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COBEM-2017-2278 A STUDY ON POLYGONAL TURNING

José Wilson Vargas Cavalcante

jwccavalcante@uol.com.br

Leandro Costa de Oliveira

Universidade Federal de Santa Maria

Centro de Tecnologia - Departamento de Engenharia Mecânica

leandro@inf.ufsm.br

Abstract. Turning is a machining method that traditionally produces circular section parts. However, with the use of a rotating tool, it becomes possible to produce polygonal sections. It is called polygonal turning. This study aims to present in detail the operation of this type of turning able to produce parts with flat surfaces through revolution movements. The first part of the study is focused on the development of two models representing the turning, having as input variables the rotational relation between tool and workpiece, the relation of the tool radius and workpiece and the number of sides and cutting edges. One model is mathematical, that with the help of spreadsheets evaluates variables. The other model is real, which facilitates understanding of the dynamics of this method and is a data source. Four variables combinations are performed in the mathematical model to understand the influence of each one on the flatness of the surface generated. A final combination of input values is performed by comparing the results between the real model and the mathematical model. This study determines curves generated by various rotating relations and gives rotation of 1:2 like more efficient. It is concluded that the flatness error is less for smaller radius relations and polygons with more sides.

Keywords: Polygonal turning, machining, flatness, mathematical model, real model.

1. INTRODUCTION

The turning is a machining process used in industry. In this process, the part revolves around a main axis, while the cutting tool moves simultaneously following an axis coplanar trajectory. Thus, this method is traditionally used for surfaces of revolution, that is, workpieces with circular section.

However, if the cutting tool also has a rotation movement along an axis parallel to the axis of rotation and with the synchronization between these two, there is the possibility of generating workpieces with polygonal section. This manufacturing process is called polygonal turning. The present work deals with in detail the operation to generating rotating parts with flat surfaces by movements of revolution (Cavalcante, 2016).

2. EXPERIMENTAL PROCEDURE

This study about polygonal turning presents the operation of this method of manufacture and the influence of its input variables in the formation of flat surface. It was proposed the creation of two models to simulate polygonal turning execution and test with different relations and quantities of sides.

One of the models developed in the work was the mathematical model, implemented in spreadsheet, which proved to be quite complete and effective simulation of this process and evaluate the relative errors of the flatness of machined surface.

To achieve the values of machined surface flatness, the mathematical model developed had as purpose to represent the drawing carried out by the cutting edge of the tool during the machining of a section on polygonal turning. So is represented the move tool performs in relation to the workpiece.

The mathematical model depends on three initial information: the relationship between radius of tool (R_f) and workpiece (R_p); the amount of sides of the workpiece (N) and edges of the tool (A); and the relationship between rotation tool (n_f) and workpiece (n_p).

The term tool radius, defined in this paper, refers to the turning radius of the tool holder set and cutting tools. The Figure 1 presents the tools set and the workpiece inscribed in circles.

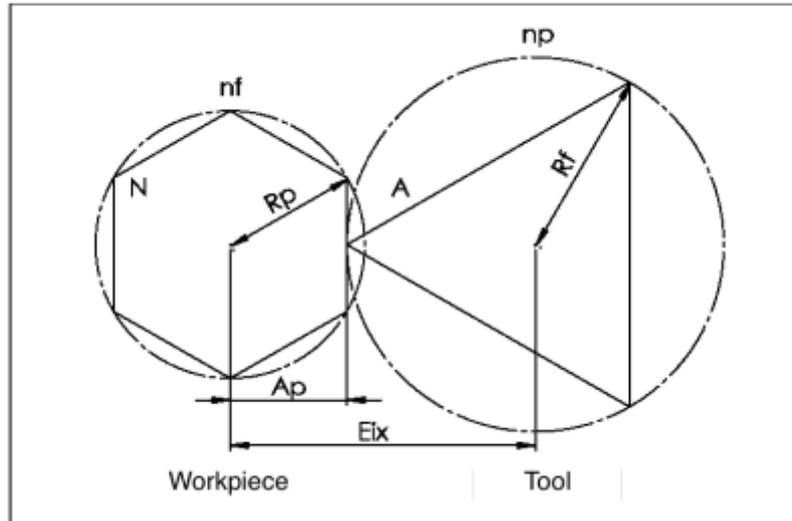


Figure 1. Representation of tool and workpiece

With the variables defined, the mathematical equations calculate the position of the mechanical system for the values X_n and Y_n as a function of the angle of rotation θ ranging from 0° to 360° . Therefore, plotting these values in the X and Y axes shows the tool tracing. So, the user interface of mathematical model in spreadsheet is presented in Figure 2.

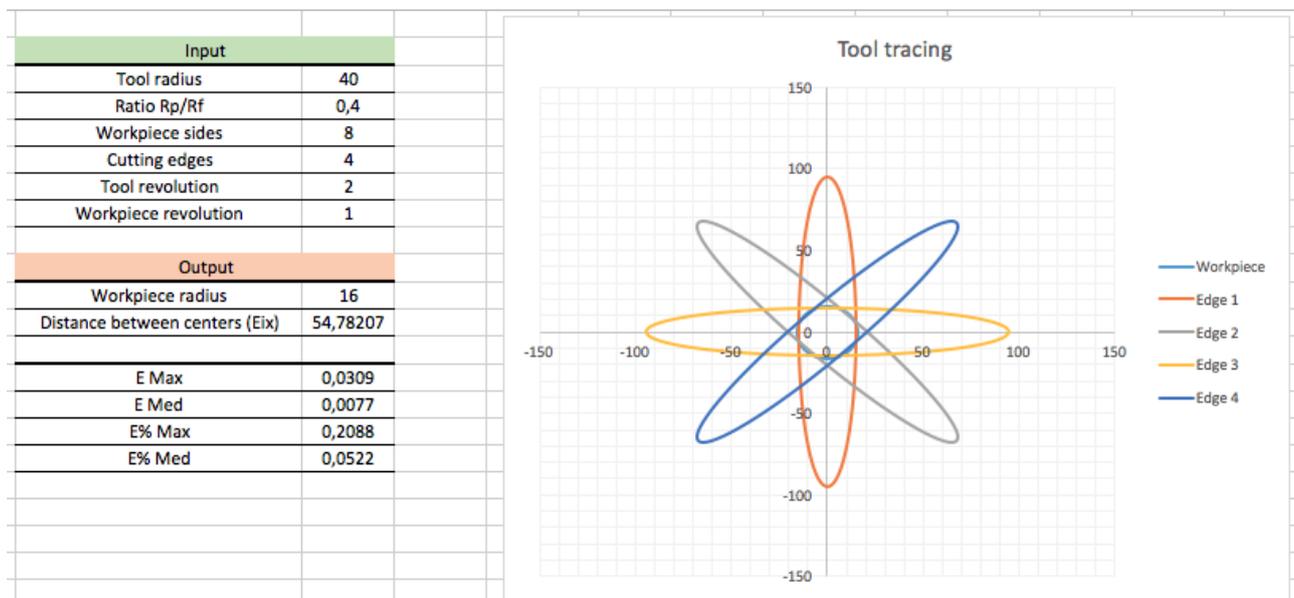


Figure 2. Drawing of polygonal section by mathematical model in spreadsheet

The simulation worksheet has a detailed investigation of the error of flatness of the machined surface, where the tracing performed by the edges of the tool is compared with an ideal polygon, that is, perfectly flat. This condition can best be understood with the visualization of Figure 3.

Variables were created regarding the quantitative error between the tool tracing and the polygon in relation to the X axis, the maximum value of the error, E_{Max} , and its mean value, E_{Med} .

An interesting aspect of polygonal turning is that the machined part itself actively participates in the process, the radius of the part influences in the results. For this reason, their maximum and average relative values, $E\%_{Max}$ and $E\%_{Med}$, were determined too.

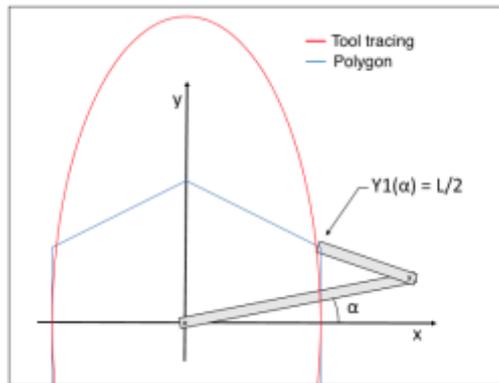


Figure 3. Tool tracing and polygon

The second model, a physical system, demonstrates the execution of polygonal turning through paper records marked for pens, equivalent to the thinning performed by the tool in the machined part. To guide the choices made for this physical system we had the simplicity of manufacturing, the low cost and the availability of the market as the main requirements. In this way, the design generated in three-dimensional drawing software presented in Figure 4 was reached.

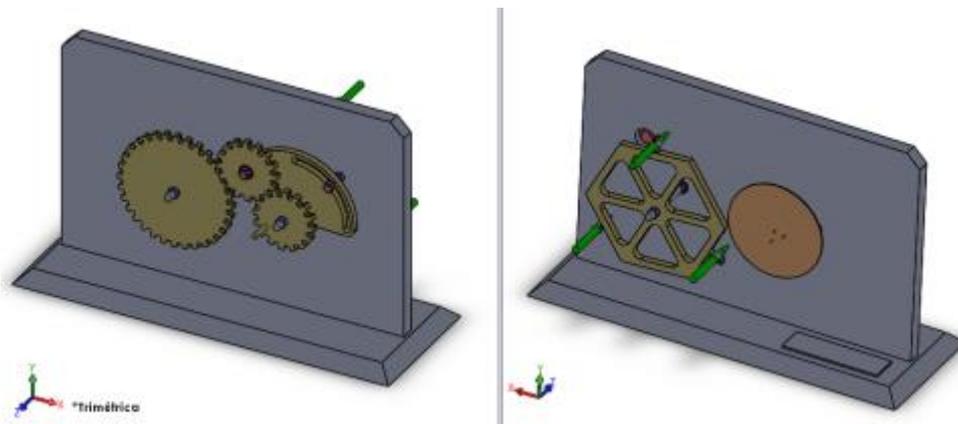


Figure 4. Conception of physical system

In the real model these gears can be changed if you want to analyze the polygonal turning for different ratios of 1:2. With the components designed properly, the results of this polygonal turning pattern are marked on the paper disk that represents the machined part.

The manufacture and acquisition of the components occurred satisfactorily. Thus, a physical system capable of simulating polygonal turning was achieved for three different wheelbase distances and, consequently, three distinct radius ratios between tool and part. With the option of using two or three cutting edges generating polygons of four or six sides. From this, it was possible to carry out the analysis of the cutting edge traces and the flatness error on the surface.



Figure 5. Real model

3. RESULTS AND DISCUSSION

As the mathematical model and the physical model of polygonal turning has three inputs that influence the flatness of machined surface: the radius ratio between tool and workpiece; the number of sides and cutting edges; and the relations of rotation. To understand the influence of each of these entries in the formation of flatness error combinations were carried out with different possibilities of turning.

From the mathematical model the first combination compared different relations to get to your influence in the process. The rotation relations were selected 1:1, 2:3, 1:2, 2:5, 1:3, 1:4 and 1:5 and combined with the radius, 0.5 0.2 and 0.8.

The resulting trajectories can be analyzed in Figure 6.

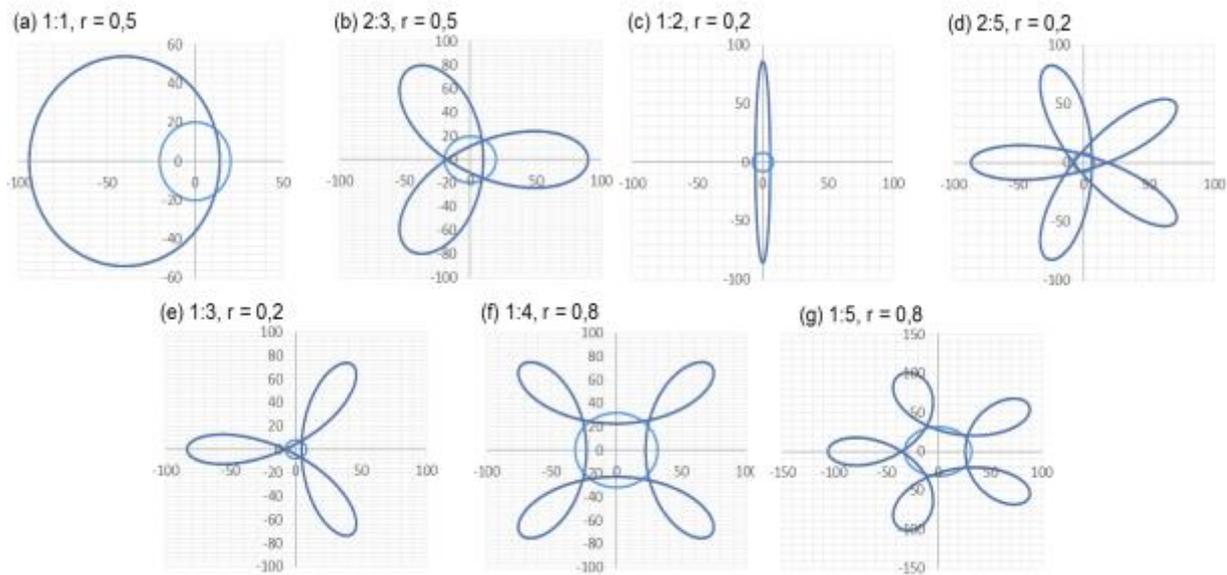


Figure 6. Investigation of tool tracing

The values of E máx, E med, E% med and E% máx are shown in Table 1.

Table 1. Investigation of formation of the polygonal section

| | | Radius Ratio | | | | | |
|------------------|---------|--------------|---------|--------|---------|---------|---------|
| | | 0,2 | | 0,5 | | 0,8 | |
| E max (mm) | E% max | | | | | | |
| E med (mm) | E% med | | | | | | |
| Revolution Ratio | 1:1 | 0,3518 | 6,2189 | 1,8796 | 13,2905 | 4,2306 | 18,6966 |
| | | 0,0880 | 1,5562 | 0,4719 | 3,3372 | 1,0667 | 4,7143 |
| | 2:3 | 0,1996 | 4,9894 | 1,2370 | 12,3698 | 3,1313 | 19,5704 |
| | | 0,0499 | 1,2485 | 0,3107 | 3,1068 | 0,7907 | 4,9420 |
| | 1:2 | 0,0123 | 0,2182 | 0,1605 | 1,1347 | 0,5568 | 2,4609 |
| | | 0,0031 | 0,0546 | 0,0402 | 0,2841 | 0,1396 | 0,6171 |
| | 2:5 | 0,0593 | 0,9169 | 0,3879 | 2,3976 | 1,0009 | 3,8663 |
| | 0,0148 | 0,2293 | 0,0971 | 0,6003 | 0,2510 | 0,9696 | |
| 1:3 | -0,1814 | 4,5338 | -0,9852 | 9,8521 | -2,2019 | 13,7621 | |
| | -0,0454 | 1,1346 | -0,2478 | 2,4780 | -0,5589 | 3,4934 | |
| 1:4 | -0,1836 | 3,2453 | -1,0174 | 7,1939 | -2,3262 | 10,2802 | |
| | -0,0459 | 0,8119 | -0,2555 | 1,8063 | -0,5878 | 2,5975 | |
| 1:5 | -0,1541 | 2,3817 | -0,8698 | 5,3756 | -2,0246 | 7,8206 | |
| | -0,0386 | 0,5958 | -0,2182 | 1,3483 | -0,5102 | 1,9707 | |

From observation of the results of this first combination and based on repeating the same behavior in all cases, it was found that:

- The relation of rotation between tool and workpiece defines the shape of the stroke of the cutting edge;
- The shape of the polygonal section cut varies with the change of the relation.
- The rotation of the tool sets the amount of times the edge cuts the workpiece;
- The error is apparently lesser for smaller radius relations.

The second test chose three relations of rotation with the appropriate number of cutting edges to produce a same type of polygon. With these analysis it was concluded which is more efficient relations and some information about the error. The results of this combination are in the Table 2.

Table 2 - Different RPM producing a hexagon

| | | Revolution Ratio | | | | | | | | | | |
|--------------|------------|------------------|--------|--------|---------|--------|------------|--------|--------|--------|---------|--------|
| | | 1:1 | | 1:2 | | 1:3 | | | | | | |
| Radius Ratio | E max (mm) | E% max | 1:1 | 1:2 | 1:3 | E% med | E med (mm) | | | | | |
| | 0,2 | 0,1708 | | | | | | 2,4651 | 0,0073 | 0,1059 | -0,0562 | 0,8107 |
| 0,4 | 0,5975 | 4,3120 | 0,0504 | 0,3639 | -0,1899 | 1,3704 | 0,1496 | 1,0795 | 0,0126 | 0,0910 | -0,0475 | 0,3430 |
| 0,6 | 1,1962 | 5,7553 | 0,1479 | 0,7114 | -0,3615 | 1,7393 | 0,2998 | 1,4424 | 0,0370 | 0,1780 | -0,0906 | 0,4360 |
| 0,8 | 1,9175 | 6,9191 | 0,3074 | 1,1094 | -0,5437 | 1,9618 | 0,4811 | 1,7359 | 0,0770 | 0,2777 | -0,1365 | 0,4927 |
| 1,0 | 2,7293 | 7,8788 | 0,5312 | 1,5335 | -0,7175 | 2,0712 | 0,6855 | 1,9788 | 0,1331 | 0,3841 | -0,1806 | 0,5215 |
| 1,2 | 3,6107 | 8,6859 | 0,8181 | 1,9680 | -0,8698 | 2,0924 | 0,9077 | 2,1836 | 0,2050 | 0,4932 | -0,2196 | 0,5284 |

In Table 2, it can be seen that the absolute values of error are positive for the revolution ratios of 1:1 and 1:2, while for a ratio of 1:3 they have a negative value. A positive error implies a deviation into the interior of the ideal polygon, forming a slightly convex surface. In turn, negative errors represent deviations out of the polygon and the formation of a slightly concave surface in the part. This fact can be evidenced in Figure 7.

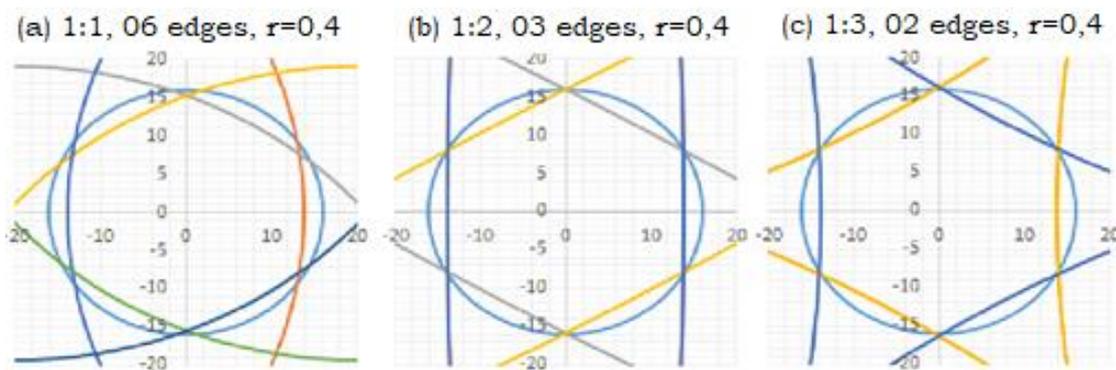


Figure 7. Hexagon produced by different revolution ratios and number of cutting edges

Again, after the analyses of this combination it was found that:

- The relation of rotation of 1:2 is the most efficient for production of flat surfaces;
- The error increases along with the relation.

A third comparative test was made to validate the use of only the relation between radius and there aren't specific dimensional values as a parameter of the error.

The test was done again for six-sided polygons and 1:2 rotation with three cutting edges. Combined relation of 0.2 and 0.5 radius with the tool radius 20, 40, 60 and 80. Follow the Table 3 with the results.

Table 3. Dimensional analysis

| | | Radius Ratio | | | | | | |
|-------------|------------|--------------|------------|--------|------------|--------|--------|--------|
| | | 0,2 | | 0,5 | | | | |
| Tool Radius | E max (mm) | E% max | E max (mm) | E% max | E max (mm) | E% max | | |
| | E med (mm) | E% med | E med (mm) | E% med | E med (mm) | E% med | | |
| 20 | 0,0037 | 0,1059 | 0,0458 | 0,5293 | 0,0009 | 0,0265 | 0,0115 | 0,1324 |
| | 0,0073 | 0,1059 | 0,0917 | 0,5293 | 0,0018 | 0,0265 | 0,0229 | 0,1324 |
| 40 | 0,0110 | 0,1059 | 0,1375 | 0,5293 | 0,0028 | 0,0265 | 0,0344 | 0,1324 |
| | 0,0147 | 0,1059 | 0,1834 | 0,5293 | 0,0037 | 0,0265 | 0,0459 | 0,1324 |

For each of the radius relations tested, the values of percentage errors remained unchanged with the change of tool. And the absolute errors have increased along with the increase in the radius of the tool. This form is validated based on the variation analyses of the relation between the tool and workpiece.

From the definition of the relation of rotation more efficient, the 1:2 relation, this was used to simulate the machining of different numbers of sides and different relations. Relations were used of 0.2 to 1.4 with 0.2 intervals for making 2 polygons, 4, 6 and 8 sides. The results follow in Table 4.

Table 4. Possibilities with 1:2 rotation

| | | Number of Sides | | | | | | | | |
|--------------|------------|-----------------|------------|--------|------------|--------|------------|--------|------------|--------|
| | | 2 | | 4 | | 6 | | 8 | | |
| Radius Ratio | E max (mm) | E% max | E max (mm) | E% max | E max (mm) | E% max | E max (mm) | E% max | E max (mm) | E% max |
| | E med (mm) | E% med | E med (mm) | E% med | E med (mm) | E% med | E med (mm) | E% med | E med (mm) | E% med |
| 0,2 | 0,0123 | 0,2182 | 0,0123 | 0,2183 | 0,0073 | 0,1059 | 0,0045 | 0,0614 | 0,0031 | 0,0546 |
| | 0,0872 | 0,7705 | 0,0872 | 0,7705 | 0,0504 | 0,3639 | 0,0309 | 0,2089 | 0,0218 | 0,1928 |
| 0,4 | 0,2619 | 1,5433 | 0,2619 | 1,5433 | 0,1479 | 0,7114 | 0,0898 | 0,4049 | 0,0656 | 0,3866 |
| | 0,5568 | 2,4608 | 0,5568 | 2,4609 | 0,3074 | 1,1094 | 0,1852 | 0,6266 | 0,1396 | 0,6171 |
| 0,6 | 0,9819 | 3,4716 | 0,9819 | 3,4716 | 0,5312 | 1,5335 | 0,3179 | 0,8602 | 0,2466 | 0,8717 |
| | 1,5408 | 4,5395 | 1,5408 | 4,5398 | 0,8181 | 1,9681 | 0,4865 | 1,0971 | 0,3874 | 1,1414 |
| 0,8 | 2,2334 | 5,6401 | 2,2334 | 5,6402 | 1,1654 | 2,4030 | 0,6891 | 1,3320 | 0,5623 | 1,4201 |
| | 0,9819 | 3,4716 | 0,9819 | 3,4716 | 0,5312 | 1,5335 | 0,3179 | 0,8602 | 0,2466 | 0,8717 |
| 1 | 1,5408 | 4,5395 | 1,5408 | 4,5398 | 0,8181 | 1,9681 | 0,4865 | 1,0971 | 0,3874 | 1,1414 |
| | 2,2334 | 5,6401 | 2,2334 | 5,6402 | 1,1654 | 2,4030 | 0,6891 | 1,3320 | 0,5623 | 1,4201 |
| 1,2 | 0,5623 | 1,4201 | 0,5623 | 1,4201 | 0,2922 | 0,6026 | 0,1726 | 0,3336 | 0,0000 | 0,0000 |
| | 0,9819 | 3,4716 | 0,9819 | 3,4716 | 0,5312 | 1,5335 | 0,3179 | 0,8602 | 0,2466 | 0,8717 |
| 1,4 | 1,5408 | 4,5395 | 1,5408 | 4,5398 | 0,8181 | 1,9681 | 0,4865 | 1,0971 | 0,3874 | 1,1414 |
| | 2,2334 | 5,6401 | 2,2334 | 5,6402 | 1,1654 | 2,4030 | 0,6891 | 1,3320 | 0,5623 | 1,4201 |

The trajectories generated by the overlapping of the action of different cutting edges can be seen in Figure 8.

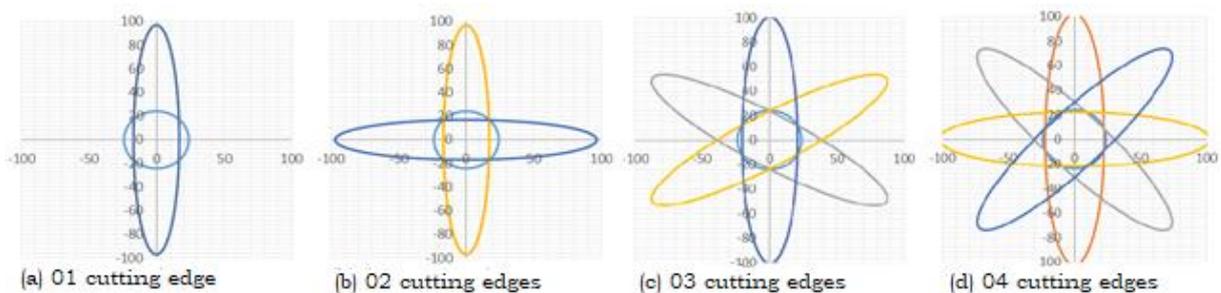


Figure 8. Overlapping of tool tracing

In the table 4, that presents the results of the latter combination, is evident the existence of a trend in the behavior of the error. Based on these data one can see that:

- The smaller the ratio, lower the flatness errors;
- The greater the number of sides, lower the values of the errors.

For the last analysis, a combination of inputs that could be performed in both models was chosen to compare the results. The simulation was done with a tool radius of 100 mm and ratio of 1:2, rotation ratio mounted on the physical system. With the use of three cutting edges, the radius ratios of 0.4, 0.8 and 1.2 were tested. In the use of two cutting edges, the ratios used were 0.49, 0.98 and 1.47.

The comparison results between the mathematical and real models were satisfactory. The tracings in all tests had the same characteristics. These results reinforce the validity of polygonal turning models.

The Figure 9 shows a comparison of the drawing in each of the models, one by Microsoft Excel charts and the other printed on the paper disks.

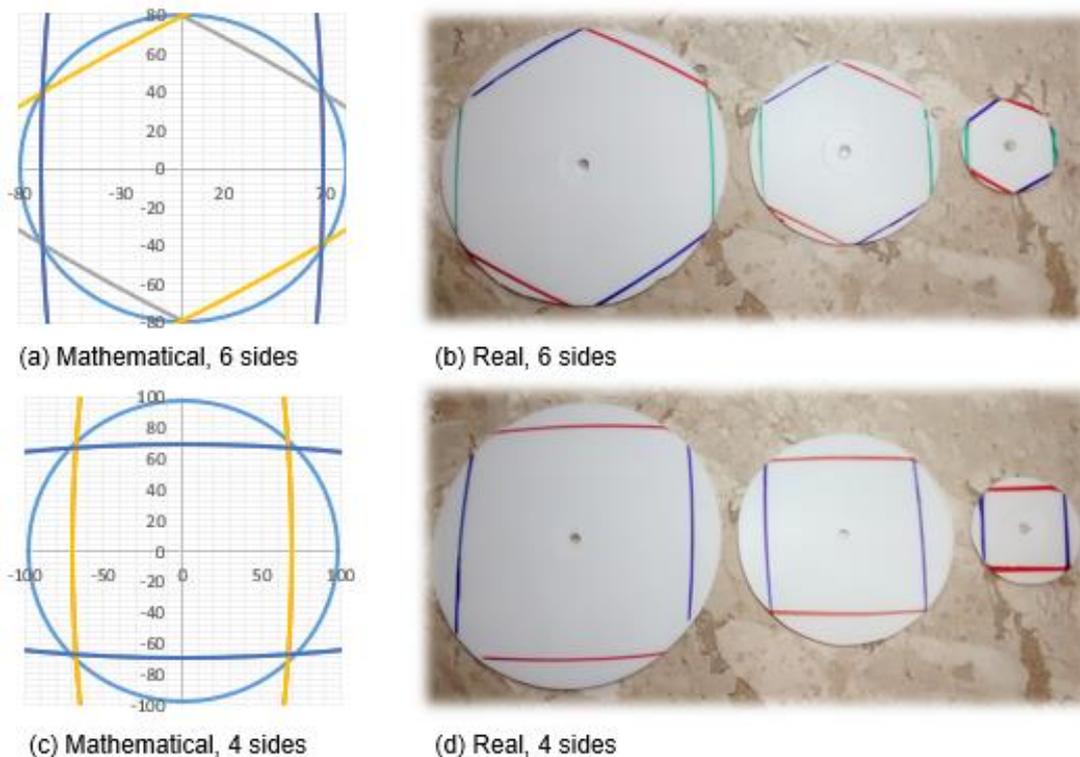


Figure 9. Mathematical model and Real model

4. CONCLUSIONS

It was concluded then that greater numbers of sides produce smaller deviations from flatness due to lower cutting range. And, as confirmed in the analysis, it was concluded that the error values are smaller for smaller relations.

In short, the formation of flat surface in polygonal turning depends of the tool, and the relation of rotation of 1:2 the way to minimize errors of flatness. And as main conclusion, flatter will be machined surface for greater turning radius of the cutting tool in relation to the machined part.

5. REFERENCES

Cavalcante, J. W. V., 2016, *Um Estudo sobre Torneamento Poligonal*. Trabalho de Conclusão de Curso, Universidade Federal de Santa Maria, Santa Maria, Brazil.

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