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Development and Analysis of Taper Tool Path for Micro Turning Operation

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Abstract

This paper presents the taper tool path scheme for micro turning of brass. Based on tool path technique for straight cutting, tool paths for taper shape are produced. This study covers the effect of cutting parameters with the use of different tool path method. The result shows that reverse cut is considered to be the most accurate as it has the smallest figure of average difference in the intended dimension. This is followed by step cut, whole cut and disk-2 cut. It shows which tool path is the most suitable for high precision machining. Defects and accuracy of the desired dimension in several tool path methods are observed and discussed.

Keywords: Micro turning, Taper turning, Cutting defects

1. Introduction

Technology progress is inevitable. Through technology advancement, the demands of part products are also changing. With parts needed are getting smaller, new manufacturing technology are developed to compensate traditional methods which are unable to carry out the needs. One of the developments in manufacturing industry is toward miniaturization. Furthermore, with a highly competitive part production industry, many manufacturing companies in various countries are changing their production into high-quality parts. Precision and smoothness is greatly considered for this advance manufacturing part production.

In micro mechanical machining, there are several operation included in this category, such as micro milling, micro press and micro turning machine. All of these processes have the same operation as their conventional counterparts, but with scaled down workpiece and part produced. However, as the workpiece becomes smaller and the features are more detailed, manual machining using conventional method is almost impossible. Thus, the use of computer numerical control (CNC) machine is necessary.

Micro machining technology is still new in the industry and some parts are not thoroughly developed. Micro machining is considered to be an operation process at a dimension of 1 to 999 micrometer. However, a new limit is set; which are 1 to 500 micrometer for micromachining and 500 to 999 micrometer for macro machining according to McGeough J, (2002). In a micro-scale fabrication industry, precision and speed are needed during operation. However, not all machines are suitable for these requirements. Therefore, computer numerical control machines are used as it is the only equipment which can provide quick and accurate machining operations for workpieces that involve complex shapes according to Lin SCJ, (1994). Several factors are needed to be checked during the operation in developing micro scale products. Precise control of the machine and machining parameters, such as feed rate, depth of cut and rpm are important (M. Azizur Rahman, et. al, 2006)

Micro turning, a part of micro scale machining process using solid tool, its material removal process is almost similar to normal turning operation. Definite 3D shapes on micro scale can be produced using micro turning operation as it uses solid cutting tools. Numerical Control (NC) programming is applied in micro turning operation to accurately and precisely control the cutting tool motions during operation (M. Azizur Rahman et. al.,2005). Precision is very essential when machining at micro scale as the tolerance becomes crucial parameter. If a tolerance of +15 µm is needed for 10mm diameter, thus in a same ratio, +15nm of tolerance is applied for 10 µm diameter. In order to work in micro scale, user control is vital according to Zinan Lu et. al.(1999). However, there are other issues having to be considered during micro turning operation.

One of the most important issues is the fact that the cutting force tends to bend the workpiece during operation. Therefore, it would affect machining accuracy and limit the machinable size (T. Masuzawa, 2000). During operation, the thrust force from the tool deflects the work piece. The workpiece would vibrate at tangential direction of the tool-workpiece contact region as the cutting tool block the vibration along the normal direction report by Lim HS et. al. (2002).

Thus, the control of reacting force during operation is important. The value of the cutting force must be lower than the value that causes plastic deformation of the workpiece to overcome workpiece deflection during operation according to Z. Lu and T. Yoneyama, (1999), and Lu. Z et. al (1999). Because, as the diameter of the workpiece is reduced, rigidity against the defection of the workpiece by the cutting force decreases. The relationship between the cutting force and the cutting speed can be seen. As the value of force is related to the cutting area, speed is increased to lower the cutting force produced. Therefore, higher speed is required in micro turning operation to get the optimum result (Zinan Lu et. al,1999).

Other than that, the depth of cut is also a very influential cutting parameter. When cutting with low depth of cut, thrust force is the dominating force. Meanwhile, if a very small depth of cut is used, plastic deformation (rubbing and burnishing) is dominant, which generate high thrust force. On the other hand, when turning at large depth of cut, tangential force is dominating over thrust force (M. Azizur Rahman et. al. (2005). Thus, the value of depth of cut must be determined beforehand with the above consideration.

In micro turning process, if the feed rate is increased, the contact area of tool and workpiece would also increases. This will raise the material removal rate, and the forces on the workpiece will be affected. As speed increases, material removal rate is decreased, which reduces the tool force due to shorter work-tool contact length (M. Azizur Rahman et. al. 2005) Cutting force decreases as the cutting speed increases. From the findings, specific cutting force increases as the cutting area is reduced and then decreases at certain limit (Zinan Lu et. al. 1999). This shows that increment of area of cut would increase cutting force. Thus, deflection and the cutting force could be controlled by adjusting the force and the present diameter of the workpiece. To minimize deflection of workpiece and preventing plastic deformation, step size can be applied. The step size can be determined using both equations above.

According to M. Azizur Rahman et.al (2006), there are 4 cutting scheme would be featured in the software that generates the NC codes. All of the cutting schemes have to be applicable for both straight and tapered features of the workpiece feature. There are namely whole cut, step cut, reversed cut and disk 2 cut. Whole or parallel cutting from a conventional turning operation, are not suggested to be applied in micro turning operation. From the findings by M. Azizur Rahman, et. al, (2006) the workpiece would tend to deflect. During the cutting operation the workpiece diameter would be reduced and the unsupported length will be increases. It is due to the low level of sustainability of the micro scale workpiece to the deflection and bending stress generated from the tool. For tapered features on part, taper turning operation has to be done. From M. Azizur Rahman, et. al, (2006), it introduce micro taper cutting by cutting parallel to the axis of the workpiece and machining parallel to the tapered surface. It concludes that turning parallel to the taper surface is relatively better in the manufacturing efficiency and time saving point of view. Tapering and chamfering design in workpiece would have high demand in near future. However, current information of tapering and chamfering cutting for micro turning operation is not in depth and comprehensive. Therefore, this study will investigate the effect of tool path for taper shape in micro turning.

2. Taper Tool Path in Micro turning

2.1 Whole Cut Taper Tool Path

Whole cutting is a simple cutting operation which applied the cutting technique of conventional turning. There are two types of tapered feature, outward and inward tapering of whole cut tool path as shown in figure 1. Outward taper is when the start diameter is smaller than the end diameter, while inward taper is vice versa. For outward tapered feature, straight rough cutting is done until the workpiece diameter is equal to diameter of the end point. The finishing cut is done with an angle of the tapered feature with finish depth of cut, as the end point of cutting tool moves. For inward tapering, straight rough cutting is done until it reaches the diameter of start point. Finish cutting is done starting from start point and ends with a finish depth of cut. This is repeated until the end diameter is equals to the end point diameter. The repeated cutting is done with the end point periodically lowered with a finish depth of cut.

2.2 Step Cut Tool Path

From figure 2, single pass of the tool path for step cut is shown for both outward and inward tapering. For outward tapering, in a single pass, straight rough cutting is done repeatedly with a rough depth of cut until it reaches the actual dimension plus a clearance of finish depth of cut. Finish cutting starts with cutting by an angle of the tapered feature and repeated until the actual dimension of the feature. While for inward tapering, repeated straight rough cutting starts until it reaches the actual dimension, plus a clearance of finish depth of cut. Then, finish cut with an angle of feature by the actual dimension of the feature.

2.3 Reverse Cut Tool Path

Single pass of tool path for reverse cut is shown for both outward and inward tapering as shown in figure 3. For outward tapering, straight rough cutting is done without a depth of cut until it reaches the actual dimension of the feature. However, it is done from back to front. Then, finish cutting with an angle of the tapered feature through the actual dimension of the feature to the start point of the pass. The pass would be repeated to meet the required feature. While for inward tapering, straight rough cutting starts without depth of cut until it reaches the actual dimension. Then, finish cut with an angle of feature by the actual dimension of the feature. The pass would be repeated to form the required feature. Both of the cutting operation starts with a shift towards the end point by L back to the original position of the pass.

2.4 Disks-2 Cut Tool Path

From Figure 4, a single pass of the tool path for disk-2 cut at tapered feature is shown. For outward tapering, it starts off with a shift by L toward the end point and then rough cut straight until reaches the diameter of the feature plus finishes depth of cut. The tool would cut toward the start point of the pass horizontal value with taped angle of the feature. Then, the tool cuts inward toward the feature. Finally tool moves toward diameter of the end of cut with an angle of the feature. While for inward tapering, the tool path is a mirror image to the tool path of the outward tapering, which can be seen on the right part of the figure.

2.5 Points Definition

For all taper cutting operations, tool paths are defined by point to point definition for the moves. These points are provided by the input from part dimension. However, there are some points position that are not provided by the part dimension for certain tool path scheme which the software have to generate. Tool path scheme which uses a cutting thickness during cutting operation would have the numerical calculation program to generate some points. The points needed are the one in horizontal plane between the start point and the end point. In the input, the user would define the start point and the end point. The feature wanted must be straight from one to another. However, the tool paths generated have to be repeated with a value of thickness parameter. Thus, there would be an end point for every pass of the operation toward the feature end point. Here, the end point has to be generated as shown in figure 5. In this study, triangle theorem is used to solve the problem. If the feature of two 90 degrees triangles is the same but only scaled down, the dimension could be attained if we know the dimension one of the triangles. This can be further explained using Figure 6.

The needed point can be obtained using the following equation:

------------ 1

where L = length between start and end point

H = height between start and end point

l = length between start and the point needed

h = height between start and the point needed

The value of start and end point can be attained from the input file and the value of L and H can be calculated. While, the value of l is actually cutting thickness used. Therefore, the value of h can be obtained using the above equation.

3. Equipment, Cutting Parameters and Part Dimension

The experiment was conducted using multipurpose miniature Mikrotools DT110 machine. It has the capability to machine a workpiece in 3 axes direction with accuracy to 0.0001 mm. The motion controller of this machine can execute NC codes. The machine was selected for its high accuracy machining facility. The machined part was measured using a NIKON VM-250 Computer Measuring Microscope (CMM) machine. Since the effect of material is not studied, only brass rods with 7.0 mm diameter were used. The cutting tool material used in this study is tungsten carbide. The cutting parameters such as spindle speed, depth of cut, feed rate and cutting thickness were used for the experiment. Part shape and size are kept constant for every machining operation. Figure 7 shows dimensions of the machined part. Table 1 shows cutting parameters used to run the experiment.

The measurements are done toward the accuracy of the features such as horizontal length (A), tapered length (B), tapered angle (C) and vertical length (D). After each workpieces have been machined with a certain cutting path scheme, measurements are taken and the accuracy percentages are calculated. Figure 8 shows a sample of machined brass rod using tapered tool path.

4. Result and Discussion

The machined part is observed and measured to check its accuracy and finishing using a CMM machine.

4.1 Whole Cut Taper Tool Path

The features from whole cutting method are considered in low condition if compared with other cutting method. Figure 9 shows an output of taper cutting using whole cut tool path. The surface finish is not fine enough for micromachining operation and the tapered feature part is not completely cut away. Other than that, during operation, the front part of workpiece is being chipped off due to long cutting size relative to its small diameter as shown in figure 10. It is because of the small workpiece being affected by deflection and bending stress.

4.2 Step Cut Taper Tool Path

By observation, the finish of step cutting method is excellent. The edges of the features are clearly visible and machined properly. Figure 11 shows a part produce using step cut tool path for taper cutting. However, defects of the part are the burrs at the end of the part as shown in figure 12. There are also undercuts from the wide angle face of the tool. Other than that, the face of the part is not fine for micromachining operation.

4.3 Reverse Cut Taper Tool Path

Features from the reverse cutting method are the best in this study. The edges are accurate and the finishing is smooth. Figure 13 shows a part produce using reversed cut tool path for taper cutting. There are no defects, except for some burrs, undercuts and unmachined part. The burrs are located at the sharp taper and the outer diameter of the part. Other than that, it is perfect.

4.4 Disk-2 Cut Taper Tool Path

The end of the part is not being cut completely in this operation using disk-2 cutting method. Some of the chips are not being cut off and still at the part as shown in figure 14. The edges between the tapered features are not fine and as sharp as reverse cutting. Moreover, there are some bumps and hills on the surface and the taper, i.e. not that smooth. Figure 15 shows a part produce using Disk-2 cut tool path for taper cutting. There are also an undercuts at the part due to the angle face of the tool. Additionally, there are some burrs at the reverse taper of the part.

4.5 Measurement

The measurements of each cutting path scheme are summarized in a graph form as shown in figure 16. It is noticed that the maximum percentage difference is at feature B (tapered length) for the entire tool path scheme and followed by feature A (horizontal length), D (vertical length) and C (tapered angle). This is due to errors occuring during reading the dimension of the workpieces because there are many burrs and uneven surface on the tapered part. Therefore, the tapered feature is hard to measure using CMM machine as it uses optical dimension/positioning.

While if compared between the tool path schemes, reverse cut is considered to be the most accurate as it has the smallest figure of average difference from the intended dimension. This is followed by step cut, whole cut and disk-2 cut. Thus, this shows which tool path is the most suitable for high precision machining. The results above are generated by using the same cutting parameters for the entire tool path scheme. However, it is impossible to require cutting parameters which are suitable for the entire cutting path. Therefore, the result would be varied from the optimal result of the tool path scheme selected.

5. Conclusions

The main purpose of this work is to explorer the behavior of different cutting tool path for taper turning. The conclusions o this study are:

1) All tool path schemes are suitable for micro turning operation as the error range of the machined part is relatively low.

2) The four types of cutting path scheme are suitable for different situation in operation. The descriptions of application of cutting path scheme are stated below:

a) Whole cut - It is suitable for small metal removal and/or when short generation time is needed.

b) Step cut - The most suitable cutting path scheme in micro turning operation because the deflection and bending stress produced on the workpiece can be kept to minimum using its cutting step size

c) Reverse cut - This type of cutting path is suitable when using reverse faced tool (face of tool is heading in opposite direction)

d) Disk-2 cut - It is suitable when using a tool with dual cutting face as this cutting path will utilize both of them.

3) Tool with small rake angle is required during micro turning operation in order to be kept to minimum level of the undercut produced on the feature of the workpiece.

4) Many defects may occur during operation such as undercut, burr and chipped off surface.

References

McGeough J, (2002), Micromachining of engineering materials, Dekker, New York.

Lin SCJ, (1994), Computer numerical control, Essentials in programming and networking. Delmar, New York.

M. Azizur Rahman, M. Rahman, A. Senthil Kumar, H.S. Lim and A.B.M.A. Asad, (2006), Development of micropin fabrication process using tool based micromachining, DOI 10.1007/s00170-004-2270-9, International Journal of Advanced Manufacturing Technology, 27: 939–944.

H.S. Lim, A. Senthil Kumar and M. Rahman, (2002), Improvement of form accuracy in hybrid machining of microstructures, Journal of Electronic Materials, 31 (10) 1032–1038.

K. Egashira and K. Mizutani, (2002), Micro-drilling of monocrystalline silicon using a cutting tool, Precision Engineering 26 263–268.

M. Azizur Rahman, M. Rahman, A. Senthil Kumar and H.S. Lim, (2005), CNC microturning: an application to miniaturization, International Journal of Machine Tools & Manufacture, 45 631–639.

Zinan Lu and Takeshi Yoneyama, (1999), Micro cutting in the micro lathe turning system, International Journal of Machine Tools & Manufacture, 39 1171–1183.

T. Masuzawa, (2000), State of the art of micromachining, Annals of the CIRP, 49 (2) 473–488.

Lim HS, Kumar AS and Rahman M, (2002), Improvement of form accuracy in hybrid machining of microstructures, Journal of Electron Materia,l 31(10):1032–1038.

Z. Lu and T. Yoneyama, (1999), Micro cutting in the micro lathe turning system, International Journal of Machine Tools and Manufacture, 39 1171–1183.

Lu Z and Yoneyama T. (1999), Micro cutting in the micro lathe turning system, International Journal of Machine Tools manufacturing 39:1171–1183.

Table 1. Cutting parameter for cutting a taper on brass rod

Cutting Parameter			Unit
Spindle Speed	Roughing	1200	rpm
	Finishing	1500	rpm
Depth of Cut	Roughing	0.5	mm
	Finishing	0.2	mm
Feed Rate	Roughing	40	mm/min
	Finishing	10	mm/min
Cutting Thickness	Constant	0.5	mm

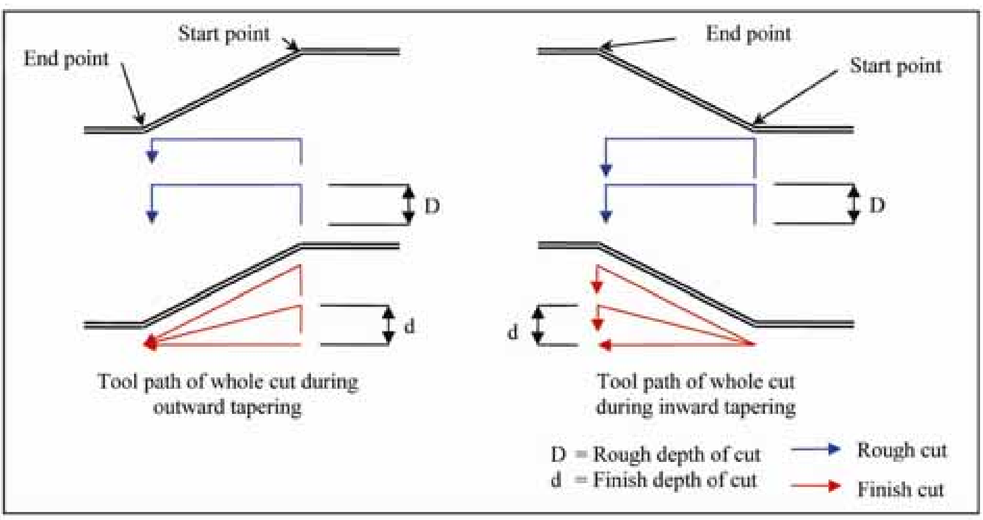

Figure 1. Whole cut tool path of tapered cutting

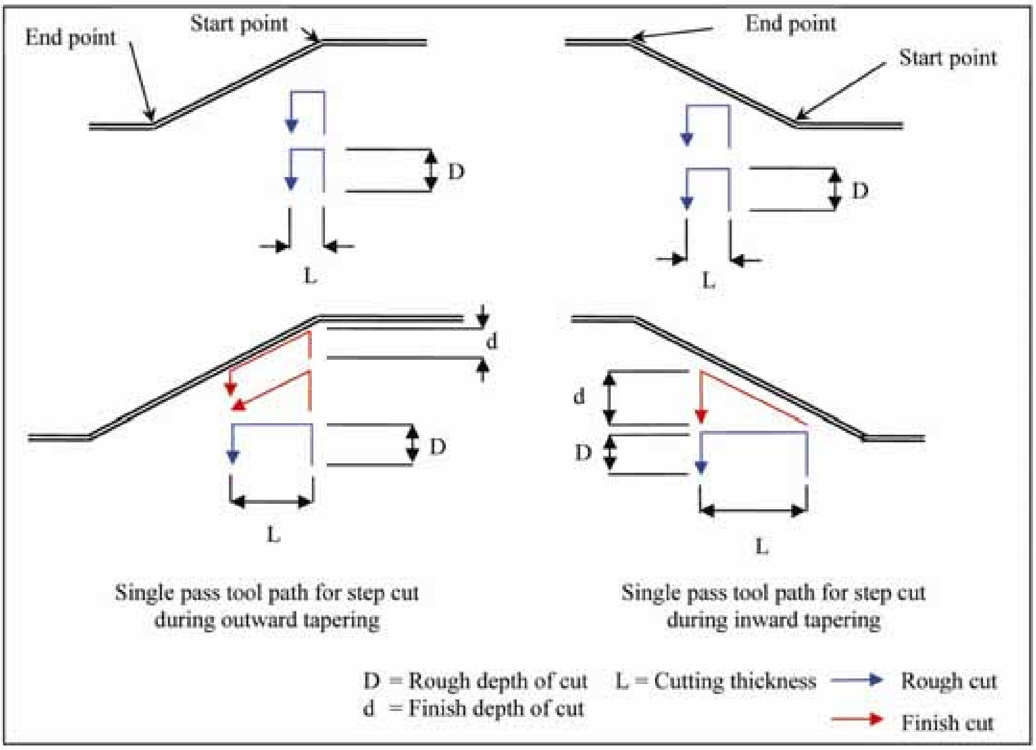

Figure 2. Step cut tool path of tapered cutting

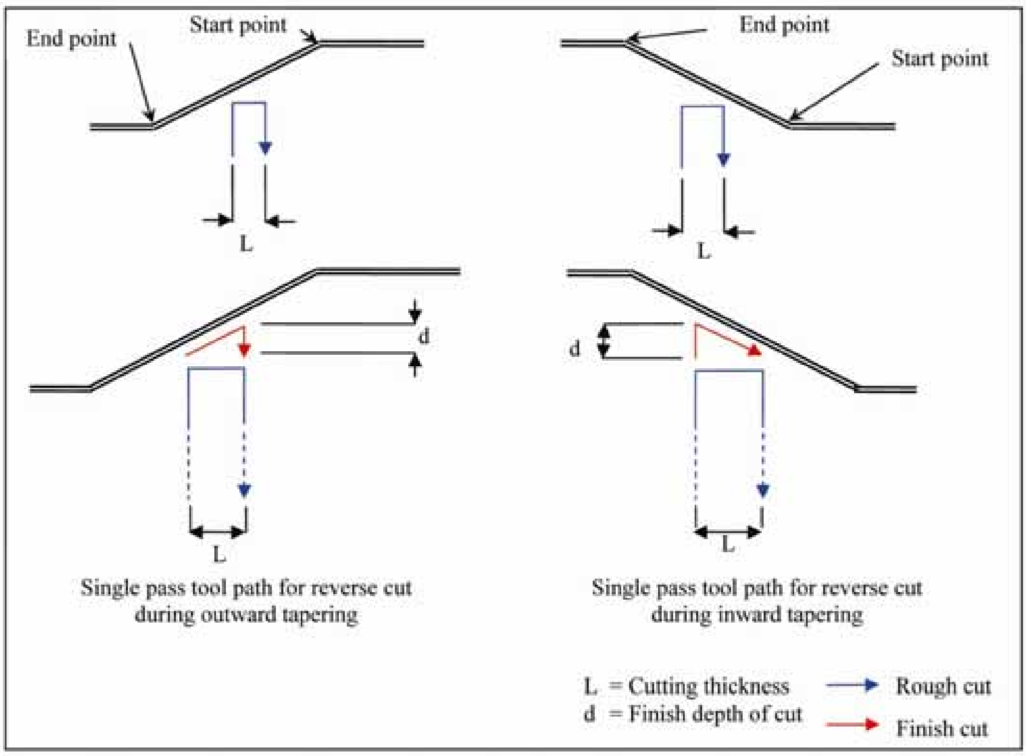

Figure 3. Reverse cut tool path of tapered cutting

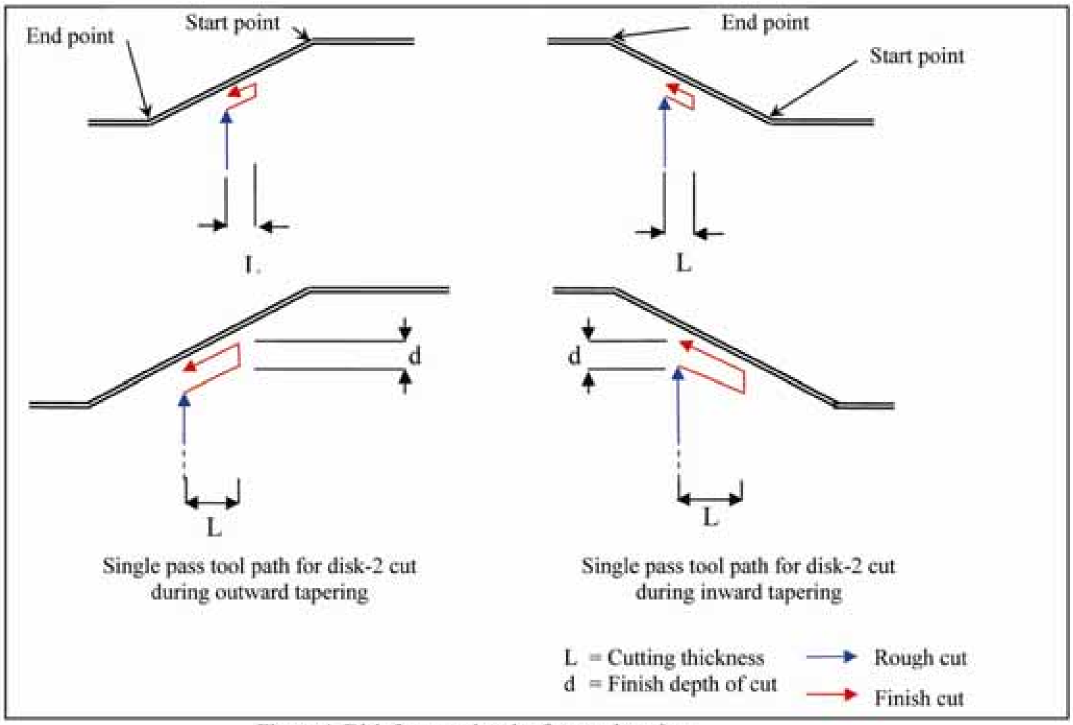

Figure 4. Disk-2 cut tool path of tapered cutting

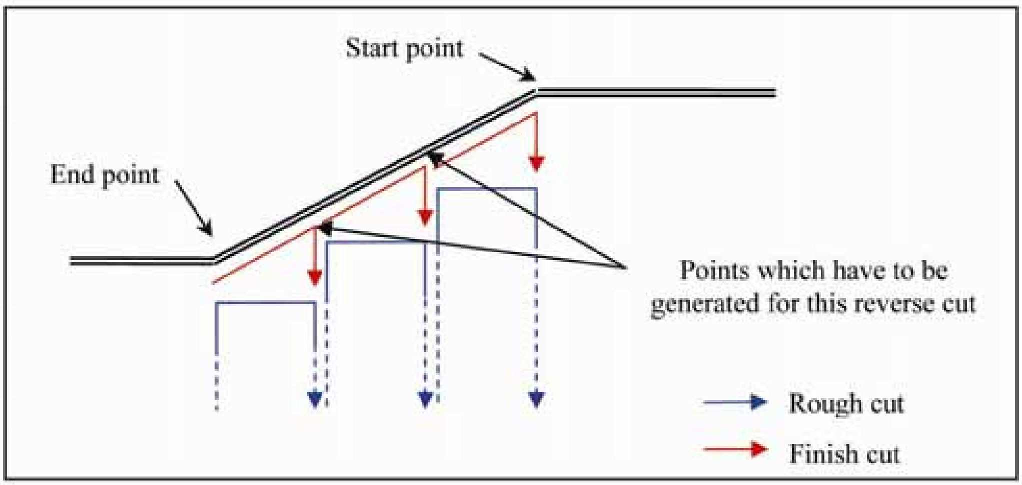

Figure 5. Points that need to be defined between start point and end point by software in reverse cut scheme

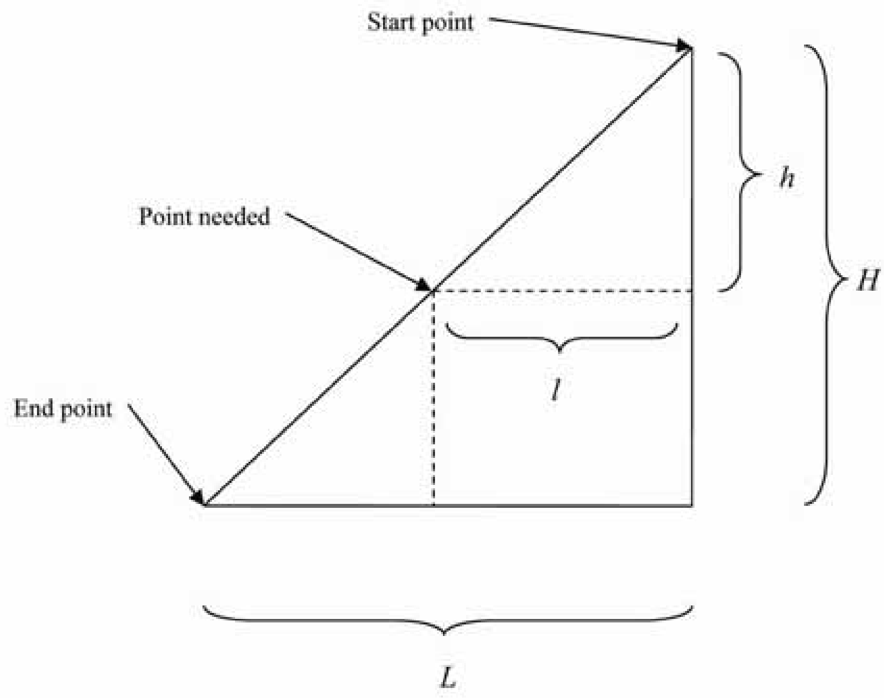

Figure 6. Picture to aid the definition of point between start point and end point

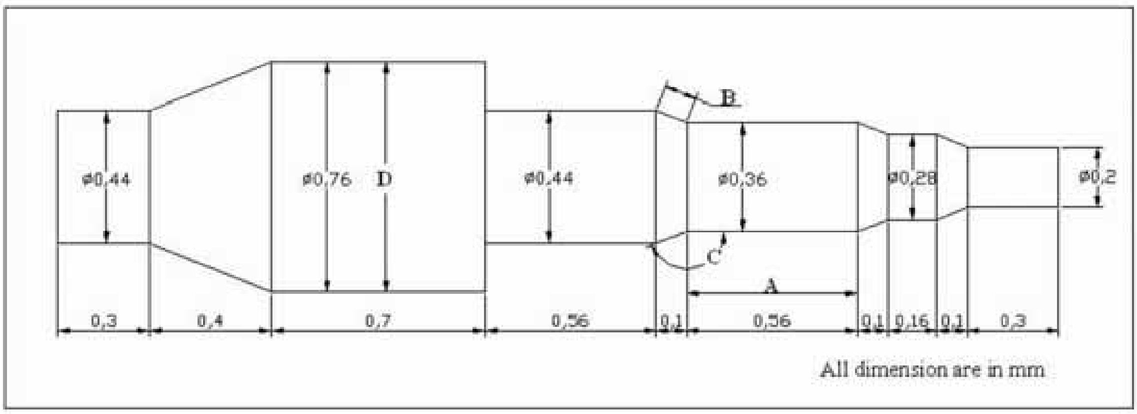

Figure 7. Dimensions of the workpiece feature for case study

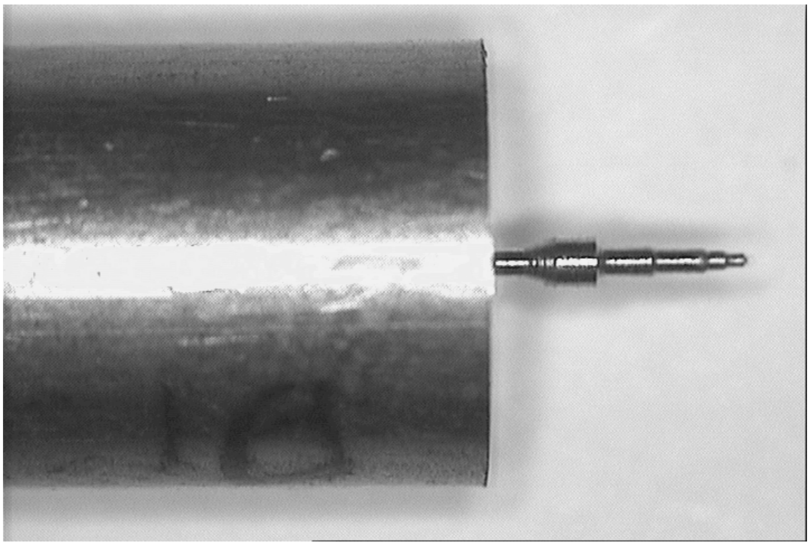

Figure 8. Sample of taper tool cutting of brass

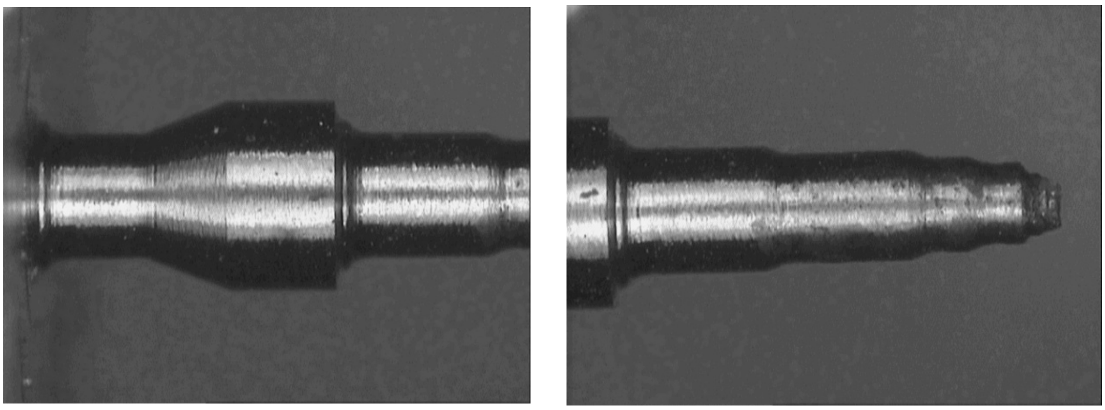

Figure 9. Taper cutting of brass rod using whole cut tool path.

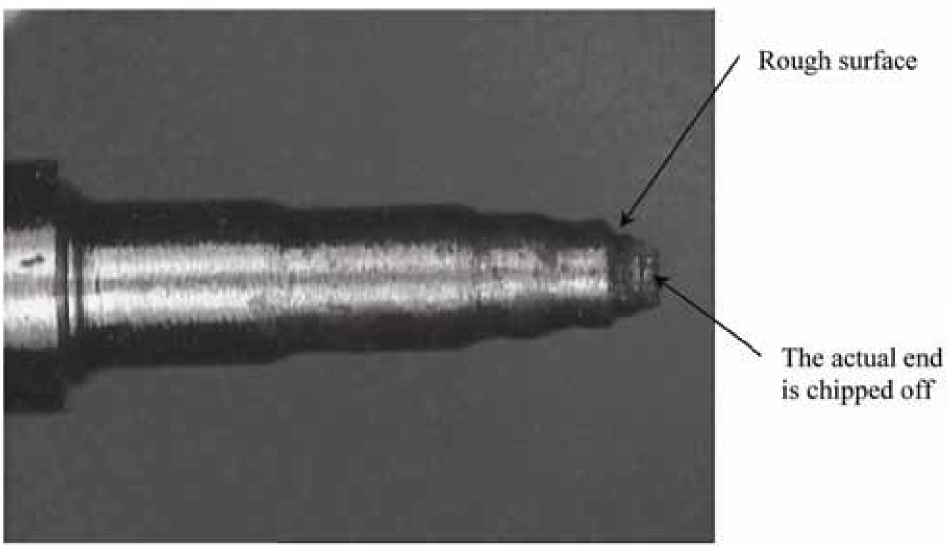

Figure 10. Defects in whole cutting operation

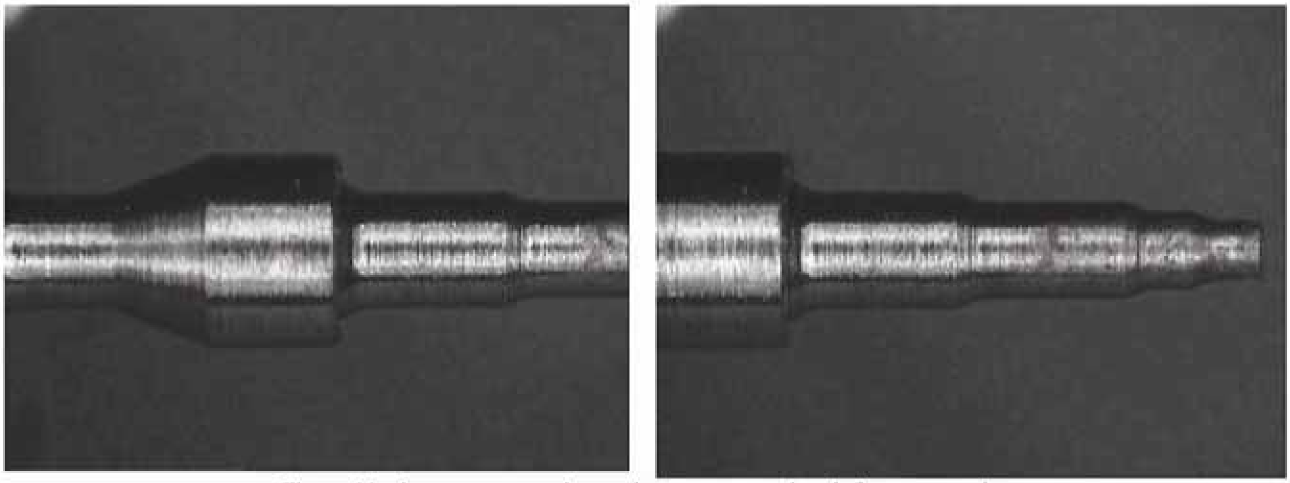

Figure 11. shows a part produce using step cut tool path for taper cutting.

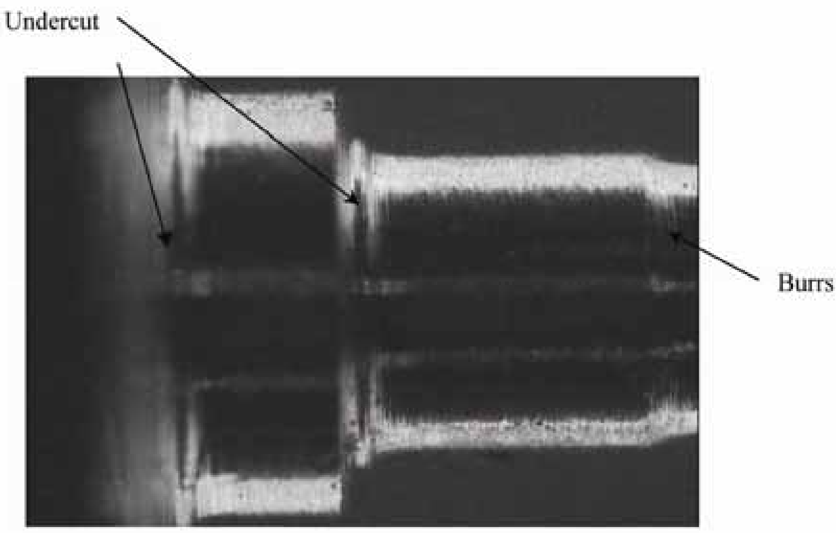

Figure 12. Defects in step cutting operation (scale of 1:0.0026)

Figure 13. A part machined using reversed cut tool path for taper cutting.

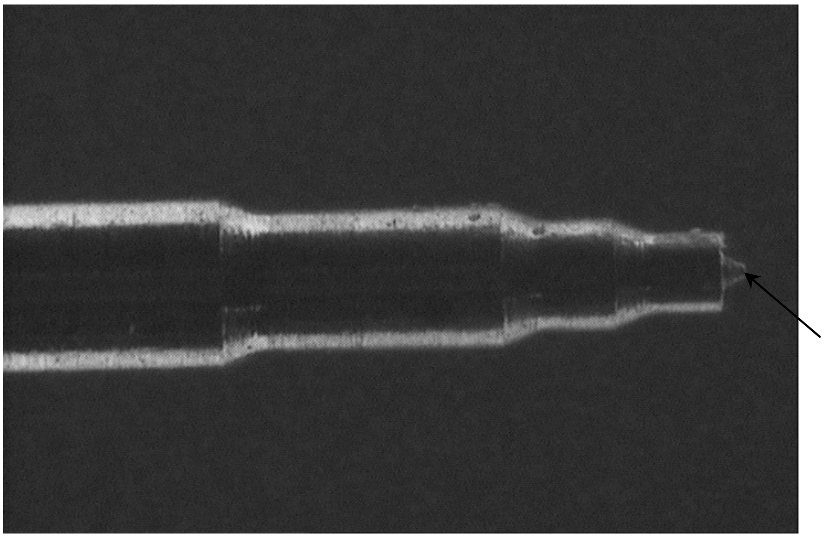

Figure 14. Defects in disk-2 cutting operation (scale of 1:0.000392)

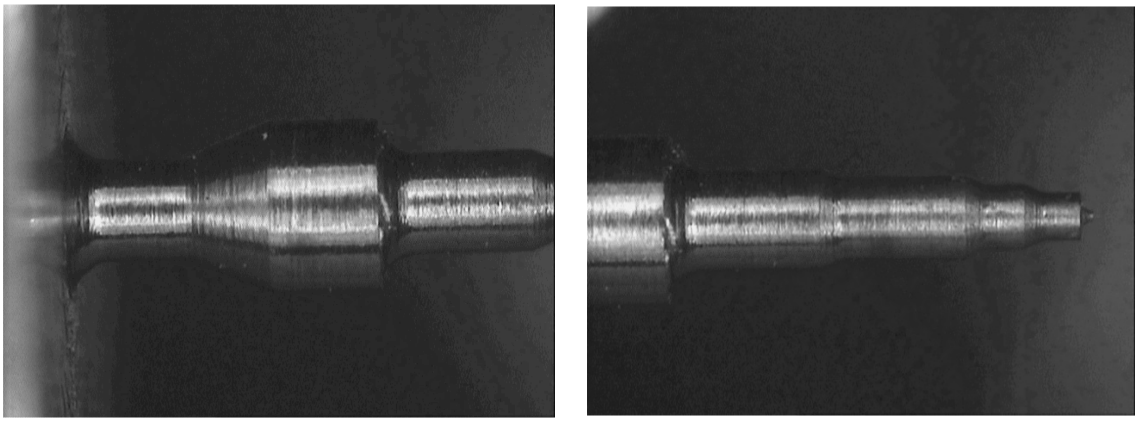

Figure 15. A part produce using Disk-2 cut tool path for taper cutting.

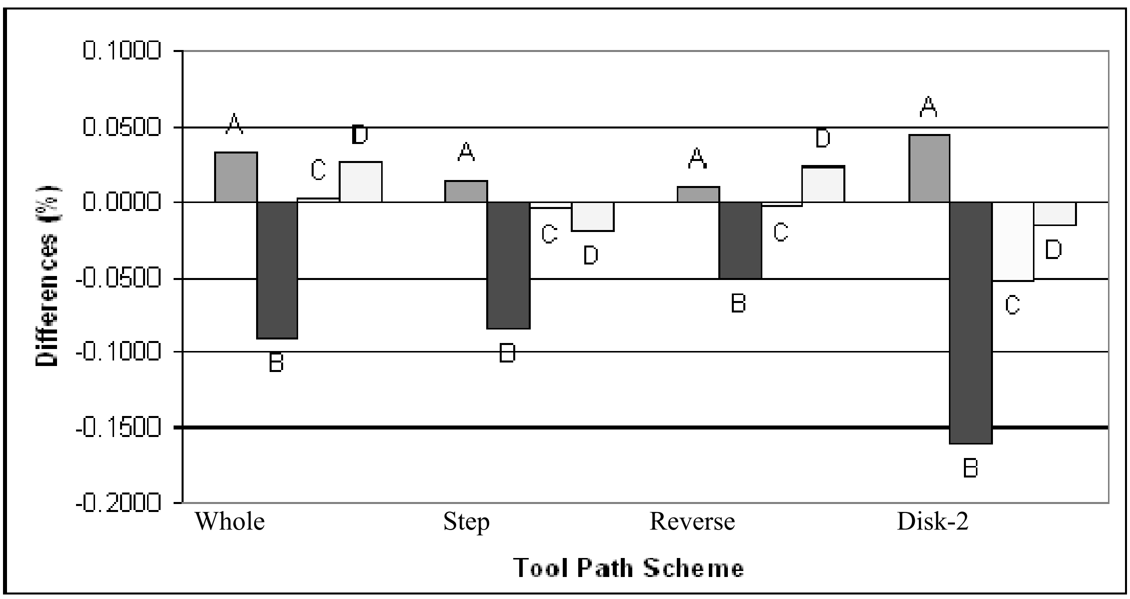

Figure 16. Graph of average percentage difference of the intended dimension from the machined part