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A FEATURE – BASED PATH PLANNING FOR INSPECTION PRISMATIC PARTS ON CMM

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Abstract – This paper presents a feature-based model for probe path planning prismatic parts. Needed geometrical information for feature description are taken from files IGES and STL. Presented model is advanced feature – based inspection approach, whose advantage is in reduction the total measurement time by reducing the time needed for the preparation of the measurements and allowed opportunities for its optimization.

Keywords: path planning, feature, prismatic parts, CMM

1. INTRODUCTION

The feature – based inspection process of prismatic parts (PPs) is composed from few key elements such as path planning, collision avoidance, accessibility analysis and a workpiece setup, as well as configuration of measuring probes. The level of development and implementation until now developed methods for generating an inspection plan defines contains mentioned elements. Complete system for inspection planning contains all of these elements. In paper [1] are represent elements such as workpiece setup and configuration of measuring probes. In [2,3] are give approaches for path planning. Several related researches show the approaches for collision avoidance [4,5], and accessibility analysis [6]. The inspection planning could be also analyzed through the local and global inspection planning [7].

An example extraction geometrical information (parameters) from CAD-model and forming input data is shown in [8].

This paper presents a feature based model for path planning based on the CAD model of the prismatic part. The path of measuring sensor is defining as a set of points, which consists of three subsets. The first subset are measurement points obtained on the basis geometric information about features and sampling strategy. The second set consists of points through the sensor passes during inspection a geometric feature. The third set of points provides a path without collisions and it is based on a principle of collision avoidance and algorithm for collision avoidance.

Input information for model are taken from IGES and STL file, while input data about tolerances on the base already created of the knowledge base [9]. Output is point-to-point measuring path without collision between measurement probe and prismatic part.

2. PROPOSED FEATURE – BASED MODEL

The elements of feature – based model for path planing are CAD modul, knowledge base and simulation (fig. 1). Metrological recognition is based on the IGES file and the parametric defining of geometric features [9,10]. The link between tolerance and geometric features is defined by metrological features [11,12]. The local plan of inspection represents the distribution of measuring points per geometric features. The global inspection plan is the plan of path sensors, presented with the local plan and algorithm for collision avoidance based on STL model of PP.

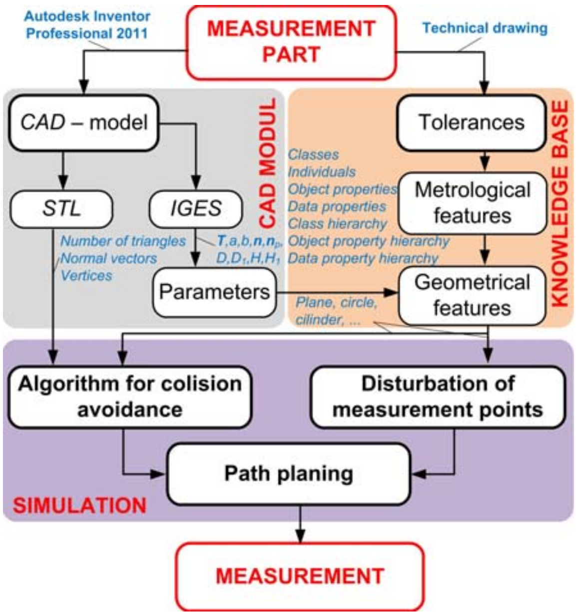

Fig. 1. A feature – based model

The extraction of parameters of a geometric feature from IGES file is based on the recognition of its structure. An IGES file is composed of five sections in the following order: start section, global section, directory entry section, parameter data section, and terminate section. All geometric entities are given in the directory entry section and parameter data section.

The extraction of parameters is performed based on the number of sequences of an entity (geometric feature).

3. PATH PLANNING FOR PRISMATIC PARTS

3.1 Sampling strategy

Sampling strategy is based on Hemmersly sequences [13] for the calculation of coordinates for two axes of a feature:

$$s_i = \frac{i}{N} \tag{1}$$

$$t_i = \sum_{j=0}^{k-1}\left(\left[\frac{i}{2^j}\right]\mathrm{Mod}2\right)\cdot 2^{-(j+1)} \tag{2}$$

where $k = \log_2 N$, and N is the desired number of measuring points, $i = 0,1,2,...,(N-1)$.

By modifying the Hemmersly sequences, we define the distribution of measuring points for basic geometric features such as point, plane, circle, cylinder, cone and hemisphere. Most often, these features are involved in creation of PP tolerances.

To define the distribution of measuring points for a feature, the Descartes coordinates system O_F, X_F, Y_F, Z_F is needed. The coordinates are denoted by $P_i(s_i, t_i, w_i)$.

For example the equations for calculation of measuring point coordinates for plane are:

$$s_i = \frac{i}{N}\cdot a \tag{3}$$

$$t_i = \left(\sum_{j=0}^{k-1}\left(\left[\frac{i}{2^j}\right]\mathrm{Mod}2\right)\cdot 2^{-(j+1)}\right)\cdot b \tag{4}$$

$$w_i = 0 \tag{5}$$

where $a[\mathrm{mm}]$ is the plane limit for x-axis; $b[\mathrm{mm}]$ is the plane limit for y-axis.

Algorithm for distribution of measurement points (ADMP) consists of five steps (figure 2). The key words are needed for the sub-routine call in the Step#3. Calculation of the point coordinates $P_i(s_i, t_i, w_i)$, $P_{i1}(s_{i1}, t_{i1}, w_{i1})$ and $P_{i2}(s_{i2}, t_{i2}, w_{i2})$ is performed on the example for plane.

The distributions of measuring points based on sampling strategy method and ADMP for features such as point, plane, circle, hemisphere, cylinder and cone, presented in figure 3.

Step#1: Reading parameters: $N; a; b; R; R_1; H; H_1; \mathbf{n}; \mathbf{n}_p; T; d_2;$
keyword=input(plane; circle; cylinder, cone; cone_zar; sphere; sphere_zar).
Step#2: Calculation: $k = \log_2 N$.
Step#3: Switch keyword
case plane
Calculation: $\overrightarrow{PP_1} = \mathbf{n}\cdot d_1$ and $\overrightarrow{PP_2} = \mathbf{n}\cdot d_2$.
For $(i = 0:(N-1))$ $\{h_i = i + (1-i)\}$
for $(j = 0:(k-1))$ $\left\{\sum_{j=0}^{k-1}\left(\left[\frac{i}{2^j}\right]\mathrm{Mod}2\right)\cdot 2^{-(j+1)}\right\}$
end
Calculation: s_i, t_i, w_i
Set $(q = s,t,w)$ and $(\lambda = 1,2)$, get $\{q_{\lambda i} = \overrightarrow{PP_\lambda}\cdot\vec{i} + s_i\}$
end
end
…
other keywords
…
Step#4: The homogeneous coordinates: $\{P = [s\ \ t\ \ w\ \ h]^T\}$
$\{P_1 = [s_1\ \ t_1\ \ w_1\ \ h]^T\}$ $\{P_2 = [s_2\ \ t_2\ \ w_2\ \ h]^T\}$
Step#5: The transformed coordinates:
$\{P^{tran} = T\cdot P\}$ $\{P_1^{tran} = T\cdot P_1\}$ $\{P_2^{tran} = T\cdot P_2\}$

Fig. 2. Algorithm for distributions of measuring points

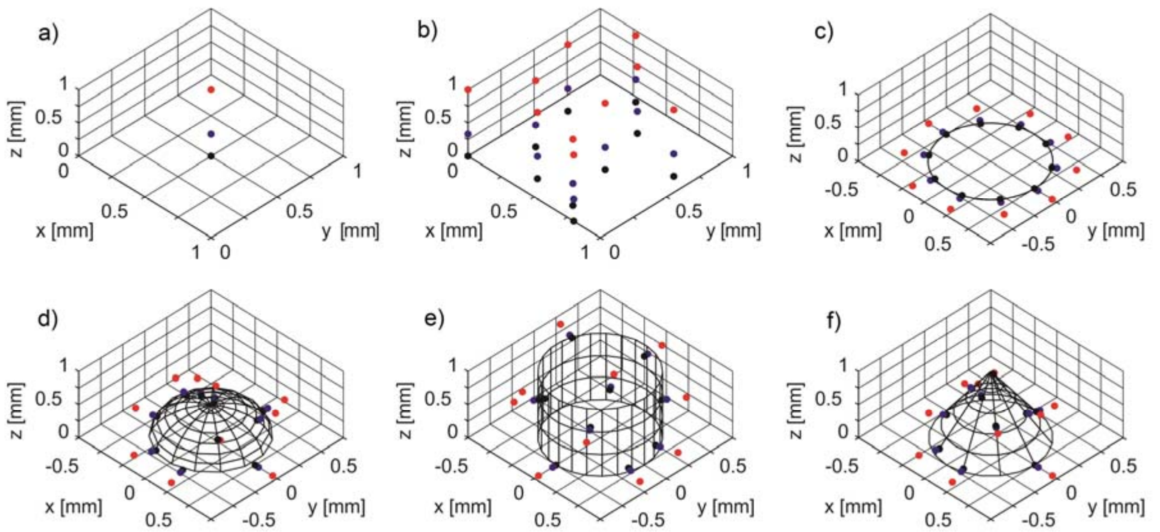

Fig. 3. The distributions of measuring points: a) point, b) plane, c) circle, d) hemisphere, e) cylinder, f) cone

3.2 Collision avoidance

Based on STL model of PP geometry, the tolerances of PP, the coordinates of the last point $P_{(N_{F1})1}$ of the feature F1 (plane_1) and the coordinates of the first point $P_{(N_{F2})1}$ of the feature F2 (plane_2), the simplified principle of collision avoidance is presented in figure 4 b).

For each triangle in STL file, the belonging plane equitation is formulated. If triangle vertexes are T_1, T_2, T_3, the procedure of formation of the plane is described by the following equitation:

$$Ax + By + Cz + D = 0 \quad (6)$$

and it begins with the formation of a normal vector

$$\vec{n} = \overrightarrow{T_1T_2} \times \overrightarrow{T_1T_3} = A\vec{i} + B\vec{j} + C\vec{k} \quad (7)$$

wherefrom the constants A, B and C could be identified. The constant D is calculated using the scalar multiplication

$$D = -\vec{n} \cdot \vec{r_1} \quad (8)$$

where $\vec{r_1} = \overrightarrow{OT_1}$. The next step is the formation of line equitation through two points $P_{(N_{F1})1}$ and , $P_{(N_{F2})1}$, based on the vector form of line equitation:

$$\overrightarrow{M} = \vec{P} + t \cdot \vec{p} \quad (9)$$

where $\vec{p} = \overrightarrow{P_1P_2}$, $\vec{P} = \overrightarrow{OP_1}$.

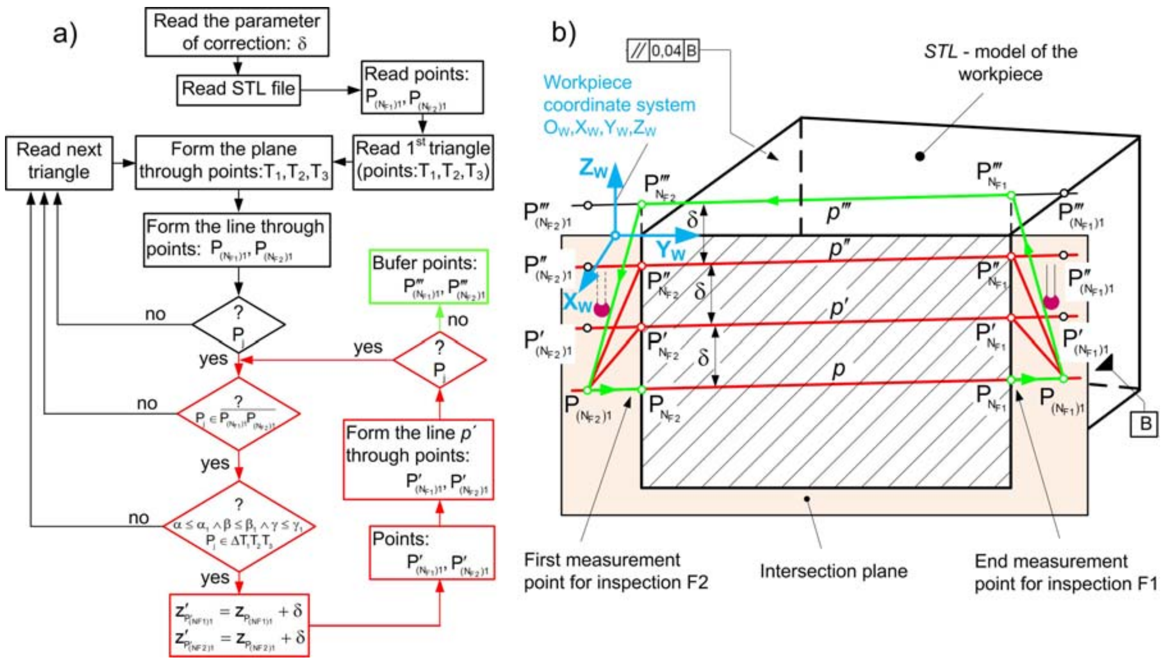

Fig. 4. Collision avoidance: a) algorithm, b) correction by z - axis

If an intersection between the line (9) and the plane (6) exists, then it is a point $P_j(x_j, y_j, z_j)$, where *j* is the number of intersection points.

Since $\Delta T_1T_2T_3$ is represented by a plane, and a line segment $\overline{P_{(N_{F1})1}P_{(N_{F2})1}}$ is represented as a part of a line *p*, it is necessary to check whether the intersection point P_j is placed at the line segment $\overline{P_{(N_{F1})1}P_{(N_{F2})1}}$ and whether it belongs to the part of the plane limited by $\Delta T_1T_2T_3$. In that case, to check whether the intersection point is placed in the surface part that is limited by the angles of triangle: $\alpha \le \alpha_1$ and $\beta \le \beta_1$ and $\gamma \le \gamma_1$.

If an intersection between a line *p* and any of the triangles from STL model exists, then using iterative procedure the points $P_{N_{F1}}, P_{N_{F2}};...;P^j_{N_{F1}}, P^j_{N_{F2}}$ are determined. The difference between the next point $P'_{N_{F1}}$ and the previous point $P_{N_{F1}}$ is in the value of z-axis, i.e. the value of the correction parameter $\delta[mm]$. The correction parameter is a constant for one PP. The procedure is repeated until there are no remaining intersections between a line and triangles from STL model. The last points $P'''_{N_{F1}}$ and $P'''_{N_{F2}}$ of this iterative procedure are the points for which there is no collision during the measuring probe crossover.

For the example shown in figure 4 b), the algorithm for collision avoidance (ACA) (figure 4a)) performed three corrections of z-coordinates and the points $P'''_{(N_{F1})1}$ and $P'''_{(N_{F2})1}$ are adopted.

The reduction of a number of triangles in the algorithm for collision avoidance results in a fast response, i.e. the coordinates of points without collision, and it does not significantly affect the processing time.

3.3 Algorithm for path planning (APP)

APP is based on ADMP and ACA. As shown in figure 5 its consists of six steps. In the first step, ADMP for feature plane_1 is loaded and gives the output: $(P^{tran})_{F1}$, $(P_1^{tran})_{F1}$ and

$(P_2^{tran})_{F1}$. In the second step, three matrixes are formed: S_{mo}^{F1}, T_{mo}^{F1} and W_{mo}^{F1}, and the arrangements of their elements correspond to the measuring probe movement.

Step#1: Reading ADMP for plane_1 $\rightarrow (P^{tran})_{F1}, (P_1^{tran})_{F1}, (P_2^{tran})_{F1}$

Step#2: Form: $S_{mo}^{F1} = \left[(s_2)_{1j}^{F1} \quad (s_1)_{1j}^{F1} \quad (s)_{1j}^{F1} \quad (s_1)_{1j}^{F1} \right];$

$$T_{mo}^{F1} = \left[(t_2)_{2j}^{F1} \quad (t_1)_{2j}^{F1} \quad (t)_{2j}^{F1} \quad (s_1)_{2j}^{F1} \right];$$

$$W_{mo}^{F1} = \left[(w_2)_{3j}^{F1} \quad (w_1)_{3j}^{F1} \quad (w)_{3j}^{F1} \quad (w_1)_{3j}^{F1} \right], j = 1,2,3,\ldots,N$$

Step#3: Reading ADMP for plane_2 $\rightarrow (P^{tran})_{F2}, (P_1^{tran})_{F2}, (P_2^{tran})_{F2}$

Step#4: Form: $S_{mo}^{F2} = \left[(s_2)_{1j}^{F2} \quad (s_1)_{1j}^{F2} \quad (s)_{1j}^{F2} \quad (s_1)_{1j}^{F2} \right];$

$$T_{mo}^{F2} = \left[(t_2)_{2j}^{F2} \quad (t_1)_{2j}^{F2} \quad (t)_{2j}^{F2} \quad (s_1)_{2j}^{F2} \right];$$

$$W_{mo}^{F2} = \left[(w_2)_{3j}^{F2} \quad (w_1)_{3j}^{F2} \quad (w)_{3j}^{F2} \quad (w_1)_{3j}^{F2} \right], j = 1,2,3,\ldots,N$$

Step#5: Reading ACA for plane_1-plane_2

$$P'''_{(N_{F1})1} = \left[s'''_{F1} \quad t'''_{F1} \quad w'''_{F1} \right];$$

$$P'''_{(N_{F2})1} = \left[s'''_{F2} \quad t'''_{F2} \quad w'''_{F2} \right]$$

Step#6: Form the matrix of movement:

$$M = \begin{bmatrix} s_{11} & s_{12} & \cdots & s_{1\mu} \\ t_{21} & t_{22} & \cdots & t_{2\mu} \\ w_{31} & w_{32} & \cdots & w_{2\mu} \end{bmatrix}, \mu = 1,2,3,\ldots,2(j+1),$$

for $\mu = 1,2,3,\ldots,j \Rightarrow s_{1\mu} = s_{1j}^{F1}; t_{2\mu} = t_{2j}^{F1}; w_{3\mu} = w_{3j}^{F1}$,

for $\mu = j+1 \Rightarrow s_{1\mu} = s'''_{F1}; t_{2\mu} = t'''_{F1}; w_{3\mu} = w'''_{F1};$

$\mu = j+2 \Rightarrow s_{1\mu} = s'''_{F2}; t_{2\mu} = t'''_{F2}; w_{3\mu} = w'''_{F2}$

for $\mu = (j+2),\ldots,2(j+1) \Rightarrow s_{1\mu} = s_{1j}^{F2}; t_{2\mu} = t_{2j}^{F2}; w_{3j} = w_{3j}^{F2}$

Fig. 5. Algoritham for path planning

The third and fourth steps are similar to the first and second step, but they refer to the feature plane_2. In the fifth step, it is necessary to call ACA and obtain $P'''_{(N_{F1})1}$ and $P'''_{(N_{F2})1}$ to complete the collision-free path for the inspection of features plane_1 and plane_2. In the sixth step, the matrix M gives all coordinates of the points, including points from the previous five steps, in the regularly established arrangement.

Measurement path simulation is based on the previously mentioned three algorithms.

3.4 Experiment

The measuring process is based on the measuring protocol obtained as the output of a simulation process.

Experiment involves measurement of two PPs that are produced for this research (figure 6a)). Testing is initially performed using the simpler workpiece, i.e. prismatic part 1 (PP1). After the successfully performed experiment on PP1, testing of the model is performed on the second, more complex workpiece – prismatic part 2 (PP2). Experiment is performed on the coordinated measuring machine ZEISS UMM 500.

In comparison to PP1, PP2 contains new types of tolerances that should be tested. Experimental setups for the measurement of PP1 and PP2 are shown in figures 6b) and 6c)., respectively. The measurement of both parts is performed in a single clamp, and the measuring probe configurations are shown at the figures.

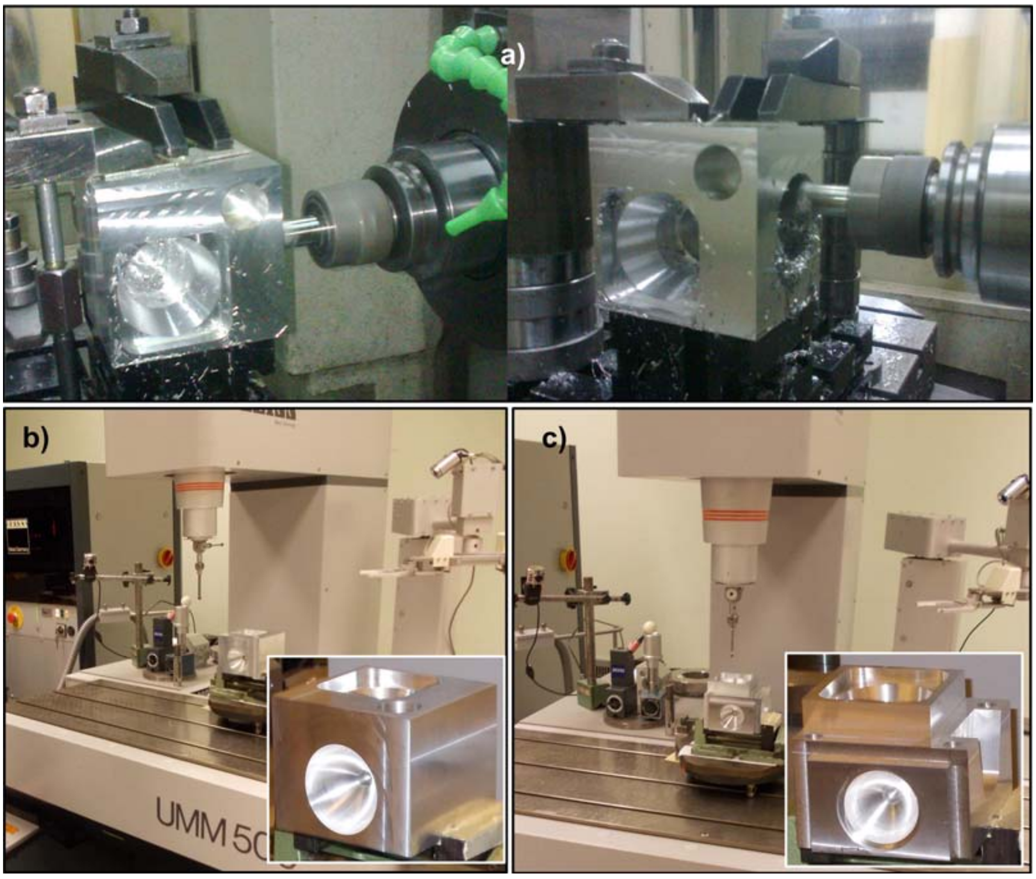

Fig. 6. The two prismatic parts: a) machining, b) measuring part no. 1, c) measuring part no. 2

In this experiment, the inspection process is composed of the preparation and measuring process. The preparation process involves: 1) setting up the workpiece, with the analysis of fixture tools and accessories; 2) configuration of measuring probes; 3) calibration of measuring probes using calibration sphere; and 4) alignment of PP.

The measuring results for both PPs are given in tables 1. As it could be seen, measurement was repeated five times and standard deviation was calculated and show in µm.

Table 1. The results of measurement workpiece no. 1 and workpiece no. 2

Part	No.	Tolerances			Measurements					
		Name	Label	Value in mm	1.	2.	3.	4.	5.	Deviation in µm
No. 1	1	Flatness	▱ 0.02	0,02	0,0005	0,0004	0,0005	0,0005	0,0004	0,1
	2	Diameter	50	±0,1	50,0851	50,0855	50,0852	50,0856	50,0855	0,2
	3	Perpendicularity	⊥ 0.03 A	0,03	0,0014	0,0024	0,0023	0,0022	0,0023	0,4
	4	Angle	Cone: 39°	±0,5	39,2991	39,2991	39,2995	39,2982	39,2991	0,5
	5	Parallelism	// 0.04 B	0,04	0,035	0,0346	0,035	0,0348	0,035	0,2
No. 2	6	Distance	70	±0,02	70,0111	70,0111	70,0112	70,0111	70,0106	0,2
	7	Cylindricity	⌭ 0.02	0,02	0,0042	0,0043	0,0041	0,004	0,0041	0,1
	8	Coaxiality	◎ 0.02 D	0,02	0,0068	0,008	0,008	0,0091	0,0092	1
	9	Roundness	○ 0.03	0,03	0,0094	0,0092	0,0092	0,0101	0,0096	0,4
	10	Position	⌖ 0.75 C B	0,75	0,6471	0,6483	0,6416	0,6481	0,6424	3,2

4. CONCLUSION

In this paper is presented a feature – based model path planning based on the CAD model of the prismatic part. The model is the basis for further development intelligent concept inspection planning of the prismatic parts on CMM. The feature - based model consists from two elements. The first element is sampling strategy or method for the distribution of measuring points for features, and second element define the method for collision avoidance between workpiece and measured probe.

The complex geometry of the PP by the model changes to the set of points whose sequence defines the initial measuring path of sensors without collision with workpiece. Presenting initial measuring path by set of points with a defined order leaves open the possibility path optimization and finding the shortest path. Finding the shortest measuring path influence to the reduction of the total measurement time, which is one of the goals of this research.

The results of the inspection of both PPs show that all tolerances are within the specified limits. This confirms the efficiency of the proposed feature – based model in an automatic inspection of PPs.

The model is especially suitable for use in case of measuring path planning for geometrically complex PPs with large numbers of tolerances.

FUTURE RESEARCH

On the basis of the presented model point-to-point measurement path, it is planned the development of optimization model using the ants colony. The main criteria would be the shortest distance of the probe travel.

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