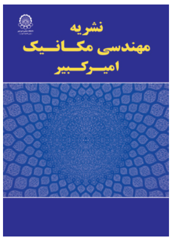

Amirkabir Journal of Mechanical Engineering

Amirkabir J. Mech. Eng., 50(3) (2018) 217-219
DOI: 10.22060/mej.2017.12303.5308

An Experimental Comparison of Dimensional and Geometrical Tolerances in Milled Holes on AISI D2 Steel

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ABSTRACT: In order to make accurate holes with traditional hole-making methods, it is necessary to use secondary operations such as reaming. Furthermore, by using this method, the tolerance of the hole has a limited range, therefore, it is not useful for shaft based systems. But it is feasible to make a hole with the desired accuracy by using new hole-making methods such as helical and profile milling only by one operation. This study investigated the nominal size, roundness and cylindricity tolerances of helical and profile milled holes in AISI D2 hardened steel. The full factorial design of experiments was used In order to study the effects of the cutting parameters on the dimensional and geometrical tolerances of the holes. The results demonstrated that the range of the dimensional tolerance of the helical milled holes was between 0.001 mm and 0.034 mm which is tighter than the profile milled holes. However, due to the fewer interpolation errors in the profile milling strategy, the geometrical tolerances of the profile milled holes were tighter. The best cylindricity tolerance was obtained by profile milling strategy with the 110 m/min of cutting speed, 0.03 mm/tooth of feed rate and 0.3 mm of depth of cut.

Review History:

Received: 30 December 2016
Revised: 30 April 2017
Accepted: 2 July 2017
Available Online: 18 July 2017

Keywords:

Hole-making strategies
Helical milling
Profile milling
Dimensional and geometrical tolerances
AISI D2 hardened steel

1- Introduction

The robust performance of a complex assembly part will be obtained by considering accurate dimensional and geometrical tolerances [1]. Hole-making is one of the most used manufacturing processes and is usually carried out as one of the last steps of the production. By introducing numerical control machines, helical and profile milling were studied as new hole-making processes. Making holes with different diameters, lower cutting force and high quality of the holes are the most advantages of these processes [2-4].
In this study, the effects of cutting parameters (cutting speed, feed rate and depth of the cut) on the nominal dimension, roundness and cylindricity tolerances of the holes are investigated using helical and profile milling.

2- Kinematics of the Processes

Fig.1 (a) shows the tool path in helical and profile milling. The tool has three simultaneous movements in helical milling; tool rotation on its axis, rotation around the helical path and axial speed.
In profile milling, the cutting tool movement through the depth of the hole is not continuous. The main difference between these two methods is that in profile milling, the interpolation of the tool orientation is in X and Y directions but in helical milling, the interpolation is in three directions of X, Y and Z simultaneously.

3- Materials and Method

AISI D2 hardened steel plate with the thickness of 10 mm and hardness of 55 HRC was selected. Table 1 shows the milling parameters and their levels. TiAlN coated end mills with the diameter of 6 mm was used. A setup of experiments is shown in Fig.1 (b). The tolerances were measured using LH87 coordinate measuring machine. 36 holes were made in total and measured at three sections; 2, 5 and 8 mm from the surface (Fig. 2).

Table 1. Milling parameters and their levels

Parameters	Levels		
	1	2	3
Cutting speed (Vc) m/min	30	70	110
Feed rate (fz) mm/tooth	0.03	0.05	0.07
Depth of cut (ap) mm	0.15	0.3	-

4- Results and Discussion

4- 1- Nominal size

Fig.3 represents the effects of cutting parameters on the nominal diameter deviation of the milled holes. As can be observed, by increasing the cutting speed the dimensional error decreases to 62% and 52% in helical and profile milling, respectively. At higher cutting speeds, the temperature of the cutting zone increases and leads to lower cutting forces and lower deflection of the tool.
Also, according to Fig.3 (b), the dimensional error increases with the increase of feed rate. This increase is 97% and 66% in helical and profile milling, respectively. Also, the dimensional error increases at the higher depth of cuts due to the higher cutting forces and tool deflection (Fig.3 (c)).
The results show that the range of the dimensional tolerance of the helical milled holes is between 0.001 mm and 0.034 mm which is tighter than the profile milled holes.

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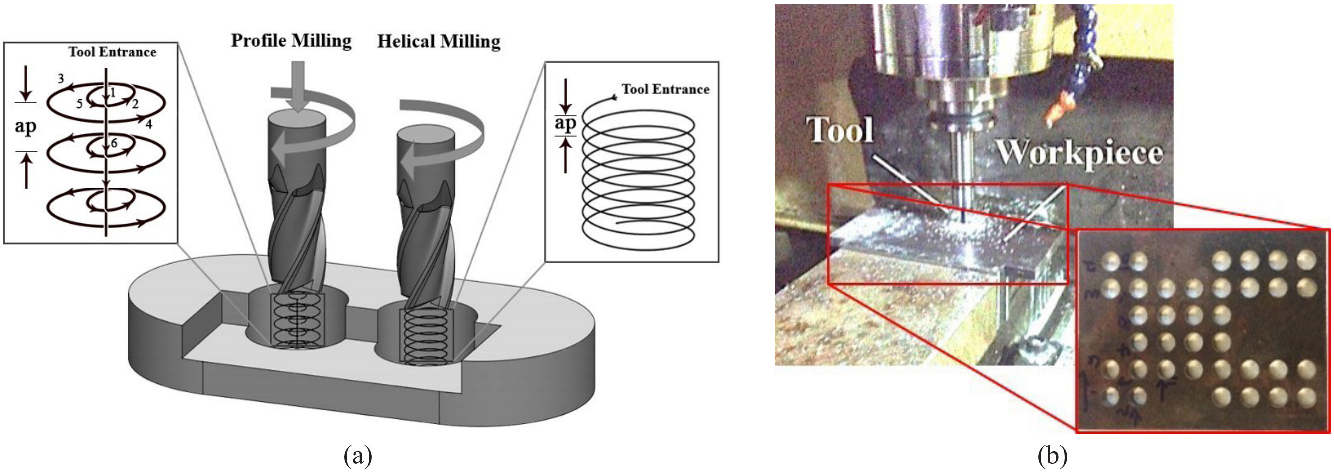

Fig. 1. (a) 3D description of tooling path in helical and profile milling methods, (b) Experimental setup and top view of the test workpiece

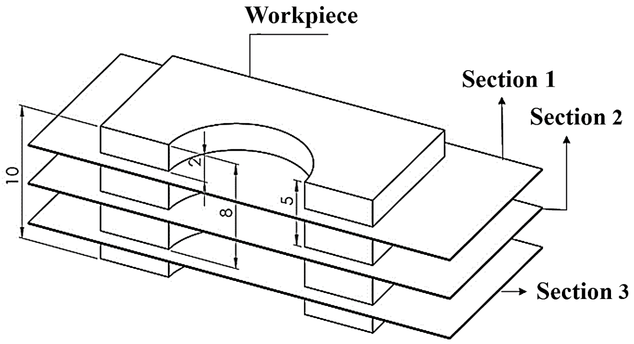

Fig. 2. Sections of the workpiece where the geometrical and dimensional tolerances were measured

4- 2- Roundness tolerance

Increasing the cutting speed leads to the decrease in roundness error around 39% and 44% in helical and profile milling, respectively. Although the roundness error decreases by increasing the depth of cut and it increases by increasing the feed rate.

The results show that the roundness tolerance in the profile milled holes is tighter than that of helical milled ones. The best and worst roundness in profile milling were 0.010 mm and 0.032 mm, respectively.

4- 3- Cylindricity tolerance

Increasing the cutting speed causes 36% decrease in cylindricity error in both strategies. Also, by increasing the feed rate, the cylindricity error increases by 62% and 68% in helical and profile milling, respectively and it decreases at the higher depth of cuts.

The best cylindricity tolerance was obtained by profile milling strategy at the cutting speed of 110 m/min, the feed rate of 0.03 mm/tooth and 0.3 mm of the depth of cut.

5- Conclusions

The holes made by helical milling had accurate dimensions while geometrical dimensions were better in profile milling. Dimensional and geometrical errors decreased by increasing the cutting speed while they increased at higher feed rates. Increasing the depth of cut cause an increase in dimensional error and decrease in geometrical error.

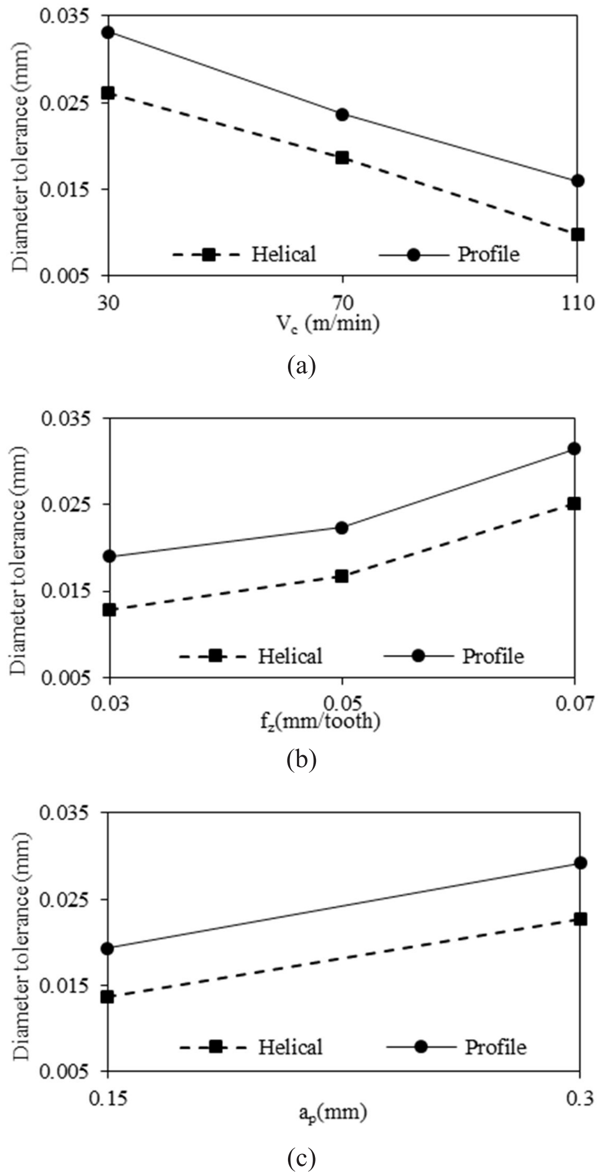

Fig. 3. Effect of (a) cutting speed, (b) feed rate, (c) depth of cut on the nominal diameter deviation of the helical and profile milled holes

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Please cite this article using:

H. Imani, J. Hashemi Khosrowshahi, M. H. Sadeghi, A. Rasti, An Experimental Comparison of Dimensional and Geometrical Tolerances in Milled Holes on AISI D2 Steel, *Amirkabir J. Mech. Eng.*, 50(3) (2018) 671-681.

DOI: 10.22060/mej.2017.12303.5308