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ISO Tolerance specification in reverse engineering

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Abstract

Since the publication of the ISO 14253-1 in 2013 [1]. we have worked in the development of a reliable measurement procedure in reverse engineering. In the beginning, it may seem to be easy to measure a part and to get the estimated value of the sizes and its uncertainties, but several times the dimensional tolerance is not considered, and geometrical tolerances are passed over (unattended).

We propose here a tested procedure, simple and practical for the Industry, in accordance with the requirements of the ISO 14253-1:2013 for fully define the sizes and tolerances of any workpiece in reverse engineering.

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Keywords: reverse engineering; tolerance assignment; functional characteristic.

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1. Introduction

The control of a part normally consists on checking its sizes, calculating the uncertainty of the measurement procedure and comparing them with the tolerance interval specified in the technical drawing as it is described in [4]. This is what it is established in the ISO 14253-1:2013 [1].

Moreover, the common practice usually recommends to use a measurement procedure with an uncertainty below the interval of tolerance. Typically, it is used

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$$U < 10\% IT \tag{1}$$

In this ratio, U stands for the expanded uncertainty of the measurement procedure and IT for the interval of size tolerance of the part (International Tolerance §3.2.8.2 ISO 286 1:2010 [2])

But there is another situation quite usual in Industry that it is not straightforward discussed in the Standardization. If the workpiece under measurement has not any technical drawing, as it is the case of Reverse Engineering, the sizes and tolerances are unknown and the scope of the measurement is to specify them instead of verifying the part. In this paper, it is presented the experience carried on different workpieces in order to develop a suitable strategy for dealing with this problem. At the final process of the Reverse Engineering process, the complete Technical drawing of the part will be available, without complex calculations as done in [5].

2. Measurement procedure

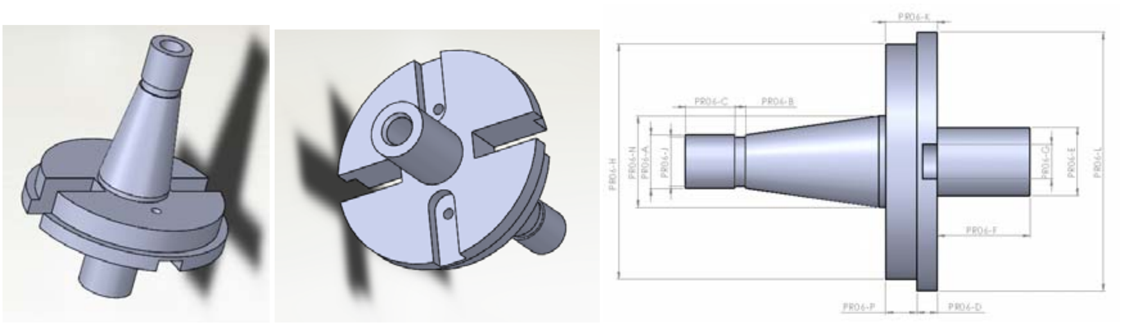
The scope of this proposal was to study the possibilities of the whole procedure, not just focusing in the selection of the measurement instrument. Therefore workpieces of low quality were used, and the instruments selected were calipers. Good enough for the demanded uncertainty and with an adequate measurement range of 140 mm for the considered sizes.

The calipers had a resolution of 20 µm and an expanded uncertainty of 30 µm.

2.1. Measured workpieces

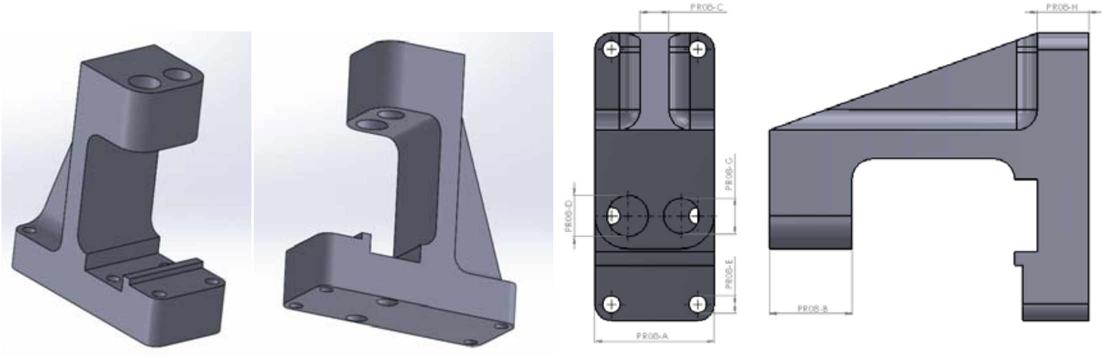
Three different parts were considered, among the ones that were available in the lab. The scope of the process was to assign the IT tolerance in Reverse Engineering, therefore, it is not of interest the final function of the parts.

In Fig. 1 to 3, there are shown the parts and the selected sizes to measure, where PR06 stands for Part with the lab codification 06, PR08 stands for Part with the lab codification 08 and PR05 stands for Part with the lab codification 05.



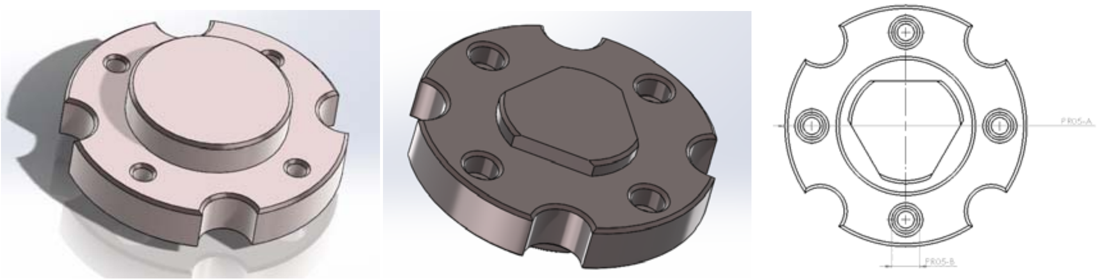
a) b) c)

Fig. 1. PR 06 part (max. length 160 mm) and measured sizes.



a) b) c)

Fig. 2. PR 08 part (max. length 155 mm) and measured sizes.



a) b) c)

Fig. 3. PR 05 part (max. length 123 mm) and measured sizes.

2.2. Measurement procedure

The measurements were carried on at the ICAI metrology lab, by qualified enough students, in order to resemble the industry operators.

As it was specified before, they used calipers to measure at least the sizes indicated in Fig. 1c, Fig. 2c and Fig. 3c.

In Fig. 4, it is shown the measurement procedure for the one of the sizes of Part PR 08, that shown in Fig. 2.

Each size was measured n times, usually more than 10 times, as the scope of the study was to validate the procedure to obtain the IT for a complete Reverse Engineering, rather than the final technical drawing for each part.

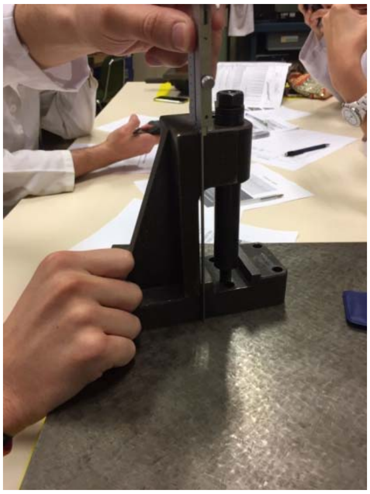


Fig. 4. Example of measurement procedure.

The lab temperature was 20°C ± 2°C with a 50%HR.

3. Tables

3.1. Measurement results

In table 1, table 2 ant table 3 below we present the following results from the measurements done:

- Average M value of the all the measurements (done by different operators on several workpieces of the same type).
- Minimum value of all the measurements for each size (Min)
- Dispersion of the data, calculated as twice the distance between the average and the further limit between the minimum and the average or the maximum size and that average, for each size (Disper)
- Maximum value of all the measurements for each size (Max)

$$\text{Dispersion} = \max\left[(\text{Maximum} - \text{Average}), (\text{Average} - \text{Minimum})\right] \tag{2}$$

- Range R of the measurement results, evaluated as the distance between the maximum and minimum value.

$$\text{Range} = \text{Maximum} - \text{Minimum} \tag{3}$$

- Median value of the measurements, evaluated as the median value between the maximum and the minimum.

$$\text{Median} = (\text{Maximum} + \text{Minimum})/2 \tag{4}$$

- The data number for each measurement, n, evaluated as the total number of measurement done for each size in all the workpieces of the same type.

For PR 06 we obtained:Tables

Table 1. Measurement results PR 06.

Size	M (mm)	Min (mm)	Disper (mm)	Max (mm)	R (mm)	Med. (mm)	n
A	25.06	24.92	1.89	26.00	1.08	25.46	32
B	4.99	4.80	0.38	5.10	0.30	4.95	20
C	23.13	23.00	0.26	23.22	0.22	23.11	16
D	9.67	9.39	0.59	9.96	0.57	9.68	24
E	31.78	31.12	1.32	32.00	0.88	31.56	32
F	42.97	42.00	1.93	43.70	1.70	42.85	20
G	15.82	15.20	1.24	16.08	0.88	15.64	20
H	79.11	78.50	1.65	79.94	1.44	79.22	20
J	24.10	23.98	0.80	24.50	0.52	24.24	20
K	24.24	24.02	2.08	25.28	1.26	24.65	16
L	89.87	88.00	3.75	90.10	2.10	89.05	24
N	44.25	43.98	0.60	44.55	0.57	44.27	24
P	14.45	14.12	0.66	14.70	0.58	14.41	16

For PR 08 we obtained:

Table 2. Measurement results PR 08.

Size	*M* (mm)	Min (mm)	Disper (mm)	Max (mm)	*R* (mm)	Med. (mm)	*n*
A	57.84	57.00	1.67	58.25	1.25	57.63	5
B	40.12	39.85	1.76	41.00	1.15	40.43	4
C	13.86	13.50	0.72	14.10	0.60	13.80	5
D	20.23	19.76	4.55	22.50	2.74	21.13	4
E	8.52	8.20	0.63	8.80	0.60	8.50	11
G	17.13	16.90	0.46	17.26	0.36	17.08	12
H	25.00	24.75	0.49	25.24	0.49	25.00	12

For PR 05 we obtained:

Table 3. Measurement results PR 05.

Size	*M* (mm)	Min (mm)	Disper (mm)	Max (mm)	*R* (mm)	Med. (mm)	*n*
A	114.01	113.80	0.43	114.22	0.42	114.01	4
B	13.88	13.40	0.95	14.20	0.80	13.80	7

3.2. IT specification

Taking into account these, we calculated which quality should be assigned to each size for an IT position JS/js according to ISO 286 [2 and 3], in two situations, using as the nominal size value the calculated average and the median. The results are shown below.

Table 4. IT assignment for size average vs median PR 06.

Size	Average (mm)	Disper (mm)	IT ave	Med. (mm) ±	Range (mm)	IT spe
A	25.06 ±	0.94	17	25.46 ±	0.54	16
B	4.99 ±	0.19	13	4.98 ±	0.15	13
C	23.13 ±	0.13	13	23.11 ±	0.11	13
D	9.67 ±	0.30	16	9.68 ±	0.29	15
E	31.78 ±	0.66	16	31.56 ±	0.44	14
F	42.97 ±	0.97	17	42.85 ±	0.85	17
G	15.82 ±	0.62	17	15.64 ±	0.44	16
H	79.11 ±	0.83	16	79.22 ±	0.72	16
J	24.10 ±	0.40	15	24.24 ±	0.26	14
K	24.24 ±	1.04	18	24.65 ±	0.63	16
L	89.87 ±	1.87	18	89.05 ±	1.05	16
N	44.25 ±	0.30	14	44.27 ±	0.29	14
P	14.45 ±	0.33	15	14.41 ±	0.29	15

Table 5. IT assignment for size average vs median PR 08.

Size	Average (mm)	Disper (mm)	IT ave	Med. (mm) ±	Range (mm)	IT spe
A	57.84 ±	0.84	16	57.63 ±	0.63	16
B	40.12 ±	0.88	17	40.43 ±	0.57	16
C	13.86 ±	0.36	16	13.80 ±	0.30	15
D	20.23 ±	2.28	bigger 18	21.13 ±	1.37	18
E	8.52 ±	0.32	16	8.50 ±	0.30	16
G	17.13 ±	0.23	15	17.08 ±	0.18	14
H	25.00 ±	0.25	14	25.00 ±	0.24	14

Table 6. IT assignment for size average vs median PR 05.

Size	Average (mm)	Disper (mm)	IT ave	Med. (mm) ±	Range (mm)	IT spe
A	114.01 ±	0.21	13	114.01 ±	0.21	13
B	13.88 ±	0.48	16	13.80 ±	0.40	16

All the dispersions and ranges were above the condition (1), IT > 10 U, that averages, none of them were smaller than 10 · 30 µm = 0,3 mm. The selected instrument fulfilled the ISO 14253-1:2013 condition [1].

From these results, we conclude that the quality grade will be equal or better when using the median as the nominal value than the average value.

Due the fact that the scope of the strategy here proposed is to be a simple and fast procedure for an estimation of the IT, we decided not to deal with complex normal distribution estimations of the measurements. The main scope is to be able to draw the workpiece with an estimated IT based on the measurements, precise enough for a first approach to the improvement of the design without complex data analysis, that what it is the first main step of the Reverse Engineering. After that, the designer will be encourage to invest as further as needed.

When comparing the intervals around the average (dispersion) versus the one related with the median (range), the first one is always bigger, but all the interval overlap similarly as in Fig. 5.

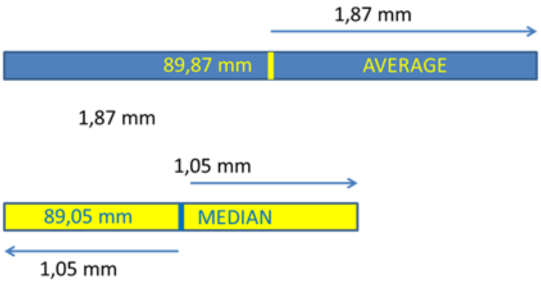


Fig. 5. Measurement distribution on the average and median intervals for PR06-L.

Although all the data lie into both intervals, the average one calculated as dispersion in (2), does not describe how the data are distributed around the nominal. Meanwhile, the median interval calculated as range in (3) does not overestimate the interval and does take into account all the measurement values.

Therefore, we conclude that the range (3) is a much more useful estimator of the IT together with the median as an estimator of the nominal size.

Due the overlapping between the range (3) and the dispersion (2) intervals, there are not statistically significant differences between the average and the median (4) for each size. Therefore, we conclude that the median (4) will be a quite good estimator of the nominal size for the purpose of Reverse engineering.

Before the improvement of the design of the part, it is quite convenient to select a js/JS interval, following the ISO 286 [2 and 3]. Consequently, the interval will be symmetrically distributed around the median (4). Although this is not a common practice in the Industry, this will provide to this procedure with a robust behaviour against outliers that may appear during the measurements. Afterwards, it will be recommended to change the IT by the designer in the improvement of the TPD (Technical Product Documentation) of the workpiece under measurement.

If the changes on the part to be done are significant enough, it will be also recommended to select the highest number for the degree of quality, in order to simplify the technical drawing. In our case it will deal with table 7.

Table VII. IT quality assignment to the whole part.

Part	IT (ISO 286)
PR06	JS/js 16
PR08	JS/js 18
PR05	JS/js 16

4. Conclusions

The range is a much more useful estimator of the IT together with the median as an estimator of the nominal size in Reverse Engineering.

The IT interval position JS/js is the recommended tolerance interval for the first loop in the Reverse Engineering Process. It may be substitute by another IT position after a detailed redesign of the part.

It will be highly recommended to select the highest number for the degree of quality in the IT.

References

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