Effects of Clamping of Machining Elements at Different Orientations on Eccentricity and Surface Roughness

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***Abstract*—Tool eccentricity is considered as the misalignment between the axis of rotation of the spindle and the axis of symmetry of the tool whereas surface roughness is enumerated by the abnormalities in the way of the typical vector of an actual superficial from its superlative form. A small eccentric offset may cause negligible effect in macro-scale milling, while in micro-scale milling, it can result in unstable periodic variations in chip load, surface roughness and cutting forces which can cause destruction in the whole machining system and will provide hurdles in the way of fulfilling the customer demands which are actually the product having high dimensional accuracy of the work piece along with high surface finish. In this case study, solution for the decrement of eccentricity and surface roughness value was provided in the form of clamping of spindle, tool holder and milling cutter at different orientations. It was proved through performing numerous experiments on CNC vertical milling by measuring the geometric imperfections of all the machining elements at different orientations with Swiss SYLVAC dial gauge and 24-test cuts were performed with different cutters by making combinations of machining elements at different orientations and after every test-cut surface roughness value was measured MarSurf PS1. Both indicated that orientations affects the eccentricity and surface roughness highly and through this technique customer demands can be fulfilled in a better way.**

***Index Terms*—clamping, orientations, eccentricity, imperfections, roughness, misalignment**

I. Introduction

Market requirements such as the greater fabrication rate by decreasing lead time, the produced work piece having low manufacturing cost along with low tooling cost and good surface finish with high accuracy and [1] precision in all extents, process constancy of the machine and etc. grants many challenges. But there are numerous critical factors which bring off disruption in the contentment of the above chores and eccentricity is one of them. Many investigators slogan the term eccentricity as run out in many investigation papers because both designates disturbance from their path and have the same geometric parameters. The cutter eccentricity or run out consists of two geometric or detracting parameters, one is eccentric offset magnitude vector e_c and second one is angular location vector λ_c as shown in Fig. 1. Tony L. et al., [1] discovered the role of cutter eccentricity on cutting forces and surface finish and for this they carried out time-domain milling simulations and different experiments for measuring the milling forces. Irene, Joan and Hernan [2] had discussed the role of eccentricity, feed and helix angle on the exterior contour which was obtained in side milling by using cylindrical tools. Liu [3] completed a case study on the spectral characteristics of milling cutting forces in order to differentiate the effect of cutter wear, cutter eccentricity and chip load from cutting forces. Qingyuan Cao [4] proposed the experimental and theoretical study that how cutter eccentricity geometric parameters offset magnitude ec and angular location λc influence the cutting forces by surrounding with different factors such as chip thickness etc. Uysal [5] proposed the aspect of cutter eccentricity on tool wear and machined surface quality for different cutting conditions by cultivating an extensive geometric process model and experiments were performed for different random inserts. Zhu [6] proposed the new approach to model five-axis cutting forces along with the establishment of parametric chip thickness model for five axis cutting force prediction and decomposition of chip thickness model to cutter run-out. They analyzed the effects of cutter run-out on cutting forces. Xiubing Jing [7] put forward a static run-out measuring method from the spindle, tool holder system by using the CCD laser displacement sensor. Matsumura and Tamura [8] given out the analytical model for the evaluation of the role of cutter run-out on the cutting forces due to the accompanied of milling operations by the cutter run-out of the cutter cutting edges which was basically persuaded by the clamping deviation or clamping error in between different machining elements such as between tool and spindle. Xing Zhang [9] given out an instantaneous uncut chip thickness model during cutter/work piece engagement with run-out effect and puts forward an enhanced SDM for milling stability prediction. Ding Chen [10] proposed an optimization method for calibrating cutting force coefficients and cutter run-out parameters by minimizing the difference between the measured force and predicted force for all force components.

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In this paper, a technique was discussed through which final eccentric error acting at the cutting edge of milling cutter can be reduced along with the surface roughness value. In order to prove it, experiments were carried out at static condition and geometric imperfections were measured from the whole combination at different orientations. Moreover, 24-test cuts were carried out with line milling operation and after every test-cut surface roughness value was measured with MarSurf PS1. Their results indicated that orientations affect the eccentricity and surface roughness highly.

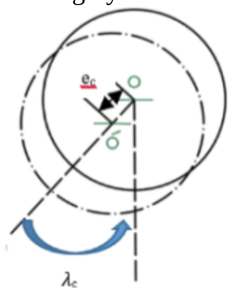


Figure 1.Offset magnitude vector e_c and location angle vector λ_c.

II. Eccentric Model Based on Geometric Imperfection and Clamping Deviation

The combination consists of three machining elements spindle, tool holder and milling cutter. There are two factors which are responsible for the cause of eccentricity and that are geometric imperfection and clamping deviation. There are two types of run-out, static run-out and dynamic run-out. Static run-out arrives from manufacturing issues or geometric imperfection, spindle error, thermal deformation, clamping deviation due to chip or dirt, coolant or oil layer present inside the taper when fixed, or insert settings. Dynamic cutter run-out arrives from uneven cutting forces or cutting force variation, unbalancing of spindle, tool holder and milling cutter, irregular evolution of tool wear and etc. Fig. 2 shows the section view of the combination displaying the eccentric errors based on geometric imperfection and clamping deviation vision.

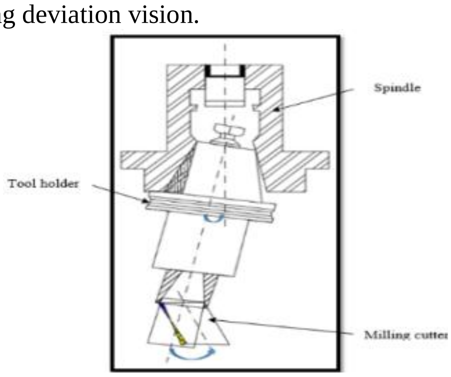


Figure 2. Section view of 2-D model exhibiting eccentric errors

III. Experimental Setup

Vertical milling center (VMC 1000P) has high metal removal rate and it has very high ability to create the difficult geometries within a work piece. All the experiments were performed on (VMC 1000P) having 20000 rpm as shown in Fig. 3 and the model no. of the tool holder used for these experiments was BT40/ER25*100H (G2.5 20000RPM) as shown in Fig. 4. 4 milling cutters were used having different diameters such as (2 cutters of 8mm, one for 10mm and one for 12mm) cutting edges (4 and 6) and same material tungsten carbide as shown in Fig. 5. The imperfections was measured with Swiss SYLVAC 905.4321 Dial Gauge which was having 0.001 mm resolution as shown in Fig. 6 and surface roughness with Marsurf PS1 as shown in Fig. 7 and # 45 material is used for the work piece.

Figure 3. VMC 1000P.

Figure 4. BT40/ER25*100H (G2.5 20000RPM).

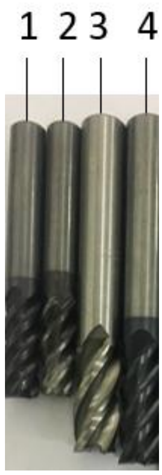


Figure 5. Milling cutters of different sizes.

Figure 6. SYLVAC dial gauge.

Figure 7. Surface roughness tester MarSurf PS1.

IV. Experimental Procedure for the Measurement of Geometric Imperfections

A. Spindle

Spindle internal circumferential surface was divided into 8 points as shown in Fig. 8 and internal taper surface length was divided into 5 levels as shown in Fig. 9. For the measurement, spindle was set at 0^0 and then dial gauge was moved inside the spindle to level 1 and attached with the internal surface from at point 1. After attaching firstly spindle was rotated for 2 revolutions for the adjustment of the readings and then stopped at the same point at point 1 the imperfection that the gauge displayed was noted down and then spindle rotated from point 1 to point 2, point 2 to point 3 and in the same way up to 8. In this way 8 points were noticed down in complete revolution and it was rotated for four revolutions more in order to have 5 values across each point and at the end average was calculated in order to avoid error. After level 1, it was loosed and moved down to level 2 and in the same way as level 1, it was measured and at the end average values were calculated. Same procedure for level 3, 4 and 5. As it was mend within the machine so it was having just one orientation and that was at 0^0.

TABLE I. Average Values of Tool Holder at Spindle Set at 0^0 When Spindle Set at 0^0

Levels	Point # 1	Point # 2	Point # 3	Point # 4	Point # 5	Point # 6	Point # 7	Point # 8
1	-0.003	-0.002	-0.002	-0.003	-0.003	-0.004	-0.004	-0.004
2	0.005	0.006	0.006	0.001	0	0	0.001	0.002
3	0.004	0.007	0.007	0.004	0.001	0.001	0.002	0.001
4	0.003	0.008	0.007	0.006	0.002	0.001	0.002	0.001
5	0.007	0.009	0.011	0.008	0.004	0.006	0.005	0.006

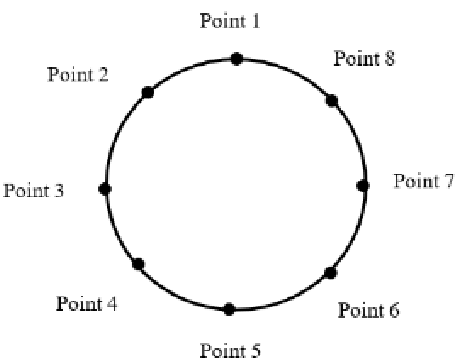


Figure 8. Division of Spindle internal surface along the circular path.

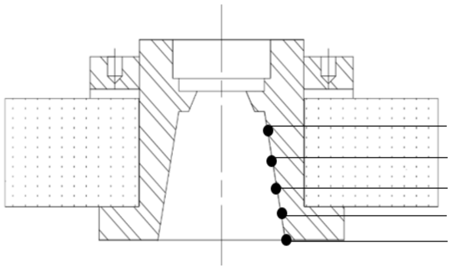


Figure 9. Section view of internal taper length surface of spindle

B. Tool Holder

After the spindle, tool holder was held inside the spindle at 0^0. Tool holder was having 2 orientations one at 0^0 and second one at 180^0 just because of having grooves at its adjacent end. Its internal circumferential surface was divided in the same way as spindle and taper length was divided into 5 levels as shown in Fig. 10 and Fig. 11 shows the measurement method for the tool holder from its internal surface whereas Fig. 12 shows the 3-d model of tool holder used for the experiments.

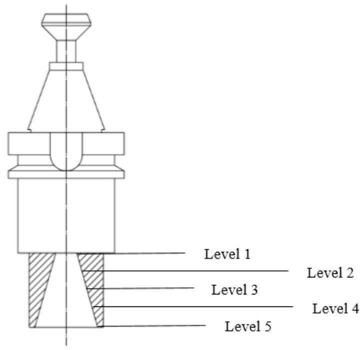


Figure 10. Division of tool holder across its taper length.

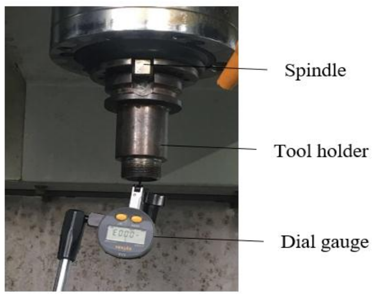


Figure 11.Measurement setup for tool holder.

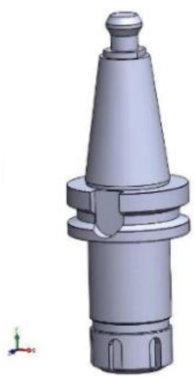


Figure 12. 3-D model of tool holder.

In the same way as spindle, every point across each level was measured 5 times and at last the average values were calculated as shown in Table I. After the measurement of tool holder at 0^0, it was loosed and 180^0 rotated and fixed again. In this particular orientation of tool holder also, 8 points across each level were measured 5 times and at last taken the average.

C. Milling Cutter

Tool # 1 was fixed from at 0^0 when spindle and tool holder also set at 0^0 it was measured in the same way as spindle and tool holder but the difference was that in case of spindle and tool holder 8 points were measured across the circumferential surface but in this casepoints were to be measured as shown in Fig. 13 and Fig. 14 shows the 3-d model of milling cutter used for the experiments having 4 tooth and 8mm in diameter and divided into 5 levels. In this way 4 points across each level were measured 5 times and at last taken the average. After this milling cutter was released from the spindle and 90^0 rotated and fixed again, at this orientation also 4 points across each level were measured five times and at last taken the average. Same procedure with milling cutter at 180^0 and 270^0, after this tool holder was released from the spindle and 180^0 rotated and fixed inside the spindle. In this orientation of tool holder also, milling cutter was fixed in the same ways as above. In total it was having 8 orientations, 4 when tool holder at 0^0 and 4 when tool holder at 0^0.

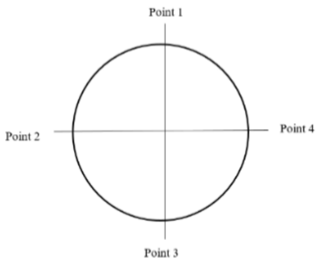


Figure 13. Division of milling cutter across the circumferential surface.

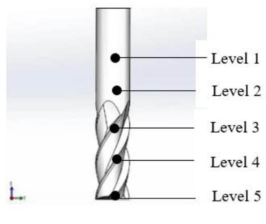


Figure 14. Division of milling cutter across the parallel surface length.

V. Experimental Procedure and Results for the Measurement of Surface Roughness Value

#45 material for the work piece was clamped on the machine table and firstly the milling cutter of 12mm diameter was clamped inside the tool holder according to test-cut # 1 positions as shown in Table II. Cutting parameters were selected randomly because the purpose the only to check the effect of orientations on the surface roughness. After making the combination according to test cut 1, the positions of X, Y and Z of machine were set up or in other words offsets and finally CNC code was generated on software and then send to machine. Machine cut the material according to commendations given to it and after the cut, surface roughness was measured with Marsurf PS1 and then the tool holder and milling cutter removed from the spindle and they were converted into a new combination according to test cut # 2 and fixed again. After this the same procedure was repeated as above and same for the next 6 cuts for tool # 2. In the same way for next 2 cutters, totally 24 test cuts were carried out, 8 cuts for one cutter. Table II shows the orientations of the elements, cutting parameters along with the surface roughness values measured after every test cut for tool # 2.

VI. Analysis of Eccentric Data

The recorded data was plotted on solid works software in such a way that firstly ideal circle was plotted and then it was divided into 8 points for spindle and tool holder and into 4 points for milling cutter. 8 average points recorded during experimentations were plotted on the divided circle and through the use of spline command that points were joined together and a new circle was obtained. Then the distance between the centers of ideal circle to actual circle was noted down through x and y components. This procedure was repeated for all the imperfection data, for all orientations of tool holder and milling cutter and offsets were found out along with x and y components. Table III shows the offsets along with x and y component of tool holder at 0^0 calculated through the Table I. Fig. 15 and 16 shows the deviation of actual circle from the ideal one calculated through relative values of spindle and amplified to 1000 times in order to view clearly. Fig. 17 shows the finding of offset for level 1 of tool holder at 180^0.

TABLE II. Surface Roughness values for Tool # 2 Along with the Orientations and Cutting Conditions

Test cut #	Orientation of Spindle	Orientation of Tool holder	Orientation of Milling cutter	Axial depth of cut (mm)	Radial depth of cut (mm)	RPM (revolution per minute)	Feed rate (mm/min)	Surface roughness (µm)
1	0^0	0^0	0^0	1	6	1000	400	1.781
2	0^0	0^0	90^0	1	6	1000	400	1.926
3	0^0	0^0	180^0	1	6	1000	400	0.938
4	0^0	0^0	270^0	1	6	1000	400	2.147
5	0^0	180^0	0^0	1	6	1000	400	2.153
6	0^0	180^0	90^0	1	6	1000	400	0.924
7	0^0	180^0	180^0	1	6	1000	400	0.5
8	0^0	180^0	270^0	1	6	1000	400	2.926

TABLE III. OFFSET VALUES OF TOOL HOLDER AT 0^0 ORIENTATION WITH SPINDLE SET AT 0^0

Levels	Offset value in X- direction	Offset value in Y- direction	Offset
Level 1	0.00918	0	0.000918
Level 2	0.00248	0.00248	0.0035
Level 3	0.0025484	0.00149	0.002953
Level 4	0.002495	0.004868	0.00254
Level 5	0.002970	0.001424	0.00329

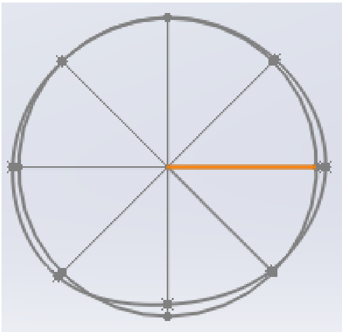


Figure 15.Deviation of actual circle from the ideal.

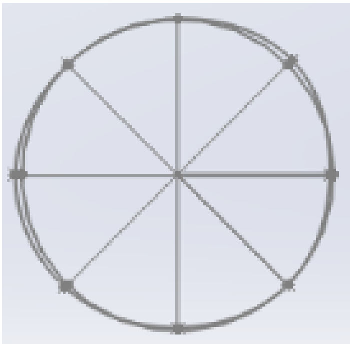


Figure 16.Deviation of actual circle from the ideal.

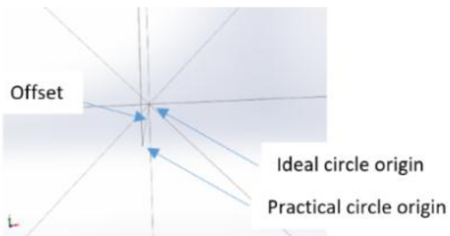


Figure 17.Finding of offset for level 1 of tool holder at 180^0.

VII. DISCUSSION

A. Geometric Imperfection

Table IV shows the final eccentric values of milling cutter # 1 from its all orientations such as when spindle, tool holder and milling cutter set at 0^0, at this particular orientation the eccentric value was 0.08545931 and when spindle and tool holder at 0^0 and with just 90^0 angular difference of milling cutter, the eccentric value was 0.03182996. When combination # 1 and combination # 5 were compared with each other then again it exhibits big difference in offset values whereas in this case position of spindle and milling cutter was same, only the position of tool holder was changed.

TABLE IV. COMPARISON BETWEEN THE FINAL ECCENTRIC VALUES OF MILLING CUTTER # 1 AT DIFFERENT ORIENTATIONS

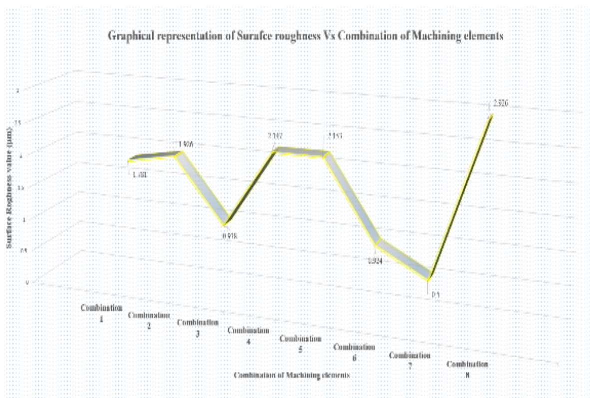
Combination #	Spindle position	Tool holder position	Milling cutter position	Bottom level offset values
1	0^0	0^0	0^0	0.08545931
2	0^0	0^0	90^0	0.03182996
3	0^0	0^0	180^0	0.0753388
4	0^0	0^0	270^0	0.00251397
5	0^0	180^0	0^0	0.02420143
6	0^0	180^0	90^0	0.02186284
7	0^0	180^0	180^0	0.0616829
8	0^0	180^0	270^0	0.00734583

The same case for all the combinations when they were compared with each other and they exhibits that orientations affects the eccentricity highly because different orientations different offsets.

B. Surface Roughness

From above Table II, it is clear that orientations have remarkable effects on the surface roughness as well. This table also indicated the importance of every particular element orientations such as across test cut # 1 when spindle, tool holder and milling cutter were set at 0^0, at that particular orientation the surface roughness value was 1.781 and just with the change in the 90^0 angular position of milling cutter means at test cut # 2, at that particular orientation the surface roughness value was 1.926 and same with test cut # 3 and 4. Moreover, when position of spindle and milling cutter were same across test cut # 1 and 5, 2 and 6, 3 and 7 and 4 and 8 and just with the change in the position of tool holder there was a big difference in between the surface roughness values such as across test cut-1 1.781 and across test cut-5 2.153 and whereas across test cut-2 1.926 and across test cut-6 0.924 and same for the next test cuts as well. Graph-1 is the pictorial representation of Table II in which variation is clearly visible and same for other milling cutters.

Graph-1. Variation in surface roughness values for different combinations for tool # 2.



VIII. CONCLUSIONS

In this paper, we have discussed the influence of different orientations of combination on eccentricity and surface roughness. Through performing different experiments on the whole combination at different orientations we believe that orientation of every element is very important for machining because at different orientations it exhibits different eccentricity and different surface roughness value. The eccentricity and surface roughness values were not even close to each other which indicated that orientations affects the eccentricity and surface roughness not in the same way and through this technique we may reduce the final eccentric error which is basically the cutting edge of milling cutter and can improve the quality of work piece.

- Orientations affect the eccentricity highly and the values changes significantly so others can't ignore it.
- Orientations affect the surface roughness value highly as well.
- A technique to fulfill the market demands with customer satisfaction.

Conflict of Interest

The authors declare no conflict of interest.

Reference

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