CONSIDERATIONS CONCERNING CMM SELECTION AND OPTIMUM NUMBER OF POINTS FOR CYLINDRICITY DEVIATIONS EVALUATION

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Abstract: Selecting the right CMM and establishing the optimum number of points cloud density is very important and may make the difference in inspection accuracy and efficiency The measurement program developed in the present paper is aimed to determine the optimum number of spatial coordinates to be inspected, that is the number of points which conducts to a stabilization of the values when evaluating the cylindricity deviations of an interior cylindrical surface on a COORD3 ARES NT CMM.

Keywords: *Coordinate measuring, circularity, cylindricity, deviations*

1. CMM selection considerations

Coordinate metrology assesses parts real dimensions and surfaces and provides a comparison with specifications (figure 1) [1].

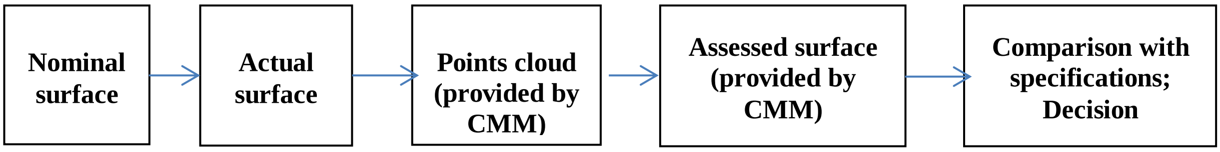


Figure 1: *Overview of the coordinate measuring processes*

CMM are measuring systems which determine the spatial coordinates of the elements, surfaces or parts to be controlled. Such systems have a tendency to replace the traditional methods of control as they not only provide higher repeatability and accuracy, but reduce the manpower and time, as well.

It is important to emphasize that in order to manufacture quality parts, the precision and characteristics of the measuring means and equipment is at least of the same importance as the performances and characteristics of the machine tools: actually a combination of high performances machine tool and low performances measuring system will provide less quality parts versus a combination of low performances machine tool and high performances measuring system [2].

Taking into account that the principles, types and ranges of CMM are extremely various, selecting the right CMM is very important and may make the difference in inspection accuracy and efficiency. In order to make the right decision, mainly with respect to the “measuring CMM range” and “accuracy/required CMM uncertainty” [2], aspects as “part to be inspected dimensions and configuration”, “specifications concerning the dimensional and geometric precision for the part to be inspected”, “batch size”, etc.., should be considered in selecting the CMM that best fits all requirements.

2. Considerations concerning points cloud density versus measurement accuracy

Usually, the parts to be measured can be considered as a combination of standard elements: plans, lines, circles, cylinders, spheres, cones. A geometric element can be defined by a minimum number of points: for example 2 points define a straight line, 3 points define a circle, 6 points define a cylinder, etc. It is however obvious that in order to highlight shape or position deviations, the spatial coordinates of a more significant number of points should be determined [3].

Although it is not necessary that the points are placed at equal distance on the surface or element to be inspected, it is recommended that their distribution assure a uniform coverage of the investigated surface or element [3].

In addition to number of points and their distribution on the considered surface or element, the result of measurement is influenced by the evaluation criteria used in the filtering and processing of the measuring data as well [3], [4]:

- LSC – Gaussian criteria (least square circle);
- MCC – exterior tangent element (minimal circumscribed circle);
- MIC – interior tangent element (maximal inscribed circle);
- MZC – minimal zone cycle (minimal zone element).

Usually, the functional properties of the investigated element should be revealed using the MCC criteria for exterior surfaces and the MIC criteria for interior surfaces [4].

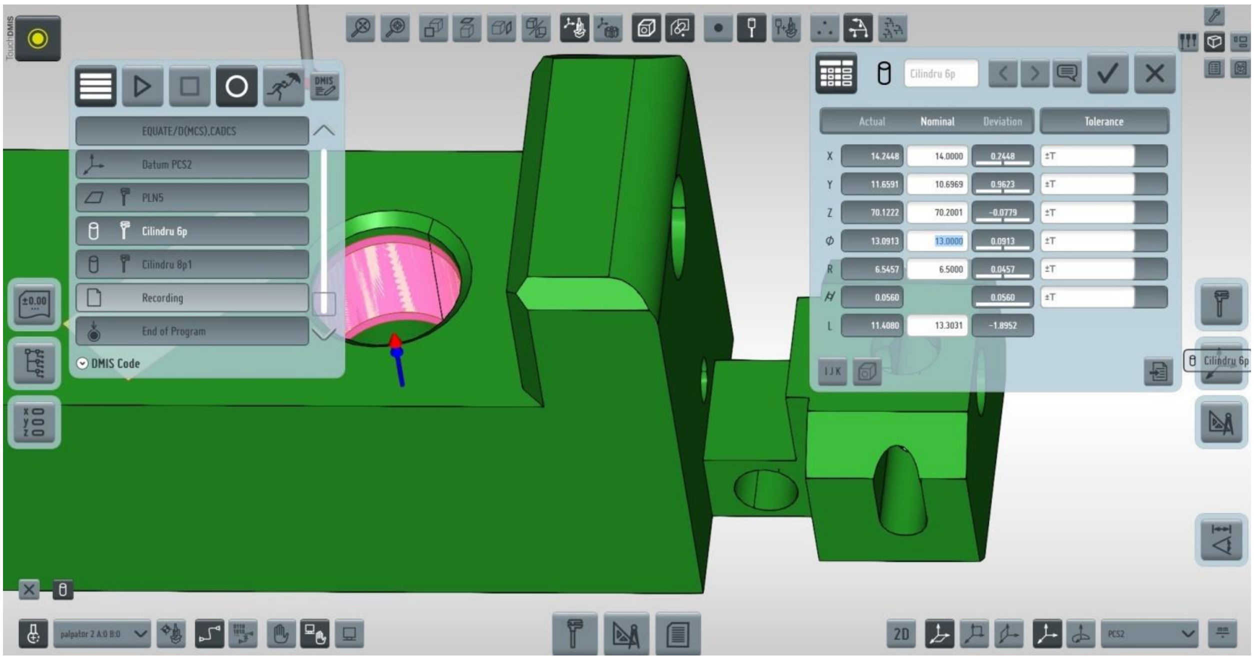
As it was already specified, the number of points to be inspected should be bigger than the minimum number of points which can define the investigated element or surface. In fact, the measurement accuracy is increasing when increasing the number of points. On the other hand, the time of inspection, the time of data processing and, consequently, the total cost of the measuring process is also higher when increasing the number of inspected points. A compromise should be realized between the measurement accuracy, on the one hand and the necessary time for producing the final results (measurement process cost), on the other hand.

The measurement program developed in the present paper is aimed to determine the optimum number of spatial coordinates to be inspected, that is the number of points which conducts to a stabilization of the values when evaluating the cylindricity deviations of an interior cylindrical surface on a COORD3 ARES NT CMM. The employed ARES series CMM offers a volumetric accuracy from 1.8+L/333, and is able to perform measurements in a 1000mm x 650mm x 500mm volume.

3. Measurement program performed on COORD3 ARES NT CMM for evaluation of cylindricity deviations of an interior cylindrical surface

For the present study, a cylindrical interior surface with a nominal diameter of 13 mm was considered. A 3D representation of the part model is shown in figure 2, in the TouchDMIS metrology software user interface. The investigated surface is highlighted in red and indicated by an arrow.

Several measurements of the surface were conducted using increasing number of points, starting from the minimum of 6 points needed to define an ideal cylinder and up to 100 points. This allowed assessing the optimum number of points needed to obtain good accuracy in the least time, thus obtaining an optimum accuracy/cost ratio.



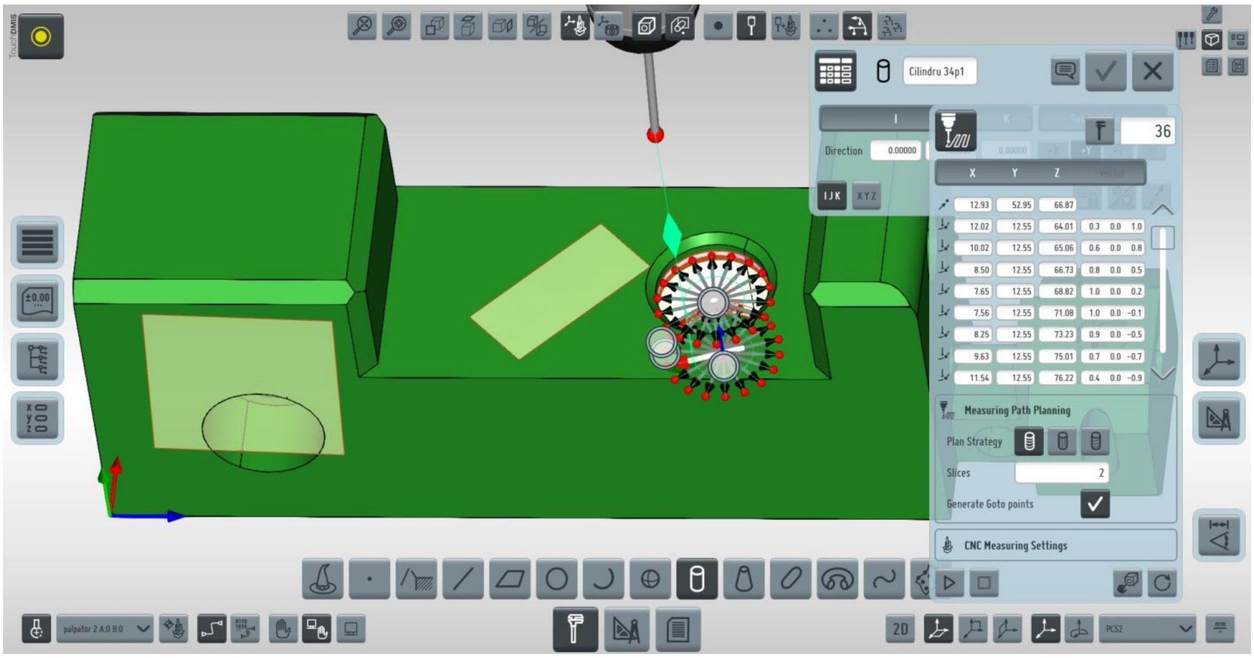
EQUATE/D(MCS).CADCS
Datum PCS2
PLN5
Cilindru 6p
Cilindru 8p1
Recording
End of Program
DMIS Code

Cilindru 6p

	Actual	Nominal	Deviation	Tolerance
X	14.2448	14.0000	0.2448	±T
Y	11.6591	10.6969	0.9623	±T
Z	70.1222	70.2001	-0.0779	±T
Φ	13.0913	13.0000	0.0913	±T
R	6.5457	6.5000	0.0457	±T
⌭	0.0560		0.0560	±T
L	11.4080	13.3031	-1.8952	

Figure 2: *Investigated cylindrical surface and metrology software user interface*

One of the programming steps taken for the development of an automated measuring program is to choose the path to be followed by the stylus during the measurement. For the present investigations, two types of measurement paths were employed, as shown by figures 3 and 4. This permits to assess which type of measuring path offers better accuracy for the considered surface.



Cilindru 34p1

Direction 0.00000

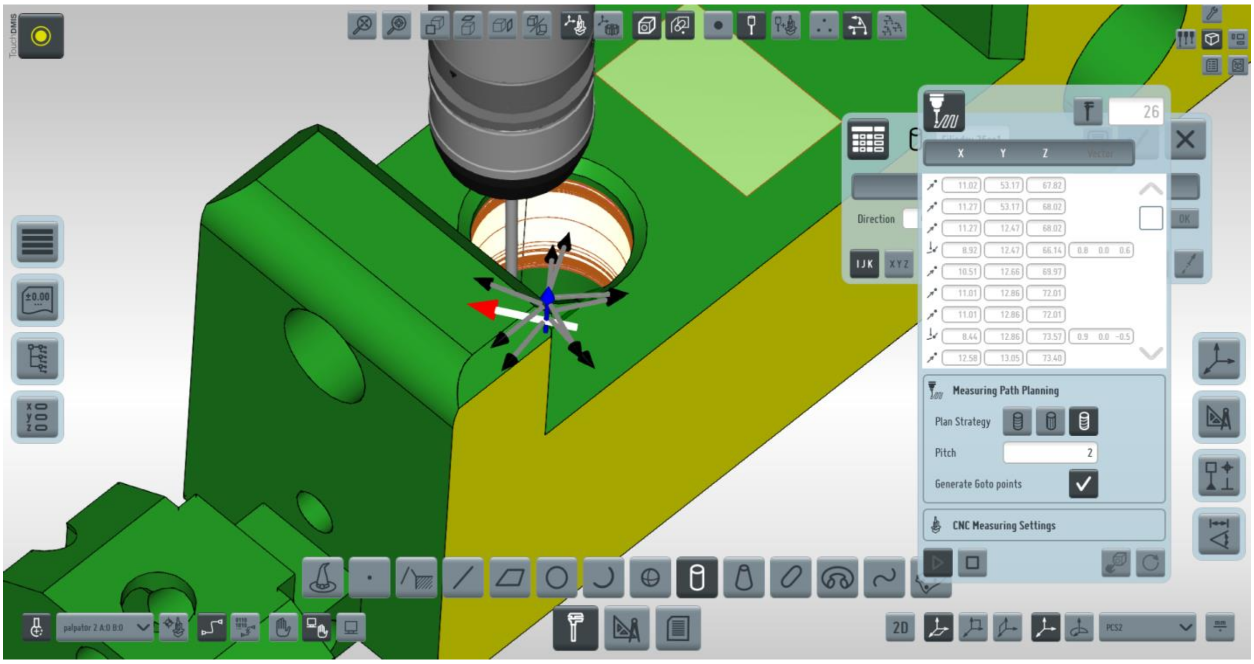
36

	X	Y	Z	Vector		
	12.93	52.95	66.87			
	12.02	12.55	64.01	0.3	0.0	1.0
	10.02	12.55	65.06	0.6	0.0	0.8
	8.50	12.55	66.73	0.8	0.0	0.5
	7.65	12.55	68.82	1.0	0.0	0.2
	7.56	12.55	71.08	1.0	0.0	-0.1
	8.25	12.55	73.23	0.9	0.0	-0.5
	9.63	12.55	75.01	0.7	0.0	-0.7
	11.54	12.55	76.22	0.4	0.0	-0.9

Measuring Path Planning
Plan Strategy
Slices 2
Generate Goto points ✓
CNC Measuring Settings

Figure 3: *Sliced measuring path*

Figure 3 illustrates an example of a measuring path consisting of several slices of the cylindrical surface. In this case, an equal number of points were measured on each surface slice. In order to verify how the total number of considered points influences measurement, accuracy this number varied from a minimum of 6 and up to a maximum of 100 points.



	X	Y	Z	Vector
	11.02	53.17	67.82	
	11.27	53.17	68.02	
	11.27	12.47	68.02	
	8.92	12.47	66.14	0.8 0.0 0.6
	10.51	12.66	69.97	
	11.01	12.86	72.01	
	11.01	12.86	72.01	
	8.44	12.86	73.57	0.9 0.0 -0.5
	12.58	13.05	73.40	

Measuring Path Planning

Plan Strategy

Pitch 2

Generate Goto points ☑

Figure 4: *Spiral measuring path*

Figure 4 graphically illustrates the second type of path considered for the present study, which implies to measure several points uniformly distributed over a spiral with constant pitch. The measurements using a spiral path along the considered cylindrical surface also employed various numbers of points, starting from a minimum of 6 and up to 100 points.

4. Results interpretation and conclusions

The present investigations, conducted on a cylindrical interior surface, consisted of automatically measuring various numbers of points from the same surface, placed on two types of paths, as described above. The resulting measurement parameters were grouped in Tables 1 and 2, each corresponding to a different type of measurement path. The considered parameters were the measured diameter, its deviation from nominal value, and surface cylindricity.

Table 1: *Measurement data for sliced path, for various numbers of points*

Measurement path 1 (cross-sections slices)									
No. of points	Nominal diameter [mm]	Measured diameter [mm]	Deviation [mm]	Cylindricity deviation	No. of points	Nominal diameter [mm]	Measured diameter [mm]	Deviation [mm]	Cylindricity deviation
6	13	13,0913	0,0913	0,056	36	13	13,0763	0,0763	0,2221
8	13	13,0824	0,0824	0,1527	38	13	13,0787	0,0787	0,2406
10	13	13,0892	0,0892	0,1672	40	13	13,0785	0,0785	0,2306

Measurement path 1 (cross-sections slices)									
No. of points	Nominal diameter [mm]	Measured diameter [mm]	Deviation [mm]	Cylindricity deviation	No. of points	Nominal diameter [mm]	Measured diameter [mm]	Deviation [mm]	Cylindricity deviation
12	13	13,0666	0,0666	0,1857	42	13	13,0775	0,0775	0,238
14	13	13,0924	0,0924	0,1947	46	13	13,0723	0,0723	0,2284
16	13	13,0783	0,0783	0,217	50	13	13,0706	0,0706	0,2179
18	13	13,077	0,077	0,2018	54	13	13,0735	0,0735	0,2409
20	13	13,0901	0,0901	0,1585	58	13	13,0742	0,0742	0,2205
22	13	13,0842	0,0842	0,2505	62	13	13,089	0,089	0,2261
24	13	13,0829	0,0829	0,2094	66	13	13,0695	0,0695	0,2343
26	13	13,0657	0,0657	0,2652	70	13	13,1204	0,1204	0,238
28	13	13,0808	0,0808	0,2052	80	13	13,1295	0,1295	0,1958
30	13	13,0948	0,0948	0,2065	90	13	13,1407	0,1407	0,2239
32	13	13,0761	0,0761	0,2342	100	13	13,0938	0,0938	0,2152
34	13	13,0919	0,0919	0,1774					

Table 2: *Measurement data for spiral path, for various numbers of points*

Measurement path 2 (spiral path with constant pitch of 2 mm)									
No. of points	Nominal diameter [mm]	Measured diameter [mm]	Deviation [mm]	Cylindricity deviation	No. of points	Nominal diameter [mm]	Measured diameter [mm]	Deviation [mm]	Cylindricity deviation
6	13	13,0901	0,0901	0,0054	46	13	13,1116	0,1116	0,172
8	13	13,1544	0,1544	0,0219	50	13	13,1034	0,1034	0,2083
10	13	13,1457	0,1457	0,0174	54	13	13,1058	0,1058	0,2141
12	13	13,094	0,094	0,1523	58	13	13,1086	0,1086	0,2006
14	13	13,0987	0,0987	0,1266	60	13	13,1112	0,1112	0,1865
16	13	13,1251	0,1251	0,151	62	13	13,1104	0,1104	0,221
18	13	13,1156	0,1156	0,1326	65	13	13,1104	0,1104	0,2189
20	13	13,1104	0,1104	0,0938	68	13	13,1396	0,1396	0,1492
22	13	13,1209	0,1209	0,1486	70	13	13,1121	0,1121	0,1757
24	13	13,1062	0,1062	0,13	72	13	13,1152	0,1152	0,1874
26	13	13,1227	0,1227	0,1366	75	13	13,1236	0,1236	0,1563
26	13	13,111	0,111	0,1951	76	13	13,1101	0,1101	0,2261
28	13	13,1116	0,1116	0,1744	80	13	13,1273	0,1273	0,1686
30	13	13,1042	0,1042	0,1915	84	13	13,1147	0,1147	0,2143
32	13	13,1188	0,1188	0,1972	88	13	13,1139	0,1139	0,2185
34	13	13,107	0,107	0,2156	90	13	13,1312	0,1312	0,142
36	13	13,1186	0,1186	0,2171	92	13	13,1162	0,1162	0,1923
38	13	13,1125	0,1125	0,1807	96	13	13,1147	0,1147	0,2052
40	13	13,1068	0,1068	0,1808	100	13	13,1242	0,1242	0,1871
42	13	13,1129	0,1129	0,2028					

Using the data from tables 1 and 2, the diagrams represented in figures 5 and 6 were plotted to illustrate the influence of the number of measured points upon the cylindricity deviation results. Figures 5 and 6 graphically illustrate the cylindricity deviation evolution with the number of measured points for the two analyzed types of measurement paths, sliced and spiral, respectively.

Both plots illustrated in figure 5 show that the cylindricity deviation first rapidly increases with the number of measured points, for up to 14 to 20 points and then tends to stabilize around a constant value. This indicates that above 20 measured points, the accuracy gain is no longer significant by report to involved costs.

Figure 6 graphically illustrates the experimental results obtained for the evolution of measured diameter deviation from nominal with the number of measured points for the two measurement paths.

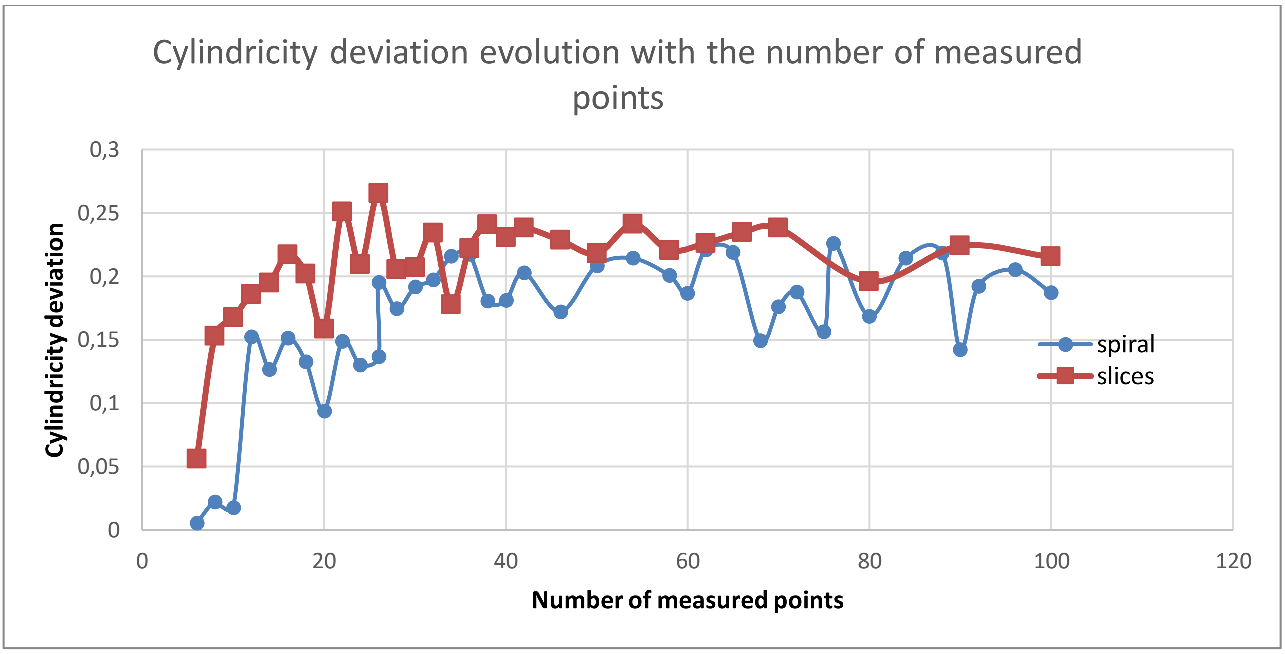


Figure 5: *Experimental results for cylindricity deviation evolution with the number of measured points in the case of slices measurement path and spiral path*

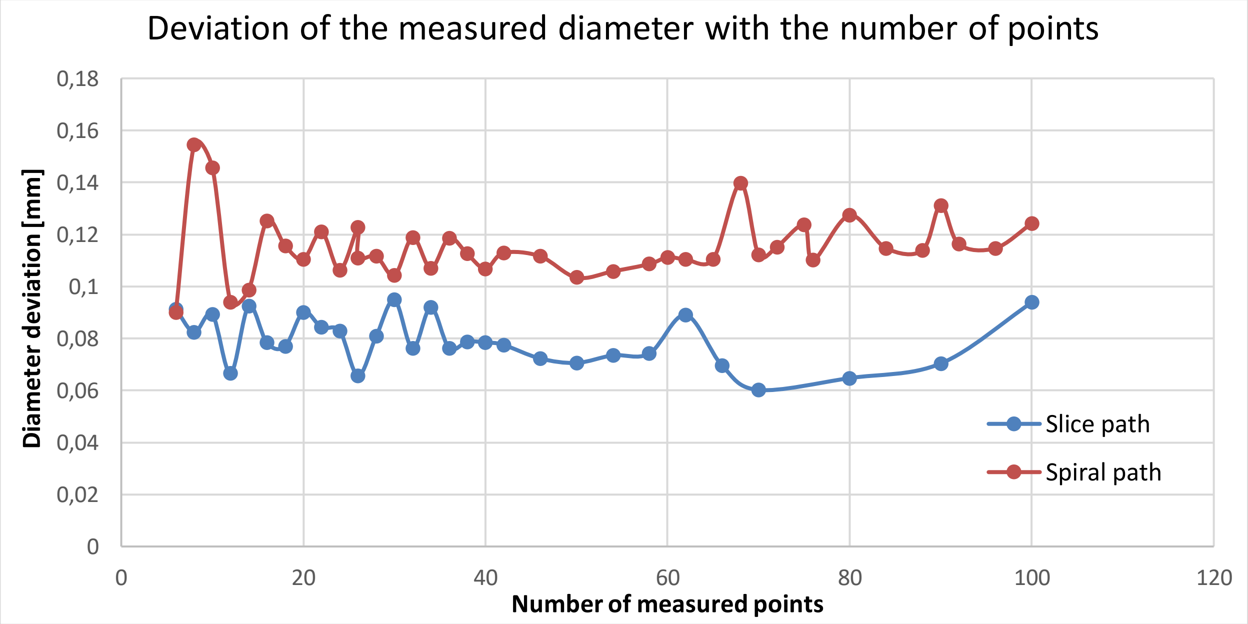


Figure 6: *Experimental results for measured diameter deviation from nominal evolution with the number of measured points for the two measurement paths*

From the plots traced in figure 6, it can be also noticed that above 14 to 20 points, the measured deviation from the nominal value tends to stabilize around a constant value.

Both types of paths seem to offer a similar evolution for both diameter and cylindricity deviations, and from the presented investigations it can be concluded that in the case of a cylindrical interior surface, the ARES NT series CMM from COORD3 offers measurement stability above 14 to 20 measured points.

The experimental results plotted in figures 5 and 6 constantly show lower values of the deviation for the spiral measurement path, both in the case of diameter and cylindricity measurements. However, the shape of the two parameters evolution is similar. This is probably due to a better surface coverage in the case of a spiral measurement path for the considered interior cylinder.

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