3]. The results of calculations in these methods are not accurate. The cutting model that is mostly used for this case is mechanistic modeling in which the cutting force is considered proportional with undeformed chip area and the edge force which is extracted from the plowing force and friction force on the cutting edge is considered proportional with the length of the engaged cutting edge [4]. In the intended model, the proportion constants are cutting and edge force coefficients that depend on the geometry of the tool, the cutting conditions, and the characteristics of the workpiece.

In this research, using mechanistic modeling equations, while calculating cutting and edge force coefficients, by modeling the workpiece and end milling tool with cutting edges of 45-degree adjustment angle, cutting forces at a constant cutting depth was predicted and compared with experimental forces, by changing the amount of feed rate for each cutting edge. In this study, for the first time, by removing the effect of the tool tip radius on the tool engagement, a computational error due to the roundness of the tool tip was eliminated and more accurate results were obtained in predicted cutting forces by mechanistic modeling.

2- Methodology

The FP4M milling machine, HF45 TC16D10-31W20L100Z02 tool holder and Kistler 9265B dynamometer and St37 steel workpiece with initial dimensions of 170 × 70 × 15 mm were used for the experiments.

According to Fig. 1, as shown by the tool engagement view with the workpiece, due to the lower tool tips than the prepared section of the workpiece, during the cutting process, the error due to friction changes in the roundness of the tool tips was eliminated in the performed experiments. As a result, the accuracy of the calculations was improved.

*Corresponding author's email: e.mirohammadsadeghi@iaukhsh.ac.ir

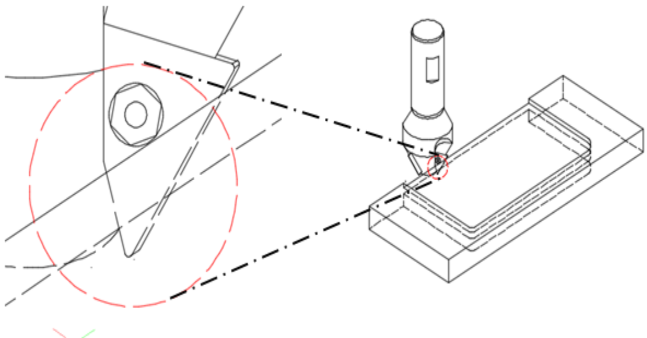

Fig. 1. 3D view of tool engagement with the workpiece

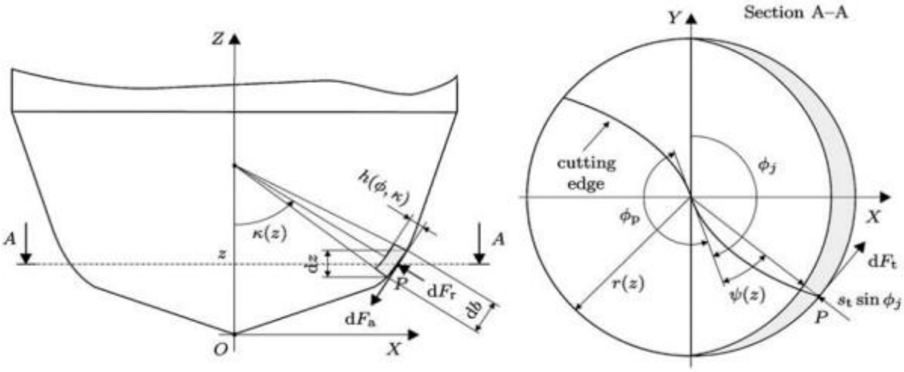

Fig. 2. Chip cross-section, adjustment angle and differential cutting forces at point *P*[7]

Generalized model of external end mill geometry proposed by Engine, Altintas and Gradišek [5-7].

In Fig. 2, the cross-sectional area of the instantaneous undeformed chip is calculated by multiplying the thickness of the undeformed chip ($h(\phi,\kappa)$), which is a function of instantaneous angles of tool engagement and cutting edge adjustment (κ) across the instantaneous chip width $\left(db = dz/_{\sin\kappa}\right)$. The instantaneous tangential (dF_t), radial (dF_r), and axial (dF_a) forces acting on the tool are also defined as mechanistic modeling equations [6]:

$$\begin{cases} dF_t = K_{tc}\cdot h(\phi,\kappa)\cdot db + K_{te}\cdot ds \\ dF_r = K_{rc}\cdot h(\phi,\kappa)\cdot db + K_{re}\cdot ds \\ dF_a = K_{ac}\cdot h(\phi,\kappa)\cdot db + K_{ae}\cdot ds \end{cases} \tag{1}$$

In Eq. (1), the parameters K_{tc}, K_{rc} and K_{ac}, are respectively tangential, radial, and axial cutting force coefficients. K_{te}, K_{re} and K_{ae} are respectively tangential, radial, and axial edge force coefficients. Also ds is the differential cutting edge engagement length of the tool with the workpiece. By considering $\left(h(\phi,\kappa) = ft\cdot\sin\phi_j \sin\kappa\right)$ at each moment, Eq. (2) are obtained [7].

$$\begin{cases} dF_{t,j}\left(\varphi_j\cdot z\right) = K_{tc}\cdot ft\cdot\sin\phi_j\sin\kappa\cdot db(z) + K_{te}\cdot ds(z) \\ dF_{r,j}\left(\varphi_j\cdot z\right) = K_{rc}\cdot ft\cdot\sin\phi_j\sin\kappa\cdot db(z) + K_{re}\cdot ds(z) \\ dF_{a,j}\left(\varphi_j\cdot z\right) = K_{ac}\cdot ft\cdot\sin\phi_j\sin\kappa\cdot db(z) + K_{ae}\cdot ds(z) \end{cases} \tag{2}$$

Eq. (2) shows that the instantaneous machining force in each direction is divided into two cutting and edge forces. the cutting force depends on the amount of feed rate (f_t) and the edge force is function of the tool cutting edge engagement length with the workpiece. By multiplying conversion matrix, differential forces on x, y and z directions are obtained [7]:

$$\begin{bmatrix} dF_{x,j}\left(\phi_j\cdot z\right) \\ dF_{y,j}\left(\varphi_j\cdot z\right) \\ dF_{z,j}\left(\varphi_j\cdot z\right) \end{bmatrix} = \begin{bmatrix} -\cos\phi_j & -\sin\kappa\sin\phi_j & -\cos\kappa\sin\phi_j \\ \sin\phi_j & -\sin\kappa\cos\phi_j & -\cos\kappa\cos\phi_j \\ 0 & \cos\kappa & -\sin\kappa \end{bmatrix} \begin{bmatrix} dF_{t,j}\left(\phi_j\cdot z\right) \\ dF_{r,j}\left(\varphi_j\cdot z\right) \\ dF_{a,j}\left(\varphi_j\cdot z\right) \end{bmatrix} \tag{3}$$

By programming, predicting model was executed.

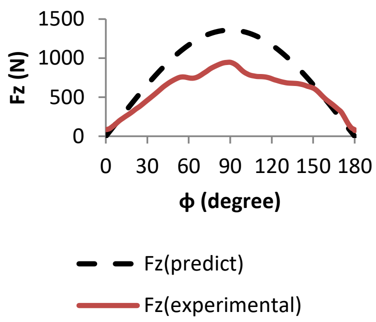

Fig. 3. Comparison of the results obtained from the dynamometer and predicting model for F_z

3- Results and Discussion

Fig. 3 shows an example of a comparison of experimental and predictive force F_z during a tool rotation half-cycle (for a cutting edge) with a feed rate of 0.025 mm/rev for one cutting edge.

By increasing feed rate, cutting speed increases, thus chip compression reduces. This factor makes the thickness of the cutting layer as well as the cutting force not increase unusually [8]. Accumulation of burrs in each rotation of the tool increases the cross-sectional area of chip during cutting, which cannot be eliminated or calculated. As the curve approaches the middle of the interval (0° to 180°), the difference between the predicting model curve and the experimental curve increases due to the greater accumulation of burrs. Since the most unintended accumulation of burrs which are adhered to the edge of the workpiece occurs in front of the tool in feed motion direction. For this reason, the largest predicting model error occurs approximately at the maximum value of the force curve.

4- Conclusions

In this research, by using mechanistic modeling, milling forces were predicted for an end-mill tool with a cutting edge of adjustment angle $\kappa = 45$. The results describe that by mechanistic modeling analysis, milling forces can be predicted proportional to feed rate with less amount of error percentage. Furthermore, at higher feed rates the percentage of milling forces increase was not completely according to the percentage of feed rate increase. This is due to the reduction of friction force share in total milling force. On the other hand, with increasing feed rate, the cutting speed increases and as a result, chip compression decreases. This factor makes the thickness of the cutting layer as well as the cutting force not increase unusually. Accumulation of burrs in each rotation of the tool sometimes increases the cross-sectional area of the chip. This event cannot be eliminated or calculated. These burrs during the cutting operation cause an instantaneous and casual (unpredictable) increase in the cross-sectional area of the chip in a moment, that in the next moment the adhering chip may be separated. So, this unintended chip cross-section increasing phenomenon will cause instantaneous variations in experimental forces. The largest difference between the values of the experimental and predicting force in the middle of the half-cycle is close to the maximum force. This is due to the greater accumulation of chips adhered to the edge of the workpiece in front of the tool due to the pressure of the tool in the direction of feed motion.

References

[1] M. Aydın, U. Köklü, Analysis of flat-end milling forces considering chip formation process in high-speed cutting of Ti6Al4V titanium alloy, Simulation Modelling Practice and Theory, 100 (2020) 102039.

[2] L. Zhou, B. Deng, F. Peng, M. Yang, R. Yan, Semi-analytic modelling of cutting forces in micro ball-end milling of NAK80 steel with wear-varying cutting edge and associated nonlinear process characteristics, International Journal of Mechanical Sciences, 169 (2020) 105343.

[3] S. Wojciechowski, M. Matuszak, B. Powałka, M. Madajewski, R.W. Maruda, G.M. Królczyk, Prediction of cutting forces during micro end milling considering chip thickness accumulation, International Journal of Machine Tools and Manufacture, 147 (2019) 103466.

[4] F. Koenigsberger, A.J.P. Sabberwal, An investigation into the cutting force pulsations during milling operations, International Journal of Machine Tool Design and Research, 1(1) (1961) 15-33.

[5] S. Engin, Y. Altintas, Mechanics and dynamics of general milling cutters.: Part I: helical end mills, International Journal of Machine Tools and Manufacture, 41(15) (2001) 2195-2212.

[6] S. Engin, Y. Altintas, Mechanics and dynamics of general milling cutters.: Part II: inserted cutters, International Journal of Machine Tools and Manufacture, 41(15) (2001) 2213-2231.

[7] J. Gradišek, M. Kalveram, K. Weinert, Mechanistic identification of specific force coefficients for a general end mill, International Journal of Machine Tools and Manufacture, 44(4) (2004) 401-414.

[8] G. Yucesan, Q. Xie, A.E. Bayoumi, Determination of process parameters through a mechanistic force model of milling operations, International Journal of Machine Tools and Manufacture, 33(4) (1993) 627-641.

HOW TO CITE THIS ARTICLE

G. R. Juzdani, S. E. Mirmohammadsadeghi, Mechanistic modeling of cutting forces in milling process by end milling with cutting edges with adjustment angle of 45 degree, AUT J. Mech. Eng., 53(Special Issue 4) (2021) 633-636.

DOI: 10.22060/mej.2020.18159.6753