Research on Measurement Points Planning based on Structural Features of Parts

Guijiang Duan[1,a], Peng Zhang[2,b]

[1]School of Mechanical Engineering and Automation, Beihang University, Beijing, 100191, China

[2]School of Mechanical Engineering and Automation, Beihang University, Beijing, 100191, China

[a]email: gjduan@buaa.edu.cn, [b]email:zhangpeng0230@126.com

Keywords: Digital Inspection; Structure Features; Measurement Points Planning

Abstract. In the process of digital inspection for parts by coordinate measuring machine, in order to assess the quality of parts more accurately, while ensuring efficiency, a method of measurement points planning based on structural features was proposed. From the viewpoints of inspection planning, structural features were identified directly from three-dimensional CAD models, based on which, the measurement points layout strategies for four typical structural features were discussed respectively. Measurement points could be arranged automatically while fine-tuning for points was enabled. Experiments showed that this method could improve the efficiency and quality of the inspection planning.

Introduction

The measuring of products with complicated features has been applied in airplane industry, automobile, mold and so on. Coordinate Measurement Machine (CMM) is playing more and more important role in those industries because of its wide measuring scope, high precision and great efficiency [1]. Recently, many related technologies revolving around CMM such as measurement features identifying, measurement points planning, and measurement path arrangement [2] were studied widely. In addition, the integration technology between CAD and CMM got more focus, which aimed to improve the inspection efficiency [3].

Measurement points are a set of discrete points with specific attribute disposed on the model surface. In order to access physical dimensions and geometrical shape of parts more accurately, planning the number and distribution of points is necessary. Generally, the more measurement points are provided, the more accurate results could be get, however the cost is increasing time and decreasing efficiency. Thus, in the measurement process by CMM system, an algorithm to provide appropriate measurement points arrangement strategies according to different inspection features has become an urgent requirement.

Currently, common points arrangement algorithms include symmetrical distribution method, random distribution method, distribution method based on digit sequence, and surface adaptive distribution method [4] etc.

In this paper a new measurement point arrangement method was proposed based on typical structural features. The number and layout of measurement points were planned automatically on the basis of feature types and sizes, then some points would be detached after reachability analysis. Unlike the traditional measurement points planning strategy which is based on topology feature [5], the measurement points were arranged on the higher level of structural feature.

Rules of measurement points in number and layout

In aviation parts, rib, hole, plane and free-form surface are four most common features, studying and establishing regulations for which is of great significance. Considering a variety of faces described in math and actual requirements in inspection process, number of measurement points for some features could be listed in the following Table1:

Table.1.Number of measurement points for some typical features

Feature Name	Least Point Number Actually	Regulations of Point number
Rib Surface	2	Increase with surface area
Hole	4	According to depth and diameter
Plane	3	Increase with surface area
Ruled Surface	4	Increase with surface width
Free-form Surface	5	Increase with curvature

Measurement point distribution should possess homogeneity, self-adaptive ability and accessibility. Homogeneity means that all the measurement points should be distributed on the surface of parts evenly with no excessive concentration nor a wide range missing, and therefore define the maximum step of two adjacent measurement points according to the feature type and tolerances. In order to keep homogeneity and control the number, points could be arranged in wave pattern. See Figure 1.

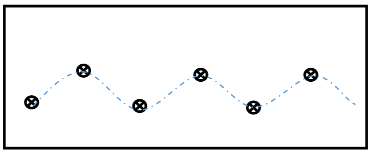


Fig.1. Points arrangement in wave pattern

Quality of special location on surface such as the large curvature, the inflection point, the junction and so on, because of its own difficult process, is more difficult to ensure. So it is a key point to inspect.

Measurement points are measured by CMM whose probe can reach or not becomes a problem to consider. To ensure the probe access to all measurement points smoothly and safely, it is necessary to make the following regulation for the distribution of measurement points:

a) Measurement points should normally be located at the nominal edge of 10mm in each of the feature;

b) Measurement points arranged at the hole should be removed (except when measuring a hole);

c) Measurement points should not be taken at sharp edges and corners.

Strategy of measurement points arrangement

Straight rib is one of the most typical features of the part, which has an effect on increasing structural strength and rigidity to overcome stress and distortion caused by external stress. In the inspection of straight ribs, position, thickness, and height are the focused. Solution of straight rib with 2 or 3 surfaces is to distribute two measurement points evenly in the rib surface, moreover according to the measurement requirement, the surface inspected may be increased appropriately. See Figure 2 (a).

Round holes inspection items mainly include diameter and depth, in order to rise inspection efficiency, one parameter is introduced: $K = \Phi / H$ if $K > 4$, stubby hole, just arrange one point at the center of the hole; If $K < 4$, elongated holes, arrange two points at a distance of 1.5-2mm from upper and lower surfaces of the hole. See Figure 2 (b).

In general, the inspection items attached to the plane include flatness, profile tolerance, parallelism and so on. In a plane, if the total number of measurement points is not limited, the total number is inversely proportional to the step of two neighboring points, $N \propto 1/D$. Therefore, using the step to control the total number is reasonable. Within a rectangular area, set up length with X, width with Y, maximum step of two neighboring points with D. $\frac{2X}{N_X} < D, \frac{2Y}{N_Y} < D, N_X \text{ and } N_Y$ was the divided number for vertical and horizontal direction. $N_X = \left[\frac{2X}{D}\right] + 1, N_Y = \left[\frac{2Y}{D}\right] + 1$, then the rectangular was gridding and measurement points ccould be arranged in waves. See Figure 2 (c).

Free-form Surface could be described as the following in math [3].

$$\vec{P} = \vec{P}(u,v) \quad (1)$$

At one point $P(u_0, v_0)$ demand $P(u,v)$ on the u and v partial derivatives:

$$\vec{P_u}(u_0,v_0) = \frac{\partial \vec{P}(u,v_0)}{\partial u}\Big|_{u=u_0} \quad (2)$$

$$\vec{P_v}(u_0,v_0) = \frac{\partial \vec{P}(u_0,v)}{\partial v}\Big|_{v=v_0} \quad (3)$$

$$\vec{n}(u_0,v_0) = \frac{\vec{P_u}(u_0,v_0)\times\vec{P_v}(u_0,v_0)}{\left\|\vec{P_u}(u_0,v_0)\times\vec{P_v}(u_0,v_0)\right\|} \quad (4)$$

If we select length of arc *s* as parameter, curvature can be describe as the following

$$\vec{p} = \vec{p}(u(s),v(s)) \quad (5)$$

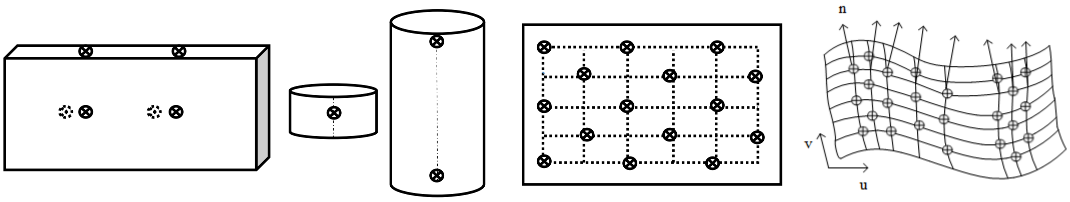
$$k_n = \ddot{\vec{p}}\, n = \vec{p}_{uu}\vec{n}(\dot{u})^2 + 2\vec{p}_{uv}\vec{n}\dot{u}\dot{v} + \vec{p}_{vv}\vec{n}(\dot{v})^2 \quad (6)$$

Firstly, make free-form surface gridding according to area like rectangular. Then set up a curvature k_0 as threshold and make an iteration traversing these vertices in the mesh from u direction and v direction. As for step the following expression is available:

$$s^{i+1} = s^i + \Delta s^i \quad (7)$$

$$\Delta s^{i+1} = \Delta s^i + G(k_n(u_i,v_i)) \quad (8)$$

As a result, number of measurement points would increase at bigger curvature position, and decrease at smaller. See Figure 2 (d).



(a) Rib (b) Holes (c) Plane (d) Free-form Surface

Fig.2. Points arrangement strategy

Conclusion

According to above discussion, overall system of measurement point arrangement based on typical features was built as showing below. See Figure 3.

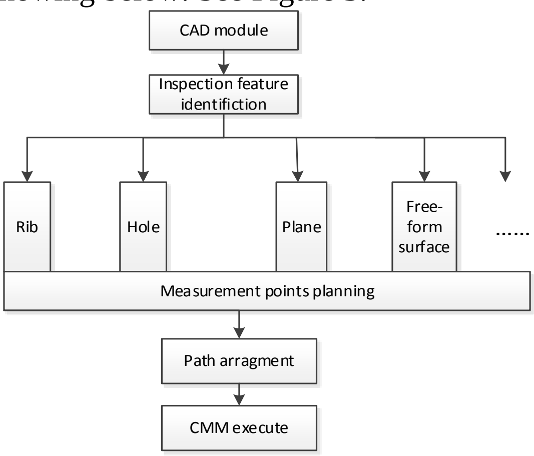


Fig.3. CMM inspection prototype system

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