

Investigation of variation in offset values of different sections of machining elements along the central axial line

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Abstract. Eccentricity is defined as deviation from the circular path and it occurs due to clamping deviation or geometric imperfection when machining elements revolves around the line parallel to the machining element axis, but not around the machining element axis. In this paper, the variation of offset values along the central axial line of different small sections of spindle, tool holder and milling cutter was explored. This work was undertaken by the observation that eccentricity implies adverse impact on the material properties, tooling properties, machining elements, machine system etc. The problem solution was found out by measuring the whole body of spindle, tool holder and milling cutter with Swiss Dial Gauge after dividing them into small sections along the z level axis. After measurement, analysis was done of the recorded data on software's by illustrating their actual profiles and variation along the Centre line of small divided sections at different orientations. After analysis, we might get the eccentricity of one part with different offsets in z level through offsets in x and y directions and profiles of elements exhibiting less offset values. This work can find its importance in various industries where milling machines are used for machining jet parts, automobile parts and many other etc.

1. Introduction

Eccentricity has been become one of the most important parameter that needs attention to be researched further to make improvements in the different machining cutting parameters, machine system, work piece dimensional accuracy and surface finish in order to fulfil the customer requirements. Previously many engineers performed theoretical analysis, experimental analysis on the milling cutter by taking eccentricity into account in different frame of mind such as eccentricity effects in turn milling operations, effects of cutter eccentricity on the cutting forces and many others etc.

Pasko, R. –Przybylski, L. & Slodki, B. [1] and Schulz H.; Moriwaki T., [2] bring off the comparison between the conventional machining and high speed machining in terms of cutting speed, roughing and finishing parameters etc. and in result they stated the high speed machining as the modern technology which gives best accuracy and quality of work piece and at the same time it decreases cost and machining time.

Cutter eccentricity is also named as cutter runout. Yun and Cho [3] presented the simple and improved method for finding out 3 dimensional cutting force co-efficients irrespective of the cutting conditions and cutter rotation angle and based upon their study they stated that cutting force co-efficients for a given cutter and work piece can be determined as constant values etc. Wan and Zhang [4] presented different methods for calibrating the cutting force co-efficients and cutter runout and in result they compared different methods and list down the methods specialties. Wan, Zhang, Dang and Yang [5] presented the new and simplified method for the calibration of cutting force co-efficients and cutter



runout for cylindrical milling using instantaneous cutting force instead of the average one and in result they stated that the validation shows that the predicted and measured results have good agreement both in shape and in magnitude. Arizmendi et al. [6] investigated the effects of cutter runout on surface topography including both grinding errors and tool axis offset for peripheral milling. Keith A. Hekman and Steven Y. Liang [7] proposed an on-line methodology for the monitoring of end milling cutter runout and the results showed that the runout characteristics vary in response to the change of cutting parameters.

Liu, Wu, etc. [8] performed the spectral analysis of milling forces in order to distinguish them from the effects of chip load, tool wear and tool eccentricity and their study proposes a new idea of identifying tool eccentricity and wear with force itself. Cao, Zhao, LI and Zhu [9] presented the influence of cutter eccentricity on the cutting forces in ball end finish milling. They developed the mathematical models for the chip thickness etc. considering the physical dimension of the cutter and inclination angle. The results are, that the offset magnitude affects the cutting forces of both the current cutting edge and adjacent cutting edge etc. Kline and De Vor [10] also discussed the influence of displacement vector e_c at the entry angle of the tooth when it starts to cut and exit angle of the tooth when it ends the cut. Not only on this but also discussed the cutting geometry and chip thickness.

The main objective of the present work is by performing experiments and by measuring the whole body of the element at every possible orientation to analyze the behavior of central axial line with offset values and might found out the eccentricity of one part and based on that we might found out the whole combination exhibiting lowest offset values means near to the central axial line.

2. Combination combining eccentricity with offset magnitude

Combination consists of three elements spindle, tool holder and milling cutter. Fact is that only the milling cutter does not exhibits eccentricity, there are other two machining elements as well which took part in the increment of eccentricity. Figure 1a and 1b shows the sample of combination combining eccentricity with their offsets.

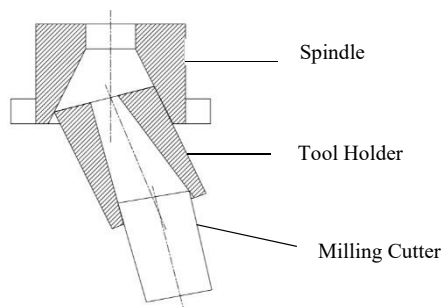


Figure 1a. Sample of combination combining eccentricity

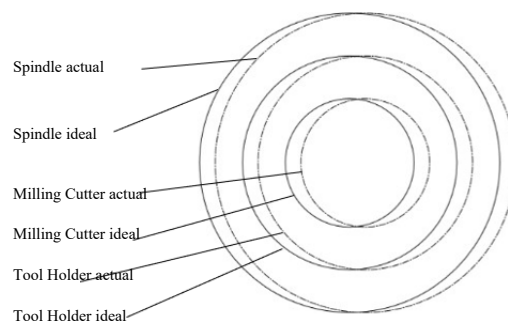


Figure 1b. Combination combining eccentricity with their offsets

The reason behind analyzing the central axial line was that the eccentricity is directly interlinked with the cutting forces. In other words you can say that eccentricity is directly proportional to the cutting forces. More eccentricity more cutting forces and if there are more cutting forces than it will damage the machine tool in different perspectives such as tool deflection, tool wear etc. Not only this but also harmful for the spindle, tool holder, different shafts within the machine, bearings, work piece surface finishing, precision and accuracy etc. Just because of its adverse effect on different elements and properties it needed to be researched more and more in order to overcome problems.

3. Measurement Setup and Data Recording Procedure

All the experiments were performed and measurements were taken or recorded on high speed machining which was having about 20000 rpm. The tool holder which was used for the measurement was

BT40/ER25*100H (G2.5 20000 RPM) and the milling cutter was 8 mm in diameter having four tooth's. The material which is best in today's world and are mostly used in industries is tungsten carbide so for these experiments the same material was selected so that it would be helpful for the industries. The bodies of different elements from different levels were measured by using the Swiss SYLVAC 905.4321 Dial Gauge which was having 0.001 mm resolution.

Firstly the measurement procedure was done with spindle and the sample of measurement setup for spindle is shown in figure 2a. Its internal taper surface length was measured and then divided into 5 levels as shown in figure 2b. The circumference path of the spindle was divided into 8 points as shown in figure 2c means 45^0 angular distance from any selected point to the next or previous like $360/8=45^0$ and was marked with chalk on the machine spindle at its external surface. The spindle was set at 0^0 and the dial gauge was attached at point 1 and at level 1 for the measurement of its imperfection. After attaching, the gauge value was set at 0 value so that when we rotate the spindle it shows the deviation from 0 value and other thing was to make calculations easy. The spindle was rotated for about 2 revolutions and was stopped at the same position at 0^0 and the imperfection that the dial gauge showed was noted down. Slightly rotated from point 1 to point 2, the imperfection was noted down and the angular distance that the spindle covered was 45^0 . In the same way from point 2 to point 3 and point 3 to point 4 and up to point 8. The total number of readings recorded in one complete revolution was 8 and the spindle was rotated for 5 revolutions means across the circumference path at particular level 1 each point imperfection was recorded for 5 times and at last taken the average.

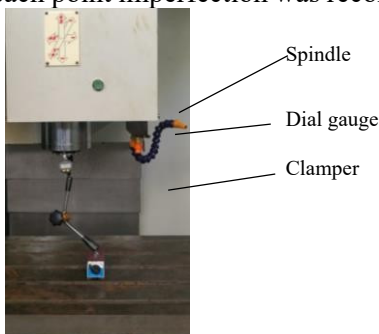


Figure 2a. Measurement setup for spindle

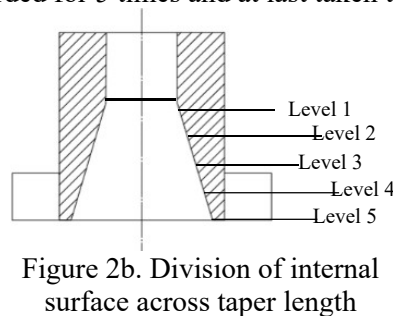


Figure 2b. Division of internal surface across taper length

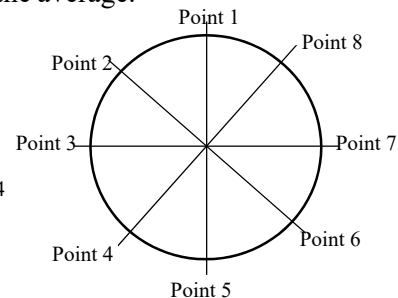


Figure 2c. Division of internal surface across the circumference path

After the measurement of level 1 the gauge was set free and slightly moved down to point 1 and level 2 of spindle. The same procedure was done with this level and with the next levels 3, 4 and 5 as well. In simple words each point across each level was measured 5 times and at last taken the average as shown below in table 1.

Table 1. Average values of spindle at 0^0

Levels	Point # 1	Point # 2	Point # 3	Point # 4	Point # 5	Point # 6	Point # 7	Point # 8
1	0.012	0.013	0.014	0.014	0.015	0.015	0.015	0.013
2	0.006	0.007	0.007	0.008	0.008	0.008	0.008	0.007
3	0.005	0.006	0.007	0.008	0.008	0.008	0.008	0.007
4	0.007	0.007	0.007	0.008	0.008	0.008	0.008	0.008
5	0.003	0.004	0.004	0.004	0.005	0.005	0.004	0.003

After the complete measurement of spindle the next turn was of tool holder and the measurement setup of tool holder is shown in figure 3a. As the internal surface of tool holder was taper like spindle so the same steps were repeated. Firstly it was divided into 5 levels across the taper length shown in

figure 3b and into 8 points across the circumference path shown in figure 3c. Spindle and tool holder were set at 0^0 and the gauge was attached with the tool holder at point 1 and at level 1. The same measurement steps were repeated as in case of spindle with the tool holder at 0^0 . After the complete body measurement of tool holder at 0^0 , the tool holder was set free from the spindle and 180^0 rotated and again holded inside the spindle for measurement. The gauge was again attached with the tool holder at level 1 and point 5 of tool holder. The same above procedure as done with the spindle at 0^0 and with the tool holder at 0^0 was done with the orientation of tool holder at 180^0 . In simple each point across each level was measured 5 times and at last taken the average. After the complete measurement of spindle and tool holder at different orientations, the final turn was of milling cutter and sample of measurement setup is shown in figure 4a. In the same way as spindle and tool holder, surface length of milling cutter was divided into 5 levels as shown in figure 4b and into 4 points across the circumference path because of its four tooth's as shown in figure 4c. Milling cutter was having 8 orientations such as 0^0 , 90^0 , 180^0 , and 270^0 when spindle and tool holder set at 0^0 and 0^0 , 90^0 , 180^0 , and 270^0 when spindle set at 0^0 and tool holder set at 180^0 . For the measurement of milling cutter at 0^0 , the spindle and tool holder was set at 0^0 , the milling cutter was holded inside the tool holder at 0^0 means point 1 of spindle, point 1 of tool holder and point 1 of milling cutter were in-line. The gauge was attached with the milling cutter at point 1 and at level 1 and the same procedure was repeated but in this case only 4 points were measured in 1 revolution. Actually it was rotated for 5 revolutions means each point was measured 5 times and at last taken the average. The next 4 levels were measured in the same way as level 1. After this milling cutter was released and slightly 90^0 rotated and again holded inside the tool holder and 4 points across 5 levels were measured 5 times and at last taken the average. The same procedure for the orientation of milling cutter at 180^0 and 270^0 . After this, the tool holder was set free and 180^0 rotated and again holded inside the spindle. The same measurement procedure was repeated for the next 4 orientations of milling cutter as well.

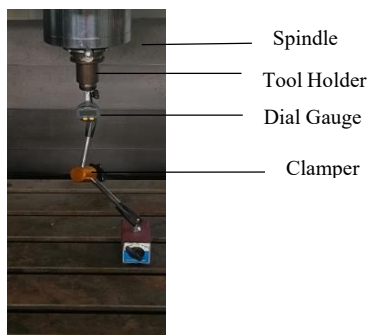


Figure 3a. Measurement setup for tool holder

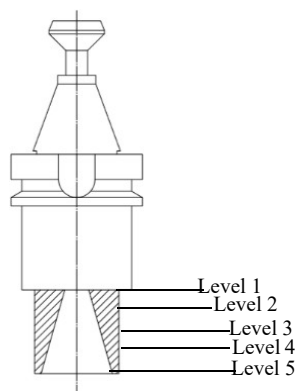


Figure 3b. Division of tool holder across the taper length

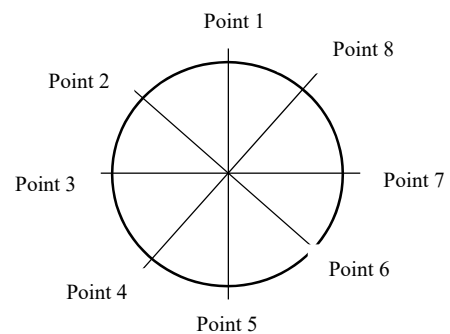


Figure 3c. Division of tool holder across the circumference path

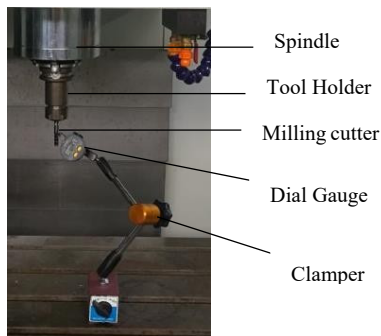


Figure 4a. Measurement setup for milling cutter

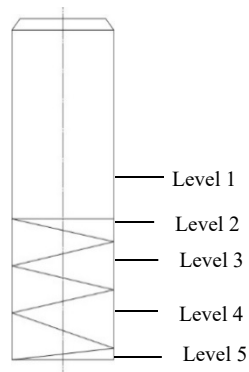


Figure 4b. Division of milling cutter across the length

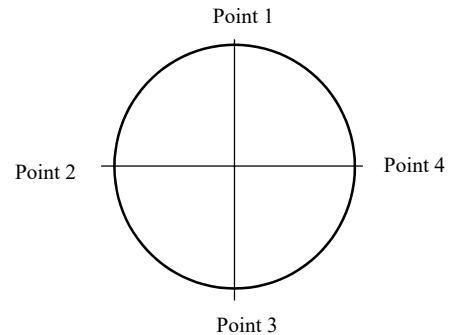


Figure 4c. Division of milling cutter across the circumference path

4. Investigation and Argumentation

The analysis began with the first element that was spindle. The average values that were recorded during experimentations as shown in table 1 were plotted on the solid works software. This element was having just 1 orientation due to fixing within the machine. All level values were plotted in such a way that firstly in case of level 1, the ideal circle was drawn then it was divided into 8 points. As 8 points were noted down for 1 particular level during experiment so by using these values 8 points were plotted on that divided circle. After plotting by using the spline command those 8 points were joined together and a new circle was plotted. Now there are 2 circles, ideal circle and the practical circle that was drawn through point values. When there are 2 circles then definitely they will be having 2 Centre's, by finding out the distance from the Centre of ideal circle to the Centre of practical circle we got the first offset value in z direction. Along with the measurement of z direction, the offset values in x and y directions were also measured. In the same way, all other 4 levels were plotted and their offset values were found out and are shown in table 2. It can be observed from the table 2 offset values that these are not equal values which indicated that this was not straight line or not having the linear relation in between them. At 1 particular level the offset value was large then at another particular level the offset value was small and again at next particular level the offset value was large which finally pointed out that the central axial line was not straight and figure 5 was plotted through using the offset values of table 2 and each offset value was amplified to 500 times in order to show.

Table 2. Offset values of spindle at different levels

Levels	Offset value in X-direction	Offset value in Y-direction	Offset value in Z-direction
Level 1	0.00053	-0.00150	0.0016
Level 2	0.00050	-0.000906	0.001034
Level 3	0.000506	-0.001513	0.001595
Level 4	0.00056	-0.0005589	0.00079
Level 5	0	-0.001014	0.001014

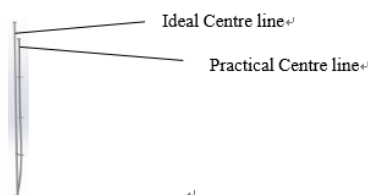
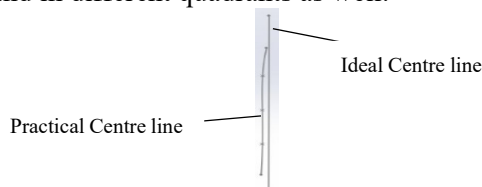
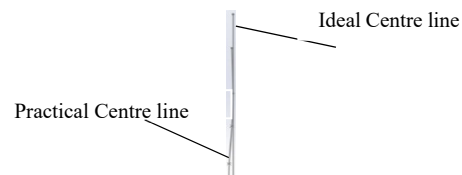


Figure 5. Central axial line of spindle

After spindle, the next turn was of tool holder. In the same way as spindle, different levels at different orientations of tool holder were plotted and their central axial lines were plotted as shown in figure 6a and 6b. Figure 6a shows the central axial line when tool holder was set at 0° and figure 6b shows the central axial line when tool holder was set at 180° . Each offset value was amplified to 500 times in order to show. Centre lines of tool holder at different orientations were compared with each other, we observed that both are different curves with different offset values in all 3 directions, not even close to each other and in different quadrants as well.

Figure 6a. Central axial line of tool holder at 0° Figure 6b. Central axial line of tool holder at 180°

Now at the end, the turn for the most important element which was milling cutter. It was an important element because it was having several orientations depending upon different orientations of tool holder. For the analysis, the same procedure was repeated as done with the spindle and tool holder different orientations. In other words 8 orientations, 8 different central axial lines as shown below and each offset

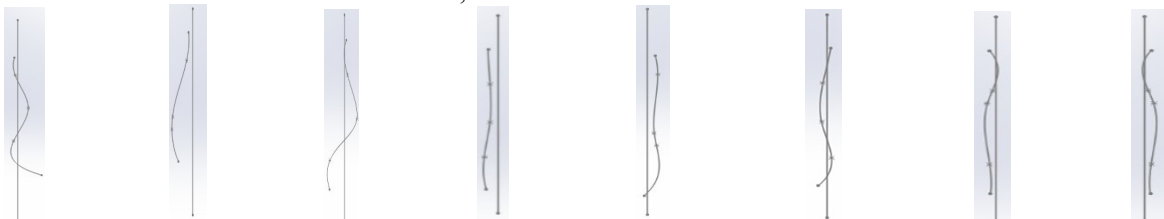


Figure 7a Figure 7b Figure 7c Figure 7d Figure 7e Figure 7f Figure 7g Figure 7h
value was amplified to 200 times. Figure 7a shows the line when the milling cutter was set at 0° , 7b shows the line when the milling cutter was set at 90° , 7c shows the line when the milling cutter was set at 180° and 7d shows the line when the milling cutter was set at 270° whereas the spindle and tool holder remained at 0° . Figure 7e shows the line when the milling cutter was set at 0° , 7f shows the line when the milling cutter was set at 90° , 7g shows the line when the milling cutter was set at 180° and 7h shows the line when the milling cutter was set at 270° whereas spindle was set at 0° and tool holder set at 180° . By taking the offset values of different orientations of milling cutter into counter, we observed that there was a large variation between the offset values of every particular level at every particular orientation. All the central axial lines are in the form of curve even we were thinking that if it will not be a straight line but it would be like the line. This all was just because of the surface error at different positions of the elements whereas the shape of the elements across the circumference path can't be a circle and their point values across the taper length can't be in-line which was proved through plotting the profiles of elements on solid works software.

5. Conclusion

Through finding different offset values in every particular orientation, we might found out the eccentricity of small section so go for that orientation of every element which was exhibiting the offset values near to ideal Centre line. It was very important to know that because during machining operation we don't bother the position of element and can't have the good dimensional accuracy of the work piece as before so through this we might come to know about the importance of position of every element in order to increase the accuracy and precision because at every orientation of different elements, we obtained different curve with large variation as compared to each other. Once you machined a part and next time just by unintentionally changing the position of any element gave you different accuracy and precision with different surface finish quality as well. People think about this a lot that what happened to the machine before it was giving different sizes and now it is giving different sizes with the same cutter or element but they are not aware with the importance of every element position or orientation.

Better selection in terms of orientation or position of every element might give you high accuracy and precision with which the demands of customer can be fulfilled easily or in other words we can say that we can have better world than before in manufacturing engineering. Today is the world of advancement and so with this research outputs can be better.

Acknowledgement

The authors acknowledge the National Natural Science Foundation of China (51375099, 51375100) for their supports.

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