

Determining Hysteresis Damping in a Steam Turbine Blade using a Finite Element Tool

A.S.N. Saiteja, C. H. Pavan Kumar

Abstract: Damping is a phenomenon by which mechanical energy is dissipated, usually converted as a thermal energy in dynamic systems. The damping caused by friction between the internal planes that slip or slide as the material deforms is called hysteresis damping or material damping. This paper deals with determining hysteresis damping of a typical turbine blade. The damping is quantified as a function of strain amplitude. ANSYS and Hyper Mesh are adopted for necessary calculations. First the natural frequencies and orthonormal mode shapes are obtained at the desired speed. Lazan’s damping law is used to determine the specific damping energy in each element of the blade. Total damping energy and strain energy are calculated by integrating them over the entire volume. With the help of these the loss factor is obtained. From the loss factor, the equivalent viscous damping ratio is determined. Procedure for one mode shape is shown.

Keywords: Damping, Hysteresis, Lazan’s Law, Mode Shapes.

I. INTRODUCTION

A turbine blade is the individual component which makes up the turbine section of a gas 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 super alloys and many different methods of cooling, such as internal air channels, boundary layer cooling, and thermal barrier coatings.

A. Turbine Blade Failure:

Turbine blades are subjected to very strenuous environments inside a gas turbine. They face high temperatures, high stresses, and a potentially high vibration environment. All three of these factors can lead to blade failures, which can destroy the engine, and turbine blades are carefully designed to resist those conditions.

Turbine blades are subjected to stress from centrifugal force (turbine stages can rotate at tens of thousands of revolutions per minute (RPM)) and fluid forces that can cause fracture, yielding, or creep failures. Additionally, the first stage (the stage directly following the combustor) of a modern turbine faces temperatures around 2,500 °F (1,370 °C) up from temperatures around 1,500°F (820 °C) in early gas turbines. Modern military jet engines, like the Snecma M88, can see turbine temperatures of 2,900 °F (1,590 °C).

Those high temperatures weaken the blades and make them more susceptible to creep failures. The high

temperatures can also make the blades susceptible to corrosion failures. Finally, vibrations from the engine and the turbine itself (see blade pass frequency) can cause fatigue failures.

B. Factors Associated with Turbine Blade Failure:

1. Resonance occurs at Blade Critical Speeds.
2. Large dynamic stresses at resonance coupled with mean stresses cause damage.
3. Surface damage produces blades/nozzles dimensional changes which result in operational stress increase and turbine efficiency deterioration.
4. Damping limits the dynamic stresses. It is important to estimate damping accurately to limit this stress.

II. DAMPING & ITS TYPES

A. Damping:

1. In Physics, Damping is an effect that reduces the amplitude of oscillations in an oscillatory system, particularly the harmonic oscillator. This effect is linearly related to the velocity of the oscillations. This restriction leads to a linear differential equation of motion, and a simple analytic solution.

$$F_c = -c \frac{dx}{dt} \dots \dots \dots (1)$$

2. The mechanism by which the vibration energy is gradually converted into heat or sound is called as damping. Although the amount of energy converted into heat or sound is relatively small, the consideration of damping becomes important for an accurate prediction of vibration response of a system.
3. A damper is assumed to have neither elasticity nor mass, and damping force exists only if there is relative force between the two ends of the damper. It is difficult to determine causes of damping in practical systems. Hence damping is modeled as one or more of following types:

B. Types of Damping:

1. Viscous Damping
2. Coulomb Damping
3. Material or Hysteresis Damping

III. HYSTERESIS DAMPING

The stress–strain diagram for a typical linearly elastic material is shown in figure below. Ideally, if the material is stressed below its yield point and then unloaded, the stress-strain curve for the unloading follows the same curve for the loading. However, in a real engineering material, internal planes slide relative to one another and molecular bonds are broken, causing conversion of strain energy into thermal energy and causing the process to be irreversible. A more realistic stress-strain curve for the loading-unloading process is shown in figure below.

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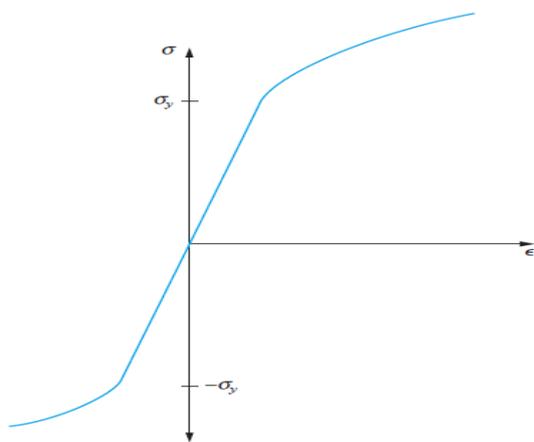


Fig1. Hysteresis Loop

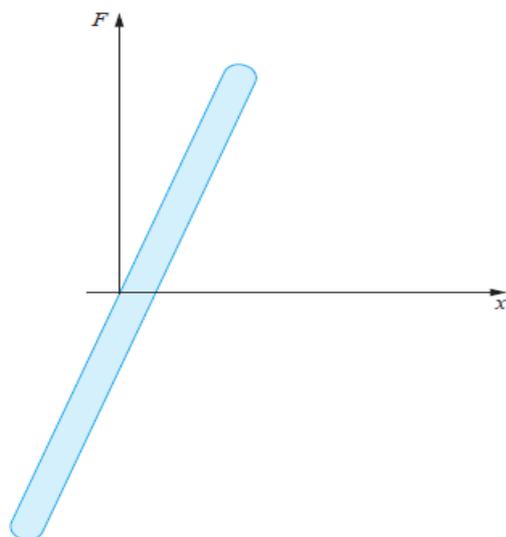


Fig2. Realistic stress strain Loop

The area enclosed by the hysteresis loop from a force–displacement curve is the total strain energy dissipated during a loading–unloading cycle. In general, the area under a hysteresis curve is independent of the rate of the loading–unloading cycle. In a vibrating mechanical system an elastic member undergoes a cyclic load-displacement relationship as shown in above figure. The loading is repeated over each cycle. The existence of the hysteresis loop leads to energy dissipation from the system during each cycle, which causes natural damping, called *hysteretic damping*. It has been shown experimentally that the energy dissipated per cycle of motion is independent of the frequency and proportional to the square of the amplitude.

The area under the above loop gives the amount of energy lost or dissipated in the form of heat or sound in the vibrating system for one cycle of vibration. Hysteresis damping is called as material damping or solid damping. The hysteretic damping coefficient cannot be simply specified for a given material. It is dependent upon other considerations such as how the material is prepared and the geometry of the structure under consideration. Existing data cannot be extended to apply to every situation.

IV. PROBLEM DESCRIPTION

1. To model the blade as per dimensions in CATIA V5 R16.
2. To conduct modal analysis on the blade in ANSYS.

3. Determine the Mode Shape (Ortho normal) at the desired speed ie 200rpm from ANSYS.
4. To estimate the equivalent viscous damping in a gas turbine blade for an ortho normal mode of vibration and at a given rotational speed (200 RPM) using ANSYS and Lazan’s damping law.
5. Estimate Specific Damping Energy in each element and integrate to get total Damping Energy using Lazan’s law.
6. Determining Loss Factor.
7. Obtain Equivalent Viscous Damping.
8. Determining damping ratio.
9. Obtaining relation between equivalent viscous damping and strain.

V.LAZAN’S LAW

There will be a lot of energy dissipation in the blade while vibrating due to the damping. Now this energy lost must be related to a function of the vibration. The damping has a great influence in this energy lost. Due to this energy loss there will be failures in the system which will ruin the process to be performed using this system, in this case turbine blade. Therefore for a Good Blade design, we should consider interfacial friction and material damping. Here we are dealing with the material damping. As we have mentioned earlier, we have to relate the hysteresis damping with the strain amplitude in order to do that we have to use ANSYS and some theoretical calculations to calculate the loss factor and damping ratio and strain energies using lazan’s law.

This law turns out to be the main concept behind this project. According to this law, the specific damping energy is directly proportional to the stress applied on it and inversely proportional to the fatigue strength. The above statement can be given by the below equation

$$D = J \left(\frac{\sigma}{\sigma_E} \right)^n \dots \dots \dots (2)$$

Where:

J=16

n=2.3

D= Specific Damping Energy Kn-m/m³/cycle

Using Lazan’s law above and the material properties, the coefficient *J* and exponent *n*, the specific damping energy, total damping energy and the total strain energy are calculated by integrating over the entire volume. The strain amplitude at a reference point near the root of the blade is monitored throughout the analysis. The loss factor, ratio of total damping energy and total strain energy is obtained. It is then converted to equivalent viscous damping for the strain amplitude considered at the reference point.

The mode shape is then modified to have different values of strain amplitude at the reference point and the specific damping energy, total damping energy and the total strain energy are correspondingly updated. Thus, the equivalent viscous damping is determined as a function of strain amplitude at the reference point for the given mode and speed. The same procedure can be applied to obtain the equivalent viscous damping values for other modes at the same speed. Here, only one mode is considered to illustrate the procedure. The steps in calculation are illustrated below for 200 RPM.



VI. DESCRIPTION OF MODEL

The dimensions of the blade considered for analysis is assumed to have following characteristics:

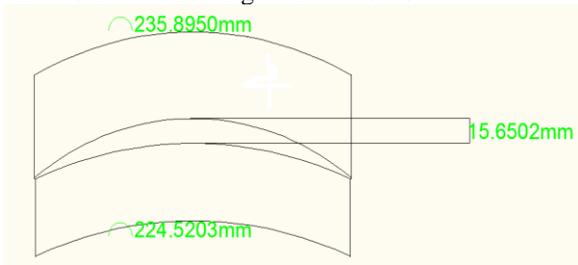


Fig3. Dimensions at the middle of Blade

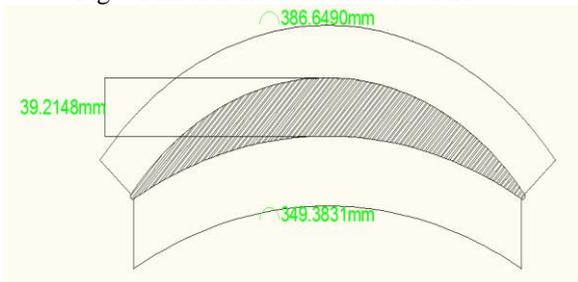


Fig4. Dimensions at the bottom of Blade

A. Turbine Specifications:

1. TYPE: 3-CYLINDER, RE-HEAT CONDENSING REACTION TURBINE
2. No of stages: HP Turbine: 18(single flow, double casing)
3. IP Turbine: 2*14(double flow, double casing)
4. LP Turbine: 2*6(double flow, triple casing)
5. Normal rating: 500mw
6. Throttle pressure: 170 atm
7. 1st stage pressure: 151.79 atm
8. Ms /HRH TEMP: 537/537°C
9. Peak loading: 545mw
10. Rated Speed: 3000rpm
11. Max/min speed (no Time limitation): 3090/2850 rpm
12. Speed exclusion range: 400 to 2850 rpm
13. Moment of inertia of LP CYLINDER: 22981 kg-m².

The blade was modeled in CATIA V5 R16 and was meshed in Hyper Mesh and later was used in ANSYS to perform modal analysis.

VII. MODEL OF BLADE

The blade was meshed in Hyper Mesh 11 and the Modal Analysis was conducted in ANSYS 13. The modal was meshed in Hyper Mesh and was exported to ANSYS to conduct Modal Analysis.

Mode shapes have been found out at the first three natural frequencies and the ortho normal mode shape was obtained at third natural frequency.



Fig5. CATIA Model of Blade

VIII. RESULTS OBTAINED

The results of the calculations performed on the steam turbine blade based on Lazan’s Law assumptions are tabled below.

SET	TIME/FREQ	LOAD STEP
1	43.82	1
2	128.79	1
3	203.81	1
4	281.81	1
5	290.2	1

Table1: Natural Frequencies Obtained

PARAMETER	VALUE OBTAINED
Natural Frequency	1279.92
Total Damping Energy	1.208 Nm
Total Strain Energy	307.156 Nm
Equivalent Viscous Damping	0.0003
Loss Factor	0.0006233
Damping Ratio	0.000311

Table2: Calculations as per Lazan’s Law

Calculations after strain is multiplied by factor F=0.1

PARAMETER	VALUES OBTAINED
Total Damping Energy	6.023*10 ⁽⁻³⁾
Total Strain Energy	3.07156 Nm
Loss Factor	3.12*10 ⁽⁻⁴⁾
Equivalent Viscous Damping	3.995*10 ⁽⁻⁵⁾
Damping Ratio	1.56*10 ⁽⁻⁶⁾

Table3: After multiplying with Factor F=0.1

Now the quantified results of equivalent viscous damping with strain amplitude are:

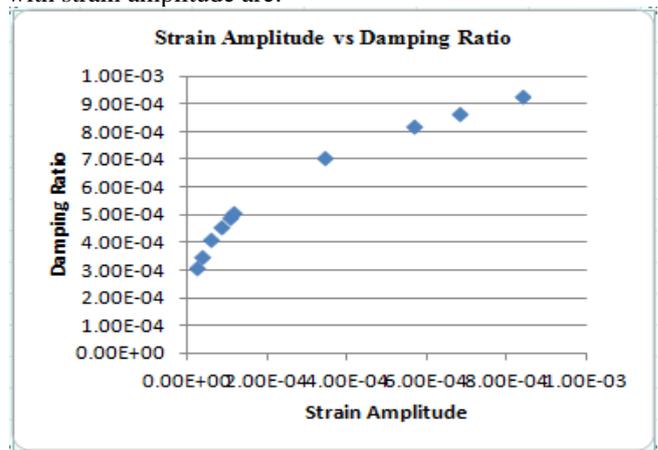


Fig6. Strain Amplitude vs Damping Ratio

IX. CONCLUSIONS

A method of determining equivalent viscous damping ratio for a rotational speed and modes as a function of displacement or strain at a reference point in a blade is presented. Hysteresis damping plays an important role in safe working of the turbine blades.



For the considered low pressure turbine blade hysteresis damping is evaluated. The obtained equivalent viscous damping is quantified in terms of strain amplitude. This methodology can be applied to any suitable finite element code.

Total damping energy and strain energy are calculated by integrating them over the entire volume. With the help of these the loss factor is obtained. From the loss factor, the equivalent viscous damping ratio is determined. The study of friction damping, combined effect of material and friction damping on the blade can be further studied.

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