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Experimental Studies on Estimation of Damping: Cantilever Beam

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ABSTRACT
Present study deals with the finding the damping ratio experimentally for different methods and diffentiate between methods, such as Logarithmic decrement. Circle fit Method, F-D curve, half power method, and Sine sweep method. The assumptions followed is linear system where its dynamic behavior can be described by a second order diffential equation in It is time invariant, It is under damped system. MATLAB coding developed for above methods. Damping ratio is formulated and discussed for different methods.

Keywords: F-D curve, MATLAB, Logarithmic

I. INTRODUCTION

Material damping is an important property of a material member. Material damping has been studied by Y. Kue and F. Hashimoto etal. [1]. Material damping calculated in terms of stress distribution function for each mode of vibration and damping stress function. It is found that the relation between the loss factor and max stress amplitude is very similar for each mode of vibration when modes vibrate with equal stress applied when stress amplitude is less 10^7 pa. Yin et al. [2] compared the damping by measuring strain at the root of the cantilever beam for varying the strain amplitudes for different techniques, i.e logarithmic decrement and frequency sweep for finding damping, conducted experiments on different strain amplitudes in the vicinity of resonance frequency of the beam. The loss factor results are described in a contour as a function of strain amplitude and frequency. Yang et al.[3] and Satake et al. [4] did experiments on a long stall building in 1st mode.

Present study on cantilever beam to find damping using five different methods and differentiate values on damping.

Log Decrement Method: Measure of damping can be made from the transient response of the system. The log decrement method computes damping from the rate of decay of the system response in the time domain. Logarithmic decrement method is used to measure damping in time domain. In this method, the free vibration displacement amplitude history of a system to an impulse is measured and recorded. Logarithmic decrement is the natural logarithmic value of the ratio of two adjacent peak values of displacement in free decay vibration.

Circle fit method: The circle fit method is the most used SDoF modal analysis method. It is based on the

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circularity of the Nyquist plot of an SDOF FRF. With structural damping, the receptance FRF traces a perfect circle on the Nyquist plane. Such a unique property gives rise to a mathematically convenient and accurate curve-fitting model for modal analysis. When this circularity property of a SDOF system is used to analyse an FRF from an MDOF system, the SDOF assumption should apply first. Of course we can assume that at the vicinity of a mode, the contributions of all other modes are negligible. This assumption is difficult to meet in reality. However, the circle fit method can rely on a more relaxed assumption. The receptance FRF of an 'N' DOF system in modal form. The derivation of the modal data from circle fitting follows the same sequential procedure as the peak-picking method, i.e. from natural frequency to damping loss factor and to modal constant. However, the accuracy of the derived modal data is improved significantly. In order to estimate the natural frequency, the first step is to fit a circle from the selected FRF data points. These points are selected at the vicinity of the resonance peak. Mathematically, it can be found that the natural frequency ωr is at the location where maximum arc change occurs on the Nyquist circle. Once the natural frequency ωr is accurately located on the Nyquist circle, the damping loss factor can be estimated from any FRF data point using theoretically, we should get an identical damping loss factor using any FRF data point. However, due to measurement noise, nonlinearity or errors, the damping loss factor estimated from different FRF points varies. Thus, the estimates of ηr become a useful indicator for the accuracy of the analysis, if the natural frequency ω_r is not located accurately, then the estimate of η_r will exhibit a systematic change from the FRF data points before or after ω_r. It is also possible to use one FRF point before the estimated natural frequency and ne after that to estimate the damping loss factor. If the data points correspond to frequencies ωb and ωa, Combining these formulae leads to an estimate of the damping loss factor: By selecting different pairs of FRF data points, one from before and one from after the natural frequency, we have an array of damping estimates. These values, when plotted against the number of data points.

Half power band width method: For the SDOF structure, the structure will possess a classic compliance response as shown in Figure .The level of damping can be subjectively determined by noting the sharpness of the resonant peak at ωo : the more rounded the shape, the more damping present in the structure. For a quantitative measure of damping, the half-power bandwidth method can be employed. the damping of the structure η can be determined from the ratio of Δω to ωo with Δω determined from the half-power point down from the resonant peak value, Amax (equal to the inverse of the amplification factor Q). On a decibel scale, this corresponds to a –3 dB drop from the peak. For that reason, this damping measurement technique is also referred to as the 3 dB method. To estimate damping ratio from frequency domain as shown in figure .In this method, FRF amplitude of the system is obtained first. Corresponding to each natural frequency, there is a peak in FRF amplitude. 3 dB down from the peak there are two points corresponding to half power point. The more the damping, the more the frequency range between this two point. Half-power bandwidth BD is defined as the ratio of the frequency range between the two half power points to the natural frequency at this mode.

Hysteresis Loop Method: Another estimate of damping can be achieved by calculating the energy loss per cycle of oscillation due to steady-state harmonic loading. Again assume the complex spring element of Figure is subjected to the cyclic stress s(t) resulting in a strain response of e(t). By plotting the instantaneous stress versus strain for a given cycle of motion, the elliptically shaped hysteresis curve of Figure is generated. The area captured within the hysteresis loop D is equal to the dissipated energy per cycle of harmonic motion. For reasonable levels of damping, the loop area can be used to calculate damping, this is given by the area of the hysteresis loop in the displacement force plane. If the initial (total) energy of the system is denoted by Umax; then the specific damping capacity, D; is given by the ratio. The loss factor, h; is the specific damping capacity per radian of the damping cycle. Hence, Note that Umax is approximately equal to the maximum kinetic energy and also to the maximum potential energy of the device when the damping is low.

The maximum potential energy per unit mass of the system is The loss factor for a viscous damped simple oscillator is given by For free decay of the system, we have v ¼ vd ø vn n; where the latter approximation holds for low damping. For forced oscillation, the worst response conditions occur when v ¼ vd ø vn ; which is what one must consider with regard to energy dissipation.

Sin sweep test:-Sweep test have been used to identify the natural frequency of various structures. However to the best knowledge using them to determine transfer functions originates .The aim of the using sweep test is minimize the time with reasonable accuracy to identify a transfer function. By applying a constant excitation force and sweeping the frequency of excitation one can measure the resulting vibration and calculate the frequency response function, and hence characterize the system. The name sweep sine arises due to the fact that the system is allowed to respond between 2 frequency limits, chosen in such a way that the suspected natural frequency may lie between these two frequency limits. At a particular instance of time, the input frequency becomes equal to the natural frequency of the system and the amplitude level increases significantly. This is the resonance peak and can be clearly distinguished in the response curve. As soon as the input frequency crosses the resonant frequency, system amplitude keeps on reducing. From analysis point of view, resonant frequency amplitude is very important. Here unlike impulse excitation technique, the structure is excited by a pure sine wave of fixed amplitude but varying frequency and the system response to this varying frequency is studied.

II. EXPERIMENTAL PROCEDURE AND TEST METHODOLOGY

A data acquisition system is used to store the record data and transfer measured data to the PC for data post-processing. Frequency response functions (FRFs) were obtained .The FRFs were processed using MATLAB programing packages to identify natural frequencies, damping of the beam.

I. Results and Discussions:-

Logarithmic decrement Method:- Measure of damping can be made from the transient response of the system. It should be pointed out that the decay of the typical displacement response only indicates that energy dissipation is taking place. The cause of the energy dissipation may be due to many different effects such as material damping, joint friction and radiation damping at the supports. However, if it is assumed that all energy dissipation is due to linear viscous damping, the free vibration response is given by the following equation.

By using above formula we can fit the exponential fit from data. The damping ratio from logarithmic decrement is 0.0043 for 1st mode. as shown in below fig 1.

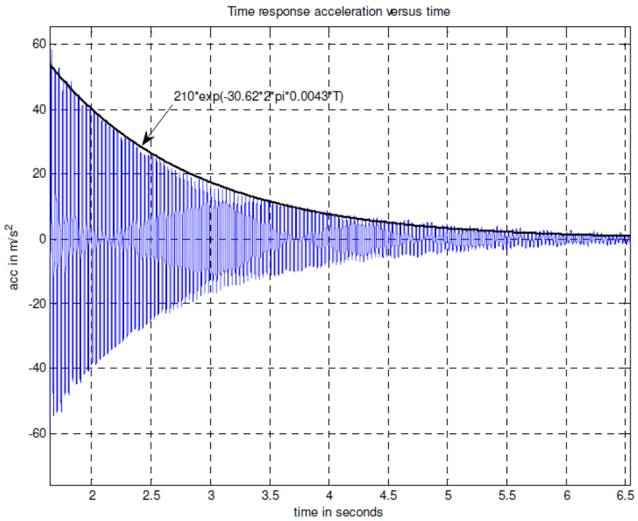

Figure 1: Logarithmic Decrement

Circle fit Method:- This method works with multi degree of freedom system.to excite the system impact hammer is used and response of the structure is acquired and processed the data and at the higher peaks resonance frequency is attained at that pints 11 points chosen and perform the circle fit method as explained before. The log log graph transfer function between tip acceleration and force applied as shown in fig 2.

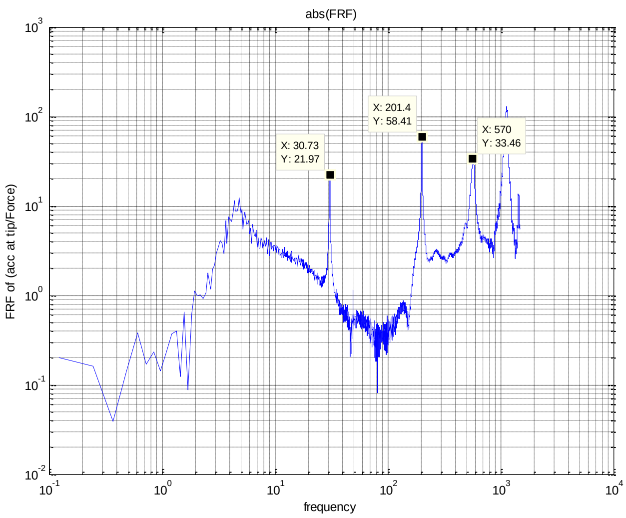

Figure 2: FRF of cantilever beam

To find damping present at the 1st resonance frequency ,choosing 10 points around the resonance frequency 30.73 Hz and fit the circle and we will get damping ratio of the 1st mode is 0.0049. The circle fit and points chosen shown in below fig. 3.

To find damping present at the 2nd resonance frequency ,choosing 10 points around the resonance frequency 201.4 Hz and fit the circle and we will get damping ratio of the 1st mode is 0.0050.the circle fit and points chosen shown in below fig 3.

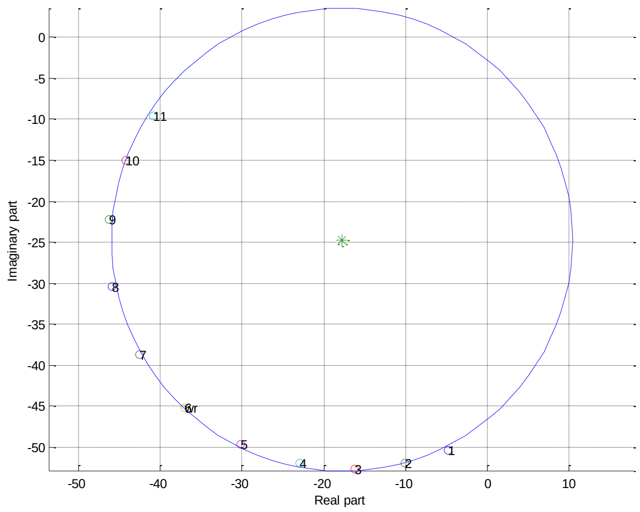

Figure 3: Real part vs imaginary part

F-D curve :- To measure the damping by using hysteresis loop .shaker to excite at Ist resonance frequency and response measures at the tip at the cantilever beam. For the 1st resonance frequency base acceleration and tip acceleration as shown in below fig 4 for one cycle and base acceleration and tip displacement curve also as shown in fig 4.

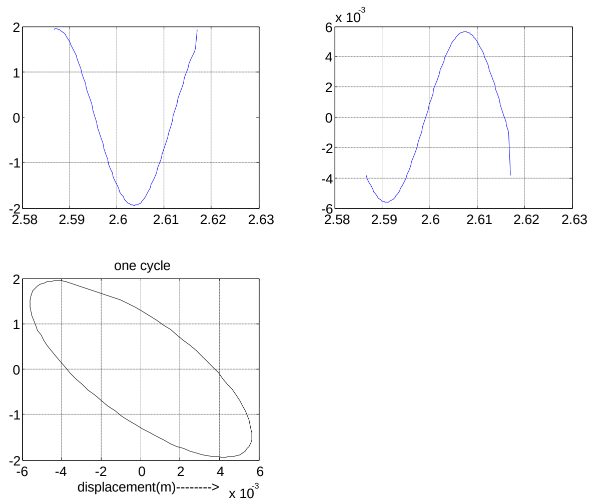

Figure 4 : 1 st mode: Signal of displacement and acceleration

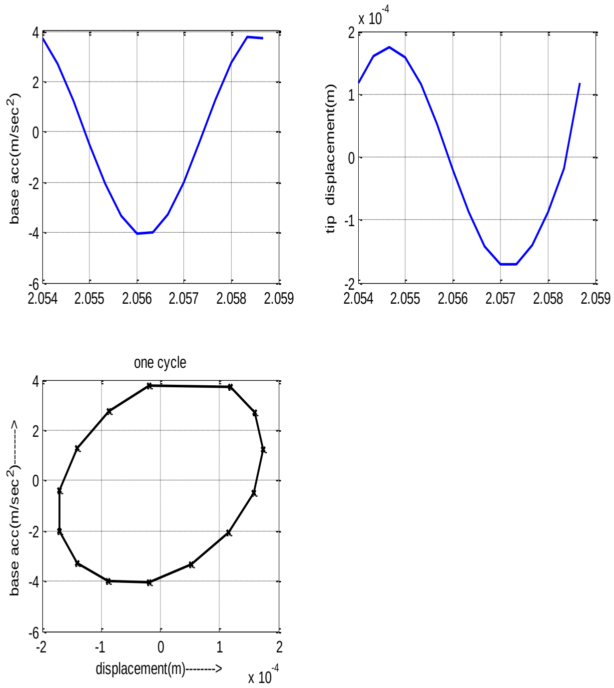

Figure 5 : 2nd mode: Signal of displacement and acceleration

The damping ratio is measured from eq is above mentioned .the damping ratio is 0.0068.

Half power band width Method:-In case of half power method each and every frequency acquired the base acceleration and tip acceleration plotted each frequency and response shown in below fig for 1st mode and 2nd mode.

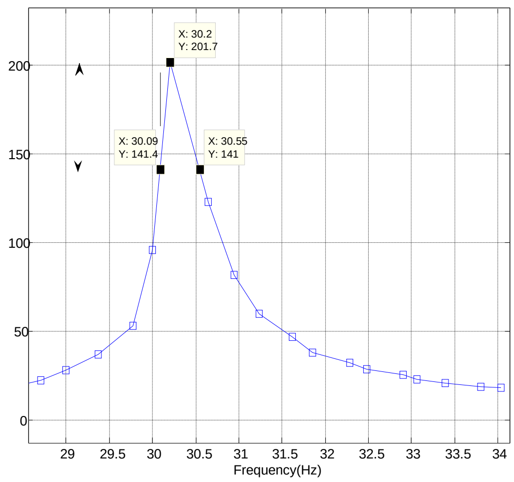

Figure 6 : 1 st mode: FRF

Sin sweep Test:-

The vibration characteristics (natural frequency & damping ratio) of aluminum beam determined by sine sweep test .Graphs for response (acceleration) with respect to constant excitation acceleration for aluminum beam has been shown in figures both in time domain as well as in frequency domain. In the time domain plot reads from start to stop varying of frequency 15 to 300 Hz in which 1st and 2nd mode frequency lies in 0.2sec as shown in fig 6. In one cycle shown in below fig.6.

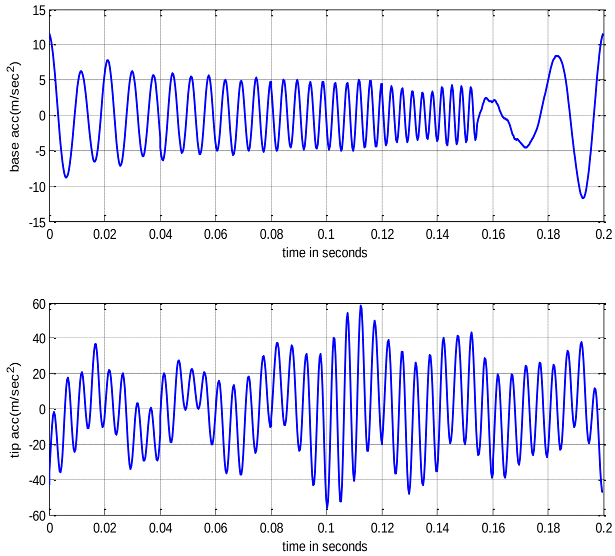

Figure 6 : Tip acceleration and base acceleration

Frequency domain plot shown in below fig 7. we can clearly show in resonance frequencies.

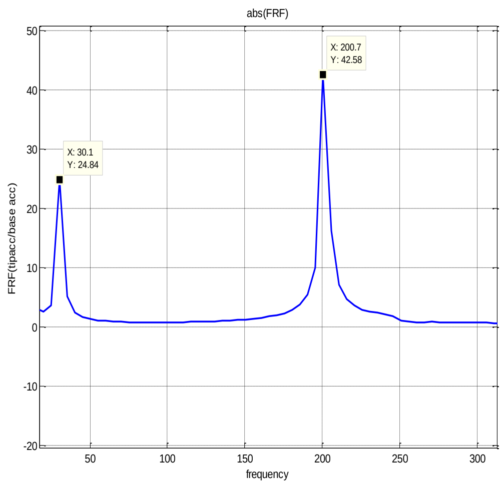

Figure 7 : FRF

Damping measured by half power method for 1st and 2nd modes are 0.06 and 0.01.

TABLE I
TYPE OF MEASUREMENT

TYPE OF DAMPING MEASUREMENT	1st mode	2nd mode
Logarithmic decrement	0.0043	
Circle fit method	0.0049	0.0050
F-D method	0.0033	0.0065
Half power method	0.0075	0.0050
Sin-sweep method	0.06	0.01

In case of half power method for 1st mode, as shown in table 1. Around the resonance frequency sufficient data is missing so we can't predict the correct results for 1st mode. In case of sin sweep method effect on the sweep rate. Results in delay the resonance frequency,. In harmonic tests resonance occurs when the excitation frequency is tuned to natural frequency of a beam vibrates for sufficiently long time. However the excitation frequency is sweep through continuously changes with time so that resonance occurs at a later time after excitation frequency. So we will not get perfect damping measurement.

III. CONCLUSIONS

In case of sin sweep method effect on the sweep rate. Results in delay the resonance frequency, in harmonic tests resonance occurs when the excitation frequency is tuned to natural frequency of a beam as long as beam vibrates for sufficiently long time. However, the excitation frequency is sweep through continuously changes with time so that resonance occurs later after excitation frequency.

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