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Productiveness Evaluation of a Machine Tool Manual Setup Compared with Automated CNC Machine

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Abstract*— *The automatic tool change of machine tools affects the productive efficiency in several ways such as starving time reduction, increase/decrease of production rate as well reliability and reduce the process related costs of manufacturing. Based on that background an analysis of experimental scenarios of manual tool change versus automatic tool change was made in order to compare and evaluate its related production rate.

Keywords*— *Automation, CNC, machine tool, productiveness, tool change.

I. INTRODUCTION

Short for "computer numerical control," CNC machining is a manufacturing process in which pre-programmed computer software dictates the movement of factory tools and machinery. The process can be used to control a range of complex machinery, from grinders and lathes to mills and routers. With CNC machining, three-dimensional cutting tasks can be accomplished in a single set of prompts. CNC machines have been facing various applications where the automation is required. It can produce simple parts or complex parts through machining center computer integrated. Although the manufacturing processes require flexibility and complexity several attributes are achieved such as flexibility, accuracy, repeatability and consequently quality [1].

The improvements of machine tools in manufacturing processes had been developed to the purpose of increase productiveness without loss of quality and equipment downtime reduction due to human interface in the process. Setup time reduction have been used by manufacturers as a solution to increase productivity and reduce the related transformation costs. Nevertheless the setup time reduction is relevant due to three simple principles: (1) faster technologies of tool change reduce the probability of human error; (2) how lower is the setup time the production behavior becomes more dynamic; and (3) increase of machining saturation of the equipment [2]. Automatic tool change (ATC) integrated to the machining centers enables the reduction of non-productive time and allows tools availability to complex parts machining [3].

The purpose of this article is to evaluate the production rate considering the usage of the ATC concept by the comparison with manual tool change.

II. THEORETICAL FRAMEWORK

Tool change time represents the total time to perform the operations independently if manual, semi-automatic or automatic. Some examples of operations are the approach, adjust, corrections and offsets. Therefore the manual tool change time calculation is made by the sum of time operation tasks that do not generate chip [4]. Automatic tool change is defined as the minimum interval required

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to change tasks during the machining process that means the non-productive manufacturing time [5].

The machining cycle time is represented by the following equation.

$$T = C + T_{machining} \quad (1)$$

C = Tool change time

$T_{machining}$ = Machining time

The machining cycle time (1) is composed by the tool change (non-productive manufacturing time) and the machining cycle (productive time with chip removal). Considering the tool change time the sum of the individuals tasks up to the kth under the non-productive time, brings to the following equation.

$$C = \sum_{i=1}^{k} t_i \quad (2)$$

Nevertheless the range of chip removal time depends on the machining mechanism [6].

$$T_{turning} = \frac{L}{n\, f} \quad (3)$$

Tturning: turning cutting process time (min)

L: part length (mm)

f: feed rate (mm/min)

n: revolutions per minute

$$T_{drilling} = \frac{L_d\, i}{n\, f_r} \quad (4)$$

Tdrilling: drilling cutting process time (min)

L_d: hole depth (mm)

i: number of holes

n: revolutions per minute

fr: feed rate (mm/rev)

$$T_{milling} = \frac{L_d}{V_f} \quad (5)$$

Tmilling: milling cutting process time (min)

L: part length (mm)

Vf : table feed rate (mm/min)

An appropriate way to estimate the productiveness rate among different kinds of machining is through hourly rate where the machining cycle is evaluated in one hour (60 minutes). Considering Ca automatic change, Cm manual change, Ta machining cycle time for automatic change, Tm machining cycle time for manual change and T as machining time, that is equivalent to all considerations, brings to the following analysis.

$$T_m = C_m + T \quad (6)$$

$$T_a = C_a + T \quad (7)$$

$$T_m - C_m = T_a - C_a \quad (8)$$

$$T_m - T_a = C_m - C_a \quad (9)$$

Based on the machining cycle time is possible to establish the productiveness ratio σ in parts per hour under the perspective of tool change.

$$\delta = C_m - C_a \quad (10)$$

$$\sigma = \frac{60\frac{1}{T_m}}{60\frac{1}{T_a}} = \frac{T_a}{T_m} \quad (11)$$

The combination of equations (9) and (10) generates to the following equation.

$$\sigma = \frac{T_a}{T_m} = \frac{T_a}{C_m - C_a + T_a} = \frac{T_a}{\delta + T_a} \quad (12)$$

III. METHODOLOGY

The first step of methodology was simulate the tool change through a programmable device an then apply the theory mentioned before and its impact in the manufacturing productiveness.

In order to simulate the application of CNC machine to the quick tool change automation the LEGO NXT 9797 kit and an educational programmable robot were used the reproduce the environment studied.

To compare the tool change technology it was used a tool plan of a CNC tool with a tool change and machining time settle-up to drilling of Ø8 mm with drill change to Ø10 mm both in single step.

The following bill of materials were used during the experiment:

- 01 commercial aluminum hub with 100 mm edge;
- 02 HSS steel drill bits Ø10 mm and Ø8 mm;
- 01 drilling machine with 60 mm maximum drilling depth;

Parameters:

- 03 different operators;
- 02 holes and one drill change per operator;
- 03 measurements per operator, totaling 18 holes and 09 drill changes;
- Pre-drill hole with Ø8 mm exchange for Ø10 mm drill;
- Rotation at 1100 rpm;
- 02 chronometer.

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IV. RESULTS

The following tables presents the each sequence measurements per operator.

Tab. 1. Operator #1 measurements

Seq.	Operator #1		
	$\sum_{i=1}^{k} t_i$	$\frac{L_d i}{n f_r}$	$\sum_{i=1}^{k} t_i + \frac{L_d i}{n f_r}$
1ª	0,750 min	0,833 min	1,583 min
2ª	0,700 min	0,700 min	1,400 min
3ª	0,766 min	0,616 min	1,382 min

Tab. 2. Operator #2 measurements

Seq.	Operator #2		
	$\sum_{i=1}^{k} t_i$	$\frac{L_d i}{n f_r}$	$\sum_{i=1}^{k} t_i + \frac{L_d i}{n f_r}$
1ª	0,566 min	0,400 min	0,966 min
2ª	0,500 min	0,283 min	0,783 min
3ª	0,616 min	0,366 min	0,983 min

Tab. 3. Operator #3 measurements

Seq.	Operator #3		
	$\sum_{i=1}^{k} t_i$	$\frac{L_d i}{n f_r}$	$\sum_{i=1}^{k} t_i + \frac{L_d i}{n f_r}$
1ª	0,750 min	0,316 min	1,066 min
2ª	0,600 min	0,300 min	0,900 min
3ª	0,683 min	0,250 min	0,933 min

The following table 4 describes the machining parameters of FAMAR CNC machine model SUB 160 2G 3 axis interpolated.

Tab. 4. Machining parameters of FAMAR CNC machine

Axis coord.	Machining description	Tool code	Tool material	Starving (min)
702, 703	drill Ø8	T2	MD	0,143
280, 281	drill Ø10	T2	MD	0,075
Total time (min)				0,218

The data collected applied in the equation (12) established the productiveness ratio between the manual tool change with automatic tool change. These data are plotted in the following figure 1.

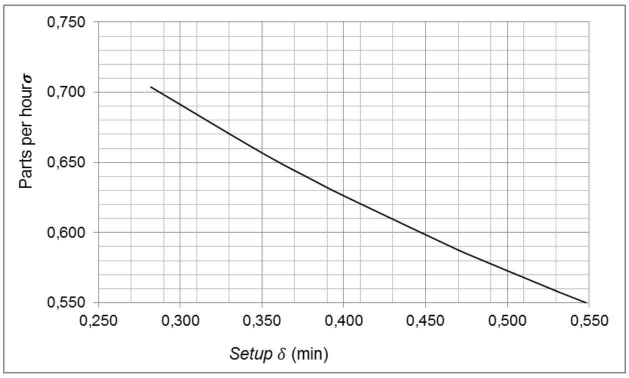

Fig. 1. Ratio between parts per hour (σ) with setup time (δ)

V. CONCLUSION

The ratio σ express the productiveness in terms of parts per hour under the manual setup perspective. It connects the manual setup with automatic setup in a way to extract the ratio between both environments there is a direct and proportional ratio between manual setup times with the need for automation of setup is verified by the results presented.

By the curve behavior interpretation the increase of difference between manual and automatic setup time results in decrease of hourly productiveness rate. Thus based on the math presented in this paper it is possible to estimate productiveness margin for both systems.

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