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Crack Detection Analysis of Steam Turbine Rotor Blade using NDT Technique

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Abstract: This paper presents study of Non Destructive Testing's for fracture analysis of the steam turbine rotor blade through mechanical analysis. The evaluation of dynamic characteristics of the blade is done by reviewing the literatures in order to identify the effective methods for detection of cracks. Turbine Blade attachment grooves and blade roots are highly stressed areas of steam turbine rotors. Serious failure can be obtained in complete turbo generator set due to an unknown crack in blade roots or blade attachments. It is strongly essential to extend the calculated life of turbo generator set since there is high demand of power energy worldwide. In case of highly stressed areas of generator rotors and turbine, the advanced NDT methods comes in demand due to extended operation cycle of turbine. Where the turbine blade roots as well as the turbine blade attachment grooves of a turbine rotor are comes in most critical range. Inspection of each blade root or blade attachment with individual design of turbine manufacturer requires separate NDT methods. In this paper the various aspects related to turbine blade crack failure such as highly stressed areas, internal flaws in steam turbine rotor blades and method to evaluate them with the help of Non Destructive Techniques are studied. This paper describes study of development of Phased Array Ultrasonic Testing (PAUT) methods and the qualification of the inspection techniques for selected application in steam turbine field-service.
Keywords: Cracks, Creep, Fatigue, Thermo-Mechanical Stress, Stress Concentration

I. INTRODUCTION

A steam turbine is a device that extracts thermal energy from pressurized steam and uses it to do mechanical work on a rotating output shaft. A turbine blade is the individual component which makes up the turbine section of a gas turbine or steam turbine. The blades are responsible for extracting energy from the high temperature, high pressure gas produced by the combustor. The turbine blades are often the limiting component of gas turbines. To survive in this difficult environment, turbine blades often use exotic materials like superalloys and many different methods of cooling that can be categorized as internal and external cooling, and thermal barrier coatings. Blade fatigue is a major source of failure in steam turbines and gas turbines. Fatigue is caused by the stress induced by vibration and resonance within the operating range of machinery. To protect blades from these high dynamic stresses, friction dampers are used.

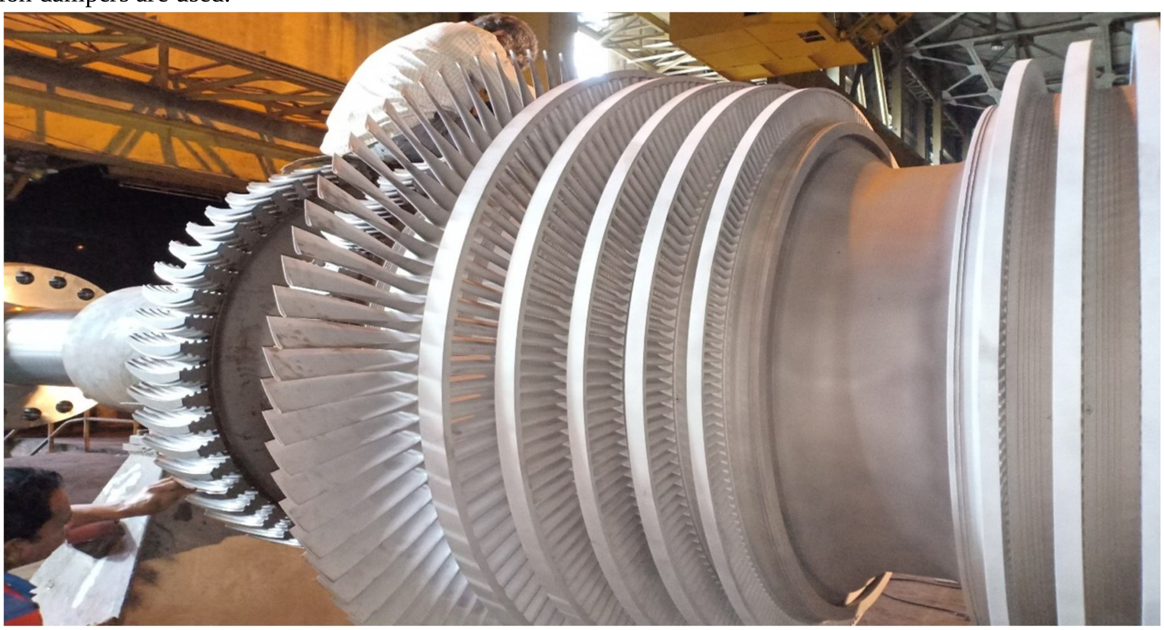

Fig. 1 Turbine

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A root attachment for a rotor blade of a steam turbine or gas turbine comprises teeth on the root section of the rotor blade and teeth on the slot of the rotor. The teeth flank surfaces of the teeth on the root section of the rotor blade are arranged at a different angle to the teeth flank surfaces of the teeth on the slot of the rotor. As the load on the rotor blade increases the teeth deflect such that the area of contact between the teeth flank surfaces of the root section and the slot increases to a maximum at the fully loaded condition. The teeth flank surfaces are substantially planar. A root attachment for a blade of a turbomachine, the attachment comprising a root on the blade which is arranged to engage within a shaped slot in a rotor, the root has a plurality of projections each one of which is arranged to engage against a corresponding projection in the slot.

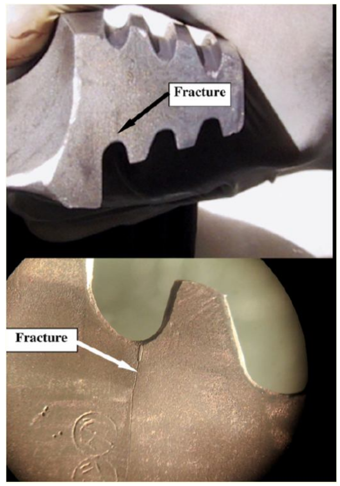

Fig. 2 Root attachment

Turbine blades have their axial dimension much greater than the cross-sectional dimensions. Further, the turbine blade is rigidly attached to a stiff rotor at the root. Crack failures continually occur in blades, which cause interruption of operation and increase costs, decrease product quality, and affect the safety. Fault detection for blades of rotating machinery at earlier stage can prevent it from breaking down and reduce maintenance time. Therefore, efficient and reliable fault diagnosis method is essential to predict the existence and state of the damage before the occurrence of crack failure. Significant efforts have been invested for developing different fault detection and diagnosis techniques for crack identification in rotating machinery.

In this rapidly expanding field, the state of the technology continues to advance. New solutions to troubling problems are emerging. In turbo machinery as blade failures can be the result of application of mechanical stresses there is a need for blade health monitoring systems.

II. TURBINE ROOT ATTACHMENT

Generally, the most of the thermal power plants turbine blades are mounted on the discs. There are various types of attachments which ensure that the blades are tightly fitted on the rotor disc. The attachments are such that it also allows the removal of blade from the rotor disc for further applications such as replacement of blade, repair of blade or for the maintenance of blade. The Straddle root attachment is most common in use. 3D model sketch shows a typical high pressure rotor of steam turbine with its disc in mounted condition that are solid with rotor. The dovetail type of grooves are provided for the attachment in which the turbine blade slides. The turbine blades are consisting of matching shape so that it provides a tight fit.

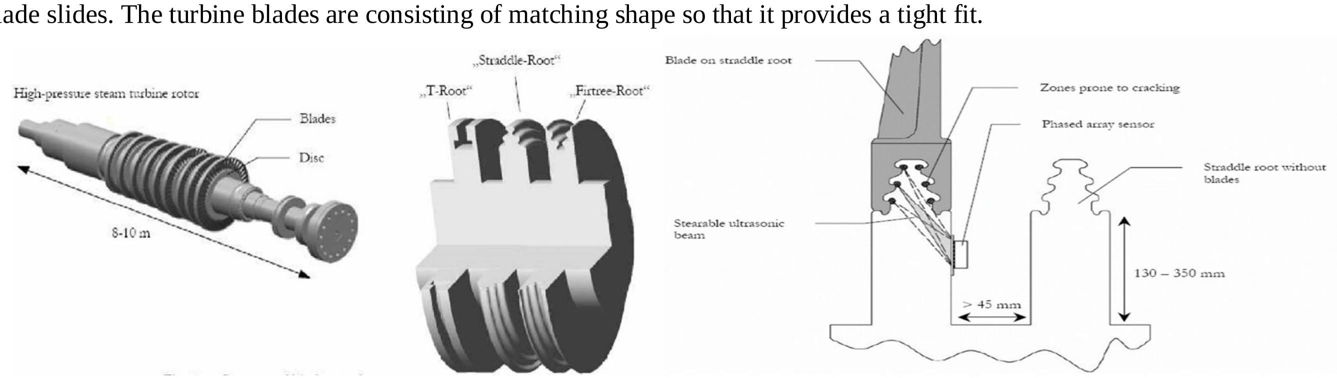

Fig. 3 Root attachment

The attachment of the turbine blades to the rotor is the most critical aspect of steam turbine design. All the forces are transmitted through the attachment to the rotor. Specially, at the low pressure end of turbines of large output, the attachment has to bear a relatively large forces due to high speed, the centrifugal force on the blade is many times its mass. Therefore, it becomes necessary to estimate the stresses in the attachment but sometimes it is difficult to get the exact value. There is always the possibility of stress concentration at the sharp corners. Therefore, selection of material is very important which can safeguard from this stress concentration and that is why the calculated stress is kept reasonably low. A careful study of the forms of attachment is also necessary because occasionally it influences the shape of the wheel, rim and stresses in the disc. The form of the attachment should be such that the centrifugal force on the blade is transmitted to the disc in the simplest and most direct manner and it should give the security of attachment.

The various forms are:

1) De-Laval Blade root attachment
2) Inverted-T attachment
3) Serrated blade root arrangement (Annular fir-tree)
4) Attachment for high pressure Crutis wheel
5) Straddle attachment
6) Modified straddle attachment
7) Side entry blades attachment
8) Shrouding strip attachment
9) Parson's end tightened blading
10) Parson's integral blades
11) Multi Fork/Finger attachment

Annular fir-tree or its modified versions are most commonly used in turbine.

Fig. 4 Multi Fork / Finger type root attachment

Fig. 5 Straddle type root attachment

III.FINITE ELEMENT ANALYSIS (FEA)

A. Fundamentals of the Finite Element Method

The fundamental concept of the finite element method is that a physical domain is discretised into a small number of sub domains, known as elements, over which a continuous field variable such as velocity, stress, pressure, or temperature can be approximated. These elements are connected at specific points known as nodes or nodal points. Since the actual variation of the field variable is not known inside the domain, approximating functions are needed to describe this variation. These approximating functions interpolate the values of the field variable at the nodal points of each element. Since the geometric and the required material properties of each element are known, suitable field equations such as equilibrium or heat balance can be written for each element. Using the principal of minimum potential energy of each unit, the elemental Stiffness matrix can be obtained for each element.

B. Description of the Problem

The Steam Turbines of Thermal Power Plants are one of the fast rotating assemblies. Which consists of a Shaft, Disc, Rim and Blades. Where blades are directly mounted on the shaft or on the disc which is mounted on shaft. These mounting of Turbine blade is done with the help of root attachment. As the whole assembly rotates at high speed, it is subjected to rotating forces such as centrifugal force which results in development of rotational stresses in steam turbine rotor blade. The distribution of stresses around the regions of high stress concentration such as root attachment regions of the blade is sources of great concern to the designer. The high stresses due to geometry and loading become particularly severe when fretting at the contact surfaces is experienced by the assembly. Indeed, it has been found that fatigue cracks tend to initiate in regions of combined high stress and cumulative fretting damage.

C. Three Dimensional Modelling of Turbine Blade and Finite Element Analysis

The Straddle type of root attachment geometry is adopted for the 3D Modelling. In this study the 3D model is prepared using software PTC Creo Parametric 3.0 and imported in Simcentre 11 with NX Nastran solver package for the further results. Finite Element Analysis were carried out on Turbine blade and Turbine Shaft Assembly. The material properties used for the modelling of the turbine blade and turbine shaft assembly were that of a typical Steel. Where the Geometrical and Material properties of turbine blade is given in below table.

TABLE I
GEOMETRICAL AND MATERIAL PROPERTIES OF TURBINE BLADE

Sr. No.	Property	Value	Unit
1	Turbine blade total surface area	75171.4096	mm^2
2	Turbine blade root area	6949.7982	mm^2
3	Mass Density	7.829 x 10^{-6}	$\frac{kg}{mm^3}$
4	Young's Modulus	206940000	$\frac{mN}{mm^2}$ (kpa)
5	Poisson's Ratio	0.288	
6	Yield Strength	137895	$\frac{mN}{mm^2}$ (kpa)
7	Tensile Strength	276000	$\frac{mN}{mm^2}$ (kpa)
8	Thermal Expansion Coefficient	1.128 x 10^{-5}	/℃
9	Thermal Conductivity	55700	$\frac{micro\ W}{mm℃}$
10	Specific Heat	434000000	$\frac{micro\ J}{kg\,k}$

TABLE III
MESHING

1	Mesh Type	3D Mesh
2	No. of element in mesh	51509
3	No. of nodes in mesh	88093
4	Tetra 10 elements	51509
5	Element type	CTETRA 10
6	Element size	3.5 mm

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D. Result

Stress Analysis is done for the Straddle type root attachment and distribution is analyzed for three different rotational loads i.e. 5000 rpm 10000 rpm and 15000 rpm. The following contour plots explain the stress distribution.

1) In figure 6 the Finite Element Analysis of Turbine blade analysed and explains the stress distribution in turbine blade 5000 rpm rotational load applied.
2) In figure 7 the Finite Element Analysis of Turbine blade analysed and explains the stress distribution in turbine blade 10000 rpm rotational load applied.
3) In figure 8 the Finite Element Analysis of Turbine blade analysed and explains the stress distribution in turbine blade 15000 rpm rotational load applied.

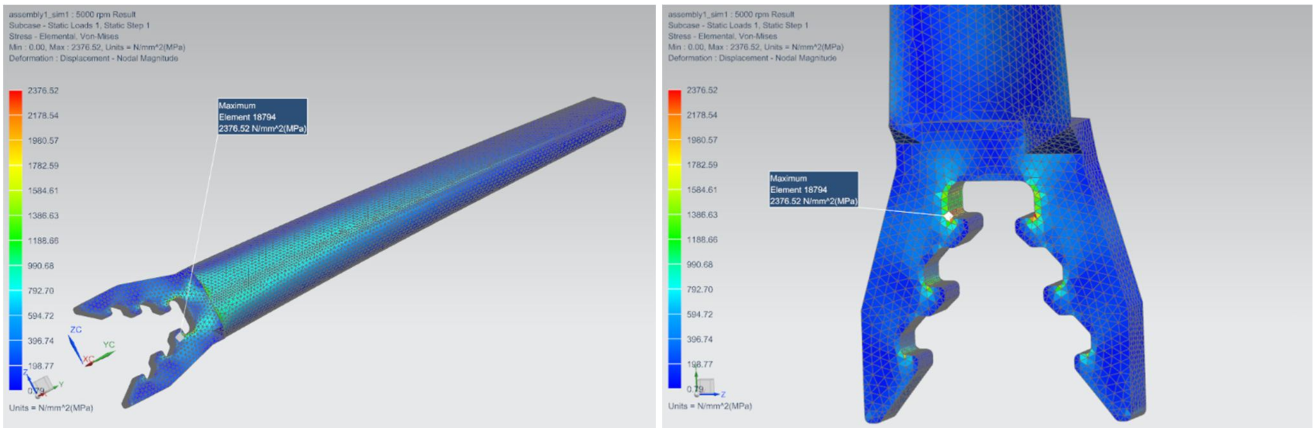

Fig. 6 Stress distribution of Turbine blade at 5000 rpm = 2376.52 Mpa

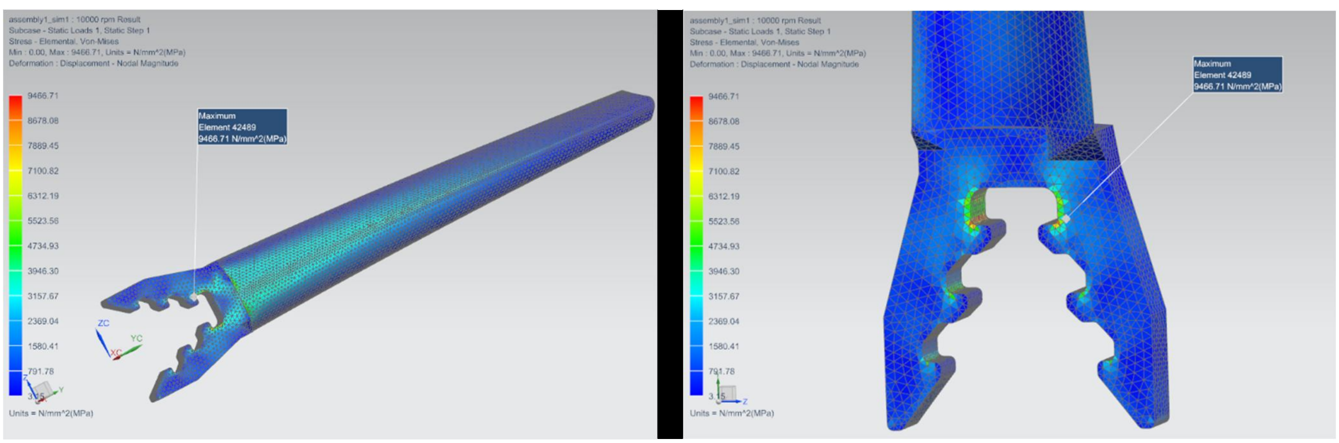

Fig. 7 Stress distribution of Turbine blade at 10000 rpm = 9466.71 Mpa

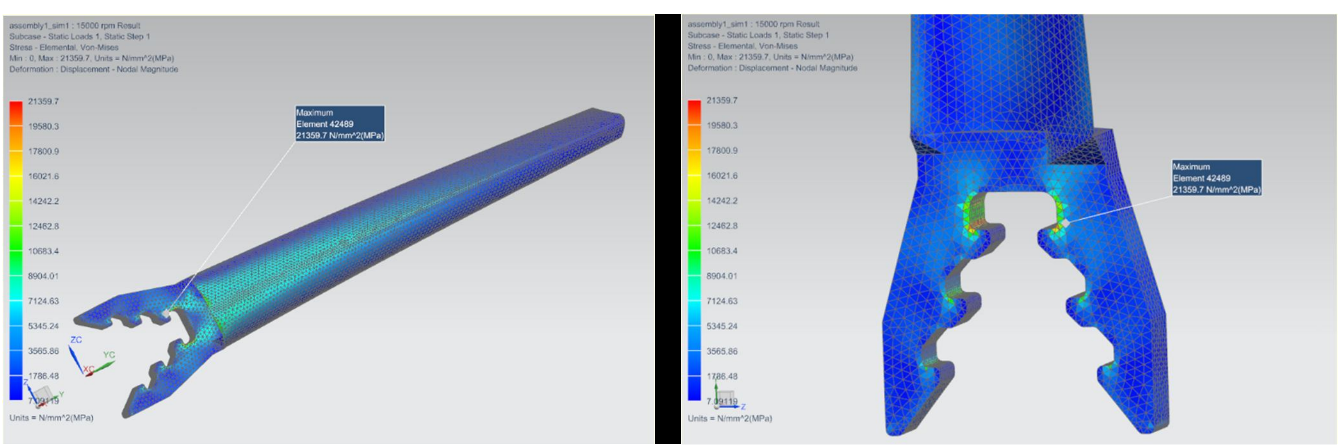

Fig. 8 Stress distribution of Turbine blade at 15000 rpm =21359.7 Mpa

IV. PHASED ARRAY ULTRASONIC TESTING (PAUT)

The Turbine blade and blade root attachments are subjected to highly stressed components of turbine. Where the blades are designed and calculated using most advanced methods in order to allow them to accommodate these high loads. Most specifically during transient loading condition the root attachments are subjected to high stresses.

Sometimes some unusual conditions occur during some unfavorable conditions such as loss of vacuum, over speed can result in blade damage at highly stressed areas of blade root attachment with possible crack initiation. In addition to that impurity of steam or low quality of steam subjected to blade to corrosion. Which cause the corrosion fatigue at blade, blade root attachment, highly stressed areas.

Development of advanced Ultrasonic Test Inspection technique is necessary to detect the cracks at Turbine blade root attachment. So that all condition has to be taken into consideration. For that, some facts have to be taken into account such as accessibility of UT inspection, orientation of the cracks, Location of the cracks.

After some theoretical study it was concluded that the Phased Array Ultrasonic Test (PAUT) Inspection is best suited for this application. Phased Array Ultrasonic Inspection offers a reliable inspection without dismantling the parts for inspection. The use Liner phased array probe provides good accessibility. The main reason of Phased Array Ultrasonic Test inspection is that it fires the ultrasonic beam at various angles at a time so that it becomes very easy to detect the cracks which has different orientations. The Productivity of Phased Array scan is very large since it covers the wide range of volume from single point.

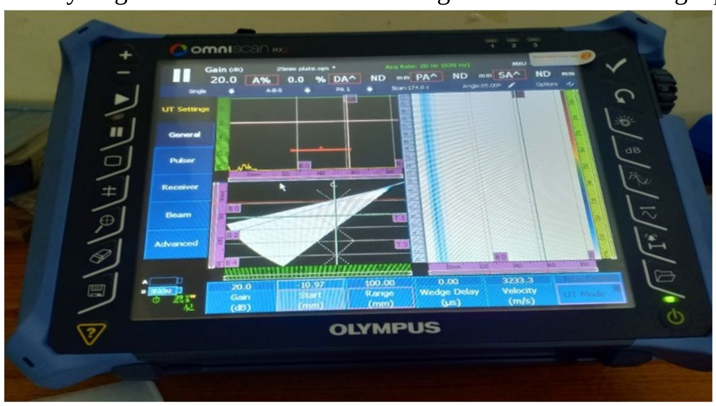

Fig. 9 PAUT Olumpus Omniscan MX2 Machine Display

The figure 9 shows the pictorial view of display of Phased Array Ultrasonic Test (PAUT) Machine Display. In which the various types of scans are shown. Whereas A scan shows the amplitude of echo at various ranges which is also called as distance amplitude curve, B scan creates side view, C scan creates top view and S scan creates Sectorial view. The Sectorial scan has an ability to scan large sector of volume without any movement of probe which allows user to scan complex geometries very easily.

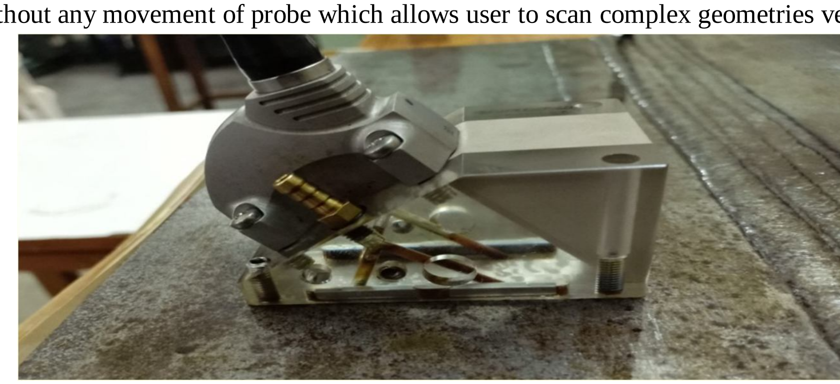

Fig. 10 PAUT Probe with Wedge

The figure 10 shows one of the Phased array probe. The Phased array probes are available in different geometries with different properties which is used for various kind of applications. A Phased array probe is a long conventional probe which consists of numbers of elements within it which is excited individually to generate the signals. It is like combination of multiple conventional probes in a single probe which excited individually. This composite technology of phased array probe gives the greater signal to noise ratio as compared to piezoelectric probes.

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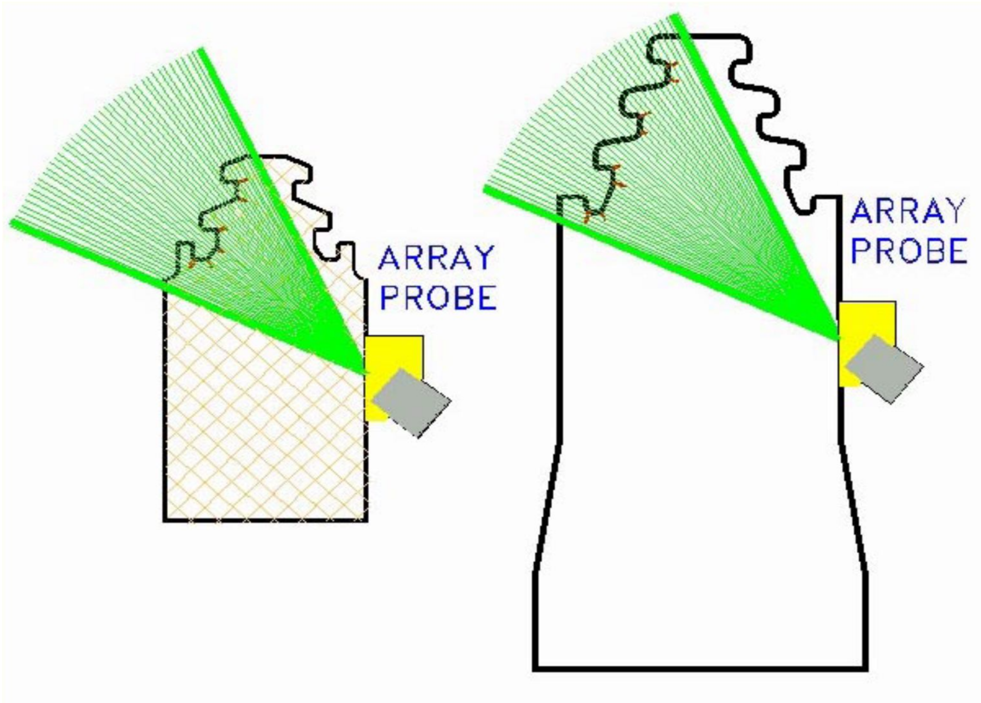

Fig. 11 Schematic view of Root attachment geometry and inspection technique

The objective of the PAUT inspection from the blade surface is to detect the various types of cracks such as thermal fatigue crack, cracks due to high stress in turbine blade root attachment. The main objective was to develop an effective PAUT inspection technique which can guaranty the detection of all possible cracks and its location in blade root attachment.

It is a fact that during inspection the geometry of the blade root attachment is not always well known. Therefor it is also essential that the ultrasonic technique should provide the blade root attachment geometry information. The probe position can be studied by use of different simulation software's which can also provide the possible interferences and inspected volume information. So that the guaranteed crack detection with accuracy can done.

Selection of accurate probe is very essential in order to meet the all requirements. The coupling of the inspection surface and probe is done with the help of wedge. The probe should be able to produce different transversal waves in order to ensure the detection of cracks. The range of these waves should be from 25 degree to 65 degree with the increment of 1 degree. In this way we can obtain the valuable information by covering large amount of volume at a time.

The main advantages of PAUT inspection technique is that it replace the destructive testing method to the non-destructive testing method. And hence the time required for the inspection is reduced as well as the 100% inspection of blade root attachment is possible. If it is possible to repair the blade then it gives the exact location of defect so that the unnecessary removal or extraction blades can be avoid. Significantly the maintenance cost is also reduced.

V. CONCLUSION

In this study the finite element analysis (FEA) concluded that the areas subjected to most stressed is located at the mating surfaces of blade root attachment. As the rotation increases the von-misses stress value also increases at root attachments. So that inspection of root attachments is very essential to avoid the failure of component at premature stage of defect.

The application of phase array ultrasonic testing inspection is better suited than any other method as it provides faster scanning, the single probe can work at different depths also the angle of incidence can vary with single probe.

VI. ACKNOWLEDGMENT

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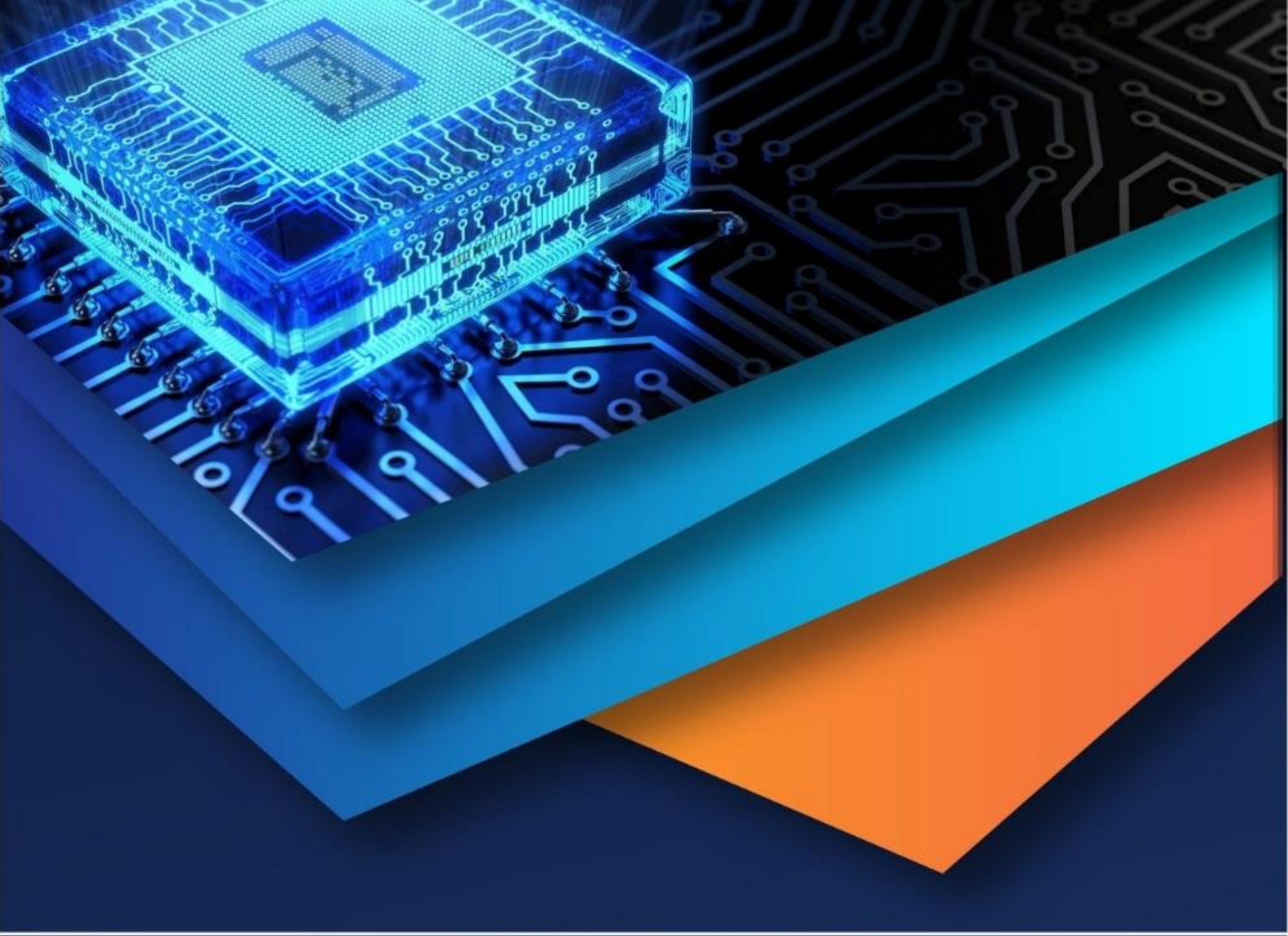

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