CHAPTER 4

SOLUTION METHODOLOGY

The first phase of this research is designing the 3D model of the radiator fan blade using Reverse Engineering concept and this tool is a boon for several fields of Science and Engineering as it can provide spares for worn out or lost components.

Adopted sequence of Reverse Engineering process is summarized below.

- Initially the physical model which needs to be redesigned, i.e. the fan blade is cleaned up and the surface is prepared.
- Scanned the physical model using scanners to get the point cloud by adopting either mechanical techniques or optical techniques. Physical contact sensors are used in the prior technique and where as in the optical technique the part is not contacted. But in both the techniques a coordinate measuring machine, CMM is used.
- Processed the points cloud includes merging of points cloud since the part is scanned in several settings. The outlines and noise are eliminated (If too many points are collected by taking multiple scans from various angles and by rotating the object, then sampling of the points can be done to get single point cloud, from which the reconstruction of objects or surfaces can be done).
- Created the polygon model and prepared STL files for rapid prototyping.
- Prepared 3D blade and is exported into CAD/CAM packages (ANSYS) for Static Analysis.

4.1 Digitization of Radiator Fan Blade

Capturing the physical model features and corresponding data and converting them into digital form is the foremost important step in Reverse Engineering methodology. First the blade is divided into sections to identify the features for digitizing. More number of sections is made at the vicinity of the embossed region and the bent region. Along with the identified sections, either contact or non-contact probing is done to get the point cloud data. The entire
outer edge of the blade is digitized to get the size of the point cloud data. Sample points collected from various positions are combined into a single point cloud and from which the surface is reconstructed.

The steps followed to obtain the coordinate point data are:

- Straight probe of 0.5mm diameter is used depending on the complex geometry of blade.
- Clamp the blade to restrict the degrees of freedom.
- Selecting the Element option in the main menu of Usoft to probe the edge coordinate of the blade root.
- Probe at different point along the aero foil section of blade.
- The output file gives the coordinates of probed points along the blade length and these coordinates are taken from fixed reference point.
- The point cloud data obtained from Digitizing technique imported in IGES format into FEA package like ANSYS and solid modeling is done.

The geometric model of radiator blade is generated using ANSYS as follows.

- The key point data for blade collected from Reverse Engineering process.
- The list of key points through which the basic outline of the structure is obtained.
- Using splines and lines as boundaries different areas are generated.

The obtained surface mesh is interpreted in the Volume Graphics VG Studio MAX 2.2 software. For the evaluation 11 characteristics were selected, including:

- dimensions
- deviations in shape and orientation (Fig. 4.1)
The comparison of various parameters of the Fan blade in Figure 4.1 is discussed in Table 4.1

![Figure 4.1 Digitizing of Fan blade](image)

Deviations between the CAD model of the specimen and the obtained mesh were evaluated independently. For optimizing the process of evaluation a template was created which included all of the evaluated and supporting characteristics. All dimensions were evaluated by the method of smallest squares (Gauss). Evaluation of the angles between the ribs is created from the symmetries between the surfaces of the ribs. The tolerance value was set to 0.1 mm; they serve only as information for the software. After the evaluations the data were exported into the XML and XLSX file format for easier processing and evaluation.
The comparison in Table no 4.1 of a 3D scan against the model was performed on the basis of the BEST-FIT function, where the first step involved a rapid, rough alignment and the next step a precision adjustment.

4.2 Comparison of Scanned data

Table 4.1 Various Parameters using Creafom EXAscan and Steinbichler Comet L3D

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Creafom EXAscan</th>
<th>Steinbichler Comet L3D</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Xp [mm/deg]</td>
<td>R [mm/deg]</td>
</tr>
<tr>
<td>Upper Surface</td>
<td>RON</td>
<td>0.1392</td>
<td>0.001</td>
</tr>
<tr>
<td>Side Surface</td>
<td>RON</td>
<td>0.134</td>
<td>0.005</td>
</tr>
<tr>
<td>Center Cylinder</td>
<td>CYL</td>
<td>0.139</td>
<td>0</td>
</tr>
<tr>
<td>LK1 to upper surface</td>
<td>PERP</td>
<td>0.2197</td>
<td>0.076</td>
</tr>
<tr>
<td>LK2 to upper surface</td>
<td>PERP</td>
<td>0.195</td>
<td>0.087</td>
</tr>
<tr>
<td>LK3 to upper surface</td>
<td>PERP</td>
<td>0.2067</td>
<td>0.079</td>
</tr>
<tr>
<td>PK1 to upper surface</td>
<td>PERP</td>
<td>0.18</td>
<td>0.033</td>
</tr>
<tr>
<td>PK2 to upper surface</td>
<td>PERP</td>
<td>0.1893</td>
<td>0.047</td>
</tr>
<tr>
<td>PK3 to upper surface</td>
<td>PERP</td>
<td>0.1883</td>
<td>0.099</td>
</tr>
<tr>
<td>Center cylinder (inner</td>
<td>PERP</td>
<td>0.069</td>
<td>0.005</td>
</tr>
<tr>
<td>surface) to upper surface</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Center cylinder (outer</td>
<td>PERP</td>
<td>0.0513</td>
<td>0.015</td>
</tr>
<tr>
<td>surface) to upper surface</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

where,
Xp - average value,
R – Variation range,
RON – flatness,
CYL – cylindricity and
PERP – perpendicularity.
Figure 4.2 Generation of Cloud Points in various angles

Using the 3D scanning digitizing technique points cloud matrix, i.e. the digital points cloud data in x, y, z coordinates are generated, from the surface geometry of a physical part. The collected geometrical information of the surface of the object stores the information in 3-dimensional coordinate system. Text files and STL file format are the common formats of
point cloud data which is the polygonal mesh representation of a point cloud. The Conceptual CAD model is created by importing digitizing process point cloud data into FEA package like ANSYS and solid modelling is done.

4.3 File Creation

The next step is the development of 3D model by importing the collected point cloud data into CAD software, Solid Works. When the tool processes the point cloud data, cleaning, deduction and removal of any redundant and undesired points which were formed while importing data in the software is also carried out to get the better blade profile.

Surface geometry reconstruction in reverse engineering process is challenging and to generate an accurate surface model from the point cloud data needs significant amount of time and skill as it involves frequent manual user interaction. But currently, a geometry input format, which consists of a list of triangular facet data, typically in Stereo Lithography, (STL) file format is used to export the digital data.

4.4 Modelling of Fan Blade

The solid models have two ways of representations such as boundary representation and feature-based representation. There are some methods to construct boundary representation models by connecting the point to point in spline manner from point clouds or triangular mesh with profile curve and some other focused on manufacturing feature based recognition for process planning purpose.

Here the geometric model of radiator blade is generated using ANSYS as follows. The key point data for blade collected from Reverse Engineering process. The list of key points through the basic outline of the structure is obtained. Using splines and lines as boundaries different areas are generated as shown in figure 4.3.
4.5 Blade Design and Analysis

Material and Manufacturing processes are the strongly influencing factors of the physical properties of blades and based on the size and application of the blade, manufacturing is a multistage process, casting or forging followed by machining the profile. The radiator fan blade material choices include the ancient material stainless steel and the latest highly alloyed metals including nickel, cobalt, chromium, titanium, molybdenum and tungsten etc.

The radiator fan blade with the existing material is analyzed first to verify the induced stresses are within the safe limits or not. The static analysis of the radiator fan blade is executed to different types of materials with the same input parameters to check and evaluate the material which withstands the dynamic and structural loads. Static analysis of the blades has been done using ANSYS where the 3D solid model of the radiator fan is considered for structural analysis. The various loads and properties are applied through the entire length of the radiator fan. The analysis leads us to the proposal of suitable material to withstand all the loads.
Blade model is created in ANSYS by calculating the various forces acting on the blade at different cross section. The assumptions considered for the design of fan blades are i). The air is considered as incompressible fluid and ii). The turbulent effects of air are neglected.

4.5.1 Forces acting on the different sections of the fan blade

Generally around the object surface the fluid velocity varies and induces a centrifugal force on the body as the object moves through a fluid. This centrifugal force on the fluid particles on the upper side i.e. convex side tries to move them away from the surface and reduces the static pressure below the free stream pressure on this side. Hence this “suction effect”, the convex surface of the blade is termed as suction side.

This centrifugal force on the lower side i.e. concave side presses the fluid harder on the blade surface, thus increasing the static pressure above that of the free stream. Therefore, this side of the blade is known as the pressure side. The magnitude of upward force on the blade is the cumulative effect of the positive static pressure on the pressure side and the negative pressure on the suction side. Lift and drag forces have been created due to this pressure difference.

4.5.2 Drag Force

Drag is the force that opposes a fan motion through the air and is generated by the interaction and contact of a solid body with air, i.e. every part of the radiator fan assembly. Drag which acts in direction that opposes the motion is not generated by a force field called gravitational or an electromagnetic field, where one object can affect another object without being in physical contact. To generate drag, the rotor body must have the contact with the fluid, the difference in velocity between the rotor fan and the air and motion between the rotor fan blade and air. There are many factors that affect the magnitude of the drag force including the shape of the body, stickiness of the air, and the speed.
4.5.3 Thrust Force

Thrust is generated most often through the reaction of accelerating a mass of gas. The fan does work on the gas and as the gas is accelerated to the rear, the engine is accelerated in the opposite direction.

4.5.4 Lift

When an object controls the direction of flow of a fluid or when the fluid is directed to move by the object passing through it the lift is generated. When the elements, object and fluid move with respect to each other and the object influences the flow of fluid in a perpendicular direction to the fluid flow, the force required to do this work creates an equal and opposite force that is called lift. The generation of lift depends on factors such as speed of the airflow, density of the air, total area of the rotor blade and angle of attack between the air and the rotor blade. Lift always acts perpendicular to the resultant relative wind and it is produced when a mass of air is deflected.

On account of considerable variation in the flow conditions and the blade section along the span, it is divided into a number of infinitesimal sections of small, radial thickness. The flow through such a section is assumed to be independent of the flow through other elements. Velocities and blade forces for the flow through an elemental section are taken for analysis and considered flow mean velocity as $\omega$ and direction $\beta$ (from the axial direction).

The lift force $\Delta L$ is normal to the direction of mean flow and the drag force $\Delta D$ parallel to it. The axial ($\Delta F_x$) and tangential ($\Delta F_y$) forces acting on the element and ($\Delta F_R$) is the resultant force inclined at an angle $\phi$ to the lift direction.

Resolving the forces in the axial and tangential directions

$$\Delta F_x = \Delta L \sin \beta - \Delta D \cos \beta \quad \text{(1)}$$
$$\Delta F_y = \Delta L \cos \beta + \Delta D \sin \beta \quad \text{(2)}$$

By definition lift and drag forces from the below equations

$$\Delta L = \frac{1}{2} C_d \rho \omega^2 (1dr)$$
$$= \frac{1}{2} \times 0.4588 \times 1.225 \times 125.66^2 \times 0.194$$
\[ \Delta D = \frac{1}{2} C_d \rho \omega^2 (ldr) \]
\[ = \frac{1}{2} \times 0.335 \times 1.225 \times 125.66^2 \times 0.194 \]
\[ = 136.524 \text{N} \]

Where,
\[ \Delta F_x \text{ and } \Delta F_y = \text{Axial and Tangential force} \]
\[ \Delta L \text{ and } \Delta D = \text{lift and drag force} \]
\[ C_a = \text{lift coefficient} \]
\[ C_d = \text{drag coefficient} \]
\[ \rho = \text{density of the fluid} \]
\[ A = \text{reference area} \]
\[ \omega = \text{velocity of the undisturbed flow} \]

From these \( \Delta L \) and \( \Delta D \) values the \( \Delta F_x \) and \( \Delta F_y \) are calculated from the Eq (1) & (2) as:

The axial thrust \( \Delta F_x = 257.214 \text{N} \)

The torque force \( \Delta F_y = 1357.258 \text{N} \)

**Table 4. 2 Axial Thrust and Torque Forces at different radii of the blade**

<table>
<thead>
<tr>
<th>R (mm)</th>
<th>( \Delta L ) (N)</th>
<th>( \Delta D ) (N)</th>
<th>( \Delta F_x ) (N)</th>
<th>( \Delta F_y ) (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>1369.624</td>
<td>136.524</td>
<td>257.214</td>
<td>1357.258</td>
</tr>
<tr>
<td>400</td>
<td>1524.548</td>
<td>168.546</td>
<td>360.523</td>
<td>1538.241</td>
</tr>
<tr>
<td>300</td>
<td>1935.526</td>
<td>248.958</td>
<td>545.658</td>
<td>1852.567</td>
</tr>
<tr>
<td>200</td>
<td>2221.515</td>
<td>298.457</td>
<td>806.156</td>
<td>2157.856</td>
</tr>
</tbody>
</table>
At different radii of the rotor fan blade such as 500mm, 400mm, 300mm and 200mm lift, ΔL and drag force, ΔD were calculated. The values of axial force, ΔFx and tangential force, ΔFy from the Table 4.2 it could be concluded that for a decrease in radius of rotor fan blade, the magnitude of lift and drag forces increases.

4.6 Causes of Failures in Radiator Fan Blades

4.6.1 Improper heat treatment of the radiator fan blade

Proper heat treatment must be done after casting process i.e. precipitation hardening, so as to increase the strength of the material. The purpose of precipitation hardening is to increase strength and hardness of heat treatable aluminum alloys, and is achieved through a sequence of solution heat treatment, quenching and natural/artificial ageing. However, certain alloys, which are relatively insensitive to cooling rates during quenching, can be precipitation hardened either by air-cooling or by water quenching directly from the elevated temperature shaping process followed by a ageing treatment.

By conducting certain laboratory tests it is observed that heat treatment is not done properly and some defects such as

- Pin holes/porosities have been revealed (in clusters at the critical zones and in scattered pattern over other locations of the fan-blades)
- Notches/deep dents have been noticed at and nearby to the hub ends of the fan blades.

One can notice that the fractured faces reveal two distinct zones having dull and bright in nature. Fractured faces of the broken blade are completely crystalline in nature.

4.6.2 Pressure variations along the length of the blade

As the fan is rotating past the fluid (air), this fluid exerts some pressure variation along the cross-section of the blade, due to this pressure changes lift and drag forces will be created, these forces depends upon the design and operating conditions. For the radiator fan, lift force has to be minimum; otherwise it may lead to the breakage of the blade.
4.6.3 Other Sundry Causes

- The radiator fan of diesel locomotives is required to work in a very hazardous environment with increase of oil dust and rain. It can be exposed to the roadside dust or fiber of various organic materials that can be in the environment of the locomotive operation such as, calcium carbonate, silica sand, aluminum, carbon black, fiber of various organic materials, oil, locomotives brake shoe dust, etc.

- Failure may occur due to cracks generated with the impact of tools, machinery items like clamps, pipes etc. during engine overhauling.

Figure 4.4 Meshed model of Fan Blade

The analysis of the radiator fan is executed to different types of materials to check and evaluate the material and process conditions which withstand the dynamic and structural loads. The various loads and properties and applied through the entire length of the radiator fan. The analysis leads us to proposal of suitable material to withstand all the loads.