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### REVERSE ENGINEERING OF A STEAM TURBINE ROTOR BLADE FOR ITS ANALYSIS

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#### ABSTRACT

Reverse engineering is the process of making a solid model of a component that has been manufactured already and is available. This paper outlines the process procedure in creating a solid model of a steam turbine rotor blade through reverse engineering process. The methodology used in this paper consists of data acquisition of the model using a 3D scanner in the form of point cloud data, pre processing the point cloud data using OPTOCAT software so as to get a polygon mesh of the model and later generating a 3D solid model by extracting the sketches and surfaces generated from the point cloud data using the Geomagic Design X software. The above methodology was used to make a 3D model of the turbine rotor blade. This 3D model was further used for various analysis.

**KEYWORDS:** Reverse engineering, White light scanner, Geomagic design X, OPTOCAT, Point cloud data, Turbine blade.

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#### INTRODUCTION

In conventional engineering design, a 3D model of a product is made in CAD software and later based on that model the product is manufactured. The reverse engineering is just the opposite of the above process in which a design is done backward from a manufactured product to a 3D model. The reverse-engineering process involves measuring an object and then reconstructing it as a 3D model. The complete process consists of two main stages, first of data acquisition and second of data processing and modeling. These are done with the help of various instruments used for data acquisition and various software's used for data processing and modeling.

#### Data acquisition

Data acquisition is the process of measuring the profile or geometry of the component. There are two main techniques of doing it: contact scanning method and non contact scanning method. Contact scanning devices employ contact probes that follow the contours of a physical surface, they are based on co-ordinate measuring machine technology. These devices have a good tolerance limit of 0.01mm to 0.02 mm and are easy to use and carry. However they are very slow and take readings of very less number of points compared to non contact scanners. Also the probes must deflect to register a point, hence a degree of contact pressure is maintained during the scanning process. This contact pressure limits the use of contact devices because soft, tactile materials such as rubber cannot be easily scanned.

Non contact scanners do not make a physical part contact, they uses light, ultrasound and X rays to capture point data. Their major advantage is that the data captured is very dense and in a very short time period. But the tolerance levels are within 0.025mm to 0.2mm. Also there are problems capturing data on the surfaces which are parallel to the axis of the laser, thus the component has to be rotated to get a large number of snap shots to cover all surfaces of the component. Also the surface has to be prepared with some temporary coating before scanning it as the light only captures the surface data that is coated. The data points obtained by scanning are known as point cloud data. The devices include active scanners like: time of flight, triangulation, photogrammetric and structured light scanners and passive scanners like: stereoscopic and photometric systems.

#### Data processing and modeling

The data measured by above techniques represents point cloud alone and lacks topological information and is therefore often processed and modeled into a more usable format such as a triangular-faced mesh, a set of NURBS surfaces and a CAD model.

It consists of two main processes i.e. data processing and solid modeling.

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**Data processing**

It is done using software's like OPTOCAT and Polyworks etc. The basic aim is to convert the point clouds into rough surfaces. The process consists of firstly aligning various point clouds obtained from various camera shots together to get the point cloud data of the complete periphery of the component. Then the point cloud data is filtered to remove the noisy or unwanted points and to include the point that are unavailable. The points are then filtered or joined together to form triangular meshes. Rough surfaces are formed with the help of these triangular meshes. Various triangular algorithms are used for this like Delaunay triangulation etc. further segmentation is done to divide the meshes into patches or surfaces. Various meshes or rough surfaces having similar profile or curvature are joined together to form natural surfaces.

**Solid modeling**

Solid modelling is done using specialised reverse engineering software like Geomagic design X, Transmagic and Polyworks etc. It involves extraction of surfaces and then making a 3D model of it. The process includes extracting 2D sketches at various cross-sections of the model. From these sketches surfaces are formed and from these surfaces a solid body is created. The accuracy or deviation between the actual model and the model made can be checked at any stage within the software.

The solid models made can then be transferred to main stream CAD software's for further analysis. The results can be transferred in standard conventional files like .STEP or .STP or directly transferred from some reverse engineering software's like Geomagic etc to main stream CAD software's without the loss of parametric data.

**Applications**

The applications of reverse engineering include optimising a component to improve its performance, analysing whether a component meets its design requirements or not, learn about a competitor's latest research by capturing data to secure the components details. It can also be done to improve the documentation about the design information of the component and to plan the preventive maintenance of the product.

**MATERIALS AND METHODS****Material**

The material of the blade is nickel based super alloy Inconel 718. The specifications of INCONEL 718 material is shown in table 1.

*Table 1: Specifications of INCONEL 718*

|   |                         |
|---|-------------------------|
| Density (Kg/m <sup>3</sup> )                | 8220                    |
| Melting point (K)                           | 1609.15                 |
| Modulus of elasticity (KN/mm <sup>2</sup> ) | 204.9                   |
| Modulus of rigidity (KN/mm <sup>2</sup> )   | 77.2                    |
| Yield strength (N/mm <sup>2</sup> )         | 1172                    |
| Tensile strength (N/mm <sup>2</sup> )       | 1407                    |
| Coefficient of thermal expansion(/°C)       | 12.8 * 10 <sup>-6</sup> |
| Poisson's ratio                             | 0.3                     |
| Thermal conductivity (W/m.K)                | 25                      |
| Specific heat (J/Kg.K)                      | 586.2                   |

**Methodology**

In present study, Reverse engineering was used to make the solid model of the blade because it was difficult to make a solid model in the absence of dimensional details, so the only way left was to make the model using reverse engineering. The technique for data acquisition was chosen to be white light scanning because of its ability to scan million of points on the surface of the blade in very less time, the levels of accuracy and resolution were also very good. Also the scanner was available at central tool room, Ludhiana. The steam turbine rotor blade had a complex aerofoil shape with both vane and root parts.

**Experimental Setup**

The scanning was done in a dark room using Smart scan white light scanner by Breuckmann. The technical specifications of the scanner are shown in table 2.

The scanner only scans the surfaces that are white, so the blade was coated with white chock powder. The blade was then fixed on a small table coated black. The table had many white stickers pasted on it for references. As the camera took a shot the co-ordinates of millions of points on the projected surface were noted along with the stickers that came

**Table 2: Technical specifications of the white light scanner**

| <b>SENSOR</b>           |  |
|-------------------------|--|
| Principle of operation  | Miniaturized projection technique                          |
| Light source            | 100 / 250 W halogen  |
| Sensor weight           | 4 Kg   |
| Imaging                 | 2 high resolution digital CCD cameras                      |
| Digitization            | 2448 * 2048 pixels per cameras                             |
| Operating distance      | 1000 mm  |
| Min. depth resolution   | 1 $\mu$ m  |
| Acquisition time        | < 1 sec  |
| <b>IMAGE PROCESSING</b> |  |
| Host computer           | Core 2 duo, $\geq$ 2 GHz, $\geq$ 2 GB RAM, $\geq$ 60 GB HD |
| Operating system        | Microsoft windows XP professional                          |
| Measurement software    | OPTOCAT for windows  |

In the shot. Again the table was rotated and another shot was taken to measure the co-ordinates of the points and stickers included in that shot. In order to align the points captured in two shots together, at least one sticker must be common in both the shots. The table was rotated to get many shots at various angles to capture complete periphery of the blade and the points in various shots were aligned and the complete point cloud data of the blade was obtained.

Many precautions were taken while taking the readings. It was insured that sufficient number of snapshots were taken to get the points on complete periphery of the blade especially the leading and trailing edges and the root portion and other small curvatures. If there were less number of points available on the narrow edges or corners it had to be shot again to get a good number of points. The blade was fixed firmly on the table so that its position with respect to the stickers on the table did not change. To increase the accuracy of the data captured, the white chock powder paste applied was as thin as possible to

prevent any unnecessary increase in blade thickness; also it covered complete blade surfaces. The white light scanner used is shown in figure 1.



*Figure 1: White light scanner*

### **Point cloud data processing**

The data obtained by the white light scanner in the form of point clouds was transferred from the scanner to software, OPTOCAT through connecting cables. OPTOCAT is Breuckmann's high-performance measuring and evaluation software used for capturing and mapping the texture of a scanned object to its digital 3D representation. OPTOCAT aligned the point cloud data as discussed earlier. The unnecessary data points were deleted like that of table and stickers after completing the alignment and any desired points were also added. The point cloud data is shown in figure 2.

### **Mesh generation and segmentation**

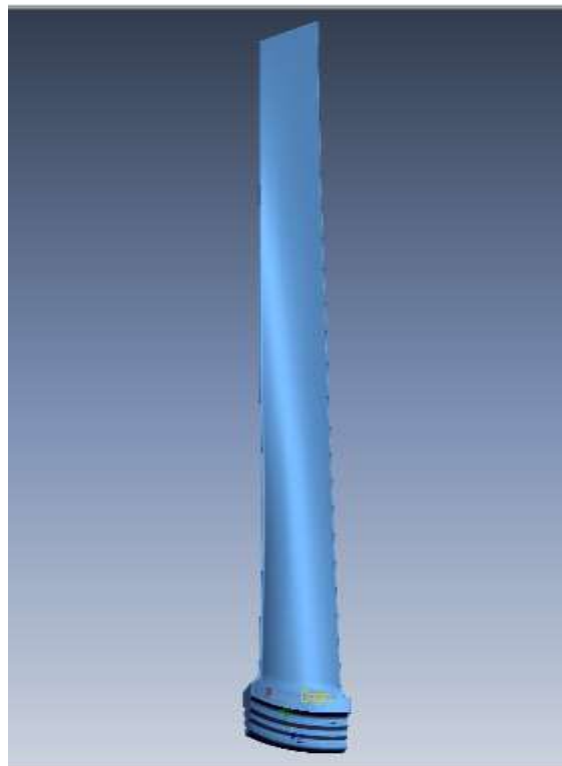
The points generated were then joined together to form a triangular mesh of the point cloud data that acts as a rough surface. The surfaces were then segmented according to their curvatures to form separate natural surfaces. This was done in OPTOCAT software only. The results were stored in form of a stereolethographic file (.stl file). The segmented blade model is shown in figure 3.

### **Solid modeling**

The solid modeling was done to create a 3D model of the blade from the .stl file obtained in pre-processing stage. It was done using Geomagic design X software which is specialised reverse engineering software.



*Figure 2: Point cloud data*



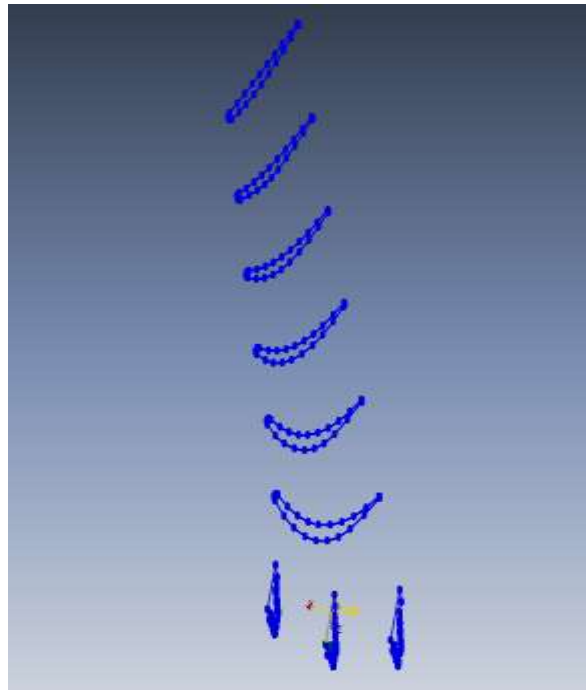
*Figure 3: Segmented blade model*

### Geomagic design X software

Geomagic design X is the professional engineering software proprietary of 3D Systems. Geomagic Design X is purpose-built to create manufacturing-ready CAD models directly from scan data. It works with every 3D scanner, and makes native, feature-based models for every major CAD application. It is very easy to use as it has similar working environment for solid modelling as used by most of the CAD softwares. The steps involved in the solid modeling were as follows:

#### 1. Designing sketch profiles

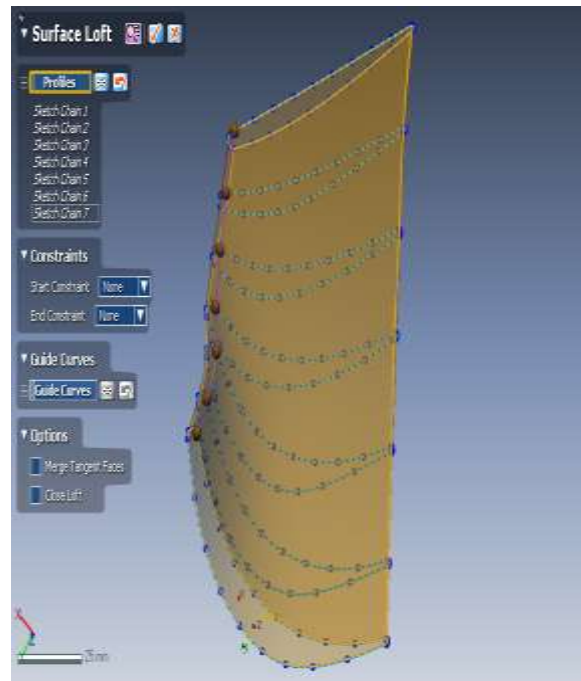
The sketch profiles were extracted from the scanned data at various sections of the vane and the root part of the blade. It involved using many sketch commands as: line, centre point arc, tangent, trim, fillet, chamfer, split, extend and offset etc. The sketches in root part were extracted at three planes and at vane part at six planes. Sketches were further analysed using accuracy analyser to check their closeness to the original model. The sketches extracted are shown in figure 4.



*Figure 4: Sketches extracted from segmented model*

#### 2. Designing the surfaces

Surfaces were made from the sketch profile using various surface commands like Loft, extrude, sweep, offset, extend, trim and merge etc. Lofting was done to connect various sketches at root section and vane section together to form surfaces. The extracted surfaces are shown in figure 5.



*Figure 5: Extracted surfaces of the model*

### 3. Creating solid bodies

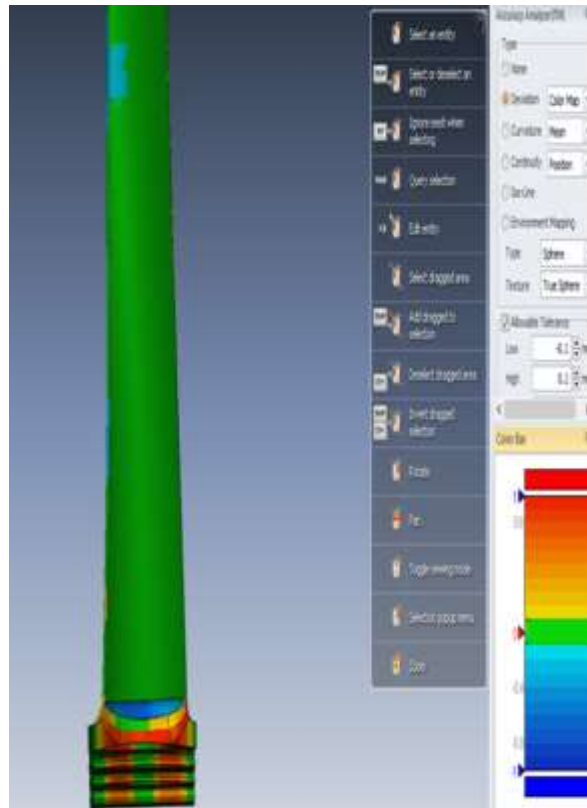
The surfaces were then combined together to form a solid body. Various solid body commands used are: Revolve, extrude, cut, sweep, loft, offset and boolean etc. The vane part and the root part were two separate solid bodies which were joined together finally to form a single solid model of the blade. The solid model made is shown in figure 6.



*Figure 6: Solid model of the rotor blade*

#### 4. Accuracy analyser

Accuracy analyser is a tool used to check the accuracy of the model. It analyses the closeness of the designed model with that of the model scanned. The permissible deviation of the designed model was set to +0.1mm to -0.1mm. The designed model was then checked to see if it met the accuracy criteria or not, the model was further modified using various commands such as fillet, chamfer and draft etc. to make it meet the accuracy criteria. Colour codes were used to show the accuracy levels of various surfaces of the model. The green band showed the surfaces within tolerance limits. Red band indicated the surfaces which were modeled more than their original values while blue indicated the surfaces which were modeled less than their original values. The solid model showing accuracy of all surfaces are shown in figure 7.



*Figure 7: Solid model showing accuracy*

## RESULTS AND DISCUSSION

The main aim of using reverse engineering was to get a parameterised CAD model of the turbine rotor blade. Using this method millions of points were obtained on the periphery of the blade surface, thus accuracy of data capture was very good. To extract the sketches seven sections were taken on the vane part and three sections were taken on the root part. The sections were taken at regular intervals and lofted to form the surfaces. Major portion of the blade is within accuracy of +0.1 mm to -0.1 mm except few portions on root having accuracy of +1.0 mm to - 1.0 mm. This can be because of very small root curvatures. The blade dimensions obtained are given in table 3. The vane portion is very large compared to the root portion in length.



**Table 3: Blade dimensions obtained**

|                   |        |
|-------------------|--------|
| Blade height (mm) | 638.57 |
| Vane height (mm)  | 597    |
| Root height (mm)  | 41.57  |
| Root width (mm)   | 114.3  |

## CONCLUSION

Reverse engineering is an effective tool to measure the profile or geometry of any component to modify it or analyse it. The methodology for data acquisition and modeling with CAD software's is presented in this paper. White light scanner is an efficient tool for data acquisition as it captures millions of points on the blade surface, also the time required for acquisition is very less. The data captured can easily be converted into a solid model using reverse engineering software's like Geomagic design X. The accuracy of modeling is also very good and can be controlled. The solid model made can be used for further analysis in CAE software's.



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