DRILLING OF GRAY CAST IRON GH - 190 UNDER DIFFERENT CUTTING CYCLES - ANALYSIS OF TOOL LIFE AND THRUST FORCE

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Abstract. *The majority of published work in machining refers to turning process, so there is interest in expanding the study to other machining processes such as drilling, which is the most used in industry, comprising around 25% in time machining and 33% in numbers of all the processes employed. In this study, it was investigated the influence of the drilling cycle (continuous and intermittent) in the life of HSS twist drills coated with TiN-TiAlN multilayer and diameter of 10 mm during the machining of gray cast iron GH-190 in dry condition and applying MQF techniques. Blind holes were drilled to a depth of 40 mm. A fractional factorial design* 2^{4-1} *was used, whose input variables are: i) - direct and intermittent drilling (with 3 stops and drill reclusion of 1 mm) ii) - cutting speeds of 45 and 65 m / min, iii) - feed rates of 0.20 and 0.30 mm / rev, and iv) - lubrication and cooling system (MQF and dry). Tool life was measured in terms of number of drilled holes, and the end of tool life criterion was the total collapse of the drill. Thrust force* (F_z) *was monitored during all the tool life tests. The results showed that the cycle with intermittent application of MQF, in general, increased tool lives and promotes the reduction of thrust force when compared to the continuous machining.*

Keywords: Drilling of cast iron, number of stops, MQF, tool life, thrust force (F_z).

1. INTRODUCTION

Holes are very common and important elements "features" in mechanical parts. Employed at various parts and products it plays important roles, as drivers of fluids, bearings housing, interior threads, coupling shafts, bushings, fasteners and others. Metallurgical industries have several options to accomplish them, depending on the forms and conditions under which they are parts.

The holes can be made through different processes, each with its own characteristics and importance within manufacturing. Among the nontraditional processes most commonly used, are: shaping, oxygen cutting, plasma cutting, laser cutting, abrasive water jet cutting, EDM wire and others, where productivity is not the main objective. Within the traditional processes, drilling and milling are important processes, and they often require a subsequent process to achieve the desired surface finish and dimensional accuracy. These subsequent processes may be reaming, boring, burnishing, grinding or even the internal broaching, all characterized by small volume of chips removed. The processes are selected according to the following conditions: the material to be machined, the type of hole to be performed, the length to diameter ratio, surface finish and dimensional and geometric tolerances.

The drilling process is the most competitive, flexible, with circular section and used to make holes in most materials, and in varying conditions. However, it is considered a rough machining process (Ferraresi, 1970, Stemmer, 1992). It also needs a large number of tools to carry out the operation when machining a huge batch of pieces, requiring tool replacement, which causes high downtime.

The finishing quality of the drilled holes (surface roughness, roundness and cylindricity) depends on several facts, including work material, cutting conditions, cutting fluid application, tool geometry, etc. Milling process is possible to generate better results because it offers better quality of surface finish and improved dimensional conditions. The milling cutters have a wider range of diameters, better length /diameter ratios and it is capable of conducting holes in full, using only one tool with large diameters and high depths, while maintaining acceptable quality. In special cases, when there is need for high quality or dimensional and geometric accuracies, shop floor managers can make use of subsequent finishing processes such as honing, reaming, or internal grinding, etc. In the case of manufacturing of small batches of parts such as molds and dies, the cost impact of the tools is very significant. Often tooling faces this problem in making big holes for fixing of columns guides. In this case special milling and boring are the process in play.

However, the drilling of a simple hole can be expensive, if the correct tool and the right conditions are not chosen. Today machine tools equipped with Computerized Numerical Control (CNC), and tools with interchangeable inserts, can supply a more flexible and competitive process. This is also possible due to new materials and geometries of tools that have emerged in the market, thereby reducing the inventory of them.

The present work investigates the performance drills when different drilling cycles (continuous and intermittent) are applied, considering the tool life and the thrust force.

2. EXPERIMENTAL SETUP

The machine tool used for testing was a CNC Vertical Machining Center; model 760 Discovery with 9 kW of power and maximum rotating speed of 10,000 rpm, manufactured by Industries Romi SA Fig. 1

Figure 1. Vertical CNC machining center used in the drilling tests

The cutting tools used in the experimental tests were AISI M42 (8% Co) HSS twist drills coated with multilayers of TiN and TiAlN designated as EX-BDR, manufactured by OSG Sulamericana de Ferramentas Ltda, with the characteristics given in Tab. 1.

Table 1. Characteristics of the drills used in the tests

Angles		Length (mm)		
Point (σ)	Helix (δ)	Total	Groove	Diameter
130°	30°	137	87	10

Fig. 2 shows a view of the "EX-BDR OSG Futures™" which according to the manufacturer:

- They allow drilling depth up to four times their diameter with no interruptions;
- They are recommended for innumerous applications with high productivity and also in conventional processes.

Figure 2. Geometric aspects of the TiN-TiAlN drills: chisel edge and clearance surface

The work material was the GH-190 grey cast iron supplied by Teksid Brazil (Betim, MG) in the form of plates with the following dimensions 500 mm x 200 mm x 45 mm. The top surfaces of the plates were face milled in order to remove the cast skin and adjust their thickness. The chemical composition and other characteristics of this material are presented in Tab. 2.

Table 2. Characteristics of the gray cast iron - GH 190 (source: Santos 1999)

Chemical composition (%)					Structural characteristics			Hardness (HV)
C	Si	Cr	S	P	Matrix	Graphite	Cementite and carbon free	
3. 20 – 3.50	2. 00 – 2.50	≤ 0. 20	≤ 0. 15	≤ 0. 10	Lamellar pearlite maximum ferrite 5%	Types B e D	Max. 1%	200

The holes were blind, 40 mm deep, distributed according to Fig. 3. Set of tests were divided in blocks. They were vertically machined, downward, without pre-hole and center hole.

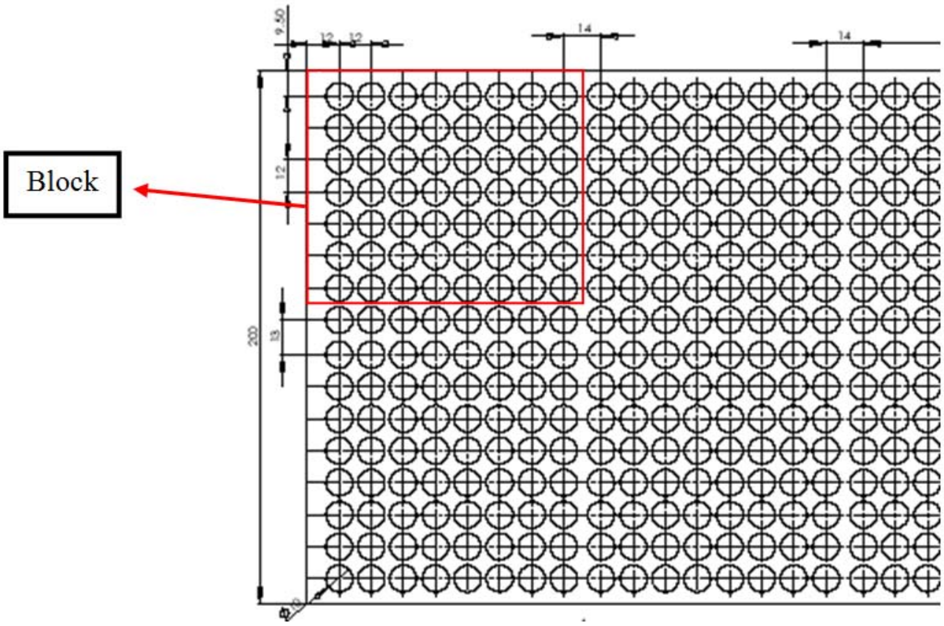


Figure 3. Illustration of the top view of the plate after the drilling operation

For each tool life test three runs, i.e., a test and two replicas were carried out and the average was the value considered for the life of the drills. Two different cycles were used: straight full length (direct cut) and cuts with three stops. In the latter cycle the stops happened after every 13.33 mm machined and the tool retrieved 1 mm upwards before getting entering into cut again, the tool was until the total length of 40 mm were drilled.

The experiments were designed in a 2^{4-1} fractional factorial design, with the effects of the variables determined by the Statistica® 7.0, with a significance level of 5% and reliability of 95%. The input variables (cutting parameters) and their levels (low and high) used are presented in Tab. 3.

Table 3. Cutting parameters used in the drilling tests

Parameters	
No. of stops	0 (direct) and 3 (three)
Cutting speed (v_c)	45 and 65 [m/min.]
Feed	0. 20 and 0.30 [mm/rev.]
Lubrication and coolant system	dry and MQF

. With the use of this DOE it was possible to analyze the influence of the drilling cycle through an array of eight planning tests shown in Tab. 4.

Table 4. Matrix of tests

Tests	No. of stops	vc (m/min)	f (mm/rev)	Lubrication and coolant system
1	0	45	0. 20	D
2	3	45	0. 20	MQF
3	0	65	0. 20	MQF
4	3	65	0. 20	D
5	0	45	0. 30	MQF
6	3	45	0. 30	D
7	0	65	0. 30	D
8	3	65	0. 30	MQF

The thrust force was monitored in some specific period of the tool life tests using a rotating dynamometer - 9123C1211 model and a charge amplifier – 5223B1 model, both manufactured by Kistler Instrument Fig. 4 illustrates the measuring system. In order to reduce time the measurement were done at the following periods: 1%, 25%, 50%, 75% and 90% of the tool lives.

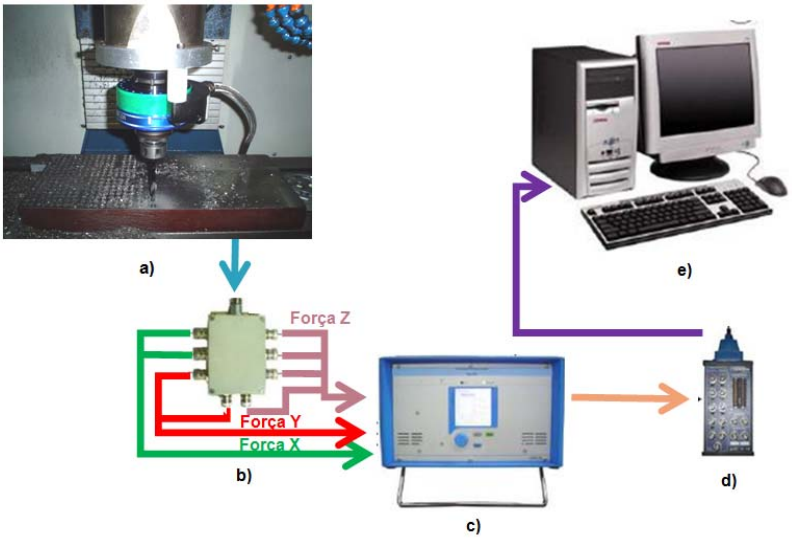


Figure 4. a) - The rotating Kistler dynamometer b) Distribution box (Kistler ˉ 5407A); c) Charge amplifier ; d) BNC connector block (Kistler – 2110), e) Computer with data acquisition board

An A/D data acquisition board - PCIMIO-16E-4 model, manufactured by *National Instruments*, and LabView ™ 7.0 software were also used. Tab. 5 presents the work ranges possible for the Kistler 9123C dynamometer.

Table 5. Technical Data of the Kistler 9123C dynamometer

Tchnical data		Value
Range 1	Fx, Fy	-5... 5KN
	Fz	-5... 20 Nm
	Mz	-200...200 Nm
Limit	Fx, Fy	< 0.02 N
	Fz	< 0.02 N
	Mz	< 0.02 Ncm
Natural Frequency		4 KHz
Protection		IP67
Weght		4.2 Ncm

Figure 5 illustrates thrust force behaviour during the machining of a hole. The start of the cut, the drill stop, the cutting period and the return of the drill can be identified in this graphic. In this example the thrust force reached a maximum of approximately 1200 N.

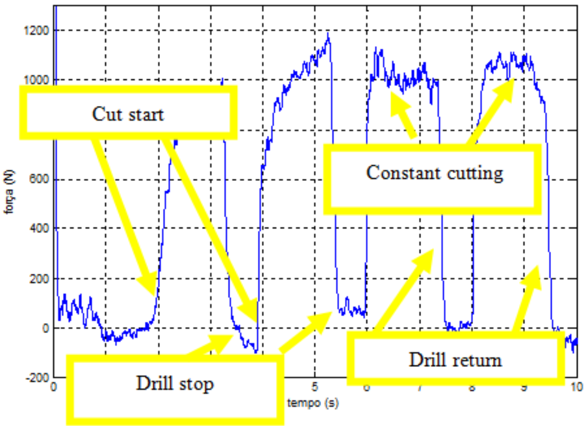


Figure 5. Illustration of the thrust force signals measured during the machining of a hole

3. RESULTS AND DISCUSSION

Tab. 6 shows the results of the tool lives of the tests planned according to Tab. 4. A test and two replicas were carried out and the result for each cutting condition is the average of them.

Table 6. Results of tool lives given in numbers of holes machined until the collapse of the drills

Test	No. of stops	vc (m/min.)	f (mm/rev.)	Lubrication and coolant system	Test	1º Replica	2º Replica	Average
1	0	45	0. 20	D	41	29	28	33
2	3	45	0. 20	MQF	108	255	139	167
3	0	65	0. 20	MQF	06	03	04	4
4	3	65	0. 20	D	3	3	3	3
5	0	45	0. 30	MQF	32	27	45	35
6	3	45	0. 30	D	45	34	34	38
7	0	65	0. 30	D	3	3	2	3
8	3	65	0. 30	MQF	3	3	2	3

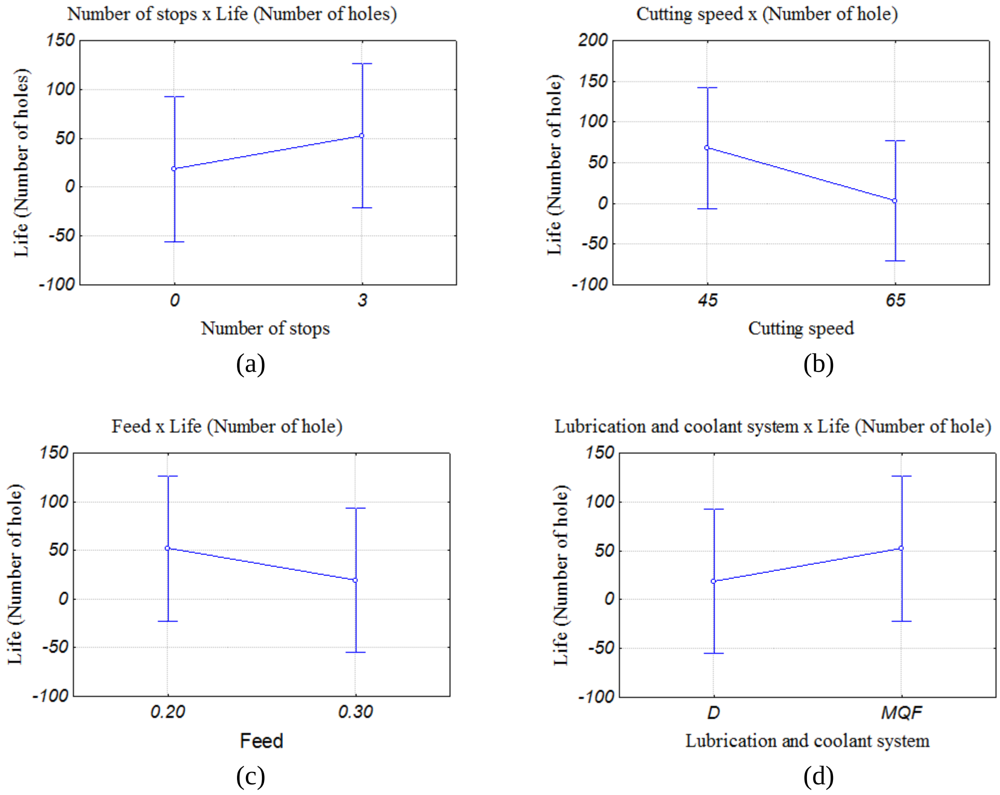
Tab. 7 summarizes the effect of each input parameter on the tool lives.

Table 7. Effects of the input parameters on the tool lives of the drills

Factor	Effects	p
No. of stops: 0 → 3	34.07	0.37
Cutting speed: 45 → 65	-64. 90	0. 14
Feed: 0. 20 → 0.30	-32. 40	0. 40
Lubrication and coolant system: D → MQF	33. 23	0. 39

The "p" level of probability informs whether the factor (input variable) is significant in determining the tool life of drills (number of drilled holes). One factor is considered significant if the "p" level is smaller than or equal to the level of significance (in this case considered 0.05).

The table indicates that no variable was significant for a reliability of 95% due to the fluctuation of the results between tests and replicas, possibly, among other factors, due to inhomogeneity in the microstructure of the work material with bad distribution of carbides, flaws arisen from the casting process and difficulties in extracting the discontinuous chip from the holes. However, observing the effects and trends for these variables, deductions can be described. When the drilling is done with no stops (zero stops or direct cut) instead of drilling with three stops the number of holes tends to increase (approximately 34 holes, Tab. 7 and Fig. 6a). This behavior seems to be most common for this situation because, as expected, the interruption of the cut (woodpecker) has the main objective of breaking the chips, which in the case of gray cast iron there is no need; however, more time is available for cooling the tool, improving the machining conditions. When the cutting speed is changed from45 m/min to 65 m/min the average number of holes machined tends to decrease (approximately 65 holes, Tab. 7 and Fig. 6b). The explanation is the higher heat generation at higher cutting speeds, accelerating the wear of the tool, agreeing with the Taylor equation (MACHADO et al., 2009). Raising the feed rate from 0.20 mm/rev to 0.30 mm/rev also tends to decrease the average numbers of holes machined (approximate reduction of 32 holes - Tab. 7 and Fig. 6c). This is due the increase in the chip-tool contact area that consequently increases the machining forces and heat generation and hence tool wear. With the use of MQF, instead of dry cutting, the tool life of the drills tends to increase on an average of 33 holes (Tab. 7 and Fig. 6d). This can be attributed to the lubricating action of the cutting fluid as well as the help in removing the chips from the vicinity of the cutting area.



(a) (b) (c) (d)

Figure 6. Graphs relating the life of the drills with the input variables: (a) No. of stops, (b) Cutting speed, (c) Feed, (d) Lubrication and coolant system

Tab. 8 shows the average of the thrust force (F_z) resulted from measurements done in periods previously specified.

Table 8. Results of the thrust forces measured during tests planned according to Tab.4

Test	No. of stops	vc (m/min)	f (mm/rev)	Lubrication and coolant system	F_z (N) (average)
1	0	45	0.20	D	1797. 31
2	3	45	0.20	MQF	1053.39
3	0	65	0.20	MQF	1368.21
4	3	65	0.20	D	1361.62
5	0	45	0.30	MQF	1373.26
6	3	45	0.30	D	1483.86
7	0	65	0.30	D	1944.59
8	3	65	0.30	MQF	1145.58

Tab. 9 shows the ANOVA results of the average of the thrust force (F_z).

Table 9. ANOVA of the thrust force

	F_z	
Factor	Effects	p
No. of stops: 0 → 3	-359. 73	0. 01
Cutting speed: 45 → 65	28. 05	0. 66
Feed: 0. 20 → 0.30	91. 69	0. 21
Lubrication and coolant system: D → MQF	-411. 74	0. 01

According to these results the variables that were statistically significant for determining the feed force within a 95% of reliability were the machining cycle (number of stops) and lubrication and coolant system. When using three stops instead of direct cuts, F_z tends to decrease on an average of approximately 360 N, as can be expected for such a situation because more time is available for lubricating the cutting area. The application of cutting fluid using the MQF technique tends to decrease F_z on an average of approximately 412 N. Although not significant the tendencies of the effect of cutting speed and feed rate are given in Table 9. The increase in the cutting speed from 45 m/min to 65 m/min tends to increase F_z on an average of 28 N and the increase of the feed rate from 0.2 mm/rev to 0.3 mm/rev tend to increase F_z on an average of approximately 92 N.

4. CONCLUSIONS

According to the statistical analysis for the experiments carried out in this investigation, it can be concluded that:

- All the input variables analyzed at the levels tested (cycle, cutting speed, feed rate and lubrication and cooling system), has no significant influence on the tool lives.
- Only the variables number of stops and lubrication and cooling system were statistically significant in affecting the thrust force F_z.
- The increase of cutting speed from 45 to 65 m/min decreased the average tool life in about 65 drilled holes and an increased the thrust force F_z on an average of approximately 28 N.
- Drilling with the feed rate of 0.30 mm/rev, instead of 0.20 mm/rev, tended to reduce the life of the drills in about 32 holes and to raise the thrust force in an average of 92 N.
- When using MQF instead of dry cuts the life of the drills tend to increase the tool life on an average of about 33 holes whereas the thrust force F_z tends to drop on an average of about 412 N.

5. ACKNOWLEDGEMENTS

The authors are grateful to OSG Sulamericana de Ferramentas Ltda, in the person of Dr. Coit Fukushima and Mr. Rodrigo Katsuda that provided the drills for the tests; the Teksid of Brazil for providing the workpieces, FAPEMIG, CAPES and CNPq for financial support.

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