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# A methodology for filtering point cloud generated by CMM to apply NURBS

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**ABSTRACT**
Nowadays, as aeronautical technology develops, an output of turbine is increasing. A BLISK is a single engine component consisting of a rotor disk and blades, which may be either integrally cast, machined from a solid piece of material, or made by welding individual blades to the rotor disk. Although there have been many previous researches, they didn't study related to measurement. A BLISK must be measured since it is critical components related to safety. A 5-axis CMM is used in product measurement system. The 5-axis CMM is suitable for measuring complex shapes because the surface is measured using a probe in contact with the object. 5-axis CMM moves the probe in contact with the surface of the workpiece, leaving a trace of points continuously. However, it is difficult to obtain the desired mesh with the existing algorithm using the data. So this paper proposes that a methodology for filtering point cloud generated by 5-axis CMM to apply NURBS.

**KEYWORDS**
5-axis CMM; NURBS; point cloud; BLISK

## 1. Introduction

Nowadays, as aeronautical technology develops, an output of turbine is increasing. A turbine is the most important part to get the propulsion of the airplane by compressing the air and injecting the fuel. As shown in Fig. 1, a BLISK is a single engine component consisting of a rotor disk and blades, which may be either integrally cast, machined from a solid piece of material, or made by welding individual blades to the rotor disk [2]. In recent years, a single material has been manufactured at one time for lighter weight, productivity, and maintainability. Due to the complicated shape of the BLISK, considerations such as raw materials and manufacturing methods are considered.

Most of the research related to BLISK are mostly about manufacturing technology. Raab has studied the efficiency of heat generation between LFW (Linear Friction Welding) and OFW (Orbital Friction Welding) [4]. Xu proposed a manufacturing method using a cathode tool [5]. Others have studied on uniformity using frequency and system mode, and Kumar shows various studies of BLISK manufacturing process by categorizing BLISK manufacturing technology [2]. In addition, Bhaumik studied the cause of the BLISK rupture, Jin proposed a BLISK measurement method using 5-axis CMM (Coordinate Measuring Machine), and David studied iso-geometric analysis of 3D virtual model [1, 3, 6].

The BLISK compresses air through rotational motion to obtain the propulsive force of the jet engine. At this time, the degree of air compression is adjusted according to the blade shape and the rotation speed. Therefore, if the blade is machined differently from the blueprint, the user will not be able to obtain the desired propulsive force, but it will cause damage to the blade and lead to personal injury. For this reason, inspection of the processed BLISK is essential. However, the existing research is concentrated on the processing method of the BLISK, so the research on the inspection is insufficient.

The most widely used method for inspection of workpieces is to use a 5-axis three-dimensional coordinate measuring machine (CMM) as shown in Fig. 2. It uses two rotary axes, one for the vertical plane and the other for the infinite rotation and positioning. In the horizontal plane. Therefore, the 5-axis CMM is suitable for measuring BLISK with curved surfaces and complex shapes. The tip of the 5-axis CMM is called the probe and is the part that comes into contact with the surface of the measuring object. The measuring method moves the probe in contact with the surface of the workpiece and continuously records the shape of the surface by calculating the center point of the probe. As show in Fig. 3, the moving path generally moves the surface at a constant speed, and the path of the probe is determined by repetitive movement of the head. The movement speed of the CMM, the

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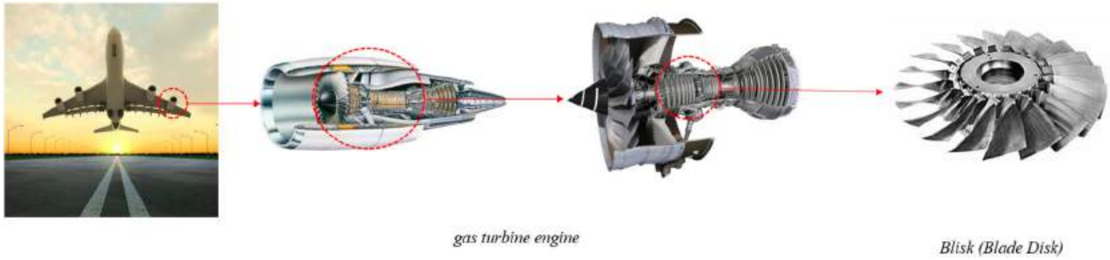


**Figure 1.** BLISK (Blade Disk).


**Figure 2.** 5-axis CMM (Coordinate Measuring Machine).


**Figure 3.** Route of 5-axis CMM.

movement speed of the head, and the cycle of calculating the probe center point are related to the accuracy of the point cloud, and the point cloud has a certain rule due to the repetitive movement of the head.

Algorithms for transforming point clouds into meshes have been extensively studied, but in most cases they are organized point-based studies. However, the point cloud obtained from the 5-axis CMM is not organized as a path tracing point of the probe and does not have a constant distribution. Therefore, it is difficult to obtain the desired meshes by using this data and using the commonly used transforming algorithm.

In this paper, we use NURBS (Non-Uniform Rational B-Spline) to convert point cloud obtained from 5-axis CMM to 3D model and propose a point cloud filtering method. One blade of BLISK was selected and measured by Renishaw's 5-axis CMM.

## 2. NURBS

In computer graphics, there are two ways to express curvature: wireframe and curvature. In the wireframe method, a curved surface is represented by a set of line

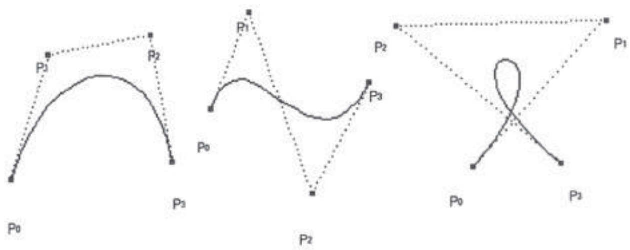

**Figure 4.** Bezier curve.

segments, and both vertices of each line segment can be represented in a three-dimensional coordinate system of X, Y and Z. In this representation method, the curve is represented by a set of short segments, so the expression of the curve differs depending on how the curve is segmented. Another way is to use a Bezier curve or a B-spline curve as a way to more accurately calculate the curvature. The Bezier curve is a method of obtaining various free curves by starting points and end points and control points located there between as shown in Fig. 4. The more control points there are, the more complicated the curves can be generated, but the longer the calculation time is. The B-Spline does not pass any control points as shown in Fig. 5, but forms a curve close to the control point. Therefore, even if it is a curve composed of the same control point, it is possible to easily draw a curved line having a smooth and gentle curvature.

## 3. Filtering method

As described above, the 5-axis CMM moves a region to be measured in a state of being in contact with the surface of a target object using a probe, and obtains coordinate points continuously. Therefore, the point cloud generated by the measurement shows the trace of the probe and cannot generate the surface through NURBS because it shows different distribution. In order to use NURBS, it is necessary to filter the point cloud appropriately. In this paper, we propose a filtering method for the point cloud obtained by measuring the blade part of the BLISK.

Fig. 6 shows that the 5-axis CMM measures the blade. The measurement is divided into six areas (two on the front of blade, two on the back of the blade, and two on both corners) and six point clouds are created. Each point cloud can overlap with each other, and each point is a position including the radius of the probe, so there is an

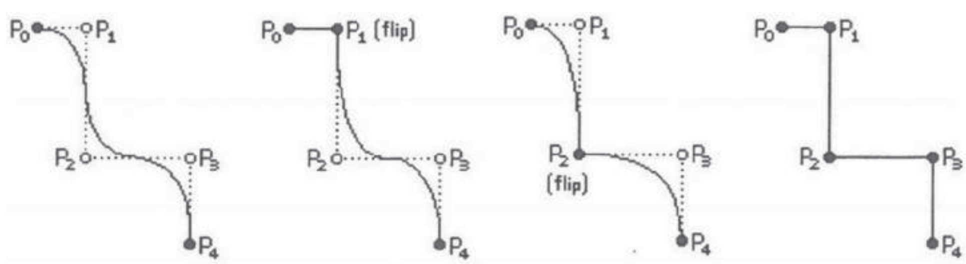


**Figure 5.** B-spline curve.

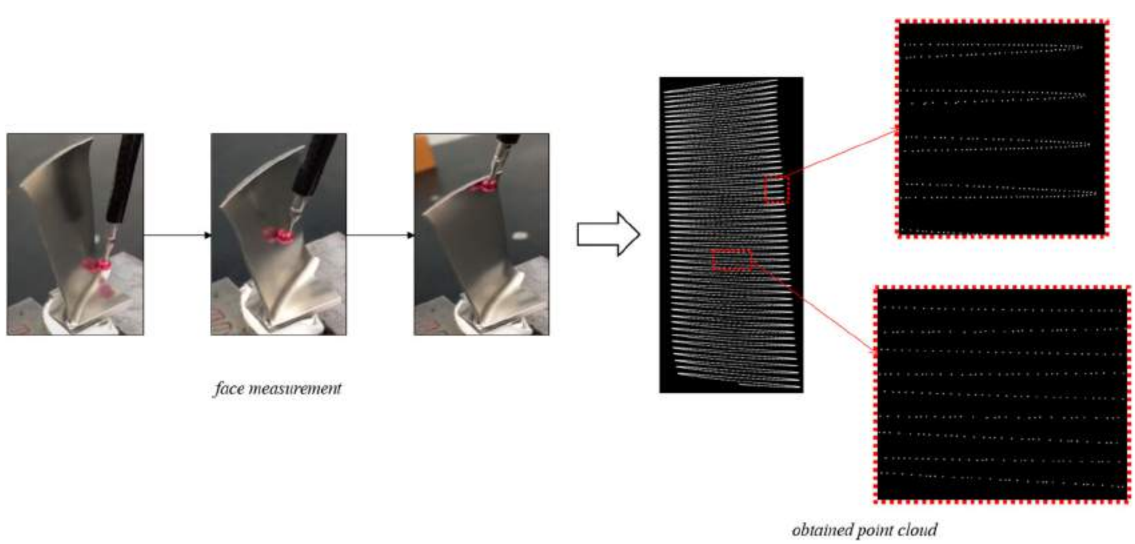


**Figure 6.** Blade measurement and Route of probe.

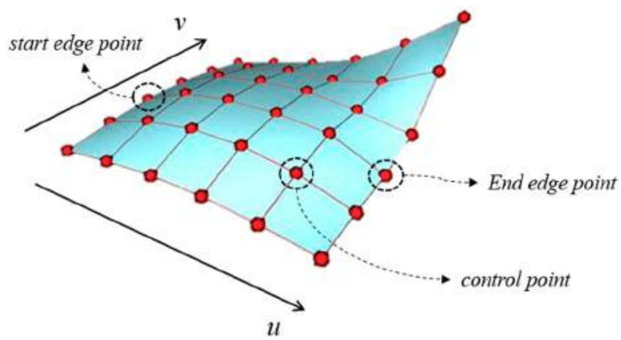


**Figure 7.** Control points & Edge points.

error as much as the radius of the original surface. This error can be ignored in applying to NURBS because it is the value used to reduce the calculated surface of the point cloud to its original shape. Therefore, in this paper, the purpose of this paper is to create a surface based on the measured point cloud.

To apply to NURBS, input the edge point and control point as parameters as shown in Fig. 7. The edge point can be divided into a start edge point and an end edge point, and a B-spline is generated between the control points there between. Therefore, each point must have an edge point and a control point defined. To create a surface, the number of control points of each B-spline must be the same. However, the point cloud obtained by the 5-axis CMM is distributed as shown in Fig. 8-(B). As shown in Fig. 8-(A), a total of 6 point clouds are generated in one blade. To apply this to NURBS, you can create a surface if you define the point where the measurement direction is bent as an edge point and the other points as control points. The feature of the raw point cloud is a sequence of points that are ordered according to the measurement route, and the z value increases as the sequence progresses. Therefore, we can obtain the edge point by comparing the vector direction of points.

## Control points filtering methodology from a point cloud

- Pt: a raw point cloud array.
- newPt: a 1/5 point cloud array of Pt.
- CompVec(p1, p2, p3): compare the p1-p2 vector with the p2-p3 vector.
- EdgeIdx: index array to indicate the beginning and ending position in u.

```
//create newPt
For(i = 0; j = 0; i < Pt.count; i++){
        If(i % 5 = = 0) {
                newPt[j] = Pt[i];
                j++;
        }
}
//find a edge point index in u-axis
For(i = 0; j = 0; i < newPt.count - 2; i++){
        If(CompVec(newPt[i], newPt[i + 1],
        newPt[i + 2]) > 0.6){
                EdgeIdx[j] = i;
                j++;
        }
}
```

The above pseudo code shows how to filter the raw point cloud for NURBS. The first step in the filtering process is to read the raw point cloud in order and filter only the point cloud of 1/5. After that, we use newPT to compare the edge points using the direction vector between points. The reason for filtering at 1/5 of the first is that if the direction vector is compared without filtering as shown in Fig. 9, an error occurs. Raw point cloud has an error because it is a numerical value that accepts mechanical error. The value of 1/5 for filtering and 0.6 for reference value of direction vector are values obtained empirically.

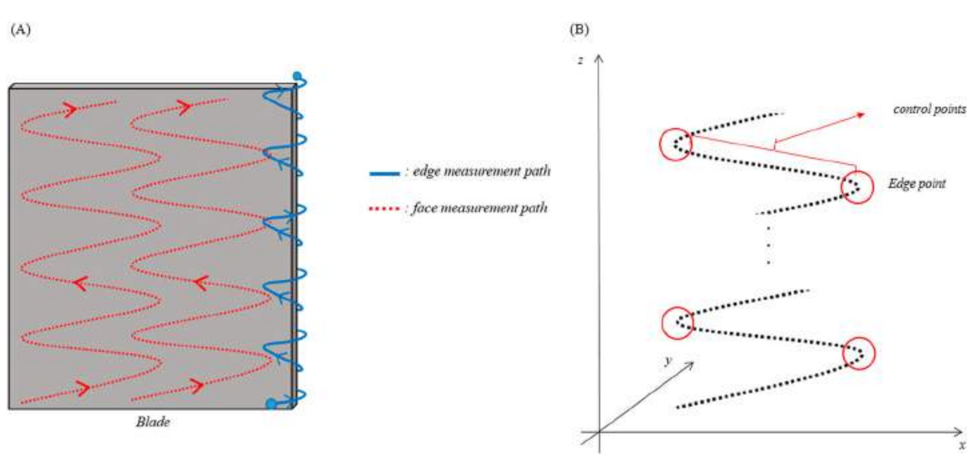


**Figure 8.** Concept of measured point cloud.

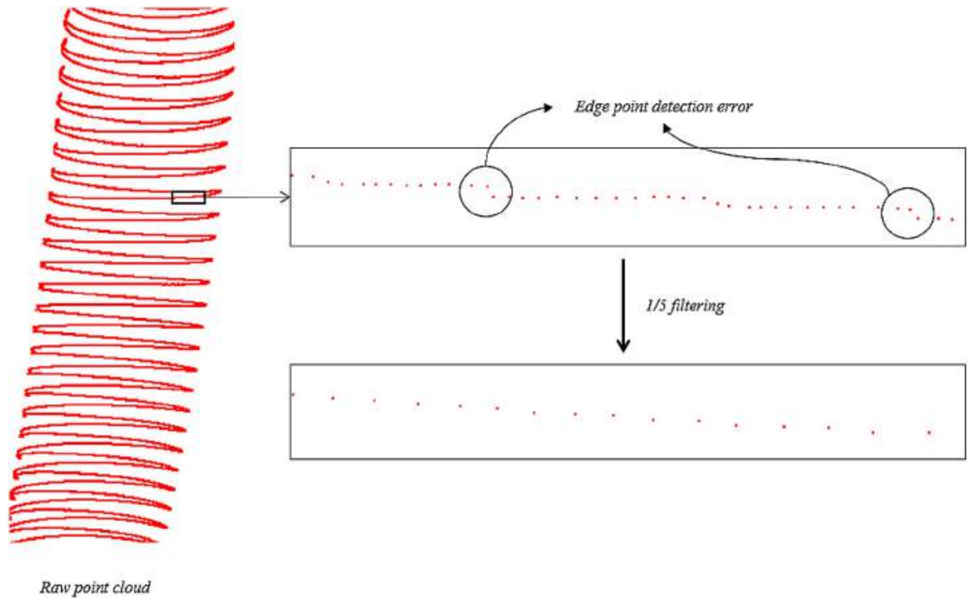


**Figure 9.** Result of 1/5 filtering.

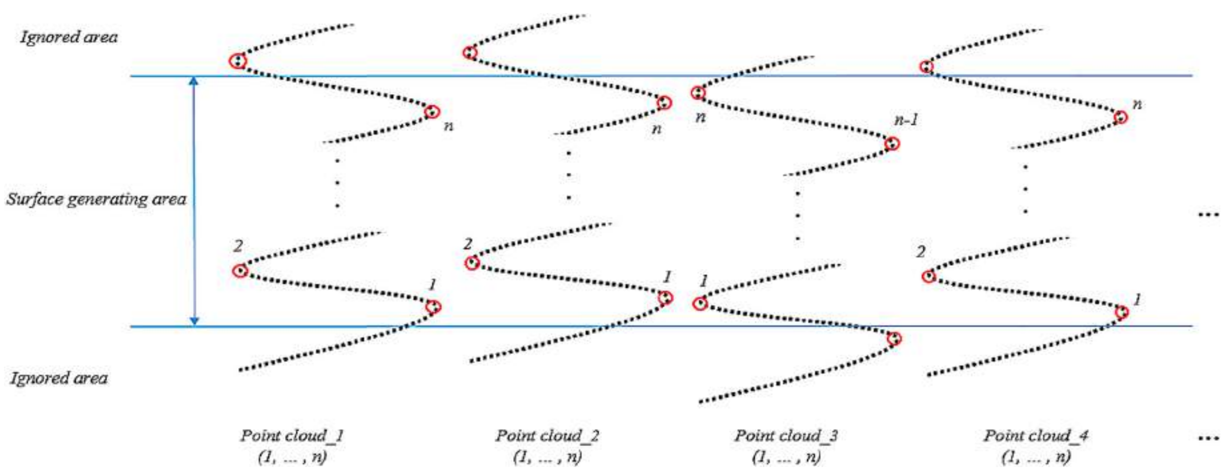


**Figure 10.** Point cloud region of interest.

There are a total of 6 point clouds on the blade and you need to create surfaces that are connected to each other. However, the position and number of edge points of each point cloud are different. In order to apply to NURBS, the number of edge points of each pint cloud must be the same, so points outside the region of interest are ignored as shown in Fig. 10. As shown in Fig. 10, each point clouds in the surface generating area has n edge points. As Fig. 11-(A), the number of edge points of the point clouds in the region of interest are the same and can be connected as shown in Fig. 11-(B) by connecting the closest edge points in the adjacent point clouds. Fig. 11-(B) shows a simple conceptual illustration of the edge point. Finally, we can identify points that can be placed in the B-spline as shown in Fig. 11-(C). After this, the number of different control points can be applied by filtering with resolution.

## 4. Result & conclusion

NURBS is created by connecting several curved surfaces, and one curved surface is called a span. The Span is generally the value used to evaluate the surface. The smaller the number of spans, the more accurately a well-created surface can be obtained. Also, the accuracy of the surface can be measured using the distance between the generated surface and the points created by the existing measurement.

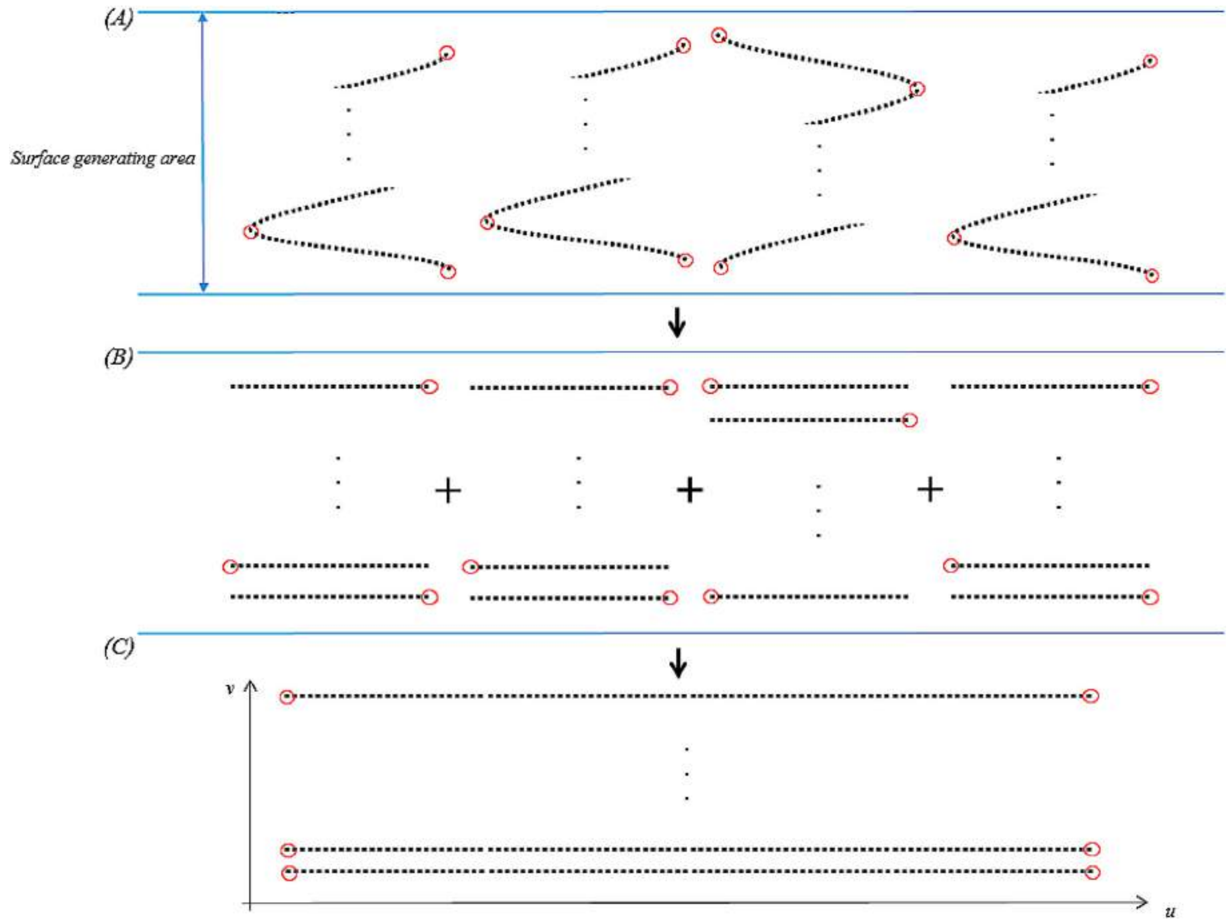


**Figure 11.** How to connect each point cloud.

This research is focused on blade which is one of the components of jet airplane turbine. The blades serve to compress the air for the engine to gain momentum and are an important part of human safety. However, the research on evaluating the finished product is in short supply. In order to solve this problem, the research from the 5-axis CMM to the 3D model generation has been carried out.

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## References

[1] Bhaumik, S. K.;Bhaskaran, T. A.;Rangaraju, R.; Venkataswamy, M. A.;Parameswara, M. A.;Krishnan, R. V.: Failure of turbine rotor blisk of an aircraft engine, Engineering Failure Analysis, 9(3), 2002, 287-301. http://doi.org/10.1016/S1350-6307(01)00017-6

[2] David, G.; Bert, J.; Helena S.; Johannes B.; Anh-Vu, V.: Isogeometric Simulation of Turbine Blades for Aircraft Engines, Computer Aided Geometric Design, 29(7), 2012, 519-531. http://doi.org/10.1016/j.cagd.2012.03.002

[3] Jin, H.; Zi, M.; Ying, H.; Yang, W.; Shuanghe, Y.: Measurement of aero-engine BLISK using industry robot, Computer and Electrical Engineering, 2008, International Conference on, IEEE, 2008, doi:10.1109/ICCEE.2008.45

[4] Kumar, B. V. R. R.: A review on blisk technology, International Journal of Innovative Research in Science, Engineering and Technology, 2(13531358.11), 2013.

[5] Pichot, F.; Laxalde, D.; Sinou, J. J.; Thouverez, F.; Lombard, J. P.: Mistuning identification for industrial blisks based on the best achievable eigenvector, Computers & Structures 84(29), 2006, 2033-2049, http://doi.org/10.1016/j.compstruc.2006.08.022

[6] Xu, Z. Y.; Xu, Q.; Zhu, D.; Gong, T.: A high efficiency electrochemical machining method of blisk channels, CIRP Annals-Manufacturing Technology, 62(1), 2013, 187-190, http://doi.org/10.1016/j.cirp.2013.03.068