Experimental Study of Milling Cutter with High Damping Alloy Sleeve

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Abstract. This paper proposed three types of milling cutter, including the normal one, the modified cutter with high damping alloy sleeve, the modified cutter with high damping sleeve and gasket, these three type of cutters are identified with type A, type B and type C respectively. The testing items including cutting force, surface smoothness and fatigue life of above three type of cutter are conducted under different working conditions respectively. The result shows that the milling cutter with high damping alloy behaves better and could improve the related performance dramatically. Specifically, the cutting force of the cutters including type B and C is lower obviously than type A at three different directions, and type C cutter has the lowest cutting force and has the best anti-vibration effects. Additionally, under working condition 1, the surface smoothness of the three type of cutters have the similar behavior. But under working condition 2, the high damping milling cutter has at least 30% improvement. Finally, at the aspect of the fatigue life, the milling cutter with high damping alloy has at least 54.55% better performance than the normal cutter, and the wear of the high damping cutter is at least 38.13% less than normal cutter.

Keywords: Milling cutter; High damping alloy; Fatigue life; Surface smoothness; Cutting force

1. Introduction

Alternating load generated by mechanical vibration of the machine could lead reduce machine’s service life, and more serious could cause catastrophic accident [1]. The brand-new control method is introduced to solve the vibration problem and improve the manufacturing precision. At the same time, it could be found that the surface quality could be affected by turning vibration, and the machine tool’s service life could be shorten as well. Additionally, the operator’s mood would be affected by the corresponding noise, and the negative influence could be brought by this negative factor.

Many researchers did a lot of study on the cutting machine’s vibration. The relationship between chatter vibration and tool wear was established and this could be used to predict tool’s wear and service life [2]. The mechanism of instability with respect to Hopf bifurcation is explained clearly [3-4]. The empirical relation of tool life and surface roughness was obtained, the cutting parameters and regression analysis are optimized by Taguchi method [5-6]. A mathematical model is established could be used to depict the friction force, and the dynamic behavior the it’s stability could be predicted [7]. The prediction model related to machining parameter and tool wear was developed [8]. The
alternative approaches was identified, which could used to finish the internal turning for long hole in hardened steel parts [9]. A new method by making use of the pressure foot was presented, which could suppress the vibration dramatically. Lot’s of experiments were conducted and verified the effectiveness of vibration suppression [10-14]. Although the related research mentioned above, but the research about the vibration and the performance of lathe Tool with the double-layer of high damping alloy could not been seen.

This paper proposed three types of milling cutter, including the normal one, the modified cutter with sleeve, the modified cutter with sleeve and gasket. The items including cutting force, surface smoothness and fatigue life of above three type of cutter are conducted under different working conditions respectively. The result shows that the milling cutter with high damping alloy behaves better and could improve the related performance dramatically.

2. Physical Model
Anti-vibration alloy is a kind of ally with high damping effect. Although the material itself has high damping, but it still have the similar mechanical property with Q235. Because of this property, this high damping alloy has been used widely in the field of submarine and warship, and also used in the field of the product with high precision, like printer and digital camera.

Figure 1 is the typical model of the milling cutter, which is composed of cutter arbor, tool bit and blade. In order to test and find out the best anti-vibration solution, three type of structure are used. The first type is the original cutter, without any modification denoted by type A. The second type is modified cutter and the cutter arbor is wrapped by sleeve which is made of high damping alloy, denoted by type B. The third type is based on the type B, and high damping gasket is added between cutter arbor and tool bit, and denoted by type C. The above three type of milling cutters will be tested respectively.

![Figure 1. Typical Milling Cutter.](image)

2.1. Related Parameter Setting
Table 1 is the list of cutter arbor and blade type, it could be seen that, for the test of milling, three type of cutter arbor are adopted, but with the same blade. Additionally, the material of work piece is 1Cr18Ni9T and the hardness is 230HB.

| Machine type | Cutter arbor               | Blade model                |
|--------------|----------------------------|----------------------------|
| Milling      | Type A Normal              | YBM253/SDMT09T312-P        |
|              | Type B With high damping sleeve |                           |
|              | Type C With high damping sleeve and 1mm thick gasket | M                         |

Table 1. List of different cutter.
The related test devices are listed in Table 2, and without any additional cooling device are utilized during testing. Further, the testing items including cutting force, surface roughness and fatigue life of the blade are conducted.

Table 2. Related Devices.

| Items             | Device Model                  |
|-------------------|------------------------------|
| Milling           | VMC1000S                     |
| Roughness tester  | TR200 Portable roughness meter |
| Load cell         | KISTLER                      |

2.2. Cutter Arbor Model

Figure 2 and Figure 3 are the two type of milling cutters with high damping alloy. Figure 2 shows the model of the cutter with high damping sleeve, which corresponding to type B. Figure 3 shows the model of the cutter with high damping sleeve and gasket, which corresponding to type C.

Figure 2. Anti-vibration Milling Cutter - Solution A.

Figure 3. Anti-vibration Milling Cutter - Solution B.

3. Experimental Study

3.1. Experiments Working Condition Setting

Two different working conditions and its corresponding parameters are listed in Table 3.

Table 3. Test Working Condition.

| Working Condition | cutting speed (m/min) | Depth of cut (mm) | Feed speed (mm/r) | Cutting width (mm) |
|-------------------|-----------------------|-------------------|-------------------|--------------------|
| 1                 | 120                   | 0.8               | 1                 | 10                 |
| 2                 | 120                   | 0.8               | 1                 | 5                  |

3.2. Cutting Force

Table 4 shows the cutting force value at X, Y and Z direction of the different type of milling cutters under working condition 1 and 2. Figure 4 shows the curves of the cutting force value at different direction. It could be seen that, under two different working conditions, Type C milling cutter generates the lowest cutting force, and Type B generates the medium force. However, the type A, the normal cutter, generates the highest force. At the direction of X, type B cutter almost has 16% lower force compared with type A, and type C cutter has 21% lower force. At the direction of Y, type B cutter has 18.5% lower force compared with type A, and type C cutter has 32.4% lower force. Similarly, at the direction of Z, type B cutter has 13 lower force compared with type A, and type C cutter has 18.6% lower force. From the above comparison, it could be seen that type B and C cutter both have better anti-vibration effects.
(a) Cutting force at X direction.  (b) Cutting force at Y direction.  (c) Cutting force at Z direction.

Figure 4. Cutting Force Comparison under Different Working Condition.

Table 4. Cutting Force Comparison.

| Working Condition | X Direction       | Y Direction       | Z Direction       |
|-------------------|-------------------|-------------------|-------------------|
|                   | Type A | Type B | Type C | Type A | Type B | Type C | Type A | Type B | Type C |
| 1                 | 3354.03 | 2816.62 | 2660.98 | 1824.65 | 1485.90 | 1223.14 | 1804.50 | 1569.21 | 1468.51 |
| 2                 | 2214.66 | 2080.99 | 1986.69 | 1633.30 | 1545.87 | 1469.42 | 1495.06 | 1552.73 | 1346.74 |

3.3. Surface Smoothness

Table 5 shows three different type of cutter’s surface smoothness of different work piece under different working conditions. It could be seen that, under working condition 1, type A cutter behaves best, and type B and C have the similar effect. Under working condition 2, type B cutter behaves best and type C behaves worst, and type B has almost 30% improvement than type A cutter. Generally, both type B and C have better anti-vibration effects, and from the point of smoothness, type B cutter has better effect than type C. In some conditions, type B and C cutter behave better than type A. The values listed in table 5 are curved in figure 5, which could express the characteristics of the different type of cutters.

Figure 6 shows the surfaces of the work pieces after milling under different working condition by type A and B cutters, it could be seen from pictures that the work piece milled by type B cutter has better surface smoothness.

Table 5. Surface Smoothness Comparison under Different Working Condition.

| Type of Cutters | Working condition (WD) | Surface roughness |
|-----------------|------------------------|-------------------|
|                 |                        | 1st | 2nd | 3th | 4th | Average |
| A               |                        | 0.833 | 0.512 | 0.964 | 0.821 | 0.783 |
| B               | 1          | 1.03 | 0.87 | 1.189 | 1.088 | 1.044 |
| C               | 1.513      | 1.163 | 1.559 | 1.71 | 1.486 |
| A               | 0.783      | 0.816 | 0.732 | 0.814 | 0.786 |
| B               | 0.368      | 0.4 | 0.709 | 0.722 | 0.550 |
| C               | 0.957      | 0.602 | 0.817 | 0.929 | 0.826 |
3.4. Fatigue and Wear

In order to obtain the characteristics of the three different type of milling cutter, a serious of test were conducted. Table 6 shows the related testing parameters. Table 7 shows the effective cutting time of the different type cutter.

| Cutting speed (m/min) | Cutting depth (mm) | Feeding speed (mm/r) | Cutting width (mm) |
|----------------------|--------------------|----------------------|--------------------|
| 120                  | 0.8                | 1                    | 10                 |

| Type of Cutter | Blade Number | Cutting time (min) |
|----------------|--------------|--------------------|
| A              | 1            | 11                 |
|                | 2            | 11                 |
| B              | 1            | 22                 |
|                | 2            | 17                 |
| C              | 1            | 24                 |
|                | 2            | 6                  |

Figure 5. Cutting Force Comparison.

Type A
(WD 1 left side, WD 2 right side)

Figure 6. Work piece surface.
Figure 7. Milling Time Comparison of Different Cutter.

Figure 7 shows the comparison of the different type of cutters, it could be seen clearly that the cutting time of type B and C has 54.55% higher than type A at least, which also represents the fatigue life of type B and C cutters is much longer than type A. Figures 8 to 10 show the blade tip shape of the different type cutters after cutting test.
The groove dimension of the different type blades after cutting are listed in table 8 and expressed by curve in figure 11. Similarly, it could be conclude that the cutters with damping alloy have less wear compared with normal one.

Table 8. Wear Groove of the Blade.

| Type of Cutter | Blade number | Groove dimension (mm) |
|---------------|--------------|-----------------------|
| A             | 1            | 0.32                  |
|               | 2            | 0.234                 |
| B             | 1            | 0.232                 |
|               | 2            | 0.198                 |
| C             | 1            | 0.260                 |
|               | 2            | 0.278                 |

Figure 11. Groove Dimension Comparison of Different Cutters.

4. Conclusions
In this paper, three type of milling cutters are test under two different working conditions. Through testing, the characteristics of the three type of milling cutters are obtained, and the validity of the high damping alloy used in cutter is verified, and some conclusions are obtained as follows:

1) The cutting force of the cutters including type B and C is lower obviously than type A at three different directions, and type C cutter has the lowest cutting force and has the best anti-vibration effects.

2) Under working condition 1, the surface smoothness of the three type of cutters have the similar behavior. But under working condition 2, the high damping milling cutter has at least 30% improvement.

3) At the aspect of the fatigue life, the milling cutter with high damping alloy has at least 54.55% better performance than the normal cutter, and the wear of the high damping cutter is at least 38.13% less than normal cutter.

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