Fatigue Failure Analysis of Twisted Blade

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ABSTRACT: *Usually turbine blades fail due to the various forces acting on the blade during operation in which centrifugal forces is important. The effect of centrifugal forces on the turbine blade is very important in the evaluation of life of the blade. In turbine blades due to the large centrifugal forces the blades susceptible to high cycle fatigue frequently. Sometimes the failure of the turbine blade is eliminated by the design. This can be achieved by twisting the turbine blades and the blade's cross section varies throughout the length of the blade. The root position of the blade is the region of interest because the stress concentration is high at the root of the blade. Here the failure analysis is done by creating the notches on the leading edge of the blade. In this paper the effect of the notches on the twisted blade is presented. Here the notches are created at the leading edge at different distances from the root of the blade. At the same time the size of the notches are also varied. Fatigue analysis is done for the notched twisted rotating blade, alternating stress, stress intensity, strain energy and life of the blade is found.*

Keywords *- High cycle fatigue, twisted blade, FEA, Centrifugal force, Angle of attack.*

I. INTRODUCTION

The purpose of turbine technology are to extract the maximum quantity of energy from the working fluid to convert it into useful work with maximum efficiency by means of a plant having maximum reliability, minimum cost, minimum supervision and minimum starting time. The gas turbine obtains its power by utilizing the energy of burnt gases and the air which is at high temperature and pressure by expanding through the several rings of fixed and moving blades [1].The major function of the turbine is to extract energy from the hot gas flow to drive the compressor and the accessory gearbox. Gas turbine blades work mostly at high temperature gradients and are subjected to high rotational velocity. High speed results in large centrifugal forces in blade and simultaneous high temperature reduces disc material strength. The service life of critical aerospace components is governed by the modes of degradation and failure such as: fatigue, fracture, yielding, creep, corrosion, erosion, wear, etc. In that fatigue is the main cause for turbine blade failure. Metals when subjected to repeated cyclic load exhibit damage by fatigue. The magnitude of stress in each cycle is not sufficient to cause failure with a single cycle [2]. Large number of cycles is therefore needed for failure by fatigue. Fatigue can be classified in to low cycle fatigue and high cycle fatigue. The main cause of turbine blade failure is high cycle fatigue. Fatigue failure is related to repeated cycling of the load on a structural member. The fatigue life of a structural member i.e. the number of load cycles it can survive is in general determined by the magnitude of the stress cycles. The exact relation between the magnitudes of the stress and the fatigue life depends on the material properties of the structural member. In general higher stresses lead to a shorter fatigue life. For some materials fatigue only occurs if stresses exceed a certain minimum level for other materials there is no minimal stress level. If the stresses that are present on the turbine blade during operation and the material properties of the turbine blade are known then an estimation of the fatigue life of the turbine blade can be made [3]. Superalloys constitute a large fraction of the materials of construction in turbine engines because of their unique combination of physical and mechanical properties. In aircraft engines, it is typical to consider density-normalized properties; thus alloy densities, which are typically in the range of 7.7–9.0 g/cm3, are of specific interest. Optimization of the relevant set of mechanical properties is of paramount importance and is dependent on a high level of control and understanding of the processes of manufacturing, because mechanical properties are a strong function of microstructure. Mechanical properties of primary interest include tensile properties, creep, fatigue, and cyclic crack growth. Depending on the details of component design, any one of these four properties may be life limiting. The super alloys are having relatively high tensile and ultimate stresses [4], [5]. The difficulties in evaluating the stress and deformations of rotating blades comes from the complex geometry of blades due to asymmetry of cross-section, pre-twist, and mounting the blades at a skew angle to the rotating disk. The pre-twist and skew of the blade cause coupling in both bending directions, and the asymmetry of the cross section causes coupling with the tensional motion of the blade [6]. In compressor and turbine airfoils, a proper camber is considered in design with the intent of having pressure and suction side. This factor increases radius of gyration and also rotary inertia and shear deformation [7].

II. METHEDOLOGY

Analysis of engineering problem is very important in reducing the design time and maintaining the more safety in operation. There are many methods by which we can analyze, in that numerical methods are effective in analysis. In that finite element analysis is used for the analysis of the twisted turbine blade. In this the element is broken down into many simple elements. The behavior of an individual element is studied. This method is one of the most practical ways for analyzing structures with a large number of degrees of freedom. To get a more accurate result from FEM, it is recommended to use some software in order to carry out the numerical computation part. A turbine blade is essentially a rotating wing. Because this wing is rotating, the velocity along the span of the wing will not be constant. Specifically, it will increase from 0 at the hub to the angular velocity times the length of the blade at the very tip. The model of the twisted blade is made using the CAD software. The inertia force plays an important role in predicting the life of the turbine blade. Since the cross section of the blade varies throughout the blade from the root to the tip the moment of inertia also varies. Here the blade considered is twisted because the relative speed differences between the tip and root of the blade, to produce an even amount of thrust/compression across the face of the disc, requires a small angle of attack. By using the twisted blade drag is less and more energy can be converted in to work. At the same time the twist angle must not be too high. The blade is meshed and analysis is carried to find the life of the blade. The blade is as shown in fig below. The effect of notch on the life of the blade is studied by considering the notches of different size and its position from the root of the blade along the leading edge of the blade.

Fig 1: Twisted turbine blade with and without notch.

III. RESULTS AND DISCUSION

Here we have taken the real turbine blade model for the fatigue failure analysis. The blade taken is twisted type. Here the life of the blade is estimated by introducing the semicircular and U-Notch at the leading edge of the blade. The size of the notches are of radius 2 mm, 4 mm, 6 mm, 9 mm, 12 mm and at a distance of 20 mm, 40 mm, 60 mm, and 80 mm from the root of the blade. The semicircular notches are considered when the damage is small and when the damage size is large it can be considered as the U- Notches. The U-notches are analyzed for a depth b=1 and b= 2 mm with the radius mentioned above. Blade model is made and analyzed by using the ansys. The finite element analysis of the turbine blade subjected to rotation of 15000 rpm is analyzed to study the effect of twist in the blade on fatigue life with damage at the leading edge.

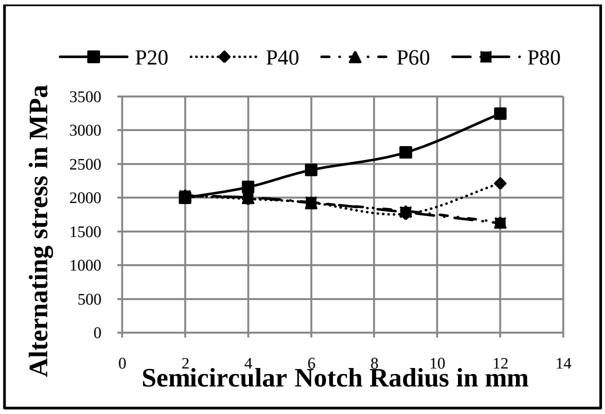

Fig 2: Alternating Stress for the Variation of Semicircular Notch in mm and Positions from the Root of the Blade along the Leading Edge.

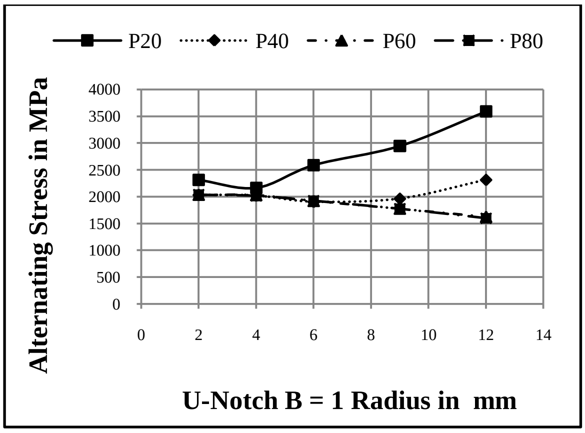

Fig 3: Alternating Stress for the Variation of U-Notch with B = 1mm and Positions from the Root of the Blade along the Leading Edge.

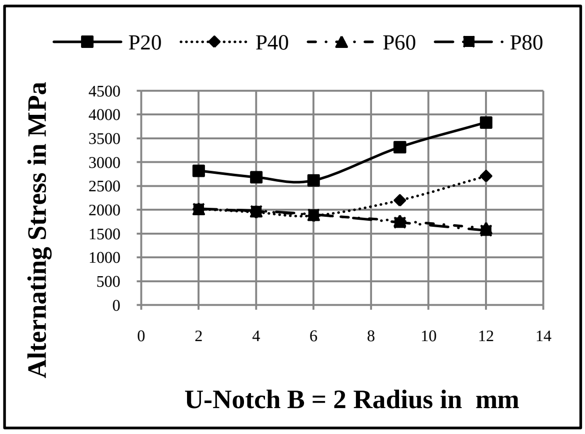

Fig 4: Alternating Stress for the Variation of U-Notch with B = 2mm and Positions from the Root of the Blade along the Leading Edge.

From the results shown in the Fig 2, Fig 3 and Fig 4 it can be observed that the stresses will be maximum at the root of the blade. As the radius of the notch increases at the root the stress also increase and this information is important in deciding the life of the turbine blade. When the position of the notch is varies the stress also varies. It can be seen from the fig that as the position of the notch moves towards tip of the blade the stress is less and the life is more. When the notch is present at the tip or near the tip of the blade it can be neglected. Since here the blade is twisted so that the stress will be concentrated over the leading edge of the blade when the notch on the leading edge it release stress and help in increasing the life of the blade.Due to which it can be seen that the stress is high for the notch radius of 12 mm at the position of 40 mm from the root of the blade When the notch size is large it is taken as the U-notch. In U- notch also the stress increase as the notch size increases but when the position of the notch is at the middle of the blade the stress decreases partially this is due the effect of twist in the blade.

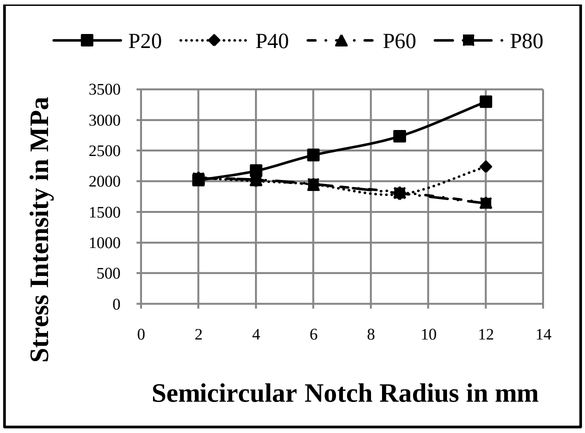

Fig 5: Variation of Stress Intensity with Semicircular Notch Radius for Different Position from Root of the Blade.

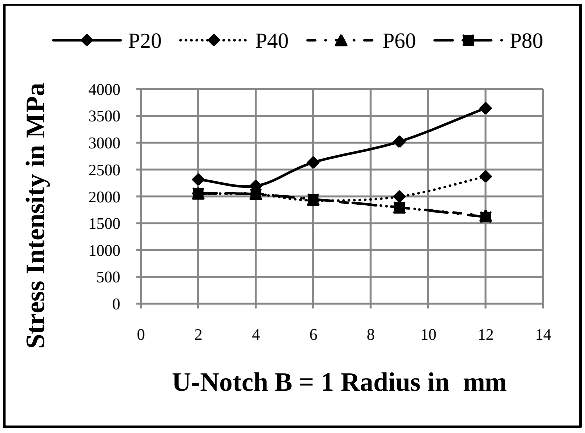

Fig 6: Variation of Stress Intensity with U - Notch B = 1 for Different Position from Root of the Blade.

Here in Fig 5, 6 and 7 the notches are considered at the leading edge of the turbine blade stress intensity plays an important role. Here the stress intensity increases as the notch radius increases and also the stress intensity is high when the notch is present at the root of the blade. Stress intensity is high in U-notch compared to the semicircular notch. In semicircular notches the intensity goes on increasing as the notch radius increases but for U-notches the intensity decreases initially and then increases. When the notch is present at the tip or near the tip the stress intensity decreases. When the notch is present at the middle portion of the blade the stress intensity increases due to twist of the blade. By knowing the notch size and its position on the turbine blade it is easy to decide whether it can be used or not.

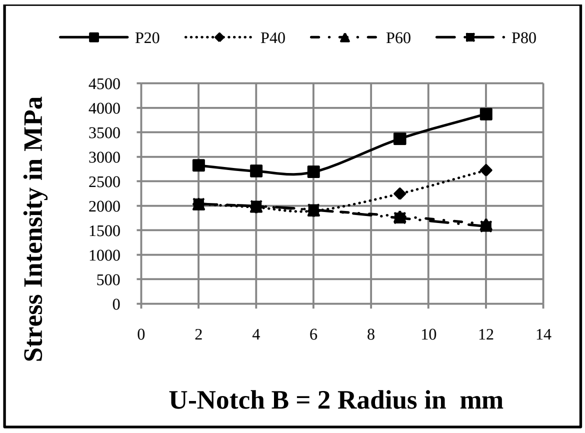

Fig 7: Variation of Stress Intensity with U - Notch B = 2 for Different Position from Root of the Blade.

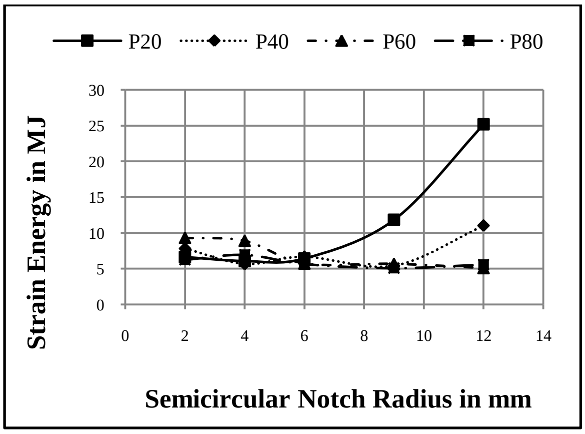

Fig 8: Variation of Strain Energy with Semicircular Notch Radius for Different Position from Root of the Blade.

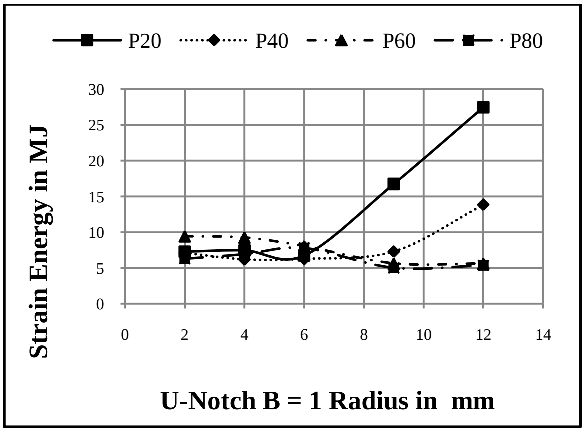

Fig 9: Variation of Strain Energy with U-Notch Radius B = 1 for Different Position from Root of the Blade.

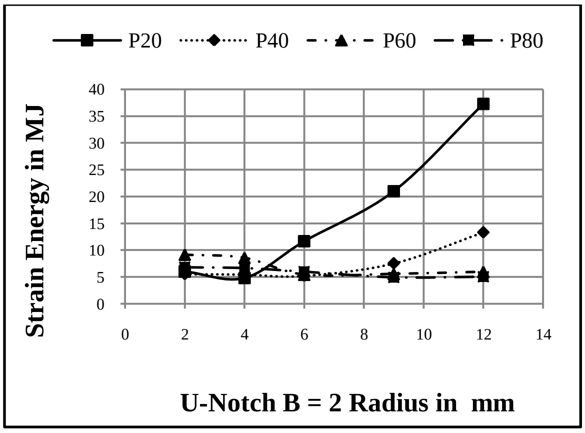

Fig 10: Variation of Strain Energy with U-Notch Radius B = 2 for Different Position from Root of the Blade.

Strain energy is very important in predicting the life of the blade. As it can be seen in Fig 8, 9 and 10in semicircular notch the strain energy nearly constant up to certain notch radius and then increases as the notch radius increases. Strain energy is high in U-notch compared to the semicircular notch. When the notch position is away from the root of the blade the strain energy increase at the beginning and later decreases as the notch size increase. Since the blade is having the twist the strain energy is increase at the middle portion of the blade and then decreases as the notch radius increases.

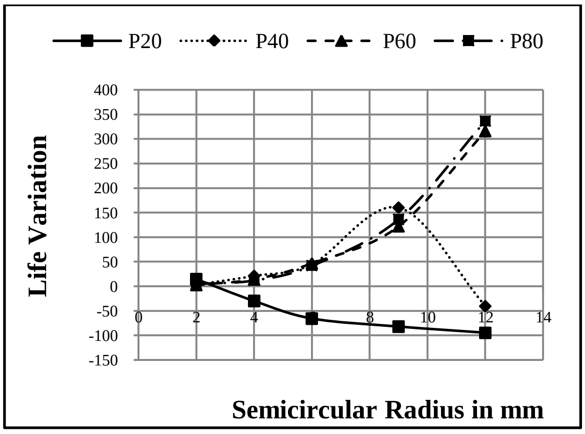

Fig 11: Variation of Percentage Error of Life with Semicircular Notch Radius for Different Position from Root of the Blade.

Life variation is very important in predicting the life of the blade. In Fig 11, 12 and 13 life of the blade without notch is compared with the notched blade. From the figures it can be seen that when the notch is present at the root or near the root of the blade the life of the blade is less. Here itcan be seenthat when the notch is small the life of the blade is slightly high as the notch size increases the life decreases.

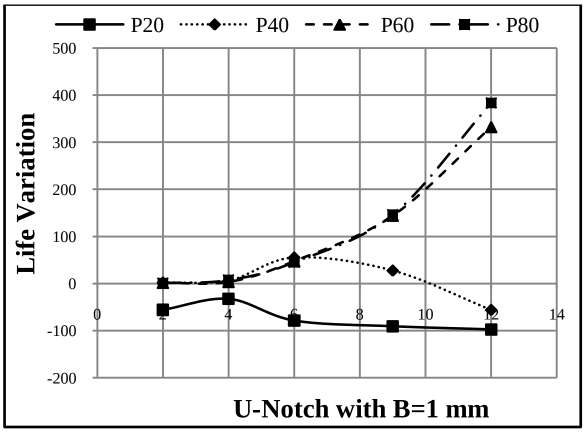

Fig 12: Variation of Percentage Error of Life with U- Notch Radius B = 1 for Different Position from Root of the Blade.

For the notch size of 12 mm the life of the blade is small it can be seen from the fig clearly. When the notch position is at the middle of the blade the life decreases because of the twist present in the blade. It can be seen from the fig that life of the blade increases as the notch size increases up to particular notch size after that as the notch size increases the life decreases drastically this behavior is due to the twist present in the blade. When the notch is present at the tip of the blade the life of the blade increases since it will not affect the operation of the blade considerably.

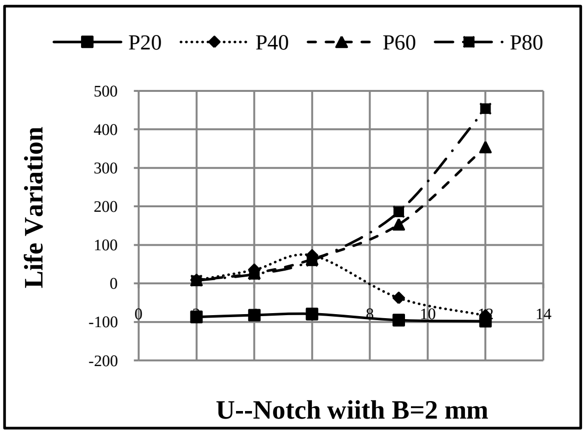

Fig 13: Variation of Percentage Error of Life with U- Notch Radius B = 2 for Different Position from Root of the Blade.

Similarly when the notch depth is large it can be considered as the U-notch with b=1 and b= 2 depending on the depth of notch. Here also the life decreases when the notch is present at the root and the life decreases as the notch size increases. At the middle position the life remains constant up to particular notch size then increases upon increasing the notch size life of the blade decrease. When the notch is present at the tip or near the tip of the blade the life increases.

CONCLUSION

In this study the twisted blade is modeled and investigated the fatigue life by considering damage at the leading edge of the blade. When the damage is present at the root of the blade the stress is increases when the notch size is large the stress is also high. Since the stress is high at the root for the larger notch size the life of the blade is less. When the notch is present at the middle portion of the blade the stress decreases when the notch size is large the stress increases. Since here the blade is twisted so that the stress will be concentrated over the leading edge of the blade when the notch on the leading edge it release stress and help in increasing the life of the blade. So the life is high for the twisted blade. The stress concentration is high at the region of twist so the life of the blade is less. When the notch is considered at the twisting region the life increases since the stress is released at the region.

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