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REAMING OF AUTOMOTIVE VALVE GUIDES WITH CARBIDE TOOLS AND HYDRAULIC MANDRILL

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Abstract. *In internal combustion engines, the valve guides have the task of adequately position the valves, which seal the combustion chambers and control the entry and exit of gases. Faults in the valves geometry cause problems such as excessive consumption of fuel, internal shots, excessive pressure in the crankcase and harmful gases. Normally, these problems occur in a natural way with the wear of the engine, but faults in the boring of the valve seats or in the reaming of the valve guides can anticipate the problem, reducing the useful life of the engine, increasing the emission of pollutant gases and damaging other components. This paper evaluates the influences of cutting speed, feed rate and reamers geometry on the roughness and roundness and cylindricity deviations of the valve guides, resulting from the reaming process with carbide tools, held with a hydraulic mandril. The automotive valve guides are fabricated from sintered steel cylinders with a 4.5 mm hole. In the tests, four geometries with varying number of cutting edges and different head formats were evaluated. The results also compare cutting forces and vibration magnitudes in order to determine the best tool.*

Keywords: *Reamer, valve guide, sintered steel.*

1. INTRODUCTION

Modern engineering requirements often demand mass production of holes with a good finish and geometric accuracy for low tolerance assembly. These requirements cannot generally be met by the conventional twist drill (Shunmugam and Samasundaram, 1990). In practice, the holes are usually machined with helical drills and reaming is performed as a second operation. This is a machining operation in which a rotary tool makes a light cut to improve the accuracy of a round hole and to reduce the roughness of the surface and the cylindricity deviations. This process is widely used for finishing holes in steel and cast iron, but is also used for soft nonferrous metals. Most of the reamed holes have 3.2 to 32 mm diameter (Metals Handbook, 1989).

Usually, the reamers working in low cutting speeds can be compared with other processes. Kress (1987) showed that new materials and new geometries are able to overcome this limitation. In general, the reamers evolution evolved with the materials used in manufacture of the tools. Dormer (2007), Hanna (2003) and Mapal (2008) are tool makers which have reamers in high speed steel, carbide, CERMET, CBN and PCBN. For the last three materials, the tool body is usually made from a low cost material and only the cutting edge is made from those expensive materials.

The powder metallurgy usage is rapidly growing in automotive industries, which know the advantages offered by this technique. According to Salgado (2007), the Brazilian market uses about 3 Kg of sintered products per vehicle and there is a tendency to increase this amount. The sintering process consumes less than half the energy consumed by conventional techniques, uses about 97% of raw material, allows the control of density and porosity, which results in less impact to the environment, lower manufacturing cost and superior quality when compared with conventional processes.

The national annual production of vehicles is around 2 million units. Most of the engines have 8 valves and the reaming process is used for the finishing of the valve guides. Therefore, this operation is made 16 million times per year only in Brazil, justifying the study to determinate the best geometry of the tool and the cutting conditions (speed and feed rate) which results in small surface roughness and minimum shape deviations of the automotive valve guides.

2. EXPERIMENTAL PROCEDURE

The valve guides are manufactured from sintered steel and its main dimensions are shown in Fig. 1a. Normally the reaming process is a subsequent operation to drilling, but in this work, the material has a 4.5 mm hole, made during the sintering process, which dispenses the use of an helical drill to create the initial hole and can be reamed without any preparation. In the evaluation of the roundness deviations of the internal hole of the valve guide, eight measurements were made along different planes, as shown in Fig. 1b. Four uncoated carbide reamers with 5 mm nominal diameter were tested. Two of them have an integrated pilot (conical part at the head of the reamer, responsible for guide him into the hole) and other two without pilot. Each tool has specific features according to the suggested use, being different from the reamers found on market. A hydraulic mandrill was used to fix them on the machine, as show in Fig 1c.

The machine tool was a ROMI Discovery 760 machining center, with 11 KW maximum power and rotation speed of 10 to 10.000 rpm. A Kistler® 9265B dynamometer measured the cutting forces and the roundness deviations were measured with a Talyrond 131 roundness device.

The results of the valve guide hardness measurements are shown in Table 1. Three samples were selected with five measurements in each. The average hardness was 74 HRB, with standard deviation of 4HRB, which represents a variation of 5%.

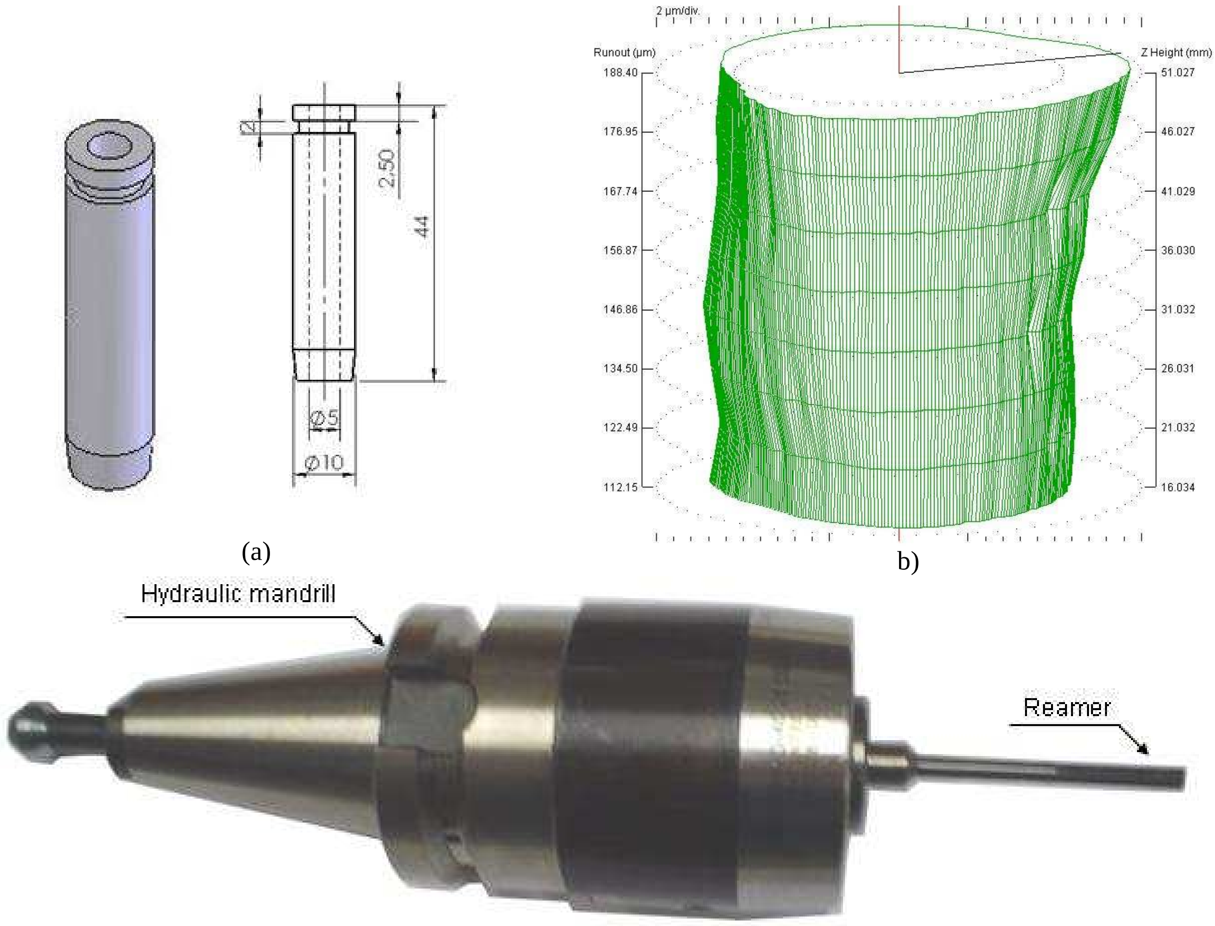


Figure 1 – a) valve guide with its main dimensions; b) example of the roundness measurement planes; c) Hydraulic mandrill with reamer

Table 1 – Hardness measurement results (HRB)

Sample	1	2	3	4	5	Average	Standard deviation	Error type 1
1	68	70	67	70	67	74	4	6
2	76	77	76	76	77			1
3	77	76	76	77	76			1

The last column of the table shows the results of the type 1 error, as described by Guedes (2004). This calculation was performed to show that the number of tests is sufficient to characterize the material hardness. The experiments were designed with cutting speeds 33, 38, 42 and 47 m/min and feed rates 0.035, 0.050, 0.065 and 0.080 mm/edge, so that the parameters recommended by the manufacturer are exactly in the middle. Table 2 shows details about the 5 mm diameter carbide reamers.

Table 2 – Reamers

Reamer	Edges	Pilot
1	4	No
2	6	No
3	4	Yes
4	6	Yes

3. RESULTS

Table 3 shows the input parameters used in each test and the averages of axial force Fz, roundness and cylindricity deviations and roughness Ra. The tests were performed twice. The design tolerances for roundness and cylindricity deviations of the valve guides are both 9 µm.

Table 3 – Results and standard deviation for Fz, roundness, cylindricity and roughness

Test	Reamer	Cutting Speed	Feed (mm/edge)	Fz (N)	Roundness (µm)	Cylindricity (µm)	Ra (µm)
1	1	33	0.035	$20.31^{\pm0.81}$	$2.11^{\pm0.68}$	$6.14^{\pm0.43}$	$0.33^{\pm0.12}$
2	1	38	0.050	$31.87^{\pm8.53}$	$2.92^{\pm0.84}$	$6.33^{\pm0.90}$	$0.58^{\pm0.13}$
3	1	42	0.065	$33.31^{\pm5.13}$	$3.17^{\pm1.31}$	$7.29^{\pm1.06}$	$0.25^{\pm0.04}$
4	1	47	0.080	$38.25^{\pm10.83}$	$2.77^{\pm0.97}$	$6.13^{\pm1.34}$	$0.38^{\pm0.13}$
5	2	33	0.050	$44.35^{\pm9.37}$	$1.80^{\pm0.82}$	$5.05^{\pm0.78}$	$0.43^{\pm0.17}$
6	2	38	0.035	$39.42^{\pm14.87}$	$2.52^{\pm0.92}$	$5.88^{\pm0.54}$	$0.57^{\pm0.29}$
7	2	42	0.080	$55.41^{\pm4.17}$	$1.96^{\pm0.73}$	$5.94^{\pm0.85}$	$0.38^{\pm0.03}$
8	2	47	0.065	$51.40^{\pm11.19}$	$2.55^{\pm1.31}$	$6.29^{\pm1.81}$	$0.36^{\pm0.08}$
9	3	33	0.065	$23.39^{\pm0.92}$	$2.58^{\pm0.83}$	$7.97^{\pm0.23}$	$0.67^{\pm0.25}$
10	3	38	0.080	$27.15^{\pm1.48}$	$1.37^{\pm0.30}$	$4.53^{\pm0.96}$	$1.29^{\pm0.50}$
11	3	42	0.035	$17.41^{\pm4.78}$	$2.44^{\pm1.44}$	$5.47^{\pm2.28}$	$0.48^{\pm0.11}$
12	3	47	0.050	$19.42^{\pm0.51}$	$1.39^{\pm0.59}$	$4.80^{\pm1.44}$	$0.56^{\pm0.06}$
13	4	33	0.080	$93.09^{\pm17.91}$	$2.45^{\pm1.33}$	$7.32^{\pm1.72}$	$0.81^{\pm0.33}$
14	4	38	0.065	$83.83^{\pm11.67}$	$2.87^{\pm1.43}$	$7.13^{\pm0.99}$	$0.45^{\pm0.05}$
15	4	42	0.050	$75.29^{\pm4.04}$	$2.68^{\pm0.67}$	$6.93^{\pm0.26}$	$0.46^{\pm0.20}$
16	4	47	0.035	$66.78^{\pm8.76}$	$3.31^{\pm1.45}$	$8.06^{\pm1.14}$	$0.55^{\pm0.11}$

3.1. Influence of the variables on Z-axis force (Fz)

The variance analysis presents the p-value to quantify the influence of each variable in the process. At this work, when this value is greater than 30% (and the significance is lower then 70%), it means that the influence of the variable is negligible. If this value is lower then the reference value (the significance is greater than 70%), the influence of the variable is considerable and is discussed in the text.

The variance analysis for Fz showed significance 100% to the variables "reamers geometry" and "feed rate". The "cutting speed" has a smaller influence, with 69%.

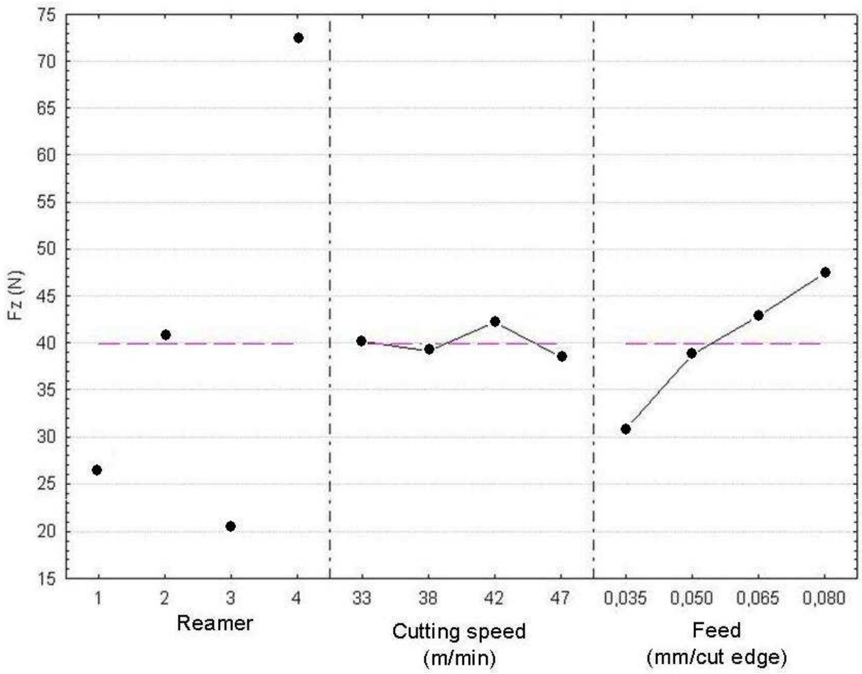


Figure 2 - Influence of variables in the Z-axis force

In Figure 2, the dashed line in the center represents the average value (40 N) and the standard variation was 21 N. In this figure, it is verified how the change in reamer geometry changes the axial force. The reamers with 4 edges produced less axial force. Due to the increased removal rate of material, it was expected that reamers with 6 cutting edges would produce bigger forces, as occurred in the second tool, but the pilot at the head of the fourth reamer produced the biggest axial force. About cutting speed, both the variance analysis and the chart show that its effect on Fz is reduced. Finally, it was observed that Fz is directly proportional to the axial feed rate, as expected.

3.2. Influence of input variables on the vibration magnitude

Bezerra (1998) observed high levels of vibration when reaming 12 mm holes in silicon aluminum alloy. The vibration caused noise and harmed the machined surface. However, during the tests required for this work were observed low intensity vibrations, with values below 0.5 m/s ², as shown in Fig. 3.

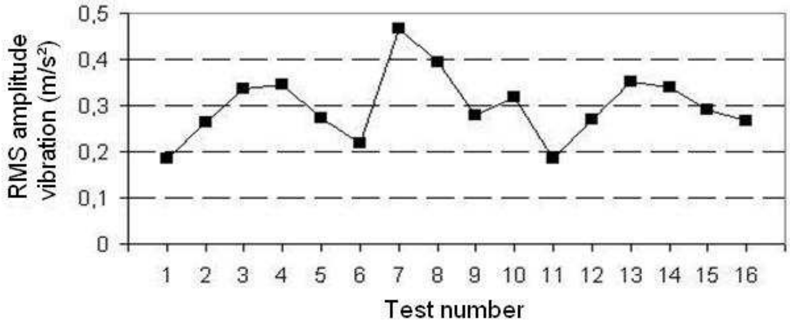


Figure 3 – RMS acceleration amplitude

According to the variance analysis, the values of significance are 96% for the reamers, 89% for the cutting speed and 100% for the feed rate. Then, all of them have great significance to the process. Thus, all independent variables change the levels of vibration of the valve guide-reamer-machine tool system. The mean vibration was 0.29 m/s² and the standard variation was 0.03 m/s².

According to Figure 4, the reamers 2 and 4 produced higher amplitudes of vibration. These reamers have six cutting edges, which create more contact points, resulting in greater vibration magnitude. With the reamers 1 and 3, the pilots guided the tools and produced less amplitude of vibration. The increment in cutting speed increased the amplitude of vibration in the process.

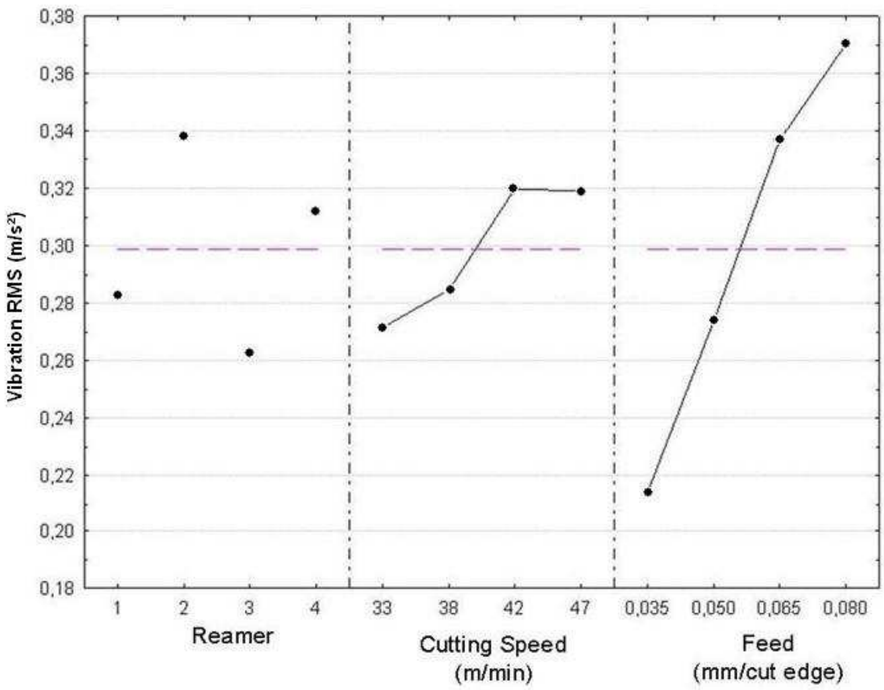


Figure 4 - Influence of input variables on the vibration

Bezerra (1998) observed that large cutting speeds harm the holes surface. He hoped that the increase in cutting speed up to 80 m/min would reduce or eliminate the built up edge, but occurred an increase in the hole diameter, beyond the nominal value, caused by increased vibration in the system.

When the feed rate was increased from 0.035 to 0.080 mm/edge, the axial force was increased from 33 N to 49 N, forcing down the workpiece against the machine tool table. By the principle of action and reaction, the reamer and mandrill were pushed against the machine arbor. Stemmer (1995) detached that this increase of force in many cases increases the process stability, reducing vibration magnitude. But in this work, no gain was observed. The increase in the feed rate raised the axial force and vibration magnitude.

3.3. Influence of input variables on the roundness deviation

The analysis of variance showed that the geometry of the reamers has significance 90%; the cutting speed, 23% and the feed rate, 76%. So, the variation of cutting speed causes little influence on the roundness deviations. The mean roundness was 2.43 µm and the standard deviation was 0.57 µm.

In Figure 5, the center line represents the mean value. It was observed that reamer 3 had better results than reamer 1. In this case, the increase in the number of cutting edges increased the number of points in contact with the hole and produced better quality holes, but different result was obtained with six cutting edge reamers. When using the reamer with 4 cutting edges, the addition of the pilot produced an improvement in the stability of the process, as observed in the tool 3. But the use of this pilot with six cutting edge produced very poor results, as seen in the Figure 5, reamer 4. The probable cause of this deterioration is the reduction of the space between cutting edges promoted by the increased number of edges. The reduced space does not contain adequately the chip, raising the adhesion on tool and raising the friction between the chip and the hole surface, changing the behavior of the process.

Although the analysis of variance shows that the cutting speed has negligible influence, the increment of this variable increments the roundness deviation, which is in agreement with other studies about reaming, as Shunmugam and Somasundoram (1990), where low cutting speed resulted small deviations from the nominal diameter, small roundness and the better surface finish.

Almeida (2008), in his research on the reaming of cast iron with coated tools, commented that the increase in cutting speed emphasized the radial runout of the reamer, resulting in increased roundness deviation. In the range of cutting speeds used in this study, this effect was not observed. The tendency of increasing the roundness deviations with the cutting speed may be attributed to the increase of the vibration magnitude.

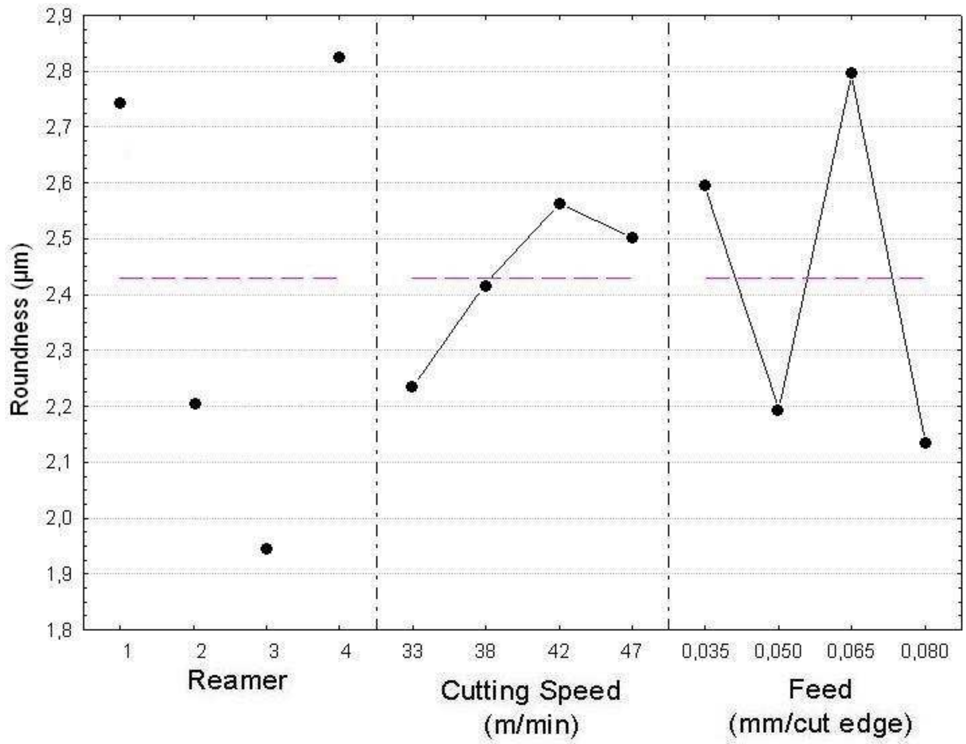
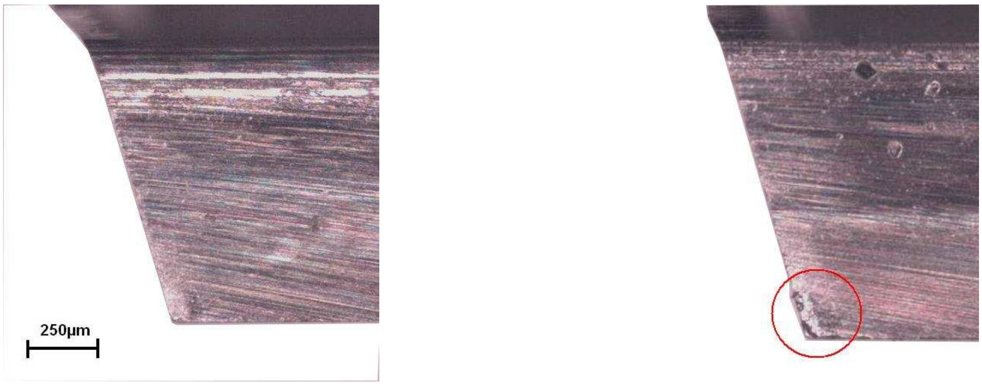


Figure 5 - Influence of input variables on the roundness deviations.

Finally, it was observed that the increase in feed rate from 0.035 to 0.040 mm/edge reduced the roundness deviation, but when feed rate increased to 0.065 mm/edge, a great increase in roundness deviation was noticed. This fact occurred for all reamers, which shows that there was a change in the chip-tool interface, probably caused by a built up edge. Figure 6 shows the occurrence of material joined in the cutting edge, being the most likely cause of this change in the behavior. When using feed rate 0.080 mm/edge, the raise of cutting force prevented this adhesion and the better results of roundness deviation and surface quality were obtained.



a) b)

Figure 6 – Reamers; a) without adhesion; b) with adhesion

3.4. Influence of input variables on the cylindricity deviations

The analysis of variance showed significance of 91% for the reamers geometry, 25% for the cutting speed and 80% to the feed rate on the cylindricity deviations. These values are slightly higher than those found to the roundness deviations, showing greater sensitivity of the input variables on cylindricity deviations. The mean cylindricity deviation was 6.32μm and the standard deviation was 1.06 μm. The cylindricity deviations results are very similar to that of the roundness deviations. The lowest value of cylindricity deviation was obtained with the reamer number 3 (four cutting edges and pilot), as shown in Fig. 7. Due to the small influence of cutting speed, the change in the curve of the graph is negligible. Again, it is noted that the feed rate of 0.065 mm/edge causes changes in the chip-tool interface, with greater cylindricity deviation.

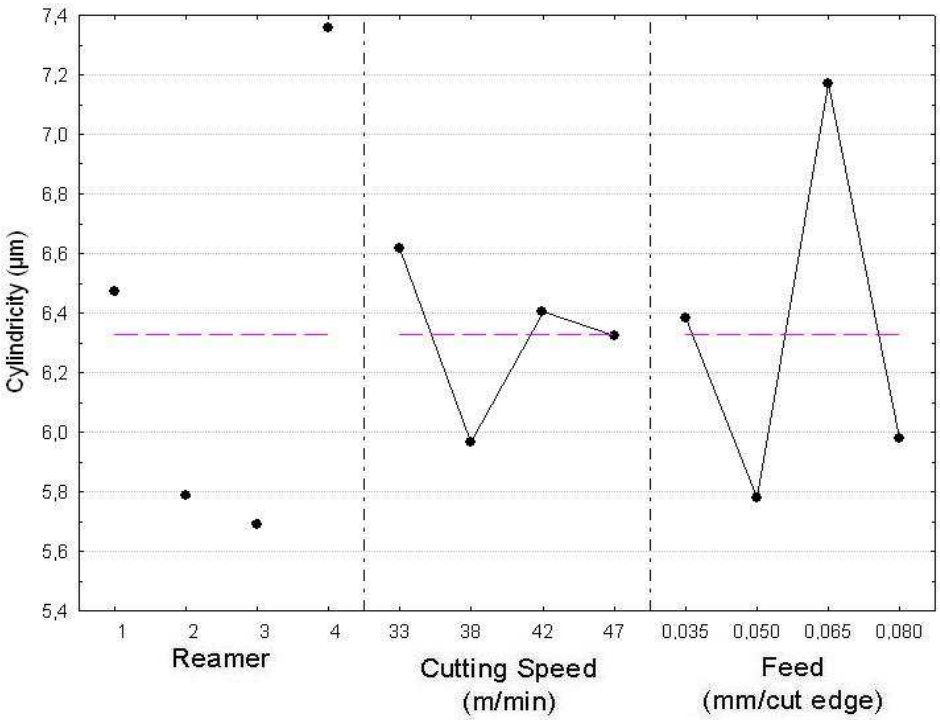


Figure 7 - Influence of input variables on the cylindricity deviations.

3.5. Influence of input variables on roughness Ra

The analysis of variance showed that all input variables are very influential on the value of roughness Ra. The reamers geometry presents significance of 94%, cutting tool, 91% and 85% for the feed rate. The mean roughness was 0.53 µm and standard deviation was 0.24 µm.

According the Figure 8, reamers 1 and 2 produced the lowest values of average roughness. The pilot (conical part) at the head of the reamer 3 and 4 reduces the depth of cut on tip tool. According to Metal Handbook (1989), too small depth of cut crushes the material instead of cut him, causing hole surface degradation. It was also observed that the number 4 reamer produced lower roughness Ra value than number 3. According Bezerra (1998), greater number of cutting edges increases the contact area of the reamer with the hole and improves the finishing of the surface. As in turning and milling processes, the increase in cutting speed improves the finish of the workpiece. But the increase in feed rate usually increases the surface roughness. Similar results were found in Bezerra (1998), Schroeter (1989) and Shunmugam and Somasundaram (1990). Again, the third feed value caused an anomaly in the curve of the graph, reinforcing assumptions about changes in chip-tool interface, probably caused by a built up edge.

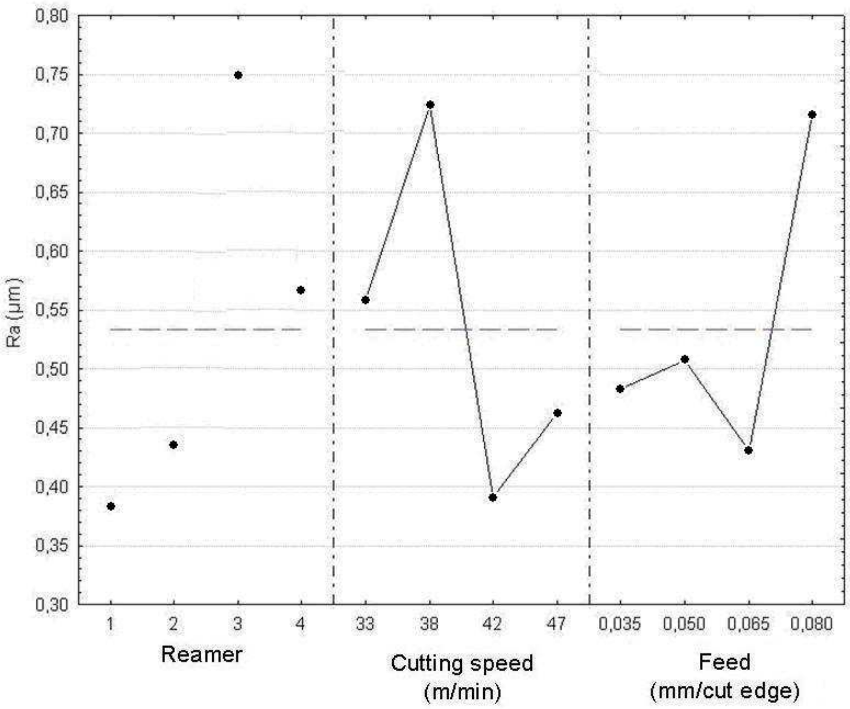


Figure 8 - Influence of input variables on Ra

3.6 – Reamers ranking

One of the objectives of this work is to choose the best reamer, but none of them is the best in all aspects. So, Table 4 presents a summary of the tests results and a classification of the reamers in the evaluated aspects to get a ranking. The first place receives 15 points, the second, 10 points and the third, 5 points. Following these criteria, the best reamer is the number 3, followed by reamers 1 and 2. Reamer 4 presented the worst results.

Table 4 – Summary of the tests results and reamers classification

	Axial force [N]	Acceleration [m/s^2]	Roundness dev. [µm]	Cylindricity dev. [µm]	Roughness [µm]	Points	Ranking
Reamer 1	26	0.28	2.74	6.47	**0.38**	45	2°
Reamer 2	41	0.34	2.20	5.78	0.44	35	3°
Reamer 3	**20**	**0.26**	**1.94**	**5.69**	0.75	60	**1°**
Reamer 4	73	0.31	2.82	7.35	0.57	10	4°

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4. CONCLUSION

The reaming of the valve guides is a delicate operation, performed with small and expensive tools with varied geometry. It was observed that the concentricity deviation between valve guide and the reamer is a very important aspect and also the radial runout of the reamer when it rotates with the machine tool arbor. Both must be kept at the minimum possible value. It was also observed that the quality of the initial hole of the valve guide affects the final results. The reamers are not capable of fix cylindricity deviations of the initial hole. Care must be employed in the fabrication of the valve guides by powder metallurgy, in order to achieve the best results.

Considering the cutting parameters, it was concluded that the feed rate is directly proportional to the axial force, vibration magnitude and roughness. The cutting speed presented small influence on the evaluated aspects and conclusions could not be taken. It was also observed that some cutting parameters ease the appearance of built up edge, which alters the cutting edge geometry and can mask the results. This effect was observed with feed rate around 0.065 mm/edge, resulting in increased geometrical shape errors.

The lower axial force, vibration magnitude, roundness and cylindricity deviations were obtained with the reamer number 3, followed by reamer number 2. However, reamer 3 produced the highest surface roughness (0.75 μm), but still bellow industry tolerances. Then, the conclusion is that reamer 3, with four cutting edges and pilot, is the best tool to perform this operation.

5. ACKNOWLEDGEMENTS

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