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Methodology for the filtering of data obtained from the measurement of surface roughness

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Abstract : Related to the objectives of this research, a robust validation of the methodology for filtering data from surface roughness measurements on surfaces was obtained by abrasive processes. The methods used was based on a hydraulic cylinder tubes which were machined with honing under different conditions, the surface roughness was measured at different points on the cylinder surface and two different criteria were used for data filtering to determine which allowed more reliable data to be obtained in the face of measurement variability. It was found that applying a filtering criterion allows to obtain more reliable average values of the measurements to characterize a surface, especially that obtained by abrasive processes that have an important random component. Chauvenet's criterion proved to be more reliable than the standard deviation criterion. This strategy of measurement and filtering is useful when it is sought to characterize the surface roughness especially in surfaces obtained by abrasive processes, since the multiple cutting points generate surfaces with an important random component in the measured data.

Key Words : filtering data, surface roughness, honing, Chauvenet criterion.

1. Introduction

One of the main characteristics of abrasive processes is the generation of surface textures with an important random component[1,2]. For this reason, the variability of the roughness values measured on the inside wall of the cylinders is studied[3].

To determine the roughness value that characterizes a cylinder obtained in a honing process, an average of 9 measured roughness values were obtained, positioned equidistant on the circular section located 150 mm from the end of the cylinder through which the tool enters.

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The average value of the 9 points and the standard deviation are calculated and two criteria the Chauvenet criterion[4] and a standard deviation discard criterion, are applied to exclude from the average the extreme roughness values which are not within the defined range of values considered as outliers. Once the roughness values have been filtered, the average is recalculated with the values not excluded and the corresponding standard deviation. This average roughness value is taken as representative or characteristic of the roughness of the corresponding cylinder.

If there are different replica cylinders of the same honing process, the roughness values of the different replicas shall be averaged, following the same methodology described, and the characteristic roughness value corresponding to each honing process shall be obtained. Therefore, a methodology has been developed to measure and characterize the roughness of honed surfaces.

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.

2.1. Initial study conditions

To analyze the variability of the roughness values measured on the surface of the hydraulic cylinders by honing using the TAYLOR HOBSON "Talysurf Series 2" profilometer, six tubes with the characteristics shown in Table 1 were machined.

Table 1. Characteristics of machined tubes

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

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[5] standard, with different coarse grain sizes.

Table 2. Machining parameters.

Process Variables	Rough	Semi-Finish	Finish
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.

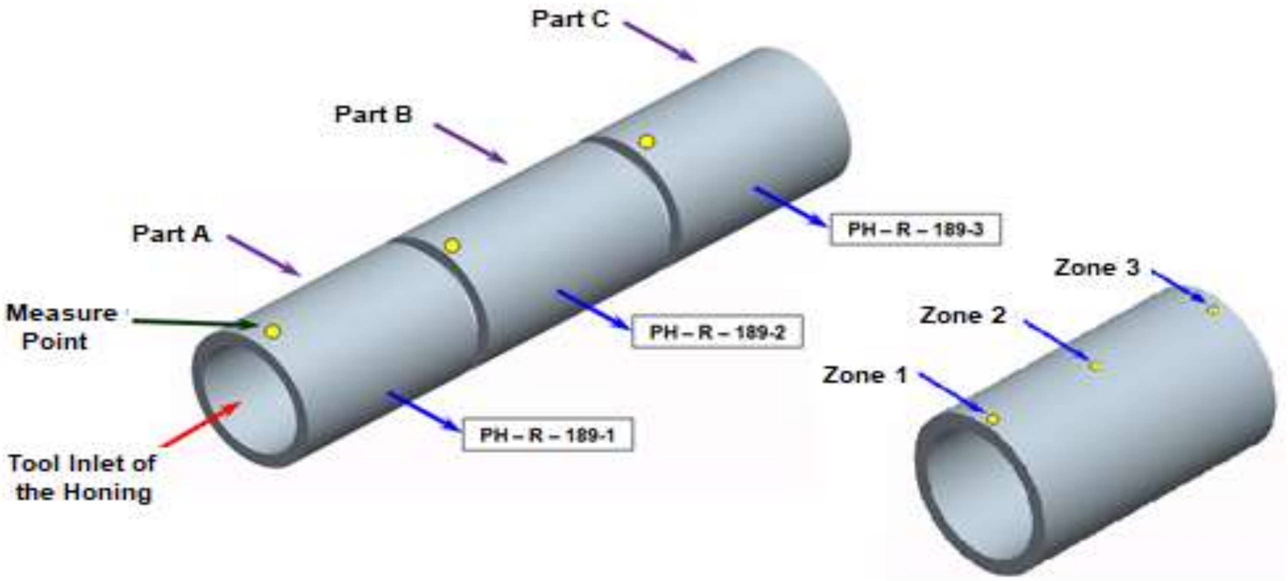

Figure 1. Test tube used in the study

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[6], ISO 13565-2[7], and ASME B46-1[8]. A more detailed description of these parameters can be found in the review by Gadelmawla[9].

Table 3. 2D roughness parameters.

PARAMETERS	
Arithmetic Average of Heights – ***Ra***	Skewness – Symmetry – ***Rsk***
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 roughness is measured 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 part.

2.3. Measured value filtering strategy

As a result of a study carried out in which a total of 162 measurements were taken for each 2D roughness parameter, a filtering strategy of the values is analyzed, based on two different methodologies to evaluate the most appropriate one. The first methodology based on a reduction criterion based on the standard deviations of the measured values. The second is based on the Chauvenet criterion, which will be described below. Both strategies are explained below.

1. Standard deviation filter criterion

This criterion is used to take the values and calculate their mean and standard deviation. Once calculated, data outside the limits of the +/- average once the standard deviation is discarded.

$$[\bar{X} + s < x_i > \bar{X} - s] \qquad \text{(Eq. 1)}$$

2. Chauvenet reduction criteria

It is a criterion for ruling out measures based on their likelihood of occurrence. Measures x_i that is complied with are discarded:

$$|x_i - \bar{x}| > K \times s \qquad \text{(Eq. 2)}$$

x_i = measure analysed
x = average of the measures analysed
s = standard deviation
K = Constant as a function of the number of measurements n

In Table 4, the values of the constant K are found as a function of the number n of measurements.

Table 4. Values of the constant K.

n	K(n)	n	K(n)	n	K(n)	n	K(n)
2	1,15	7	1,80	20	2,24	100	2,81
3	1,38	8	1,86	25	2,33	300	3,14
4	1,54	9	1,92	30	2,40	500	3,29
5	1,65	10	1,96	40	2,48	1000	3,48
6	1,73	15	2,13	50	2,57		

3. Result and Discussion

3.1. Result and analysis of the data filtered with each of the strategies

Once the values obtained in the measurement of each of the pieces are grouped, the following results are obtained for each of the strategies proposed.

1. Standard deviation filter criterion

In Table 5, you can see the values of the nine measurements made on each piece of the tube. For each of them, the mean and standard deviation have been calculated. The upper and lower limits have been defined as defined in the previous item, then the values that were outside the limits have been filtered, and the mean and standard deviation of the new values have been recalculated. In shading, the values excluded by the filtering are marked.

Table 5. Roughness values and filter limits by deviation.

Rough		1	2	3	4	5	6	7	8	9	Aver. (μ)	Devia.(s)
189-1	Ra	2,145	3,098	2,835	3,007	2,779	3,047	3,116	2,792	3,065	2,876	0,304
189-2		2,972	3,098	2,964	3,034	2,882	3,224	3,251	3,295	3,548	3,141	0,209
189-3		3,445	3,636	4,620	3,172	3,209	2,844	2,836	3,237	2,930	3,325	0,554
190-1		3,204	3,585	2,896	3,967	3,405	2,645	3,511	2,920	3,257	3,266	0,406
190-2		3,002	3,123	2,640	2,732	2,559	3,925	2,976	2,999	2,780	2,971	0,404
190-3		3,459	3,028	2,986	3,019	3,400	3,483	2,603	2,865	2,967	3,090	0,298

Rough+Semi-Finished		1	2	3	4	5	6	7	8	9	Aver. (μ)	Devia.(s)
191-1	Ra	2,008	1,731	1,866	2,112	1,841	1,689	1,861	2,364	1,816	1,921	0,210
191-2		2,303	2,044	2,292	2,288	1,989	2,652	1,887	1,963	1,720	2,126	0,282
191-3		1,992	1,976	2,419	2,029	2,023	2,048	1,894	2,047	2,206	2,070	0,155
192-1		1,887	2,315	2,019	1,941	2,146	1,718	1,796	1,697	1,631	1,906	0,225
192-2		2,102	2,309	2,403	2,409	1,714	1,741	2,330	2,056	2,155	2,135	0,263
192-3		2,139	2,232	2,634	2,123	2,280	2,093	2,627	2,092	2,046	2,252	0,227

Rough+S-F+Finished		1	2	3	4	5	6	7	8	9	Aver. (μ)	Devia.(s)
193-1	Ra	0,176	0,209	0,164	0,207	0,197	0,213	0,242	0,191	0,223	0,202	0,024
193-2		0,227	0,241	0,185	0,216	0,218	0,183	0,219	0,248	0,183	0,213	0,025
193-3		0,237	0,206	0,216	0,225	0,204	0,195	0,183	0,190	0,209	0,207	0,017
194-1		0,219	0,196	0,179	0,179	0,189	0,198	0,187	0,179	0,201	0,192	0,013
194-2		0,210	0,203	0,197	0,208	0,197	0,201	0,216	0,201	0,270	0,211	0,023
194-3		0,221	0,189	0,233	0,218	0,204	0,206	0,205	0,207	0,230	0,213	0,014

2. *Filtering criteria by Chauvenet*

In Table 6, you can see the values of the measurements made on the tubes and in the shading the values that have not met the Chauvenet criterion and must be filtered from the total values.

Table 6. Roughness values and filtered values after applying the Chauvenet criterion.

Rough		1	2	3	4	5	6	7	8	9	Aver. (μ)	Devia.(s)
189-1	Ra	2,145	3,098	2,835	3,007	2,779	3,047	3,116	2,792	3,065	2,876	0,304
189-2		2,972	3,098	2,964	3,034	2,882	3,224	3,251	3,295	3,548	3,141	0,209
189-3		3,445	3,636	4,620	3,172	3,209	2,844	2,836	3,237	2,930	3,325	0,554
190-1		3,204	3,585	2,896	3,967	3,405	2,645	3,511	2,920	3,257	3,266	0,406
190-2		3,002	3,123	2,640	2,732	2,559	3,925	2,976	2,999	2,780	2,971	0,404
190-3		3,459	3,028	2,986	3,019	3,400	3,483	2,603	2,865	2,967	3,090	0,298

Rough+Semi-Finished		1	2	3	4	5	6	7	8	9	Aver. (μ)	Devia.(s)
191-1	Ra	2,008	1,731	1,866	2,112	1,841	1,689	1,861	2,364	1,816	1,921	0,210
191-2		2,303	2,044	2,292	2,288	1,989	2,652	1,887	1,963	1,720	2,126	0,282
191-3		1,992	1,976	2,419	2,029	2,023	2,048	1,894	2,047	2,206	2,070	0,155
192-1		1,887	2,315	2,019	1,941	2,146	1,718	1,796	1,697	1,631	1,906	0,225
192-2		2,102	2,309	2,403	2,409	1,714	1,741	2,330	2,056	2,155	2,135	0,263
192-3		2,139	2,232	2,634	2,123	2,280	2,093	2,627	2,092	2,046	2,252	0,227

Rough+S-F+Finished		1	2	3	4	5	6	7	8	9	Aver. (μ)	Devia.(s)
193-1	Ra	0,176	0,209	0,164	0,207	0,197	0,213	0,242	0,191	0,223	0,202	0,024
193-2		0,227	0,241	0,185	0,216	0,218	0,183	0,219	0,248	0,183	0,213	0,025
193-3		0,237	0,206	0,216	0,225	0,204	0,195	0,183	0,190	0,209	0,207	0,017
194-1		0,219	0,196	0,179	0,179	0,189	0,198	0,187	0,179	0,201	0,192	0,013
194-2		0,210	0,203	0,197	0,208	0,197	0,201	0,216	0,201	0,270	0,211	0,023
194-3		0,221	0,189	0,233	0,218	0,204	0,206	0,205	0,207	0,230	0,213	0,014

Once the limits have been determined, filtering is carried out. In each case, values that exceed the limits established by each criterion are discarded. In the case of deviation filtering, it is observed that it is necessary to discard several measurements, as can be seen in Table 7.

Table 7. Roughness, mean and deviation values with deviation filtration.

Rough		1	2	3	4	5	6	7	8	9	Aver. (μ)	Devia.(s)
189-1	Ra	--	3,098	2,835	3,007	2,779	3,047	3,116	2,792	3,065	2,967	0,142
189-2		2,972	3,098	2,964	3,034	--	3,224	3,251	3,295	--	3,120	0,137
189-3		3,445	3,636	--	3,172	3,209	2,844	2,836	3,237	2,930	3,164	0,286
190-1		3,204	3,585	2,896	--	3,405	--	3,511	2,920	3,257	3,254	0,271
190-2		3,002	3,123	2,640	2,732	--	--	2,976	2,999	2,780	2,893	0,176
190-3		--	3,028	2,986	3,019	--	--	--	2,865	2,967	2,973	0,065
Rough+Semi-Finished		1	2	3	4	5	6	7	8	9	Aver. (μ)	Devia.(s)
191-1	Ra	--	1,731	1,866	--	1,841	--	1,861	--	1,816	1,823	0,055
191-2		2,303	2,044	2,292	2,288	1,989	--	1,887	1,963	--	2,109	0,179
191-3		1,992	1,976	--	2,029	2,023	2,048	--	2,047	2,206	2,046	0,076
192-1		1,887	--	2,019	1,941	--	1,718	1,796	1,697	--	1,843	0,128
192-2		2,102	2,309	--	--	--	--	2,330	2,056	2,155	2,190	0,123
192-3		2,139	2,232	--	2,123	2,280	2,093	--	2,092	2,046	2,144	0,083
Rough+S-F+Finished		1	2	3	4	5	6	7	8	9	Aver. (μ)	Devia.(s)
193-1	Ra	--	0,209	--	0,207	0,197	0,213	--	0,191	0,223	0,207	0,011
193-2		0,227	--	0,185	0,216	0,218	--	0,219	--	--	0,213	0,016
193-3		--	0,206	0,216	--	0,204	0,195	--	--	0,209	0,206	0,008
194-1		--	0,196	--	--	0,189	0,198	0,187	--	0,201	0,194	0,006
194-2		0,210	0,203	0,197	0,208	0,197	0,201	0,216	0,201	--	0,204	0,007
194-3		0,221	--	--	0,218	0,204	0,206	0,205	0,207	--	0,210	0,007

While the case of *Chauvenet* filtering is usually only necessary to discard one of the measurements made, Table 8.

Table 8. Roughness, mean and deviation values with Chauvenet filtering.

Rough		1	2	3	4	5	6	7	8	Aver. (μ)	Devia.(s)
189-1	Ra	3,098	2,835	3,007	2,779	3,047	3,116	2,792	3,065	2,967	0,142
189-2		2,972	3,098	2,964	3,034	2,882	3,224	3,251	3,295	3,090	0,152
189-3		3,445	3,636	3,172	3,209	2,844	2,836	3,237	2,930	3,164	0,286
190-1		3,204	3,585	2,896	3,405	2,645	3,511	2,920	3,257	3,178	0,331
190-2		3,002	3,123	2,640	2,732	2,559	2,976	2,999	2,780	2,851	0,201
190-3		3,459	3,028	2,986	3,019	3,400	3,483	2,865	2,967	3,151	0,251
Rough+Semi-Finished		1	2	3	4	5	6	7	8	Aver. (μ)	Devia.(s)
191-1	Ra	2,008	1,731	1,866	2,112	1,841	1,689	1,861	1,816	1,866	0,138
191-2		2,303	2,044	2,292	2,288	1,989	1,887	1,963	1,720	2,061	0,216
191-3		1,992	1,976	2,029	2,023	2,048	1,894	2,047	2,206	2,027	0,088
192-1		1,887	2,019	1,941	2,146	1,718	1,796	1,697	1,631	1,854	0,176
192-2		2,102	2,309	2,403	2,409	1,741	2,330	2,056	2,155	2,188	0,225
192-3		2,139	2,232	2,627	2,123	2,280	2,093	2,092	2,046	2,204	0,188
Rough+S-M+Finished		1	2	3	4	5	6	7	8	Aver. (μ)	Devia.(s)
193-1	Ra	0,176	0,209	0,164	0,207	0,197	0,213	0,191	0,223	0,198	0,020
193-2		0,227	0,241	0,185	0,216	0,218	0,183	0,219	0,183	0,209	0,022
193-3		0,206	0,216	0,225	0,204	0,195	0,183	0,190	0,209	0,204	0,014
194-1		0,196	0,179	0,179	0,189	0,198	0,187	0,179	0,201	0,189	0,009
194-2		0,210	0,203	0,197	0,208	0,197	0,201	0,216	0,201	0,204	0,007
194-3		0,221	0,233	0,218	0,204	0,206	0,205	0,207	0,230	0,216	0,012

To evaluate the performance of the values when they are filtered, two indicators have been defined, one of which is the relative difference between the measured values (R*Dif*), expressed as a percentage:

$$\mathrm{R}Dif(\%) = \left(\frac{X_{max} - X_{min}}{\bar{X}}\right) \times 100 \qquad (3.3.)$$

Where *Xmax* is the maximum value of the measured values, *Xmin* is the minimum value of the measured values and *X* is the mean of the measured values.

Another indicator used is the coefficient of variation of pearson CV(%). This coefficient is an indicator of the degree of dispersion of the values as well as of the heterogeneity of the range of values analysed, in the case of high values of the coefficient, or of the homogeneity, in the case of low values of the coefficient. It is expressed as:

$$CV(\%) = \frac{s}{\bar{X}} \times 100 \qquad (3.4.)$$

Where s is the standard deviation and X is the mean of the measured values. Once these indicators have been defined, the effect of filtering on the values obtained by each strategy can be analysed. For the case of filtering by deviation limits, the corresponding indicators can be seen in Table 9.

Table 9. Indicators of the values filtered by Standard Deviation limits.

		Unfiltered Data		Data Filtered	
Rough		RDif(%)	CV(%)	RDif(%)	CV(%)
189-1	Ra	33,76	10,59	11,36	4,77
189-2		21,20	6,65	10,61	4,39
189-3		53,65	16,67	25,29	9,05
190-1		40,48	12,43	21,17	8,33
190-2		45,98	13,61	16,69	6,08
190-3		28,48	9,64	5,48	2,19
Rough+Semi-Finished		RDif(%)	CV(%)	RDif(%)	CV(%)
191-1	Ra	35,14	10,96	7,41	3,02
191-2		43,83	13,26	19,72	8,49
191-3		25,36	7,46	11,24	3,69
192-1		35,90	11,82	17,47	6,93
192-2		32,55	12,34	12,51	5,62
192-3		26,11	10,06	8,68	3,89
Rough+S-F+Finished		RDif(%)	CV(%)	RDif(%)	CV(%)
193-1	Ra	38,53	11,72	15,48	5,52
193-2		30,47	11,55	19,72	7,61
193-3		26,06	8,23	10,19	3,71
194-1		20,85	6,90	7,21	3,08
194-2		34,52	10,80	9,31	3,28
194-3		20,70	6,62	8,09	3,50

Table 10. Indicators of the values filtered by Chauvenet limits.

		Unfiltered Data		Data Filtered	
Rough		RDif(%)	CV(%)	RDif(%)	CV(%)
189-1	Ra	33,76	10,59	11,36	4,77
189-2		21,20	6,65	13,37	4,93
189-3		53,65	16,67	25,29	9,05
190-1		40,48	12,43	29,58	10,40
190-2		45,98	13,61	19,78	7,06
190-3		28,48	9,64	19,61	7,98
Rough+Semi-Finished		RDif(%)	CV(%)	RDif(%)	CV(%)
191-1	Ra	35,14	10,96	22,67	7,40
191-2		43,83	13,26	28,29	10,46
191-3		25,36	7,46	15,39	4,35
192-1		35,90	11,82	27,77	9,50
192-2		32,55	12,34	30,53	10,30
192-3		26,11	10,06	26,36	8,51
Rough+S-F+Finished		RDif(%)	CV(%)	RDif(%)	CV(%)
193-1	Ra	38,53	11,72	29,87	10,02
193-2		30,47	11,55	27,75	10,71
193-3		26,06	8,23	20,64	6,77
194-1		20,85	6,90	11,67	4,81
194-2		34,52	10,80	9,31	3,28
194-3		20,70	6,62	13,46	5,43

There is a significant improvement in the variability of the values after filtering by both strategies. Although the Chauvenet criterion shows a significant improvement in the values analysed, the indicators are better because of the deviation criterion. This can be explained by the fact that, because of the deviation criterion, more data have been deleted, which has a significant influence on the final values.

4. Conclusions

A measurement methodology has been proposed for honing machined cylinders, this methodology has the advantage that it can be easily implemented in industrial environments and does not involve the destruction of the tube to be measured.

For the characterization of the area, it is considered appropriate to use a filtering criterion to rule out abnormal or unrepresentative values of the area measured. The use of filter criteria reduces the relative difference of the measured values and the variability by around 50 %. The Chauvenet filter criterion allows you to exclude values that are not within limits defined by the mean and the deviation. This criterion is used as it allows the number of measurements taken to be taken into account and is more closely aligned with statistical theory and data analysis and exploration.

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