A study of accuracy of finished test piece on multi-tasking machine tool

M. Saito[1], Y. Ihara[1], K. Shimojima[2]
[1]*Osaka Institute of Technology, Japan*
[2]*Okinawa National College of Technology, Japan*
yukitoshi.ihara@oit.ac.jp

Abstract

Recently, machine tools with both lathe function and milling function have been developed to meet the requirements of the end users. Sometimes such kinds of machine are named as five-axis machining center or multi-tasking machine tool even if there have similar processing functions. The multi-tasking machine tool does not currently have a specific accuracy test standard; however, it is possible to apply the accuracy test standard of both the turning center and the machining center considering the ability of the machine. In this study, the accuracy of finished test piece, which is one of the accuracy tests, is dealt with. That is, the difference between test conditions and observations of the accuracy tests provided in ISO13041-6 M3, ISO10791-7 M1, and M4 are compared. And then, the finished test piece accuracy is actually inspected in a real machine, and which test method is more suitable, or the problems of test procedure are examined from those results.

1 Introduction

Recently, the reduction of machining time and cost is demanded on the site of production. A machine tool that has both the functions of turning and milling has been developed according to the demand of the users, because the complex machining is done by one machine tool although it was done by plural machine tools. The machine tool that has milling function with swiveling the milling spindle based on the lathe is provided as a multi-tasking machine tool [1].

The standard of accuracy test for the multi-tasking machine tool does not exist because the definition of the multi-tasking machine tool is not exact. To evaluate a machining ability, a certain test should be executed. If the ability of multi-tasking machine tool is considered, both of the standards, for the turning center and for the machining center, can be applied. However, because these standards are only for the turning center or for the machining center, it is not known if they can be applied, or if they are suitable for the multi-tasking machine tools.

In this report, a small size multi-task machine tool was tested based on the accuracy of finished test pieces on ISO standards (ISO13041-6 M3 [2], ISO10791-7 M1 and M4 [3]), and then the feasibility or suitableness of these tests for the multi-axis machine tools are discussed.

2 Accuracy of finishted test pieces for machining centers

Accuracy of finished test pieces for machining centers is prescribed in ISO10791-7:2014. In the standard, cyrindricity, straightness, squareness, flatness or angularity are measured on finished test pieces in various conditions. The new standard, ISO10791-7:2014, that is revised from ISO10791-7:1998 for adapting five-axis machining centers, there are four tests named as M1~M4 as listed below.

- M1 is a positioning and contouring test piece. It checks the performance of the machine under different kinematic conditions, i.e., only one axis feed, linear interpolation of two axes and circular interpolation by machining five bored holes and a series of finishing passes on different profiles.
- M2 is a face milling test piece. It checks the flatness of a surface machined by a finish face milling operation performed by bidirectional two cuts.
- M3 is a cone frustum test piece. It checks the cutting performance of five-axis machining centers under the five-axis simultaneous feed motion by machining the cone-shaped test piece with flank milling.
- M4 is a three-step square test piece. It checks the accuracy of angular positioning and of the position of rotary axis average lines.

In this report, M1 and M4 test piece are considered.

2.1 ISO10791-7 M1

Three sizes of M1 test piece are prepared, as size 80, 160, 320. Figure 1 shows the diagram of size 80. Machining features by end milling are listed below in details:

1. Faces B, F, G, H are machined by one linear axis feed.
2. Cylinder P is machined by the circular interpolation.
3. The diamond (K-L-M-N) on the upper face of the square shall only be machined when two linear axes are used (e.g., X and Y).
4. Sloping faces (I and J), with an angle of 3° and a depth of 6 mm on the top of the external square sides, should only be machined when two linear axes are used (e.g., X and Y).
5. The center hole C.

6. The bored holes (E) shall be approached in the positive direction of the positioning axes, the counterbored holes (D) shall be approached in the negative direction.

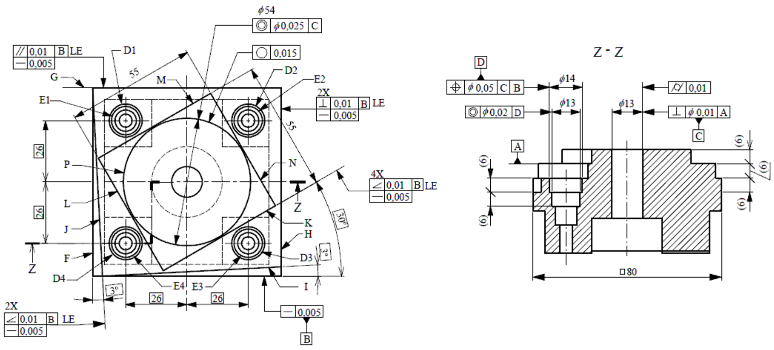

Figure 1: ISO10791-7-M1_80

The same tool can be used to machine all the contouring test surfaces; an end mill with a cutting edge 35 mm long and 30 mm in diameter is recommended. A boring tool may be used for holes. Cutting speed should be about 50 m/min for cast iron and 300 m/min for aluminium. Feed rate should be about 0.05 mm/tooth to 0.1 mm/tooth.

2.2 ISO10791-7 M4

Three sizes of M4 test piece are also prepared, as size 80, 160, 320. Figure 2 shows the diagram of size 80. The processing sequence is different according to the machine type or moving range of the machine tool tested. Machining features by end milling are listed below in details:

- Top square shall be machined by end milling using two linear motions.
- Middle square shall be machined by end milling using one linear and one rotary axis with the following machining sequence.
  - First plane is machined by X- or Y-axis feed, and then remaining planes are machine by the same linear axis feed after C-axis is rotated by every 90°.
  - This feature is not applicable for machines with two rotary axes in the spindle head.

In the case of machining the bottom square and radial holes, there are two kinds of sequence in accordance with the moving range of the swivelling axis or tilting head. If the swivelling axis or tilting head does not move along ±90°, the test sequence shall be the case of (1), on the other hand, the swivelling axis or the tilting head moves along ±90°, the sequence shall be the case of (2).

- Bottom square (1) shall be machined by face milling using one linear and two rotary axes with the following machining sequence.
  - Move the swiveling axis or the tilting head to 90° first. The first plane is machined by X- or Y-axis feed, and then remaining planes are

machined by the same linear axis feed after C-axis is rotated by every 90°.

- Radial holes (1): Move the swiveling axis or the tilting head to 90° first. Bore the hole on the first face, and then bore the remaining face in the same manner as the bottom square.
- Bottom square (2) shall be machined by face milling using one linear and two rotary axes with the following machining sequence.
  - Move the swiveling axis or the tilting head to 90° first. The first plane is machined by X- or Y-axis feed, and then the second plane is machined by the same linear axis feed after 180° rotation of C-axis. Then move the swiveling axis or the tilting head to -90°, the third plane is machined, rotate C-axis 180° and the fourth plane is machined.
- Radial holes (2): Move the swiveling axis or the tilting head to 90° first. Bore the hole on the first face, and bore the hole on the second face after 180° rotation of C-axis. Then move the swiveling axis or the tilting head to -90°, bore the hole on the third plane, rotate C-axis 180° and bore the hole on the fourth plane.

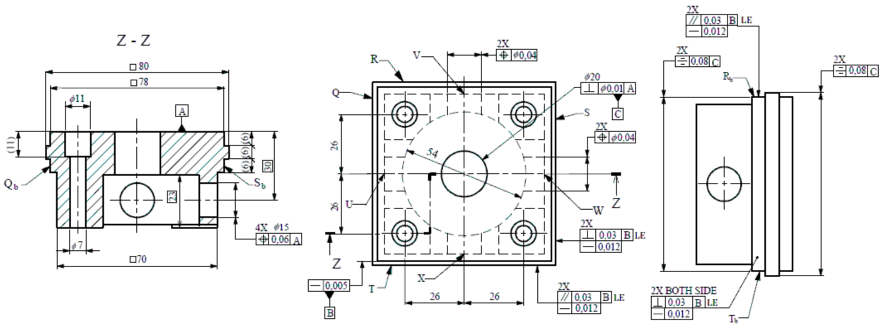

Figure 2: ISO10791-7-M4_80

When the machining center that has rotary axes is tested, it is prescribed that M1 test and M4 test can be executed on one test piece, as shown in Fig. 3. In that case, it is also prescribed that top square shall be machined using one linear motion, not using two linear motions, in order to machine the datum surface of B on M1 test.

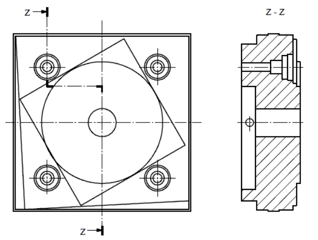

Figure 3: ISO10791-7-M1&M4

3 Accuracy of finishted test pieces for turning centers

Accuracy test of finished test piece of NC lathe and turning centers are prescribed in ISO13041-6:2009. In the standard, four kinds of tests named as M1 to M4 are prescribed.

- M1 is a test piece of turning a cylinder. It checks the roundness and difference of diameters from the three cylinders turned in the same size.
- M2 is a test piece of flatness. It checks the flatness of surfaces perpendicular to the spindle axis.
- M3 is a test piece of positioning and contouring performance. It checks the performance of the machine under different kinematic conditions.
- M4 is a test piece of roundness. It checks the circular deviation of a 100° arc on a test piece.

In this report, M3 test piece is considered. Three sizes of M3 test pieces are prepared, as size 80, 160, 320. Figure 4 shows the diagram of size 80.

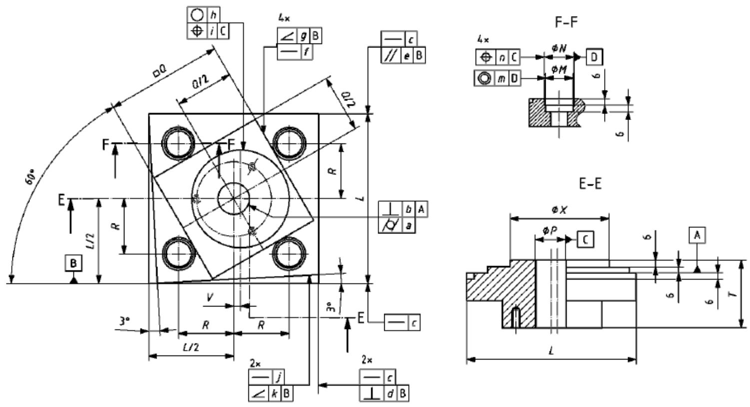

Figure 4: ISO13041-6-M3

Because this standard was made referring to the accuracy test of the machining center, the shape of the workpiece is almost the same as that of the machining center. It is prescribed that all the features of this test piece are finished by using the interpolation motion of C- and X-axis or X- and Y-axis. In the case of the turning center without Y-axis feed, it will be machined by the interpolation motion of C- and X-axis. The circle in the upper part of the test piece is thought to be eccentric, machined by the interpolation motion of C- and X-axis.

Unlike the accuracy test of the machining center, neither the tool, the material nor the cutting condition used are defined in this standard.

4 The multi-tasking machine tool

Figure 5 shows the multi-tasking machine tools used in this report. The specifications of feed axes and spindles are listed in Table 1. The machine has three linear axes (X, Y, Z). There are two rotary axes, one is the rotary axis (B) for tilting the milling spindle around Y-axis, and the other is the C-axis of the workholding spindle rotating around Z-axis.

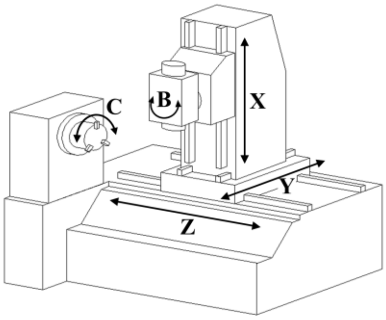

Figure 5: The multi-tasking machine tool used in this report

Table 1: Specifications of axes and spindles

		Specificatios
Axis	X-axis	380mm
	Y-axis	±105mm
	Z-axis	460mm
	B-axis	±120°
	C-axis	360°
Spindle	Spindle speed	12000 rpm
	Form of tool shank	Capto C5

If the machine is thought to be a 5-axis machining center that has one rotary axis on the workpiece side and one rotary axis on the tool side provided for ISO10791-6 Annex C, the accuracy test of the machining center can be applied to this machine. On the other hand, if the machine is thought to be a turning center with milling spindle provided for ISO13041-1, considering the milling spindle as a turret, the accuracy test of the turning center can be applied to this machine.

5 Problems when the standard test is applied

5.1 Problem of the workholding

The test piece for the machining center is not assumed to be held with the chuck. The jig to hold it with the chuck is necessary to hold the test piece in the multi-tasking machine tool. Because radial holes of M4 test of the machining center are located in the vicinity of the bottom surface of the test piece, it is necessary to thrust out the test piece far from the chuck in consideration of the interference of the cutting tool and the chuck of the workholding spindle.

5.2 Problem of moving range of linear axes

When the contour machining, drilling or boring are done in the XY plane with the machine used in this report, B-axis is moved to -90°. In this condition, there are only -50mm margins of X-axis moving range from the center of the workholding spindle. In the case of M4 test or the combination of M1-M4 test of the machining center, it is better to hold the workpiece in the center of the workholding spindle because the C-axis motion is one of the test targets. If the endmill of 30 mm diameter recommended in the standard is used, the position of the tool center has to be moved 55 mm from the center of the workholding spindle for milling the side of test piece of size 80. However, the tool center can be moved 50 mm only. Therefore, the tool diameter has to be changed to less than 20 mm in the machine tested.

However, in the case of M1 test of the machining center and no C-axis motion, the recommended endmill of 30 mm diameter can be used, by changing the location of workpiece higher from the center of wokholding spindle. Moreover, if the center of the workpiece is located +45 mm from the center of the workholding spindle in X-axis, the test piece of size 160 can also be machined by using the endmill of 30 mm diameter.

5.3 Options of processing method concerinig the rotary axes

Because the moving range of tilting axis (B-axis) is ±120° in the machine used in the report, it seems that the processing method for the machine that has a moving range of ±90° of tilting axis in M4 test of the machining center should be applied. However, as described in section 5.2, the B-axis of this machine is positioned in -90° for milling in XY plane. Because B-axis does not move along ±90° from this position, the machining method of bottom square radial holes in M4 test of the machining center for the machine whose tilting axis does not move along ±90° should not be applied.

5.4 Problem of evaluation axis of turning center

Table 2 shows the check items of test piece of M1&M4 test of machining center and M3 test of turning center. There are two options, such as X- and Y- axis or C- and X- axis for machining the test piece of turning center, however, regardless of which is chosen, the evaluation items remain the same.

When M3 test of the turning center is processed using X- and Y-axis, the influence that the machine has on the accuracy of the test piece is the same as that of M1 test in the machining center.

Because M4 test of the machining center is machined using the rotary axes, they can be evaluated. When M3 of the turning center is processed by the interpolation motion of C- and X axis, it is possible to evaluate the angular positioning accuracy of C-axis by paying attention to the position of bored holes because C-axis is used for the positioning before the holes are bored.

However, M3 test of the turning center cannot evaluate rotary axes as M4 test of the machining center because there is no process using either Y-axis or B-axis.

Table 2: Check items of test pieces

	ISO10791-7 M1&M4	ISO13041-6 M3
Central hole	• Cylindricity of the bored hole C • Perpendicularity between the hole C axis and datum plane A	• Cylindricity of the bored hole C • Perpendicularity between the hole C axis and datum plane A
Top square	• Straightness • Perpendicularity of the datum plane B • Parallelism of the datum plane B	• Straightness • Perpendicularity of the datum plane B • Parallelism of the datum plane B
Diamond	• Straightness • Angularity of 30° to datum plane B • Angularity of 60° to datum plane B	• Straightness • Angularity of 30° to datum plane B • Angularity of 60° to datum plane B
Circle	• Roundness • Concentricity of the circle and Central hole	• Roundness • **Position of the circle and Central hole**
Sloping faces	• Straightness • Angularity of 3° to datum plane B • Angularity of 93° to datum plane B	• Straightness • Angularity of 3° to datum plane B • Angularity of 93° to datum plane B
Bored holes	• Position of the hole to datum hole C • Concentricity of inner hole with respect to outer hole	• Position of the hole to datum hole C • Concentricity of inner hole with respect to outer hole
Middle square	• Straightness • Perpendicularity of the datum plane B • Parallelism of the datum plane B • Symmetry to datum hole C • Difference of size between planes in X and Y	
Bottom square	• Straightness • Perpendicularity of the datum plane B • Parallelism of the datum plane B • Symmetry to datum hole C • Difference of size between planes in X and Y	
Radial holes	• Difference of hole position in distance to datum plane A • Difference of hole U position to hole W • Difference of hole V position to hole X	

6 Exprimental study

6.1 Cutting condition

In this report the test piece of M3 of the turning center was processed using X- and Y-axis as an example. Table 3 shows the cutting condition from the problems given in Chapter 5.

6.2 Measurement method and result

The test piece was measured on the milling machine equipped with a touch probe made by RENISHAW and linear scales made by HEIDENHAIN. The measurement software was FormControl made by BRUM. Figure 6 shows the picture of finished test piece and Table 4 shows the measurement result.

Table 3: Cutting condition

		ISO13041-6 M3
Material and designation of the test piece	Material	A2017
	Test piece size	80
Material, dimensions, and number of teeth of the tool	Material	High speed steel
	Tool diameter	10 mm
	Number of teeth	2
Contouring	Spindle Speed	3000 rpm
	Feed Speed	300 mm/min
Bored holes	Spindle Speed	1500 rpm
	Feed Speed	150 mm/min
Depth of cut	The radial direction	0.2 mm
	The axial direction	6 mm

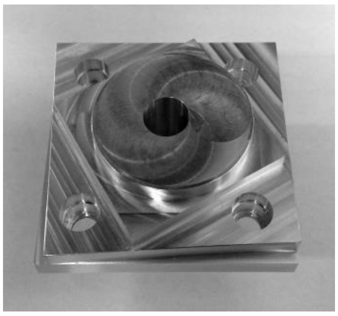

Figure 6: ISO 13041-6-M3_80 test piece

It is found that the accuracies of the central hole, the circle and the bored holes that were machined by a circular interpolation are worse than the accuracy on other feature. It is thought that there was a problem in the circular interpolation motion of the machine.

As future tasks, M3 test with C- and X-axis of the turning center and M1&M4 combined test of the machining center will be performed. Then, from the result, the influences of the accuracy of multi-task machine tools to the accuracy of finishing will be confirmed. If possible, the accuracy test method that is suitable for the multi-task machine tools is examined.

7 Conclusion

The test method and check items of the finished test piece of machining center and turning center are confirmed, and then the problems considered when applying to an actual multi-task machine tool were examined.

The influence that the multi-task machine tool gave on the accuracy of the finished test piece was confirmed by machining and measuring an actual test piece.

Acknowledgements

We would like to express our gratitude to Machine Tools Technologies Research Foundation (MTTRF) for renting the multi-tasking machine tool used in the experiments.

Table 4: Measuring result

Inspection items				On-machine (μm)	Tolerances (μm)
Central hole	Cylindricity of the bored hole C			173.8	10
	Perpendicularity to datum plane A			56.9	10
Square	Straightness	1		1.4	30
		2		1.8	
		3		0.0	
		4		2.3	
	Perpendicularity of the datum plane B	1		1.4	30
		2		2.4	
	Parallelism of the datum plane B			2.2	30
Diamond	Straightness	1		1.8	30
		2		1.4	
		3		4.3	
		4		2.0	
	Angularity to datum plane B	1		1.8	30
		2		1.5	
		3		10.8	
		4		2.0	
Circle	Roundness			29.1	30
	Position to Central hole C			38.0	40
Sloping faces	Straightness	1		3.8	30
		2		3.0	
	Angularity to datum plane B	1		4.8	30
		2		4.3	
Bored holes	Position to Central hole C	φ14	1	28.2	50
			2	38.9	
			3	29.7	
			4	28.7	
		φ16	1	30.9	50
			2	30.4	
			3	30.9	
			4	30.6	
	Concentricity of inner hole with respect to outer hole	1		3.0	20
		2		1.2	
		3		2.0	
		4		2.0	

References

[1] History and Current Situation of Multi-Tasking Machine Tools, http://www.sme-tokyo.org/journal1-mazak-eng.pdf

[2] ISO13041-6 Test conditions for numerically controlled turning machines and turning centres -- Part 6: Accuracy of a finished test piece (2009)

[3] ISO10791-7 Test conditions for machining centres -- Part 7: Accuracy of finished test pieces (2014)

[4] ISO10791-6 Test conditions for machining centres -- Part 6: Accuracy of speeds and interpolations (2014)

[5] ISO13041-1 Test conditions for numerically controlled turning machines and turning centres -- Part 1: Geometric tests for machines with a horizontal workholding spindle (2004)