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Experimental Study of the 2D Variability Roughness in the Honing Process of the Steel Cylinder

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Abstract

This article presents the study of the surface roughness inside cylinders, machined by honing in industrial honing machines, with a detailed review of the variability of the values obtained in the measurement of the machined surface. The determination of the amount of measurement data on the cover is displayed to get characteristic mean values of the measured surface. For this reason, and due to the randomness of the surfaces machined by honing, an experimental study has been proposed to carry out this analysis, where the roughness has been measured with a roughness meter with a contact probe, since this type of instrument is widely used academically and especially industrially, and is apparently standardized by international standards such as ISO 3274 or ASME B46.1.

Keywords: Honing process, manufacturing process, roughness

1. Introduction

One of the primary methodologies in the study of machining processes is oriented to characterize and model the processes and their variables as a function of surface quality [1]. The characterization of machining processes by surface roughness is an appropriate methodology since surface quality is a trace of the process that has been used in different jobs in obtaining the surface [2-3] and is even related to the functional characteristics of the component being machined [4].
The correct characterization of the surface studied has played a fundamental role in the processes used to obtain the surface texture, such as in abrasive methods that introduce a crucial random characteristic that can be seen reflected in this surface texture [5-6]. Therefore, characterization has been a necessary step in the development of process control methods or models and all the variables involved in this [7-8].
Different measurement techniques have been used to measure these variables [9], however, the most widely used method has been the use of the contact probe roughness meter, as this type of instrument is commonly used in academia and especially in industry, which is described in international standards such as ISO 3274 [10] or ASME B46.1.
Considering that the use of machining tools with multiple cutting points, such as in abrasive processes, introduces high variability in the measured data values [11], the main contribution of this article is to present the results of an experimental statistical study of the surface roughness values measured inside honing machined cylinders in industrial honing machines for their correct characterization.

2. Methodology

To study the variability of the measurement of the surface roughness of the machined surface, the amount of surface measurement data required to obtain characteristic mean values of the measured surface was initially determined. For this reason, and due to the randomness of the surfaces machined by honing, an experimental study has been proposed to carry out this analysis, which is detailed below based on international standards.

2.1. Initial study conditions

A TAYLOR HOBSON "Talysurf Series 2" profilometer was used to measure the variability of the roughness values on the surface of the hydraulic cylinders by honing. Six tubes were considered with the characteristics shown in Table 1.

Table 1. Characteristics of machined tubes

# CYLINDER	*NUMBER*	*MATERIAL*	*MACHINING*
2	189 – 190	ST-52	ROUGH
2	191 – 192		ROUGH + SEMI-FINISHED
2	193 – 194		ROUGH + SEMI FINISHED + FINISHED

All the tubes were machined on a machine of the manufacturer HONINGTEC of reference N842. The conditions of each of the machining operations used are shown in Table 2. The abrasive stones used were CBN, the grain density in the binder was 50 according to the FEPA [12] standard, with different coarse grain sizes.

Table 2. Machining parameters

Process Variables	**Rough**	**Semi-Finished**	**Finished**
Abrasive Stone (FEPA)	B252	B126	B30
Rotational Speed (rpm)	230	260	340
Axial Speed (m/min)	40	40	40
Pressure N/cm^2	700	700	700
Coolant	Sunnen MB30		

Figure 1 shows a description of the tubes used, where the length was 607 mm, outer diameter 70 mm, and inner diameter after honing was 60 mm.

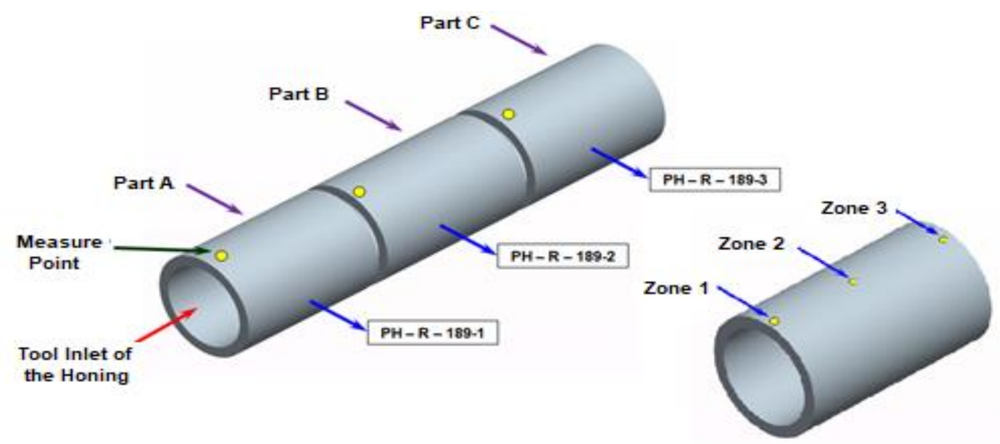


Figure 1. Test tube used in the study

In the roughing operation, 7 hundredths of a diameter were removed from the tube with approximately 10 passes, while in the semi-finish process, 5 hundredths of a width were removed from the machine with approximately 10 passes, and finally in the finishing operation, 2 hundredths of a diameter were removed from the tube with about 20 passes of the machining tool.

2.2. Selection of roughness parameters

Table 3 shows the two-dimensional roughness parameters used in this study, which are described in International Standards ISO 4287 [13], ISO 13565-2 [14], and ASME B46-1. A more detailed description of these parameters can be found in the review by Gadelmawla [15].

Table 3. 2D roughness parameters

PARAMETERS	
Arithmetic Average of Heights – ***Ra***	Skewness – Symmetry – ***Risk***
Root Medium Root Roughness Square – ***Rq***	Kurtosis – Shape – ***Rku***
Maximum Profile Height – ***Rt***	The depth of the trimmed roughness profile - ***Rk***
Ten Height Points – ***Rz***	The height of peaks in the profile – ***Rpk***
	The depth of valleys in the profile – ***Rvk***

In each of the three cut pieces of the cylinder, the roughness was measured in three circular sections, one at each end and the other in the middle of the cylinder piece. In each circular part, the severity was determined according to the cylinder generator, at three equidistant points located at 120º, allowing for the measurement of the roughness at 9 points of each piece, and taking into account the three parts of each cylinder, for a total of 27 measuring points in each bottle.

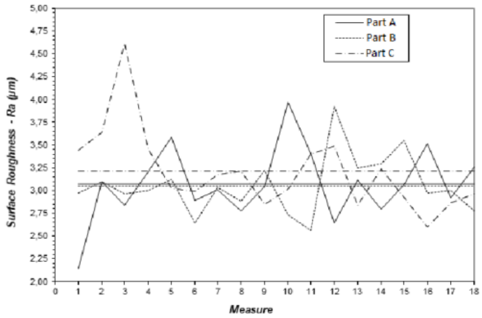
3. Results and discussion

The experimental results obtained and the control charts of the roughness measurements for the different pieces of the tubes studied are presented below. In Figure 1 the surface roughness measured in the areas of each piece is marked with different types of line, and the straight lines represent the average of the measurements in each of these pieces (Piece A, Piece B, and Piece C). For each section, 18 measurements were made corresponding to 3 zones x 3 points x 2 replicates, and in the three measurement points P-1, P-2, and P-3 equidistant 120º in the similar diametral measurement plane, whose experimental results are shown in Figure 2a according to the measurement methodology exposed.

Figure 2b shows the behavior in the control charts of the measured data, where it is shown that the values of the averages of the different pieces of the tube present similar costs, and the difference over the average is presented in the front area of the tube, where the tool enters, highlighting a deviation of nearly 45% above the average value of roughness that Part C should have in the third measurement. However, the percentage deviation of the roughness does not exceed 20% of the average value for Part A and B in the tool exit region, which shows that this parameter depends primarily on the orientation of the machining operation.

	Ra (µm)	PHR-189							PHR-190						
		P - 1	P - 2	P - 3	Average	Dev.	Average	Deviation	P - 1	P - 2	P - 3	Average	Dev.	Average	Deviation
Rough	A--1	2,145	3,098	2,835	2,6927	0,4922	2,8760	0,3044	3,204	3,585	2,896	3,2283	0,3451	3,2656	0,4060
	A--2	3,007	2,779	3,047	2,9443	0,1446			3,967	3,405	2,645	3,3390	0,6635		
	A--3	3,116	2,792	3,065	2,9910	0,1742			3,511	2,92	3,257	3,2293	0,2965		
	Average	2,7560	2,8897	2,9823					3,5607	3,3033	2,9327				
	Deviation	0,5319	0,1805	0,1279					0,3839	0,3440	0,3076				
	M--1	2,972	3,098	2,964	3,0113	0,0752	3,1409	0,2088	3,002	3,123	2,64	2,9217	0,2513	2,9707	0,4043
	M--2	3,034	2,882	3,224	3,0467	0,1714			2,732	2,559	3,925	3,0720	0,7438		
	M--3	3,251	3,295	3,548	3,3647	0,1603			2,976	2,999	2,78	2,9183	0,1204		
	Average	3,0857	3,0917	3,2453					2,9033	2,8937	3,1150				
	Deviation	0,1465	0,2066	0,2926					0,1489	0,2964	0,7050				
	B--1	3,445	3,636	4,62	3,9003	0,6305	3,3254	0,5544	3,459	3,028	2,986	3,1577	0,2618	3,0900	0,2978
	B--2	3,172	3,209	2,844	3,0750	0,2009			3,019	3,4	3,483	3,3007	0,2474		
	B--3	2,836	3,237	2,93	3,0010	0,2097			2,603	2,865	2,967	2,8117	0,1878		
	Average	3,1510	3,3607	3,4647					3,0270	3,0977	3,1453				
	Deviation	0,3050	0,2389	1,0015					0,4281	0,2742	0,2926				
	Average	*2,9976*	*3,114*	*3,23078*	**3,1141**				*3,1637*	*3,0982*	*3,0643*	**3,1087**			
	Deviation	*0,3647*	*0,27378*	*0,56566*	**0,4145**				*0,4239*	*0,3191*	*0,4234*	**0,3789**			

a)



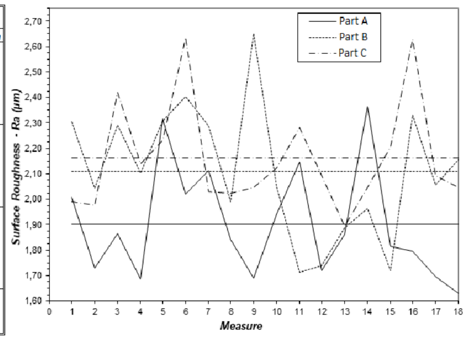
b)

Figure 2. 2D measurements of parameter Ra for roughing, a) tabulated results, b) control charts

Figure 3a shows the data for the roughing honing and semi-finishing honing test tubes, with their respective control charts in Figure 3b, which indicates that the behavior of the measured data is highly dispersed with respect to the average values, given that using an intermediate abrasive stone grain size does not eliminate the characteristics of the roughing honing. However, the percentage deviation presented was less in average than that obtained in the roughing process alone, and the maximum deviation value received was 28% above the average roughness value for Part B in the ninth measurement.

	Ra (µm)	PHR-191							PHR-192						
		P - 1	P - 2	P - 3	Average	Dev.	Average	Deviation	P - 1	P - 2	P - 3	Average	Dev.	Average	Deviation
Rough+Semi-Finished	A--1	2,008	1,731	1,866	1,8683	0,1385	1,9209	0,2104	1,687	2,315	2,019	2,0070	0,3142	1,8833	0,2369
	A--2	2,112	1,841	1,689	1,8807	0,2143			1,941	2,146	1,718	1,9350	0,2141		
	A--3	1,861	2,364	1,816	2,0137	0,3042			1,796	1,697	1,631	1,7080	0,0830		
	Average	1,9937	1,9787	1,7903					1,8080	2,0527	1,7893				
	Deviation	0,1261	0,3382	0,0912					0,1274	0,3194	0,2036				
	M--1	2,303	2,044	2,292	2,2130	0,1465	2,1264	0,2819	2,102	2,309	2,403	2,2713	0,1540	2,0954	0,2433
	M--2	2,288	1,989	2,652	2,3097	0,3320			2,049	1,714	1,741	1,8347	0,1861		
	M--3	1,887	1,963	1,72	1,8567	0,1243			2,33	2,056	2,155	2,1803	0,1387		
	Average	2,1593	1,9987	2,2213					2,1603	2,0263	2,0997				
	Deviation	0,2360	0,0414	0,4700					0,1493	0,2986	0,3345				
	B--1	1,992	1,976	2,419	2,1290	0,2513	2,0704	0,1546	2,139	2,232	2,634	2,3350	0,2631	2,2518	0,2265
	B--2	2,029	2,023	2,048	2,0333	0,0131			2,123	2,28	2,093	2,1653	0,1004		
	B--3	1,894	2,047	2,206	2,0490	0,1560			2,627	2,092	2,046	2,2550	0,3230		
	Average	1,9717	2,0153	2,2243					2,2963	2,2013	2,2577				
	Deviation	0,0698	0,0361	0,1862					0,2865	0,0977	0,3268				
	Average	*2,0416*	*1,99756*	*2,07867*	**2,0393**				*2,0882*	*2,0934*	*2,0489*	**2,0769**			
	Deviation	*0,1643*	*0,17206*	*0,33577*	**0,2308**				*0,2789*	*0,2384*	*0,328*	**0,2738**			

a)



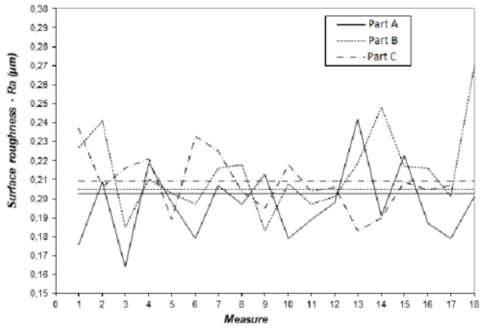
b)

Figure 3. 2D measurements of parameter Ra for roughing+Semi-finished, a) tabulated results, b) control charts

The measured data for the roughing, semi-finished and finished honing tubes are shown in Figure 4b, which shows that the mean values in the three zones of the cell are very similar, and the dispersion of the measured data is low as indicated by the standard deviation value in Figure 4a, experimental results that correspond to the theoretical fundamentals of this manufacturing process.

	Ra (µm)	PHR-193 P - 1	PHR-193 P - 2	PHR-193 P - 3	PHR-193 Average	PHR-193 Dev.	PHR-193 Average	PHR-193 Deviation	PHR-194 P - 1	PHR-194 P - 2	PHR-194 P - 3	PHR-194 Average	PHR-194 Dev.	PHR-194 Average	PHR-194 Deviation
Rough+Semi-Finished+Finished	A--1	0,176	0,209	0,164	0,1830	0,0233	0,2024	0,0237	0,219	0,198	0,179	0,1987	0,0200	0,1921	0,0133
	A--2	0,207	0,197	0,213	0,2057	0,0081			0,179	0,189	0,198	0,1887	0,0095		
	A--3	0,242	0,191	0,223	0,2187	0,0258			0,187	0,179	0,201	0,1890	0,0111		
	Average	0,2083	0,1990	0,2000					0,1950	0,1887	0,1927				
	Deviation	0,0330	0,0092	0,0316					0,0212	0,0095	0,0119				
	M--1	0,227	0,241	0,185	0,2177	0,0291	0,2171	0,0219	0,21	0,203	0,197	0,2033	0,0065	0,2114	0,0228
	M--2	0,216	0,218	0,183	0,2057	0,0197			0,208	0,197	0,201	0,2020	0,0056		
	M--3	0,219	0,248	0,217	0,2280	0,0173			0,216	0,201	0,27	0,2290	0,0363		
	Average	0,2207	0,2357	0,1950					0,2113	0,2003	0,2227				
	Deviation	0,0057	0,0157	0,0191					0,0042	0,0031	0,0410				
	B--1	0,237	0,206	0,216	0,2197	0,0158	0,2072	0,0171	0,221	0,189	0,233	0,2143	0,0227	0,2126	0,0141
	B--2	0,225	0,204	0,195	0,2080	0,0154			0,218	0,204	0,206	0,2093	0,0076		
	B--3	0,183	0,19	0,209	0,1940	0,0135			0,205	0,207	0,23	0,2140	0,0139		
	Average	0,2150	0,2000	0,2067					0,2147	0,2000	0,2230				
	Deviation	0,0284	0,0087	0,0107					0,0085	0,0096	0,0148				
	Average	0,2147	0,21156	0,20056	**0,2089**				0,207	0,1963	0,2128	**0,2054**			
	Deviation	0,0226	0,02071	0,01986	**0,0212**				0,0147	0,009	0,0272	**0,0192**			

a)



b)

Figure 4. 2D measurements of parameter Ra for roughed+Semi-finished+finished, a) tabulated results, b) control charts

In Table 4, the roughness values for the Ra parameter of the tubes machined in the different processes have been averaged for each of the pieces of the cell, where it can be concluded that although there is a dispersion between the measured values in each section, the averages of all the parts are similar to each other and using one of these averages for the characterization of the tube, the error obtained with respect to using the standard of all the pieces is between 3% and 7%, which can be considered as acceptable in this process.

Table 4. Averages of the roughness value Ra in the different measuring zones.

		Part A	*Part B*	*Part C*	*GLOBAL*
Disbast	Average of each piece (µm)	2,876	3,141	3,325	**3,114**
	Error concerning the global average (%)	7,64	0,87	6,78	
Disbast + Semi-finished	Average of each piece (µm)	1,921	2,126	2,07	**2,039**
	Error concerning the global average (%)	5,79	4,27	1,52	
Disbast + Semi-finished + finished	Average of each piece (µm)	0,202	0,217	0,207	**0,209**
	Error concerning the global average (%)	3,35	3,83	0,96	

4. Conclusions

In honing machined tubes with different types of finish, 27 2D roughness measurements were made on the surface of each cell, where it was observed that there is significant variability in the roughness values measured at different points over the entire surface. The variability in the roughness values is due, among other things, to the abrasive action with varying points of cutting and the dynamic response of the rough stone on the surface.

The variability presented in the results is especially accentuated in the cylinder inlet and outlet surface, which makes it necessary to take into consideration the effect of the tool dynamics on the machining process, as it is a factor that influences the variability of the surface roughness values.

The roughness values measured on the inner surface of the tube have been analyzed for three different pieces: at the inlet, in the middle and at the end of the pipe, outside the extreme zones of the pipe corresponding to the tool inlet and outlet, where comparing the average values of the pieces it is observed that when using the average value of one of the pieces instead of the average cost of all the parts an error between 3% and 7% is made.

The errors obtained are acceptable, and therefore you can choose any of the pieces to characterize the roughness of the tube, and within the section, you can choose any area to measure the severity.

The type of abrasive stone is determinant of the value of the surface finished since in the control charts it was observed that the roughness tends to decrease to the extent that a more beautiful stone is used. Finally, the abrasive rock is a decisive factor to take into account in future research in the study of the parameters that influence the process.

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