TESTING DRILLING TOOL INTERGRATING DAMPING SYSTEM USING MACHINING TEST METHOD

Ho Duong Dong

The University of Danang, University of Science and Technology; hddong@dut.udn.vn

Abstract - In this paper, machining test in lathe machine is used to check the characteristics of damped drilling tool and damped clamp tool. The testing results are then compared with those of conventional drilling tool and clamp to see the differences. The damped tool achieves better quality surface while mounting in the conventional clamp. The damped clamp helps the conventional tool improve the damping ratio significantly, however, it does not give any improvement for the damped tool. Taguchi method is conducted to find the optimal cutting parameters for each combination of drilling tools and clamping devices. This paper follows the results of the published article on The Journal of Science and Technology – The University of Danang December 2017, named "Research on characteristics of drilling tool intergrating damping system using Experimental Model Analysis".

Key words - Machining test; drilling tool; damping system; surface quality; optimal cutting parameter

1. Literature Review About Chatter Vibration in Drilling

Chatter can accelerate tool wear and breakage, accelerate machine tool wear and cause damage to machine tool and work piece. There are a lot of research about chatter mechanism in many kinds of machine tools and machine operations. In long drill operation, S. Ema and his colleagues got a significant understanding about chatter vibration and whirling vibration [1]. He set up experiments with a drill fixing on the tool post of a conventional lathe. A three-jaw chuck holds a work piece and the drill feeds forward the work piece by the feed mechanism of the lathe. Two gap detectors are used to measure the horizontal displacement x and the vertical displacement y of the drill as shown on Figure 1.

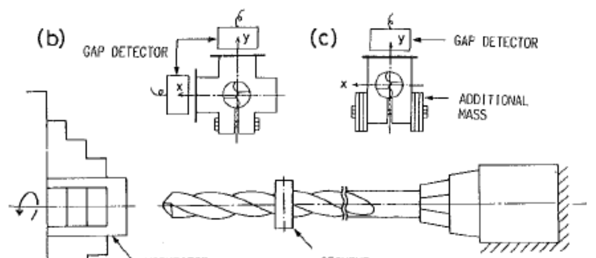

Figure 1. *S. Ema Long Drill Operation Experiment*

The tool has a 9mm diameter and 210mm overhang length. The cutting parameters are spindle speed of 1200 rpm, feed rate of 0,044mm/rev, and pilot hole diameter of 2.5mm [1]. At the beginning of the drilling operation, whirling vibration starts as shown in Figure 2. After the drill lip has penetrated the work piece at the hole deep of Hl, the whirling vibration is damped. However, when the drill just reaches the hole deep of Hci, the frequency f steeply increased, from which time of the chatter vibration started [1]. During the chatter vibration, the vertical amplitude Ay was much larger than the horizontal amplitude Ax.

S. Ema draws a conclusion that the chatter vibration of long drill operation is a regenerative chatter and the undulation on a machine work piece surface is due to the inclination of the drill point.

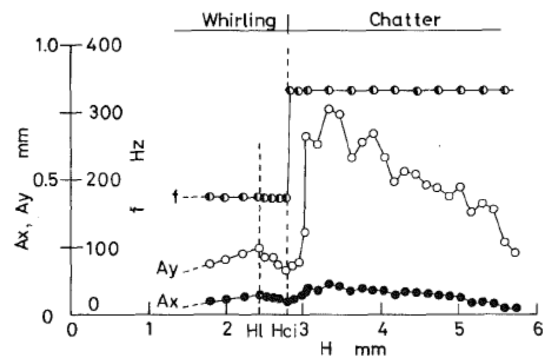

Figure 2. *S. Ema Long Drill Operation Result [1]*

Beside the displacement of tool drill point, the research shows that cutting speed and feed rate also affect machined surface's quality in long drill operations. Increase of cutting speed will decrease the surface roughness, however higher cutting speed will lead to higher interface temperature and severe tool wear. The increase in feed rate will increase the surface roughness as well as chatter, therefore higher feed rate can cause higher tool wear.

2. Taguchi Method in Machining Test

Taguchi method was carried out to reduce the time required for experimental investigation. Taguchi method is a simple and robust technique for optimizing the process parameters involving reduction of process variation [2]. The result is the optimization of cutting parameters; Moreover, only a limited combination of cutting parameters were tested instead of testing all possible combinations of feed rate and cutting speed. It is expected that the damped drilling tools shall have either higher productivity or lower surface roughness than the conventional tool in view of the optimum cutting parameters.

In any process, there are many different factors that affect the process performance. Taguchi method firstly determines the number of these parameters and the number of levels at which they should be varied.

In drilling operation, cutting speed, feed rate, cutting fluid etc. can affect the process. However, cutting speed and feed rate are the most important parameters. Therefore, the number of factors is two.

Determine what level of a variable to test requires an in-depth understanding about the process, including the minimum, maximum, and the current value of the parameter. The damped tools are designed with a maximum feed rate of 0.2 (mm/min). The minimum feed rate is 0.05 (mm/min). Lower feed rate can create more heat due to the increase of the friction between tool and workpiece. The cutting speed ranges from 200 (rpm) to 500 (rpm). The cutting speed cannot set high because it will cause high interface temperature and tool wear.

Table 1. *Factors and Levels used in the experiments*

	Level 1	Level 2	Level 3	Level 4
Cutting speed (rpm)	*200*	*300*	*400*	*500*
Feed rate (mm/min)	*0.05*	*0.08*	*0.12*	*0.18*

After determining the parameters affecting the processes and how the levels should be varied, Taguchi method uses orthogonal array to organize them. Two factors with four levels of each one gives sixteen experiments to be performed and the fractional factorial design selected is a standard L_{16} orthogonal array.

The objective is to calculate the signal – to – noise (S/N) ratio. The S/N ratio will be calculated for each experiment conducted. According to Taguchi, the S/N ratio is classified into three groups: nominal is the best, smaller the better characteristic, and larger the better characteristic. Each group has different calculations for S/N ratio. In this paper, the purpose is to find the optimum cutting parameter to get a better surface roughness. It means that the smaller surface roughness, the better. And therefore, the S/N ratio is in group *the smaller the better*. It is calculated as:

$$SN_i = -10^{*}\log\left(\sum_{u=1}^{N_i}\left(\frac{y_u^2}{N_i}\right)\right)$$

Where i = Experiment number; u = Trial number; N_i = Number of trials for experiment.

The surface roughness was measured in three common roughness parameters, R_a (arithmetic average of absolute values of roughness profile), R_z(average distance between the highest peak and lowest valley of roughness profile in each sampling length), and R_q (root mean squared of roughness profile).

$$R_a = \frac{1}{n}\sum_{i=1}^{n}|y_i|$$

$$R_z = \frac{1}{5}\sum_{i=1}^{5}(R_{pi} - R_{vi})$$

where R_{pi}, R_{vi} are the i^{th} highest peak, and lowest valley.

$$R_q = \sqrt{\frac{1}{n}\sum_{i=1}^{n} y_i^2}$$

For each combination of drilling tool and clamping device one table is established. According to Taguchi method, L_{16} orthogonal matrix table is chosen as shown in Table 2. $T_{i,\ j}$ represents the different trials with i = experiment number and j = trial number.

Table 2. *L16 Orthogonal Matrix*

Expe. No.	**Cut. Speed**	**Feed Rate**	**R_a**	**R_z**	**R_q**	**S/N**
1	1	1	$T_{1,1}$	$T_{1,2}$	$T_{1,3}$	SN_1
2	1	2	$T_{2,1}$	$T_{2,2}$	$T_{2,3}$	SN_2
3	1	3	$T_{3,1}$	$T_{3,2}$	$T_{3,3}$	SN_3
4	1	4	$T_{4,1}$	$T_{4,2}$	$T_{4,3}$	SN_4
5	2	1	$T_{5,1}$	$T_{5,2}$	$T_{5,3}$	SN_5
6	2	2	$T_{6,1}$	$T_{6,2}$	$T_{6,3}$	SN_6
7	2	3	$T_{7,1}$	$T_{7,2}$	$T_{7,3}$	SN_7
8	2	4	$T_{8,1}$	$T_{8,2}$	$T_{8,3}$	SN_8
9	3	1	$T_{9,1}$	$T_{9,2}$	$T_{9,3}$	SN_9
10	3	2	$T_{10,1}$	$T_{10,2}$	$T_{10,3}$	SN_{10}
11	3	3	$T_{11,1}$	$T_{11,2}$	$T_{11,3}$	SN_{11}
12	3	4	$T_{12,1}$	$T_{12,2}$	$T_{12,3}$	SN_{12}
13	4	1	$T_{13,1}$	$T_{13,2}$	$T_{13,3}$	SN_{13}
14	4	2	$T_{14,1}$	$T_{14,2}$	$T_{14,3}$	SN_{14}
15	4	3	$T_{15,1}$	$T_{15,2}$	$T_{15,3}$	SN_{15}
16	4	4	$T_{16,1}$	$T_{16,2}$	$T_{16,3}$	SN_{16}

3. Machining Test Experiment Set-up

The damped drilling tools and the conventional tool are shown in Figure 3. It is important to note that the damped tool's length is greater than the conventional one (248mm compared to 205mm) and it needs a special tool holder. Each tool was tested two times with two different clamp devices, the conventional clamp ETP Hydro-fix NBB-42/50-62 and the viscoelastic composite material interface clamp ETP Hydro-fix NBC- 42/50-62.

Figure 3. *Tools and Clapming Devices*

The machining test was carried out in a lathe SWEDTURN 300 lathe. Experiment setup was kept unchanged with previous EMA tests. The work-piece is a cylinder of 75 mm diameter and 13 mm thickness as shown in Figure 4. The work piece is made of carbon steel. Face turning was carried out at both sides of the work piece to make sure good contact between the work piece and the drill tool point.

The work pieces were clamped in a three-jaw chuck of the machine and rotated. The drilling tool was mounted on the machine turret and fed toward the work piece by the feed mechanism of the lathe. Cutting fluid was used in all experiments as illustrated in Figure 5.

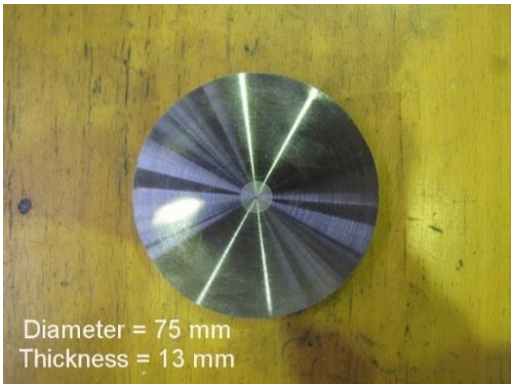

Figure 4. *Workpiece Dimensions*

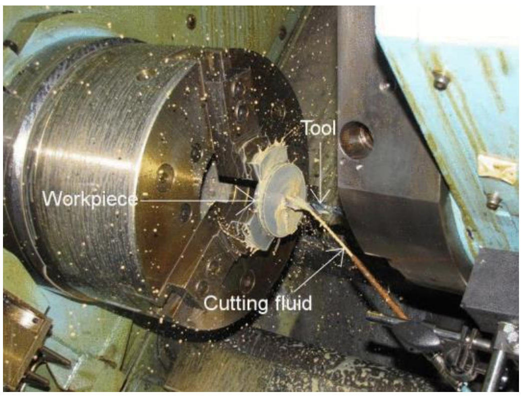

Figure 5. *Machining Test in the Lathe Machine*

It is required that the cutting speed and the feed rate are changed for each experiment based on Taguchi L_{16} orthogonal matrix. The procedure of machining test was therefore carried out exactly as shown in Table 2. For easy reference, the workpieces were marked with numbers after machining as shown in Figure 6.

Figure 6. *Workpiece Marked with Number After Machining*

The surface roughness of the machined holes was measured by Mitutoyo tester model SJ301. This equipment allows the measurement of three common roughness parameters: R_a, R_z, and R_q. Each machined hole was measured four times at four different positions for statistical accuracy. The measurement positions were marked on the work piece as illustrated in Figure 7.

The two new damped drilling tools are made by adding damping rings. These rings are made of viscoelastic composite material and they are glued together on the tool. The new tools therefore are expected to have higher damping ability than the conventional tool. Theoretically they would absorb more vibratory energy from the cutting process and the machined surface quality would be improved.

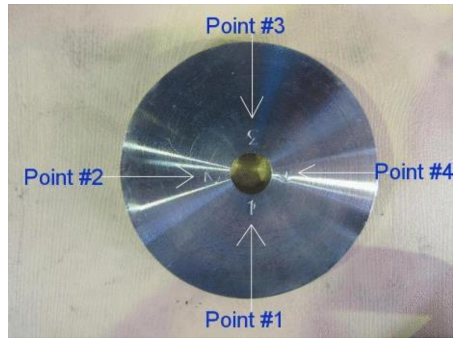

Figure 7. *Surface Roughness Measured Points*

4. Machining Test Results

The S/N ratio for each level of R_a is calculated based on Taguchi method *the smaller the better*

$$SN_i = -10^{*}\log\left(\frac{y_1^2 + y_2^2 + y_3^2 + y_4^2}{4}\right)$$

where y_1, y_2, y_3, and y_4 are the R_a value at the positions 1, 2, 3, and 4, respectively.

The data for computed S/N ratios is represented in Table 3.

From piece No. 1 to piece No. 16 are computed S/N ratios of the conventional tool mounted in the conventional clamp.

From piece No. 17 to piece No. 32 are computed S/N ratios of the damped tool #1 mounted in the conventional clamp.

From piece No. 33 to piece No. 48 are computed S/N ratios of the damped tool #2 mounted in the conventional clamp.

From piece No. 49 to piece No. 64 are computed S/N ratios of the conventional tool mounted in the damped clamp

From piece No. 65 to piece No. 80 are computed S/N ratios of the damped tool #1 mounted in the damped clamp.

From piece No. 81 to piece. 95 are computed S/N ratios of the damped tool #2 mounted in the damped clamp.

The average surface roughness of a hole is calculated as

$$R_a^c = \frac{y_1 + y_2 + y_3 + y_4}{4}$$

where y_1, y_2, y_3, and y_4 are the R_a value at the positions 1, 2, 3, and 4, respectively.

The data for surface roughness average is shown in Table 4 and Table 5. The yellow values are the optimal cutting parameters obtained.

It can be seen from the tables that when the drilling tools are clamped in the conventional clamp, the damped tool #1 obtains lowest surface roughness at the optimal cutting parameters (2.25μm) whereas the surface quality does not have any difference between the conventional tool and the damped tool #2 at their optimal cutting parameters (3.02μm).

When the conventional and damped tool #2 are clamped in the damped device, there is a significant improvement in surface roughness, but the situation does not change for the damped tool #1.

Table 3. *Computed S/N Ratios*

Piece No.	S/N Ratios	Piece No.	S/N Ratios	Piece No.	S/N Ratios
1	*-10.82*	33	*-7.27*	65	*-10.31*
2	*-10.12*	34	*-11.54*	66	*-8.37*
3	*-10.02*	35	*-8.90*	67	*-9.59*
4	*-9.64*	36	*-9.63*	68	*-11.18*
5	*-11.54*	37	*-12.46*	68	*-9.37*
6	*-10.89*	38	*-11.24*	70	*-8.13*
7	*-9.26*	39	*-10.83*	71	*-11.22*
8	*-10.64*	40	*-10.47*	72	*-12.68*
9	*-11.86*	41	*-13.51*	73	*-9.07*
10	*-11.60*	42	*-10.80*	74	*-8.81*
11	*-11.61*	43	*-11.80*	75	*-10.73*
12	*-9.63*	44	*-10.59*	76	*-11.19*
13	*-12.53*	45	*-11.00*	77	*-9.84*
14	*-10.60*	46	*-11.60*	78	*-9.62*
15	*-10.69*	47	*-10.55*	79	*-12.51*
16	*-10.50*	48	*0.87*	80	*-6.57*
17	*-9.76*	49	*0.03*	81	*-10.68*
18	*-9.05*	50	*-2.04*	82	*-7.74*
19	*-7.34*	51	*-5.70*	83	*-5.90*
20	*-8.33*	52	*-0.15*	84	*-4.67*
21	*-10.34*	53	*-0.54*	85	*-9.69*
22	*-11.57*	54	*-1.57*	86	*-8.11*
23	*-9.00*	55	*-6.17*	87	*-7.60*
24	*-11.74*	56	*-3.19*	88	*-6.91*
25	*-10.19*	57	*-6.60*	89	*-6.78*
26	*-8.30*	58	*-4.77*	90	*-7.62*
27	*-9.08*	59	*-9.24*	91	*-8.30*
28	*-13.20*	60	*-2.37*	92	*-9.36*
29	*-11.62*	61	*-6.59*	93	*-8.17*
30	*-8.78*	62	*-6.77*	94	*-8.07*
31	*-9.32*	63	*-10.54*	95	*-10.83*
32	*-10.69*	64	*-14.12*		

Table 4. *The Ra average values of the tools in the conventional clamp*

Cutting speed level	**Feed rate level**	**Ra average (µm)**		
		Conventional tool in the conventional clamp	**Damped tool #1 in the conventional clamp**	**Damped tool #2 in the conventional clamp**
1	1	3.40	2.79	2.27
1	2	3.12	2.72	3.65
1	3	3.14	**2.25**	2.75
1	4	**3.02**	2.59	**3.02**
2	1	3.69	3.13	3.93
2	2	3.40	3.45	3.41
2	3	2.84	2.78	3.43
2	4	3.39	3.84	3.28
3	1	3.89	3.18	4.37
3	2	3.75	2.56	3.25
3	3	3.71	2.75	3.88
3	4	2.99	4.55	3.23
4	1	4.19	3.59	3.49
4	2	3.33	2.70	3.46
4	3	3.42	2.90	3.31
4	4	3.33	3.38	3.57

Table 5. *Ra avarage value of the tools in the damped clamp*

Cutting speed level	**Feed rate level**	**Ra average (µm)**		
		Conventional tool in the damped clamp	**Damped tool #1 in the damped clamp**	**Damped tool #2 in the damped clamp**
1	1	**0.85**	4.25	1.87
1	2	0.81	3.19	3.01
1	3	1.12	2.58	2.25
1	4	1.84	2.95	1.93
2	1	0.98	3.20	1.59
2	2	1.03	2.87	2.95
2	3	1.09	**2.49**	2.19
2	4	1.89	3.63	2.10
3	1	1.39	3.89	**1.96**
3	2	2.11	2.78	2.02
3	3	1.69	2.67	2.21
3	4	2.89	3.38	2.49
4	1	1.27	3.01	2.68
4	2	2.12	3.06	2.38
4	3	2.14	2.98	2.25
4	4	3.26	4.00	3.40

5. Conclusion

From the modal analysis, the damped drilling tool has higher damping ratio than the conventional one. From the machining tests, the damped tools have better surface quality while mounted in the conventional clamp device. The damped clamp helps the conventional tool improve the damping ratio significantly. However, it does not give any improvement for the damped tool.

Taguchi method was conducted, and it shows that the optimal cutting parameters between drilling tools do not have much difference while mounted in the conventional clamp. For the conventional tool, it is a cutting speed of 200 rpm and a feed rate of 0.18 mm/min. For the damped tool, it is a cutting speed of 200 rpm and a feed rate of 0.13 mm/min. However, the damped tool achieves lower surface roughness than the conventional one, 2.25 µm compared to 3.02 µm.

From the results of Taguchi method for tools in damped clamp, the conventional tool has a extremely low optimal cutting parameters with a cutting speed of 200 rpm and a feed rate of 0.05 mm/min. However, the surface quality is significantly higher than the damped tool, 0.85 µm compared to 2.49 µm (Table 5).

From Table 4 and Table 5, the conventional tool in a damped clamp achieved extremely low surface roughness in all cutting parameters tested. The author advises the use of conventional tool in damped clamp in industrial machining.

The drilling tools were tested with only four levels of spindle speed (200 rpm, 300 rpm, 400 rpm, and 500 rpm) and four levels of feed rate (0.05 mm/min, 0.08 mm/min, 0.12 mm/min, and 0.18 mm/min) based on Taguchi method therefore it would be interesting to run more tests beyond the range of these parameters. These tests could not be done in this paper because of the time constraint, but they possibly would reveal more about the tool’s behaviors.

The surface roughness was measured with Mitutoyo model SJ301 machine. However, in order to have better evaluation, other geometrical tolerances of the machined holes should be measured as well. Among them, the most important standard is the hole circularity. This measure has not been possible yet because special measurement equipment is needed.

REFERENCES

[1] S. Ema, H. Fujii, and E. Marui, *Chatter Vibration in Drilling”,* Journal of Engineering for Industry, 1988.

[2] DomnitaFratila, Cristian Caizai, “*Application of taguchi method to selection of optimal lubrication and cutting conditions in face milling of ALMG3*”, Journal of Cleaner Production, 2010.

[3] E. Kilickap, *“Optimization of cutting parameters on delamination based on Taguchi method during drilling of GFRP composite”,* Expert systems with applications, 2010.

[4] David A. Stephenson, *“Metal Cutting Theory and Practice”*, Second edition, 2006.

[5] S.S. Dimov and Bertrand Fillon, *“2nd International Conference on Multi-Material Micro Manufacture”*, 2006, pp.30-32.

[6] Rivin Eugene l, *“Tooling structure: Interface between cutting edge and machine tool”*, Wayne State University, Detroit, USA.

[7] Lorenzo Daghini, “Theoretical and Experimental Study of Tooling Systems – Passive control of machining vibration”, Licentiate Thesis, KTH Stockholm, Sweden, 2008.

(The Board of Editors received the paper on 14/11/2018, its review was completed on 15/02/2019)