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Systematics for checking geometric errors in CNC lathes

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Abstract: Non-idealities presented in machine tools compromise directly both the geometry and the dimensions of machined parts, generating distortions in the project. Given the competitive scenario among different companies, it is necessary to have knowledge of the geometric behavior of these machines in order to be able to establish their processing capability, avoiding waste of time and materials as well as satisfying customer requirements. But despite the fact that geometric tests are important and necessary to clarify the use of the machine correctly, therefore preventing future damage, most users do not apply such tests on their machines for lack of knowledge or lack of proper motivation, basically due to two factors: long period of time and high costs of testing. This work proposes a systematics for checking straightness and perpendicularity errors in CNC lathes demanding little time and cost with high metrological reliability, to be used on factory floors of small and medium-size businesses to ensure the quality of its products and make them competitive.

1. Introduction

Machine tools play a significant role in the development of a country, and are essential for modern metal-mechanical industry and in evolution of machinery and equipment, adding improvements to human quality of life by manufacturing consumer goods that provide comfort and well-being. Machine tools have undergone significant evolution in the last 30 years with the contribution from various fields of knowledge (mechanics, electronics, information technology and new materials) [1], which evolved from simple mechanical machines to automated machines with mechatronic systems, through the introduction of the computer numerical control (CNC). In the 80's, about 10% of the machines produced in the most highly industrialized nations were machine tools, and approximately 10% of the workforce were focused on building these machines [2]. Under the current scenario, companies seek more and more to adopt quality standards in order to gain competitiveness, and thus seek to implant in their production processes speed, flexibility, high performance, reliability and cost reduction, because if they do not comply to these standards they will quickly reach failure [3]. However, it is not easy to achieve excellence in the face of numerous difficulties that arise on a daily basis, it is necessary to look continuously for improvements in all steps involved in the production process [4]. Common are the losses generated by a manufacturing system due to its inefficiency, which in turn raises the costs of the process due to waste of time and materials. It is not different for machining processes, which have great loss of material but give the piece a high added value, since they are commonly used as a final step in the manufacturing process, providing the shape, size and finish of the material. However, accuracy levels can be achieved in the machining process which are impractical in other processes, justifying its use especially in finishing processes [5-6].

Machine tools are not perfect and have imperfections that reflect directly on the geometry and dimensions of machined parts. In order to minimize those undesirable effects, improvements were implanted initially in the mechanical assembly, but mechanical optimization alone will not eliminate the geometric and dimensional errors from the non-idealities in the mechanical assembly of the machines. Geometric testing of machine tools is used alternatively. Besides providing information on the possible deviations of shape and size generated by the machine tool, the user finds out its dimensional tolerance in manufacturing parts [7]. The geometrical errors are present in all machine tools, primarily as a consequence of mechanical imperfections and misalignment of machine elements. These errors cause wrong positioning and orientation of the cutting tool relative to the workpiece. For each axis of a machine tool there are 6 sources of geometric errors, three of translation, where one of these errors relates to position and the other two are of straightness, and three angular errors known as *roll*, *pitch* and *yaw*. Also, there are perpendicularity errors between the axes. Figure 1 shows the movement scheme of a machine guide indicating the error components present. Considering a machine tool that has three linear axes perpendicular to each other, there will be 21 sources of geometric errors.

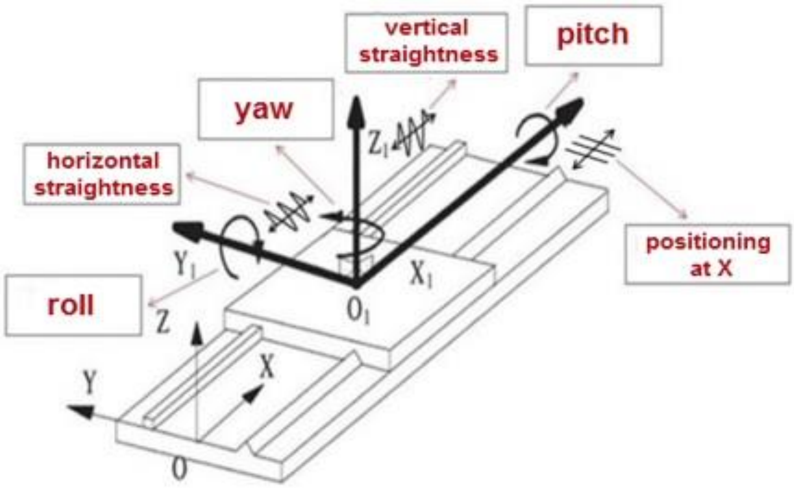

Figure 1. Geometric errors with movement along axis X (adapted from OKAFOR, 2000).

2. Objective

The aim of this work is to propose a systematics for checking straightness and perpendicularity errors demanding little time and low cost with high-reliability metrology to be applied in CNC lathes, which can be used on the factory floor by users of small and medium-sized companies to thereby assess the geometric errors of their machines and ensure the quality of their end product so that they can remain competitive because, despite the importance of the use of geometric tests as a tool aiding in quality control, they are not yet applied on a large scale due to the fact that traditional methods are expensive and demand long periods of time.

3. Materials and methods

Steel billets SAE 1020, 349 mm long and with a diameter of 58 mm, were used, following preset cutting parameters, and three specimens (staggered cylindrical - Figure 2, and non-staggered cylindrical - Figure 3) were machined, using an almost new Romi CNC Centur 30D lathe (Figure 4).

The cutting parameters were determined carefully in order to minimize maximum efforts involved in the machining process and thereby avoid bending deformation of the tool-holder and specimen. The values used were: cutting depth 0.5 mm, cutting speed 200 m/min, roughing operation advancement 0.3 mm/rev and advancement in finish operation of 0.2 mm/rev.

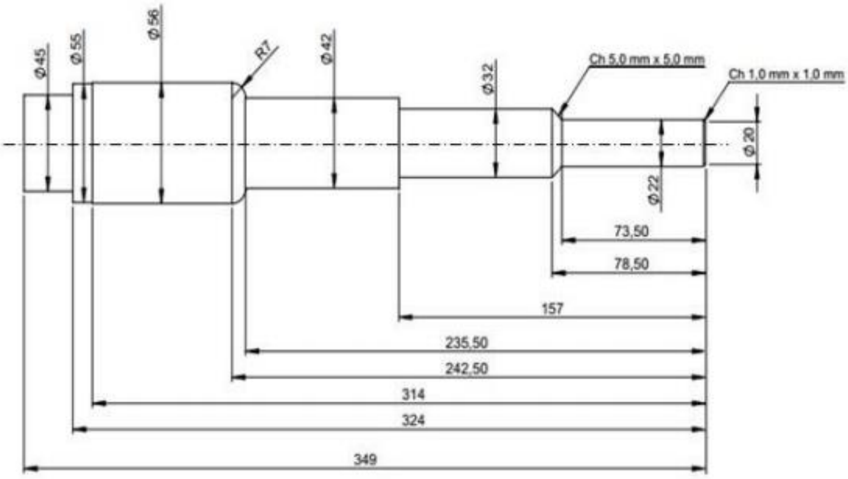

Figure 2. Staggered cylindrical piece (in mm).

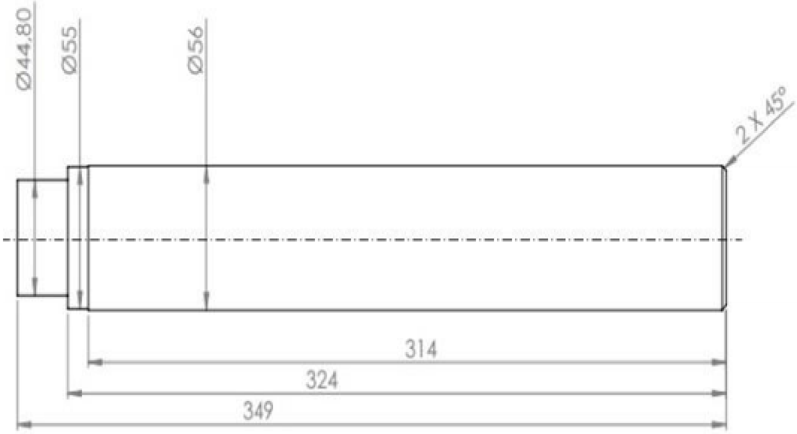

Figure 3. Non-staggered cylindrical piece (in mm).

Figure 4. CNC ROMI Centur 30D Lathe.

For each workpiece, a brand-new cutting edge was employed, and cutting tools used were made of hard metal for turning, Sandvik Coromant, ISO code CMT 11 T3 08-UR 4025. A 25 mm x 25 mm square-section Sandvik Coromant tool-holder was used (ISO Code SDJCR 2525M 11) (Figure 5).

Figure 5. Tool-holder for turning.

Six specimens were machined: three staggered pieces and one non-staggered piece by using MQL (compressed air and cutting oil) and three staggered pieces and one non-staggered piece using cutting fluid in abundance, to determine which of the two conditions has a better performance.

3.1. Thermography of the specimens

Through a FLIR SYSTEMS (FLIR SC 660 model) thermographic camera (Figure 6), thermographic filming was performed (Figure 7) on the piece machined on the two lubrication conditions, in order to check temperature distribution along the parts.

Figure 6. FLIR FC 660 Thermographic Camera.

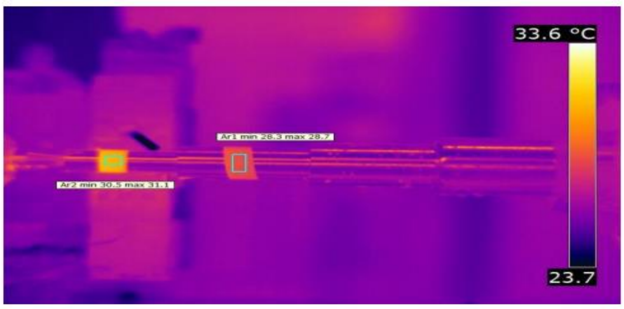

Figure 7. Thermography of a machined piece.

After thermographic analysis, the maximum temperature values obtained were (75.1 ± 1.5) °C using MQL and (31.1 ± 1.5) °C using abundant cutting fluid.

3.2. Scanning Electron Microscopy of cutting tools after machining

Through the HITACHI TM 3000 scanning electron microscope (Figure 8), images were obtained (60x) of both the brand-new and the used cutting tools after machining operation (Figures 9 and 10), with both lubrication conditions, in order to perform a qualitative analysis of possible cutting tool wear and breakdown.

Figure 8. HITACHI TM 3000 scanning electron microscope.

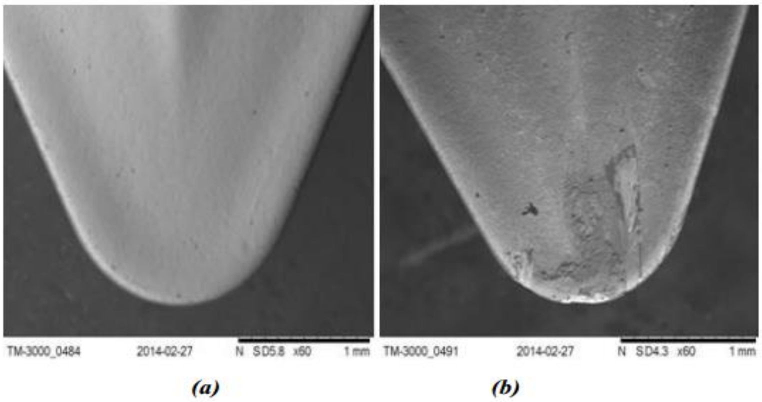

Figure 9. Comparison of the new cutting tool (a) to the used one with MQL (b).

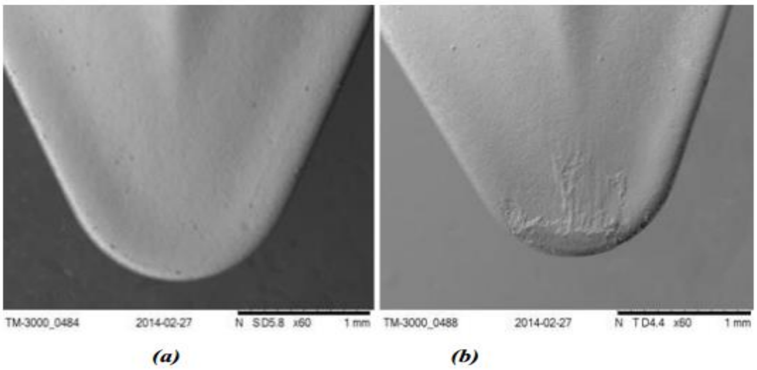

Figure 10. Comparison of the brand-new cutting tool (a) to the used one with abundant cutting fluid (b).

3.3. Cutting force calculation according to Kienzle

In 1951 , Kienzle created a quite accurate formula the result of which is closest to the actual values observed in practice through direct measurement of machining forces.

For this reason this formula is the most widespread and used today [8]:

$$F_c = K_{s1} \, . \, h^{1-z} . \, b \qquad (1)$$

K_{s1} and z are the constants of the material, h is the nominal thickness of cut and b is the chip length.

Table 1. Kienzle's coefficient values for SAE 1020 steel.

Material	K_{S1} *(N/mm^2)*	*1-Z*
SAE 1020 steel	1800	0,83

Replacing the Kienzle coefficient values for SAE 1020 steel in equation (1) gives the following cutting values: 331.40 N for the roughing condition and 236.70 N for the finishing condition, which in turn are too small values to cause bending in tool-holder and/or in the part.

3.4. Computer Simulation

Through the ANSYS 14.0 software computer simulations were performed considering the cutting strength values found by using equation (1) in order to check tool-holder behavior according to the loads applied in both the roughing and finishing conditions. Figure 11 shows the result of computer processing.

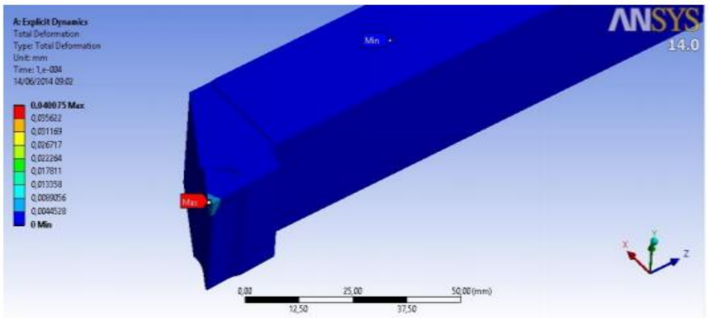

Figure 11. Computer tool-holder simulation.

3.5. Roughness measurement of non-staggered piece

Using an Instrutherm RP-200 rugosimeter, shown in Figure 12, measurements were performed on several parts of the non-staggered piece, resulting in the average roughness value of (1.032 ± 0.018) µm.

Figure 12. Measurement of roughness on the piece.

3.6. Measurement of pieces

After the machining operation, straightness measurements were performed on the non-staggered pieces and of perpendicularity on the staggered pieces with a Mitutoyo Beyond - Crysta C measuring machine by coordinates, shown in Figure 13, with calibration certificate number (RBC) 03206/13.

Figure 13. Measurement of pieces.

Measurements of straightness and perpendicularity of pieces were carried out at a temperature of (20 ± 1) °C, whose control was performed with a MINIPA MTH model 1380 thermo-hygrometer, shown in Figure 14, with calibration certificate No. 6285/14 (REMESP).

Figure 14. MINIPA MTH-1380 thermo-hygrometer.

3.7. Measurement results

Table 2 shows the mean values of performed measurements: straightness for non-staggered pieces and perpendicularity for staggered pieces.

Table 2. Straightness and perpendicularity values.

Straightness	(6,48 ± 2,82) µm			
	Length	Piece 1	Piece 2	Piece 3
Perpendicularity on plane x-y, µm	$Ø_1$ = 56 mm	10,42 ± 4,05	13,57 ± 4,20	10,42 ± 4,05
	$Ø_2$ = 42 mm	10,18 ± 4,01	13,57 ± 4,20	10,66 ± 4,09
	$Ø_3$ = 32 mm	10,66 ± 4,06	13,33 ± 4,18	11,39 ± 4,12
	$Ø_4$ = 22 mm	9,66 ± 3,81	12,84 ± 4,15	11,63 ± 4,14

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4. Results and discussion

From the analysis of the results it was evident that the machining condition using cutting fluid in abundance should be used for verification of errors in the proposed system. This finding can be observed by the state of the tool which presented to the electronic microscope a light wear without compromising the geometry of the workpiece. From the calculated values of cutting force it was found by the classical equation of Kienzle and computer simulation that the tool holder did not deform during machining operations, thus not compromising the geometry of the workpiece.

With the roughness measurement of the machined specimens, it was concluded that the specimens had good surface finish and average roughness values well below the straightness values.

5. Conclusions

The systematics presented here provides machining operations with minimal effort, low temperatures and good surface finish of the parts, with little wear of the cutting tools, allowing a good quality of form and dimension of the pieces obtained. Therefore, it can be concluded that it is a simple and low-cost systematics, with high practicality of application for checking straightness and perpendicularity errors on lathes with computerize numerical control with a reduced bus. This checking systematics is presented as an essential tool and an option for decision making when choosing more sophisticated testing methods.

6. References

[1] Rolim T L 2003 *Sistemática Indicadora de Método para Calibração de Máquinas de Medição por Coordenadas* Doctoral thesis in mechanical engineering (Brazil: Federal University of Paraíba)

[2] Weck M 1984 *Handbook of Machine Tools – Metrological analysis and performance tests* vol 4 John Wiley and Sons

[3] Souza, André Roberto 2000 *Padrões Corporificados e Tecnologia de Medição por Coordendas – Inovando a Qualificação Geométrica de Centros de Usinagem* Doctoral thesis in mechanical engineering (Brazil: Federal University of Santa Catarina)

[4] Ueno, Shigeru 1996 *A máquina da próxima geração tem múltiplas funções e é rápida e precisa* Máquinas & Metais pp 42-53

[5] Ferraresi D 1977 *Fundamentos da usinagem dos metais* vol 1 ed Edgard Blücher (Brazil: São Paulo).

[6] Grasson Thomas 1997 *Machine tool builder's future goes on display* American Machinist pp 154 – 167

[7] Eckhardt M et al. 2008 *Avaliação geométrica de máquinas-ferramenta CNC através do método de padrões corporificados* Máquinas & Metais pp 120 – 129

[8] Erdel Bert 1997 *O impacto da usinagem a alta velocidade na produção* Máquinas & Metais pp 36 – 41