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INFLUENCE OF TOOL SPEEDS ON FORCES IN SINGLE-PASS HONING

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Abstract. *Single pass honing is a process that consists of removing material in only one complete stroke (down and up stroke) of the tool. In this process, the tool diameter is preset. The objective of this study was to verify the influence of axial speed and tangential speed of the tool on the cutting force and the moment generated during the single pass honing on sliding bearings. A complete 3² factorial design was carried out, with nine conditions evaluated resulting in 27 tests, considering one test and two replicas. The varied input parameters were: axial speed at 3.3; 3.9 and 4.5m/min and tangential speed at 16; 21 and 26m/min. An expanded tool was used to remove 15µm of material in a 195mm stroke. Thus, it was found that the axial and tangential speed have a significant influence on the generated forces. It was observed that the cutting force can be reduced by up to 50% and the moment by up to 30% depending on the tangential speed adopted. However, there is an increase in cutting force by up to 50% and the moment by up to 20% with an increase in axial speed. It was also verified that there are machining forces acting during the return stroke of the tool to its initial position due to the elastic return of the material.*

Keywords: *single pass honing, machining force, speed, tool.*

1. INTRODUCTION

According to Sunnen (1993) and Nagel (1994), single pass honing is a variant of long stroke honing, and the main differences between both is the number of passes in each process and the diameter of the tool. In single pass honing, the tool, which has a previously set diameter, passes through the machined part only once and returns to its the starting position. In this process, if it is necessary to remove a larger volume of material, the tool diameter must be adjusted by any new pass or several tools with different diameters must be used in sequence.

According to Schmidt (1999), the ability to not expand and contract the cutting parts of the tool during each cycle, combined with the low wear characteristic of superabrasives, allows the single pass process to reach maximum dimensional control of the hole size. The front part of the single-pass tool is designed with an adequate taper that allows the tool to enter in the pre-existing hole guided.

König (1989), Paull et al. (1967) and Marvin (1994) mention in their works that lower values of roughness are obtained in honing with higher peripheral speeds and lower axial speeds. König (1989) also points out that the increase in the cutting speed has directly influence on the honing rate and that the contact pressure determines the number of chips. Furthermore, the improvement in cylindricity and circularity can be correlated with the components of the cutting speed during the process.

According to Peres (1994), the input variables that have the greatest influence on the circular deviation of the honed surface are: the initial cylindricity, the combination of axial and tangential speed and, finally, the material allowance of the part, in this order of relevance. Furthermore, among the most recent research on honing with abrasive tools, Pereira et al. (2017) investigated the effect that rotation, axial speed and number of passes have on the roughness obtained in GG20 cast iron hermetic compressor blocks honed with flexible tools. Based on the results obtained, the authors concluded that the number of passes is the most influential factor on the roughness of the bearing surface. Freitas (2018) analyzed the influence of tool wear on the shape and texture errors of compressor bearing holes, he verified a random behavior in the shape deviations and roughness of the honed bearings with a new tool and noted that the magnitude of the deviations from cylindricity of the honed bearing with a worn tool was greater than that obtained with the honed bearing with a new tool.

Yang *et al*. (2020) presented an analytical model that predicts tool life with low stiffness on single pass honing. For this, the 2D projection contour of the tool was made by measuring by parallel light projection. By extracting the contour

parameters from the 2D projection, the relationship between the contour and the grain distribution parameters on the tool surface was established. Based on the grain distribution parameter and the maximum radial height distribution, a 3D contour characterization model of the tool was developed.

When analyzing the microscopic contact between the part and the tool, the authors established a relationship between the machining parameters and the tool parameters. The wear evolution was predicted by simulation, the deviation between the predicted and the measured tool contour was less than 2 µm. Thus, the empirical equation of the relationship between the tool and the hole diameter was adjusted and verified, which made it possible to control the hole diameter and tool wear. The authors found that by increasing the dressing tolerance of the tool, tool life can be extended, but the cost increases. Therefore, tool life and dressing cost should be considered comprehensively to reserve an adequate coating tolerance (Yang *et al.*, 2020). Considering the aforementioned studies, the relative difficulty in finding scientific works related to single pass honing, we sought to evaluate the influence of input parameters on the cutting efforts generated during single pass honing in sliding bearings.

2. EXPERIMENTAL PROCEDURE

The honing experiments were carried out on a 5-axis machine from the manufacturer MAZAK, model Variaxis J-600, equipped with the Mazatrol SmoothX computer numerical control. The drive power on the spindle is 11 kW, and can reach speeds of up to 12000 min-1. The coolant used was an emulsion with a concentration of 5%. The cutting tool, Figure 1, used is of the rigid type with five abrasive inserts and adjusted to remove 15 µm of material from the bearing diameter.

Figure 1. Rigid type tool with abrasive inserts.

The tool stroke was 195 mm, so that the entire length of the tool was through the block bearing bore. The tool data are shown in Tab. 1:

Table 1. Tool characteristics

Nominal Diameter	Granulometry	Binder	Dimensions	Cutting Zone
13 mm	D107	Metallic (Cu-Sn-Fe-Ni)	Ruler 5x90mm	50 mm

The test specimens used were 27 sliding bearing holes with a nominal diameter of 12,960 mm in gray cast iron GG20, with type B lamellar graphite. The manufacture of the bearings comprises drilling and reaming operations, consecutively, to obtain minimal variations in the allowance in the part and to guarantee the acceptable dimensional tolerances for honing. The specimens were fixed on the machine in order to have two degrees of freedom and minimize deviations in positioning and straightness between the axis of rotation and the bore.

During the execution of the tests, the input parameters were varied: axial speed (v_a) at 3.3; 3.9 and 4.5 m/min and tangential speed (v_t) at 16; 21 and 26 m/min. These parameters were based on the data used by the partner company to manufacture the blocks. A complete 3^2 factorial experimental design was employed. A total of 9 tests were carried out, totaling 27 tests, considering one test and two replicas. The level of significance was α=0.95.

The measurement of the axial component of the axial cutting force (F_a) on the Z axis of the dynamometer and of the moment (M_z) during the honing process was performed using a force measurement system manufactured by Kistler Instruments®. The force measurement system consists of a rotary dynamometer model 9123C1111, a stator model 5221B1 and a signal conditioner with multiple channels model 5223B. The rotary dynamometer is used for measurements of three components of force, and momentum.

The acquisition of the signals from the analog outputs, related to the components of the machining force, of the signal conditioner was performed through a device for data acquisition (DAD) from the manufacturer National Instruments®, model NI USB-6218, with 32 inputs analog and 16-bit resolution. The voltage range that the analog inputs of the DAD can receive varies between ± 10 V. The algorithm used for the acquisition and the processing of the signals was elaborated in the LabView™ software.

The signal conditioner supplies the analog signals to the DAD and performs low-pass filtering on the analog signals with a cut-off frequency of 1 kHz. After the analogue filtering of the conditioner, the signal is sampled by the DAD, converting the signal to the digital domain. The sampling rate used was adjusted in the data acquisition algorithm developed to a value of 10000 Hz, defined according to Nyquist's theorem.

All acquired force signals were processed with a 70 Hz cut-off low-pass filter, defined based on analysis of the frequency spectrum of acquired force signals. In all filtering procedures, the aim was to preserve the amplitude of the

signal over time, as this characteristic is of paramount importance in relation to process forces. The equipment assembly diagram is shown in Figure 2.

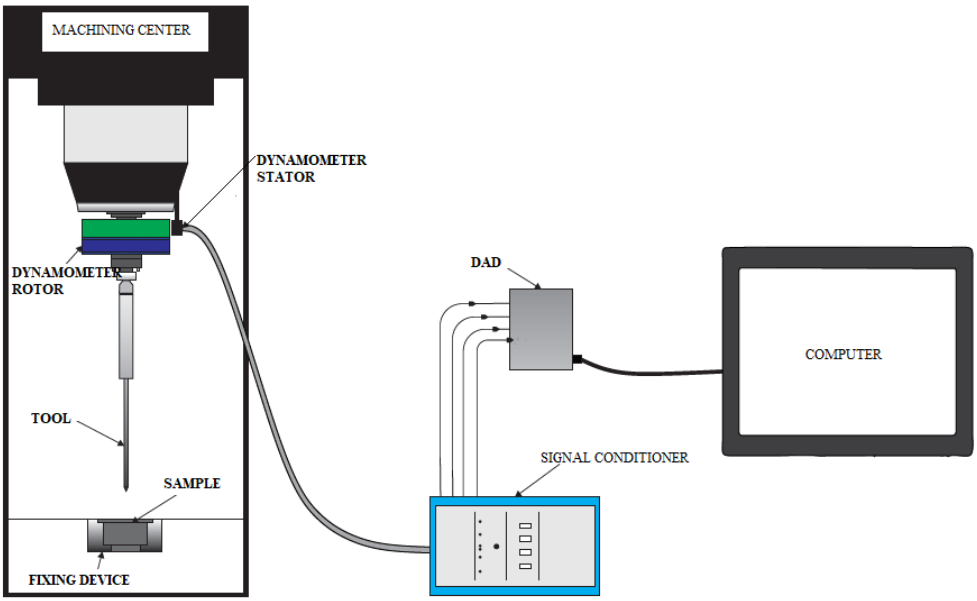

Figure 2. Equipment assembly structure

The honing tool was fixed to the rotating dynamometer with a device designed to leave it with a degree of freedom in the X and Y directions to allow its axis of rotation to be adjusted at an angle to the axis of symmetry of the hole to be honed. Thus, using the assembly shown in Figure 2, it is possible to measure the forces along the honing by varying the axial and tangential speeds of the tool.

3. RESULTS AND DISCUSSION

Figure 3 shows the F_a and M_z signs of the honing process of long stroke and single pass acquired in this work. When honing, the abrasive stone must come out of the hole completely. This ensures that the entire length of the hole is calibrated and has the tolerances of dimension, shape and texture. The moment when the abrasive insert leaves the honed hole completely can be identified through Figure 3 and corresponds to the time interval in which F_a and M_z reach the zero value, in such moments there is no material removal.

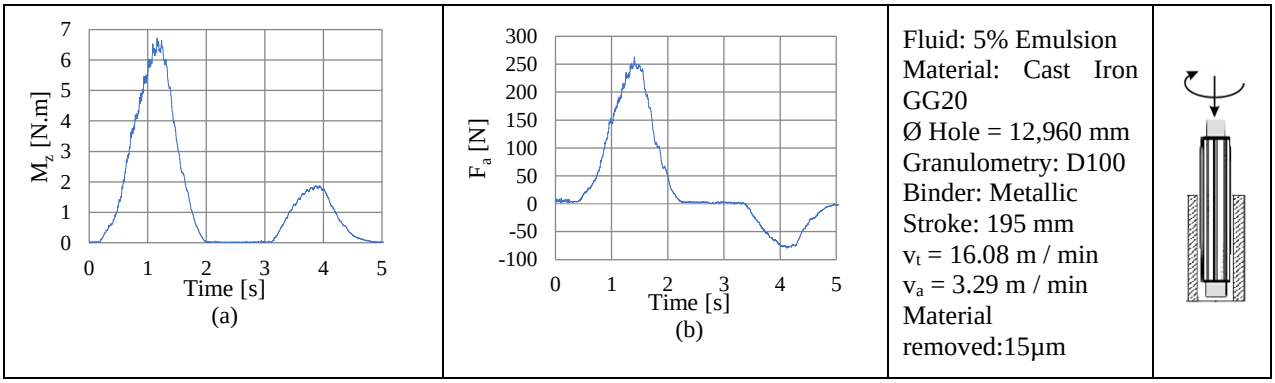

Figure 3. Signs of (a) moment and (b) axial force acquired during the honing process.

The removal of a large part of the material occurs in the positive axial advance movement and generates a resultant force of greater magnitude, representing the process in a single oscillation cycle. The fact that Fa assumes positive values during the downward axial feed can be explained by the direction of the reaction force that the wall of the hole makes on the honing tool. This reaction force is in the Z + direction of measurement of the rotating dynamometer.

After this movement, the return of the tool starts, if there was no elastic deformation in the specimen, theoretically, there should be an extremely low effort during the return movement of the tool due to the friction of the abrasive grain

tips, because all the material it should have already been removed in the downward movement of the tool. However, it appears that the axial force and the moment at the return of the tool do not have extremely low values, these efforts are generated by the friction of the abrasive grains due to the elastic return of the material, which influences the dimension, roughness and shape of the parts.

Concerning the deformation, two components are involved: plastic and elastic. The plastic portion of the deformed material is removed by the diamond abrasive grains. The deformed elastic portion is not removed, consequently, there is an elastic return of the material just after the tool leaves the hole and reaches the bottom dead center of its stroke. In this way, during the return of the tool to the initial position, the portion of material resulting from the elastic return generates a force resulting from resistance to this movement.

The negative values displayed in the Fa graphs can be explained by changing the direction of the reaction force exerted by the honed hole on the tool, assuming the Z- direction of measurement of the dynamometer. The same behavior described above was also verified for the moment, however, it does not change its direction, it remains Z + both when descending and when ascending the tool.

Figure 4 shows the behavior of the cutting force (F_c) and M_z in their average values on the variation of axial speed and rotation of the tool. Figure 4 shows that there is a tendency to reduce the average value of the cutting force as the tangential speed increases. This reduction occurs due to the reduction of the chip section and also the reduction of the number of kinematic edges acting. By increasing only the tangential speed of the tool, the material removal rate remains constant. Thus, the same grain penetrates the material of the part with less depth, since it passes through the same region of the part more times per unit of time. The amount of material removed per rotation of the tool is reduced and consequently also the chip section is reduced. As the amount of material removed per grain is less, that is, less penetration of cut, the amount of kinematic edges acting on the part is also reduced. Such changes favor the attainment of small forces (König, 1989).

This behavior is also verified by Freitas (2018), who observed a linear behavior inversely proportional between the cutting force and the tangential speed and directly proportional between Fc and the axial speed. In addition, the author concluded that for the cutting force there is no interaction between the tangential and axial speeds, being independent from each other.

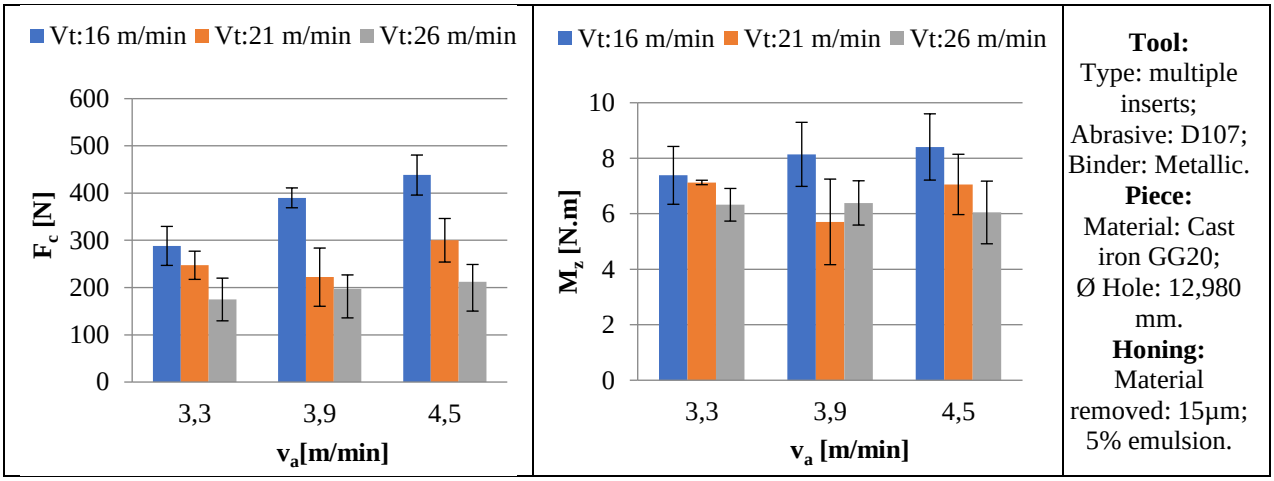

Figure 4. Average of the efforts acquired during honing under the variation of the rotation and axial speed of the tool.

In addition to the relationship between the cutting force and the tangential speed, it is noted that the average value of the force increases with the increase in axial speed for the condition v_t = 16 m/min. This behavior was expected, since the tool removes the same amount of material in a shorter period of time. In this way, each abrasive grain removes a greater amount of material, which increases the contributions of friction and deformations of the part material on the cutting force. Eq. (1) shows the increase in material removed rate with the increase of the axial speed, this causes the cutting force to increase as well. The equation represents the rate of material removal in the single pass honing process.

$$\dot{Q} = \frac{1}{240}\pi(D^2 - d^2)v_a \tag{1}$$

Where $\dot{Q}$ is material removal rate [mm^3/s], D is diameter adjusted on the tool [mm], d is hole diameter [mm], v_a is axial speed [mm / min]. Considering the diameter adjusted in the tool equal to 12.980 mm and the diameter of the hole equal to 12.965, the value of the material removal rate for each axial speed analyzed is given by Table 2.

Table 2. Value of material removal rate

v_a [m/min]	$\dot{Q}$ [mm³/s]
3,3	16,76
3,9	19,84
4,5	22,92

When the confidence interval is evaluated, it is observed that there is an increase in the forces and in the moment variation rate. The explanation for such behavior is correlated to the use of the tool in conditions of early tool life (Freitas, 2018). The use of the tool at the beginning of its life was responsible for the great variation of the confidence interval. Table 3 shows the percentage of increase, for positive values and reduction, for negative values, of the moment and the cutting force (F_c) in relation to the tangential and axial speeds.

Table 3. Percentage of variation of the moment and cutting force in relation to the variation of the axial and tangential velocities.

	v_t (m/min)	Moment (M_z)	Cutting Force (F_c)
	16 → 21	-3%	-14%
v_a:3,3 m/min	21 → 26	-11%	-29%
	16 → 26	-14%	-39%
	16 → 21	-30%	-43%
v_a:3,9 m/min	21 →26	12%	-11%
	16 → 26	-21%	-49%
	16 → 21	-16%	-32%
v_a:4,5 m/min	21 →26	-14%	-29%
	16 → 26	-28%	-52%
	v_a (m/min)	**Moment (M_z)**	**Cutting Force (F_c)**
	3,3 → 3,9	10%	35%
v_t:16 m/min	3,9 → 4,5	3%	12%
	3,3 → 4,5	14%	52%
	3,3 → 3,9	-20%	-10%
v_t:21 m/min	3,9 → 4,5	24%	35%
	3,3 → 4,5	-1%	21%
	3,3 → 3,9	1%	13%
v_t:26 m/min	3,9 → 4,5	-5%	7%
	3,3 → 4,5	-4%	21%

The behavior of the moment is governed by the behavior of the tangential force. Considering the mean values of the moment for the rigid tool of multiple inserts, there is a tendency of reduction of the moment with the increase of the tangential speed as shown in Figure 4. When analyzing the behavior of the moment with respect to axial speed, a pattern of behavior is not verified. When assessing the confidence interval associated with the measurement, there is no significant difference between the moments in all cutting conditions. This high confidence interval value can be generated by the deviation of positioning that exists between the tool and the part, by the variation of excess material removed and by the beginning of the tool's life (Freitas, 2018; Zumpano, 2020).

4. CONCLUSIONS

This study consisted of evaluating the influence of the cutting parameters on the forces generated during the single pass honing process on sliding bearings, varying the tool's v_t and v_a. It was found that the advance of the tool, as well as its rotation, have a significant influence on the forces generated throughout the process. It was observed that the axial force and the moment are inversely proportional to the cutting speed, this is due to the reduction of the chip section, as

well as the reduction in the number of kinematic edges acting. The increase in force and moment with the increase of the axial speed of the tool was expected due to the studies cited that present an increase in roughness and cylindricity caused by the tipping of the tool and the increase in the removal rate.

It was observed that, although the material removal occurs in a tool oscillation cycle, there are machining forces during the return stroke of the tool to its initial position. It was concluded that these forces exist due to the elastic return of the component material after the end of the tool stroke, as the amount of material removed is very small. Therefore, it is believed that there is a portion of the force that is proportional to the elastic deformation that the tool induces on the component.

5. ACKNOWLEDGEMENTS

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