Design of Cyclone System to Reduce Tiny Flying Dust in Resin Machining. Case Study: CNC Machining for Jewellery Master

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Abstract. This paper dealt with an attempt to overcome dust problem to improve health in working area. Dust are side product of machining process in jewellery master machining using CNC. Resin material is showing good performance to be used as jewellery master material. Its machineability resulting high quality surface when machined using CNC. Unfortunately, its small size and light density resulting very light tiny dust that able to pass-through the vacuum cleaners filter. Moreover those dust are fly to anywhere and makes working area become dirty and severe for respiratory problem. In this paper, cyclone method is discussed to trap dust into chambers. Multiple cyclones is used to increase efficiency of filtering mechanism. As a result an alternative filter is introduced but it can only reduce about 60% of dust.

1. Introduction  
Production activity of jewellery industry especially for repetitive product is increased. Mass or limited edition product need to be produced repeatedly. Moreover, people also need customized product with shorter delivery time. In this condition CAD/CAM implementation in design and CNC to realize is needed significantly.

The use of resin material as an alternative to solve jewellery master material had been introduced. Although the result is satisfying, another peobles is occure such as flying tiny dust [1].

In finishing process using CNC machine, thickness allowance from machining strategy just before finishing is usually 0.2mm or less. If the step over during finishing is 0.02mm then it is understood that the chip volume, is very small.

Chips from cutting process is about 0.03mm³, very small size and able to pass through the filter of vacuum cleaner, and very light mass so that it can fly in the air. Those dust become serious problem when it enter critical machine part (bearing) and disturbing machine performance (see figure 1). Moreover, that become serious problem for worker or human respiratory health and cleanness of the room.
Idea to overcome those problems is come from cyclon mechanism that will sink material downward. Using that mechanism, it is hoped that tiny dust can be sunk to make healthy and clean working area.

2. Theory

2.1. Design
Jewellery design is mostly complex and the final weight should be compromised with ergonomic aspect and material cost. On the other hand it should be eye catching so that outer size and material weight should be compromised. To provide eye catching, jewellery is designed with big outer size and attractive symbol, colorful or shiny object or stone. As it is seen in figure 2, those big sized is then completed with small sized ornament to make it beauty.

![Typical Complex Jewellery Design](image)

Figure 2. Typical Complex Jewellery Design

2.2. Material
To realize digital 3D design into master, wax and resin is common used material in jewellery making. Resin is made up of an epoxy resin and a curing agent (usually called as hardener or catalyst) and sometimes use additives such as organic solvents, fillers such as fiberglass or sand, and pigments [2].

When chemical and the curing agent are mixed, long chains of molecules (polymers) is formed. Mixture of both become a hard polymer. Some epoxies cure in a few minutes at room temperature, others need additional time or heat to harden [2].

In a two-component epoxy product, the epoxy resin and the curing agent are packaged separately. Each component can be hazardous. They must be mixed together just before being used. The hardened, finished polymers are almost non-toxic [3][4]. Single-component systems are usually safer, because the hazardous chemicals are already combined into less toxic polymers and because as a single-component they do not evaporate into the air easily [2].
2.3. Machining using CNC

Jewellery design are mostly complex and the final weight should be compromised with ergonomic aspect and material cost. On the other hand it should be eye catching so that bigger outer size with material weight should be compromised. Concerning to the condition mentioned above, care should be taken for successful machining of the model. Due to the strength of the structure, there are small and weak structure that should be machined, hence careful machining strategies and proper additional bridge become very important for successful machining.

Finishing is the most important step in machining strategy, careful decision in setting the machining parameter is key point. Fastest process with the best surface quality is a must, where contrary the condition of the work-piece structure is complex and weak. Illustration of sample machining strategy is shown in figure 3.

For jewellery master machining, to minimize cutting forces during machining, material allowance before finishing process is usually about 0.2 mm and rotation speed is about 20000 rpm. It can be understood that chips produced in finishing process is very small.

![Figure 3. Machining Tool Path](image)

2.4. Micromachining

Micromachining is defined as fabrication of tiny devices: the techniques used in fabricating the miniaturized devices and moving parts into which microelectronic circuitry is integrated (Encarta, Encyclopedia).

Another definition as machining strategy where extremely small tool diameters are used. The tool characteristics are: diameter is in the range of 0.1 to 2 mm, small cutting length, high accuracy, coated [5]. Due to critical geometry of the product, micromachining requires high spindle run-out accuracy, high spindle rotation, thermal stability against thermal growth during operation, etc.

The area of micromachining is production of cavity, holes or detail engraving in many type of material. Micromachining is common process with laser cutting, 3D printing, etching, etc, and usually done in production of semiconductor, bio mechanics, jewelry, etc.[5]. In this paper, micromachining is done on resin material using CNC milling machine with single-lip tool as shown in figure 4, 5, and 6. Tool dimension is 10 degree of half angle (\(\epsilon\)) and 0.1mm of tool tip diameter (R) as shown in figure 3 until figure 5.
Refer to figure 6, \( a \) is depth of cut, which in this case equal to material allowance before finishing process is and conical half angle is \( \phi \), then:

\[
    r = a \tan \phi \tag{1}
\]

and hipotenusa \( h \) is:

\[
    h = \frac{a}{\sin \phi} \tag{2}
\]

When step over is \( t \) then volume of chip, \( V \), is approximated as:

\[
    V = \frac{\pi \alpha^2 t}{2 \cos \phi} \tag{3}
\]

by substituting Equation (1) and (2) into Equation (3), then:

\[
    V = \frac{\pi \alpha^2 t}{2 \cos \phi} \tag{4}
\]

2.5. Cyclone Separator
Cyclone separator is a device where the object is set into spiral motion by its path flow. The centrifugal forces acting on the object accelerate them radially outwards. At wall, the particles lose their and kinetic energy due to reduction of velocity by direction changes and friction with the wall and finally the object drop down into the collecting chamber. The cleaned air stream is discharged by means of pipe. Geometric scheme of the single cyclone is shown in figure 7.
Figure 7. Geometry of Single Cyclone [6]

Figure 8. Performance Curve of Standard high Efficiency Cyclone [6]

Performance curve shown in Figure 8 is used as reference to calculate the cyclone dimension. Using scaling factor the cyclone dimension can be calculated by equation (5):

\[
d_2 = d_1 \left( \frac{d_{c2}}{d_{c1}} \right)^3 \times \frac{Q_1}{Q_2} \times \frac{\Delta P_1}{\Delta P_2} \times \frac{\mu_2}{\mu_1} \right)^{1/2}
\]

(5)

where:
- \(d_1\) = particle diameter in standard condition, depend on separation efficiency.
- \(d_2\) = known particle diameter, same separation efficiency.
- \(d_{c1}\) = standard cyclone diameter = 8 inci (203 mm)
- \(d_{c2}\) = diameter cyclone yang diinginkan
- \(Q_1\) = standard flow rate for high efficiency = 223 m³/h. For high rate throughput design = 669 m³/h
- \(Q_2\) = designed flow rate
- \(\Delta P_1\) = standard moisture density in standard condition = 2000 kg/m³
- \(\Delta P_2\) = known moisture density
- \(\mu_1\) = viscosity (1 atm, 20°C) = 0.018 mN/s/m²
- \(\mu_2\) = known viscosity
3. Cyclone Design

Volume of chips can be calculated using equation (4) by considering that step over (t) = 0.05mm, depth of cut (a) = 0.2mm, half angle (f) = 10 degree, hence:

\[ V = \frac{\pi a^2 t}{2 \cos f} \]

\[ = 0.003 \text{ mm}^3 \]

From the vacuum pump that is used in this experiment, it is known that:

\[ A_1 = 5.06 \times 10^{-4} \text{ m}^2 \]

\[ v_1 = 7.38 \text{ m/s} \]

and from figure 8, the optimum speed to make cyclone [6] is:

\[ v_2 = 15 \text{ m/s} \]

From those known parameters and standard dimension to make cyclone as shown in figure 9, the cyclone apparatus dimension as a result of calculation is shown in figure 10.

According to dimensions that have been calculated, 3D model is made using CAD as it is shown in figure 11.
4. Experiment Result

Using resin chips that were produced in master jewellery’s machining, experiment is done by puffing approximately 18 grams resin chips into cyclone. As a result using only single cyclone, only about 3.5 grams are collected in the chamber and others are flew away.

It can be understood because chip volume in finishing machining is very small, 0.003mm3. This value is much more smaller than particle size of resin that is about 160-200µm [4].

Concerning that situation, modification is then done by arranging cyclone design to be multi-stage cyclone as shown in figure 12. In this design the collecting chamber is divided by 4 separated chamber. It is desiret that particle which pass the previous cyclone can be trapped in the next following cyclone. In this arrangement, output of the first cyclone will become input for the next following cyclone.

Experiment shows that from 12 grams of resin chips, only 7.5 grams are collected in 4 chambers. That mean only 60% of tiny chips can be trapped using this multi-stage cyclone.

This condition can be understood since the chips size may be smaller than it is expected since resin is previously in the liquid phase. That means that in cutting process the resin structure may be broken into very small grain and very light so that centrifugal force cannot stop it when hit the cyclone wall.

5. Conclusion

Successful usage of resin material in jewellery master machining using CNC is still have problems in resin dust that are resulted during machining. Very small density and tiny size (about 0,003 mm3) make these particles cannot be collected since they can pass the vacuum cleaner filter. Research about cyclone mechanism is still fail to collect the dust because 40% of the dust cannot be trapped and collected, since at air speed of 15m/s makes resin dust fly in the air and follow the air flow. However, these are not good for respiratory health and make working environment dirty. Further research should be done to support successful achievement in jewellery master production with better environment condition by eliminating the existence of these particles.

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