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STUDY OF SENSITIVITY OF MODE SHAPES IN DAMAGE IDENTIFICATION USING CONTINUOUS WAVELET TRANSFORM

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ABSTRACT

In this project the existing damage identification methods are studied and new method of damage detection is introduced. Plate structure is modeled and the damage is identified by the new method. The damage is located using Daubechies wavelet transform in the form of peak at high wavelet coefficient value in the three dimensional wavelet plotted in scale translation plane. To create damage in plate model percentage of thickness of specific elements are reduced. The proposed method is numerically evaluated on a simple finite element turbine blade model. The results of analysis to indicate that the proposed continuous wavelet transform based damage identification method effectively identify single as well as multiple damages using only the fundamental mode shape. Hence, it is to show that proposed method has the potential to identify damage in structures.

Keywords: modal analysis, plate, wavelet transforms, condition monitoring.

1. INTRODUCTION

Damage present in the element affects the functioning of structure. Crack initiated in the structure leads to rapid failure. To avoid such problems damage detection techniques are required. There are mainly two categories of damage detection techniques. Destructive and non- destructive methods. Non-destructive methods do not alter the physical and mechanical properties of the structure, so they are widely used. In the previous studies, many authors have studied the effects of cracks upon the dynamic behavior of cracked beams.

The early detection of failure in structure is given greater importance so that the scheduled shutdown and repair can be planned. There are several methods available for the early detection of failure, and one of the most useful of these is vibration analysis.

The basic principle of vibration analysis is that a small variation in mechanical system leads to change in natural frequency of vibration of the system. In simple systems, this change in the amplitude of the total vibration can be easily detected with simple instruments. For complex systems, more sophisticated techniques may be needed if the damage is to be identified. The changes in the vibration of a blade which are produced when a defect is small may also be small, and may not be readily detected. It is possible to enhance the clarity of the changes in the time domain average by digital signal processing.

Conventional signal processing techniques like time-domain statistical analysis and Fourier transform are generally used methods for signal analysis and damage detection.

Wavelet processing is one of the modern and most effective techniques of damage detection. It is the extension of conventional Fourier's transform which eliminates the drawbacks of it. Using wavelets the crack location can be investigated by the utilization of zooming and focusing options to provide more details of damage and multiple levels of approximations.

P. D. Mc Fadden [1] explained a paper on signal processing of time domain average of meshing vibration for early detection of failure in gears. The residual signal, which is obtained by subtracting the regular signal from the original time domain average, gives the departures of the vibration from the average. Y. Narkis and E. Elmalah [2] demonstrated the possibility of crack identification using natural frequency variations of a cantilever beam. It is verified by numerical simulation for its feasibility to identify crack location. Long Qia [3] explained a paper on a signal-based pattern-recognition method was applied to detect structural defects with a single or limited number of input/output signals. This technique is based on the extraction of sensitive features of the structural response under a known excitation that present a unique pattern for any particular damage scenario. Frequency-based features and time frequency- based features of the acceleration response were extracted from the measured vibration signals by Fast Fourier Transform (FFT) and Continuous Wavelet Transform (CWT) to form one-dimensional or two- dimensional patterns, respectively. D. Boulahbal *et al*., [4] developed a technique to show the effectiveness of continuous wavelet analysis in finding developing fatigue cracks in gears. Amplitude and phase wavelet maps were used together to to obtain details about tooth condition. P. Zinina *et al*.,[5] explained a paper on detection of cracks using a acoustic microscopy in concrete composites. A complete interpretation of the obtained results has been made by combining high and low frequency acoustic microscopy, scanning acoustic microscope (SAM) operating in the frequency range 100±400 MHz is used to detect cracks at the aggregate/paste interface and subsurface cracks in aggregates with high sensitivity. Leontios J. *et al*.,[6] proposed a new method for crack detection in beam structure based on kurtosis analysis. The

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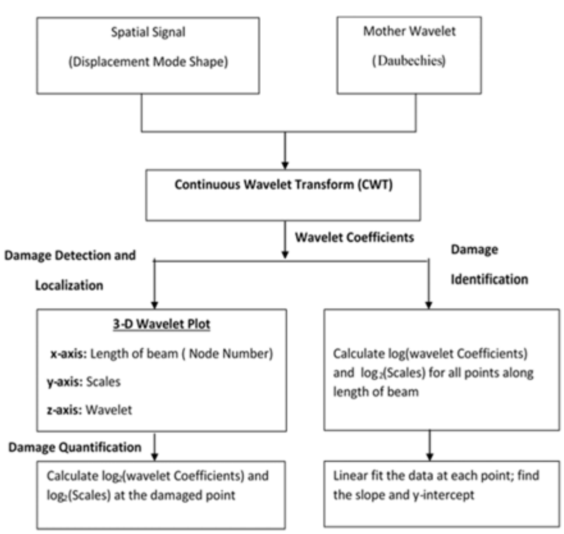
location of the crack was investigated by the abrupt change in the spatial variation of the analyzed response, while the size of the crack was related to the kurtosis estimate. Chih-Chieh Chang, Lien-Wen Chen [7] gave a method to identify the crack using special wavelets which were used to detect the cracks positions and depths and it also has high sensitivity to the crack depth. Jinhee Lee [8] proposed a simple method of crack detection for a beam. Cracks are modelled as rotational springs without mass. Euler-Bernoulli theory is used to solve the problem. N. Wu, Q. Wang [9] conducted an experiment on defect finding of beam structures with wavelet analysis. A laser sensor is used to measure the deflection of cantilever beam with a crack. To amplify the perturbation at crack Gabor's wavelet is used. Reddy and Swarnamani [10] explained FRF curvature energy based damage index for damage detection in plate like structures. Mangesh S. Kotambkar [11] presented a technique of detecting cracks in turbine blade. A crack on beam introduces considerable local flexibility due to the strain energy concentration in the vicinity of the crack tip under load. Ertugrul Cam, *et al*.,[12], analyzed cracked beam structure to get depth and location of crack using impact echo method and compared the values in frequency domains.

Above references used different techniques which were sensitive to detect the damage up to certain limit. Damage detection using wavelet transform is much sensitive and advanced technique compared to conventional methods. N. Wu, Q. Wang [9] and Reddy, Swarnamani [13] used wavelet transform for damage detection in two dimensional structure. Damage detection technique for three dimensional structure is explained in this paper.

2. METHODOLOGY OR APPROACH INTENDED TO BE ADOPTED IN THE EXECUTION OF THE PROJECT

The following block diagram indicates the steps of the project. There are multiple levels in diagram giving the details about the techniques and sequence used to complete the process of damage detection.



3. NUMERICAL SIMULATION

At the first stage of the work plate structure is modeled in ANSYS 12.0. The length and width of model are 1.25 m and 0.345 m, respectively. *Inconel 738* alloy is taken as turbine blade material. Its corresponding young's modulus value 201 GPA, poison's ratio value 0.37 and Density 8010 Kg/m ^{3} are given as material properties. The length of the turbine blade is equally divided into 50 elements and width is divided into 25 elements. The model has total of 1250 shell elements. Damage is simulated by reducing the stiffness of some elements (reduction in thickness of specific elements in ANSYS) at 2 locations of the model

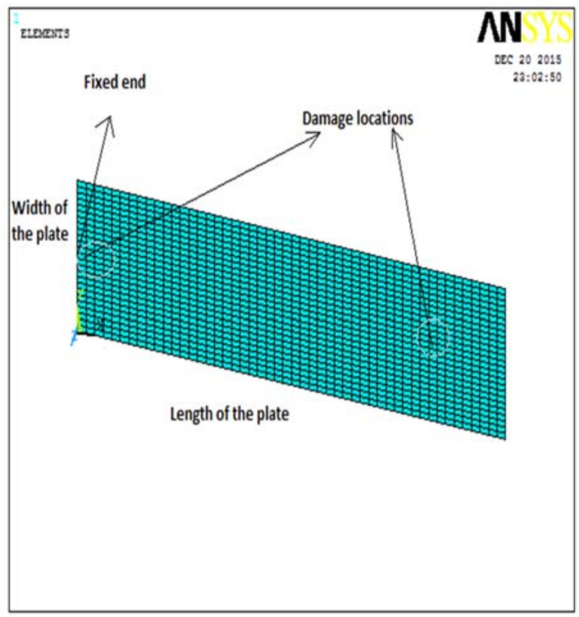


Figure-1. Plate model in ANSYS 12.0 fixed at one end (meshed).

Table-1. First 5 natural frequencies of undamaged and damaged cases of the model

	1	2	3	4	5
Undam	2.7072	16.913	19.329	47.577	60.163
Case 1	2.6734	16.661	19.294	46.883	59.822
Case 2	2.6782	16.705	19.299	46.990	59.872
Case 3	2.6930	16.814	19.299	47.300	60.013
Case 4	2.6997	16.862	19.321	47.433	60.083

One at the fixed end and another damage towards the lateral edge as shown in Figure-1. Different damage cases and corresponding reduction in stiffness and damaged elements numbers are tabulated as shown in Table-1. Modal analysis is performed on the structure to estimate the modal parameters namely natural frequencies and mode shape for undamaged and all damaged cases.

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4. RESULTS AND DISCUSSIONS

The first five natural frequencies obtained from modal analysis for all damaged cases are tabulated in Table-2. For 5 natural frequencies there are 5 modes in which first, second and fourth modes are translational modes and third and fifth are rotational modes. In order to locate damage accurately only translational modes are considered and rotational modes are ignored.

Table-2. Different damage cases with element numbers of damaged locations.

Damage cases	% of stiffness reduction in elements	Damage element number	
		Set 1	Set2
1	80	551,552,601 602,651,652	685,586,635 636,685,686
2	50	551,552,601 602,651,652	685,586,635 636,685,686
3	20	551,552,601 602,651,652	685,586,635 636,685,686
4	10	551,552,601 602,651,652	685,586,635 636,685,686

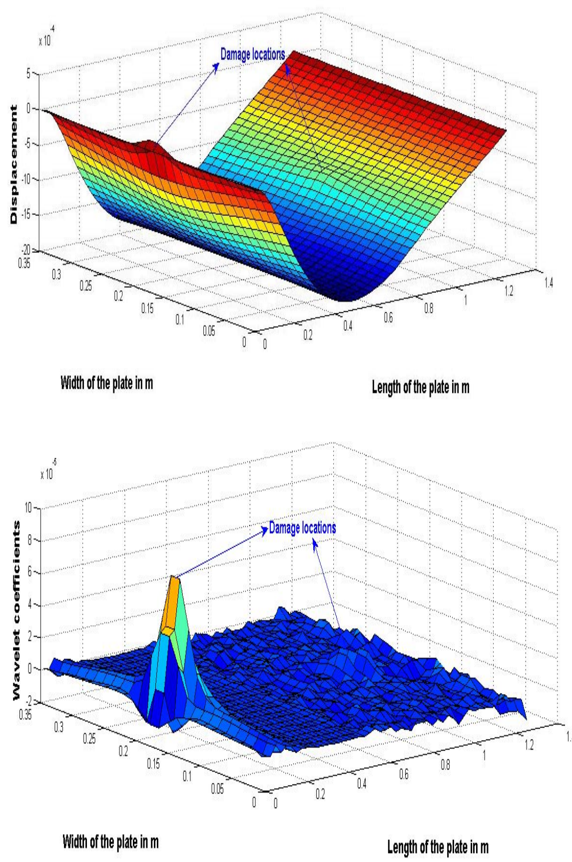

Figure-2. (a) Difference of undamaged and damaged mode shapes for first mode with 80% reduction in thickness case (b) Difference of undamaged and damaged wavelet coefficients for 80% reduction in thickness case.

It is observed that the mode shape data shown in the Figure-2(a) is not showing the deviation at damage locations. So in order to detect the damage wavelet coefficient difference of undamaged and damaged cases is plotted using "Daubechies continuous wavelet "as shown in the Figure-2(b). From this figure we can observe that it locates damage (in the form of peak) at fixed end of the plate but not at lateral side of the plate. So in order to obtain the damage location details accurately the same process is repeated for other modes.

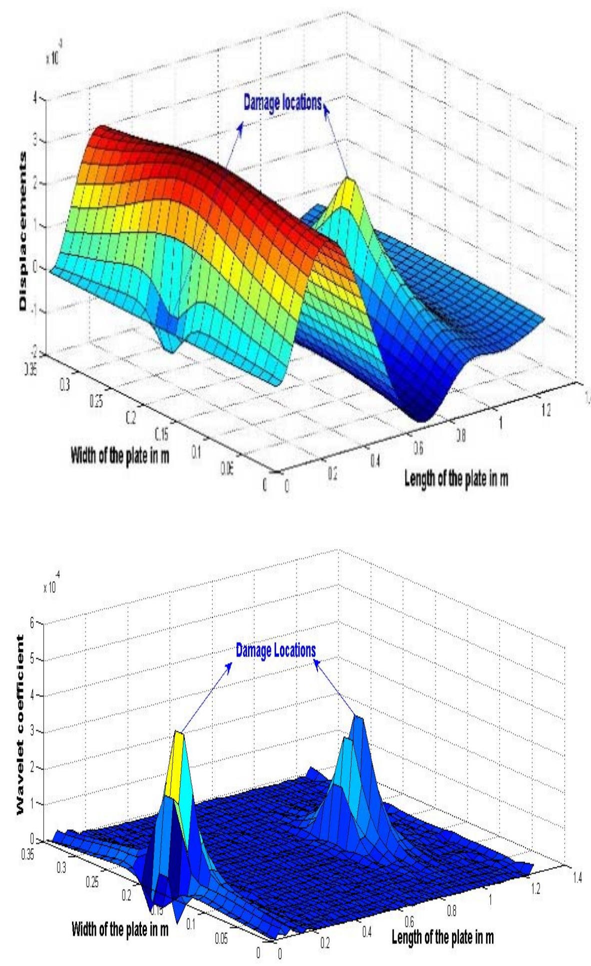

Figure-3. (a) Difference of undamaged and damaged mode shapes for second mode with 80% reduction in thickness case (b): Difference of undamaged and damaged wavelet coefficients for 80% reduction in thickness case.

Figure-3(a) showing the mode shape difference between undamaged and 80 percent damaged cases at first mode is not able to indicate two damage locations properly. So Figure-3(b) showing the wavelet coefficients difference of undamaged and damaged cases is plotted

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showing peaks at the damage at fixed and towards lateral edge accurately.

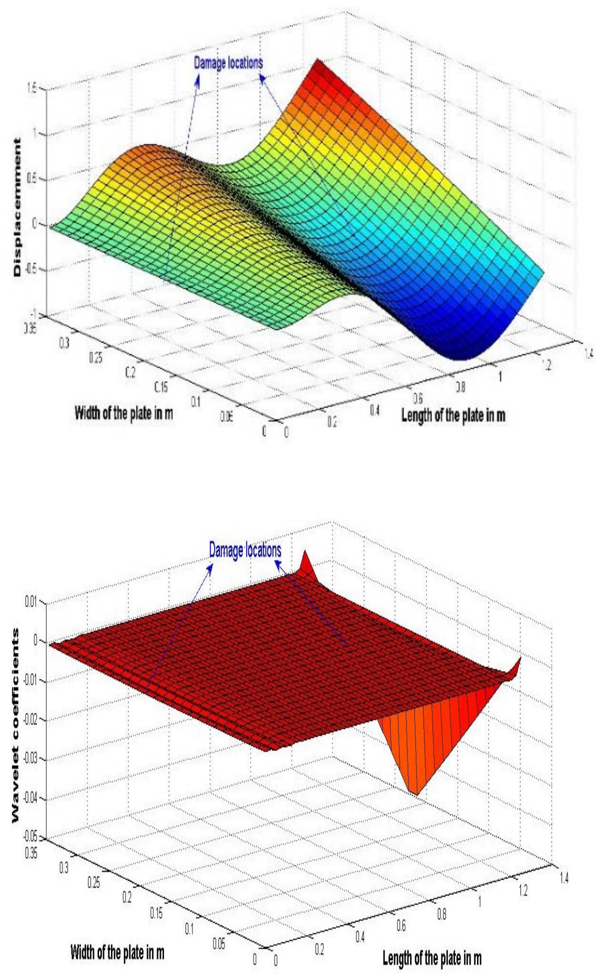

Figure-4. (a) Difference of undamaged and damaged mode shapes for fourth mode with 80% reduction in thickness case (b): Difference of undamaged and damaged wavelet coefficients for 80% reduction in thickness case.

Figure-4(a) indicating the mode shape difference between undamaged and 80 percent damaged cases at fourth mode is not giving any peaks at 2 locations. And also Figure-4(b) indicating the difference of wavelet coefficients between undamaged and damaged cases is also not showing any peak values at damaged locations. By comparison of the wavelets at 3 modes it is clear that second mode is giving more accurate location details of damage comparing to first and fourth modes. Therefore only second mode is considered for further deformation cases.

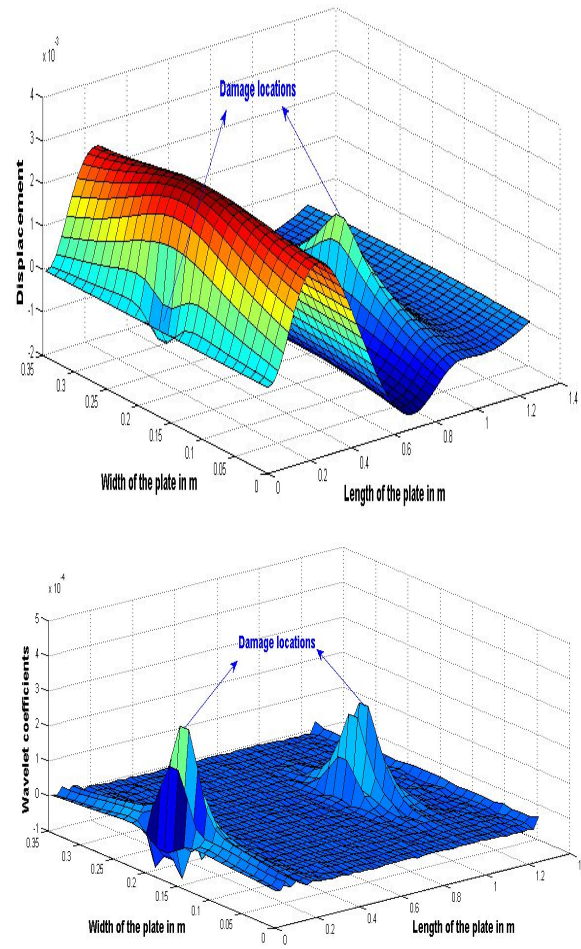

Figure-5. (a) Difference of undamaged and damaged mode shapes for second mode with 50% reduction in thickness case (b): Difference of undamaged and damaged wavelet coefficients for 50% reduction in thickness case.

Figure-5(a) indicating the mode shape difference between undamaged and 50 percent damaged cases at second mode is giving good peaks at 2 locations. Figure-5(b) indicating the difference of wavelet coefficients between undamaged and damaged cases is showing 2 peak values that indicates the damage at both fixed end and also towards lateral edge. But as the amount of damage is lesser the amplitude of peak is reduced compared to 80 percent damaged case.

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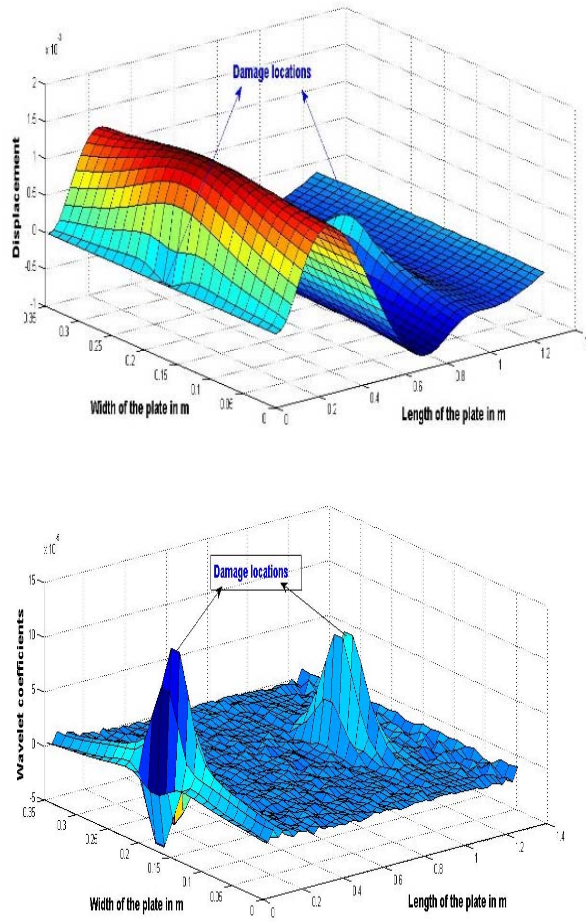

Figure-6. (a) Difference of undamaged and damaged mode shapes for second mode with 20% reduction in thickness case (b): Difference of undamaged and damaged wavelet coefficients for 20% reduction in thickness case.

Figure-6(a) indicating the mode shape difference between undamaged and 20 percent damaged cases at second mode is giving good peaks at 2 locations. Figure-6(b) indicating the difference of wavelet coefficients between undamaged and damaged cases is showing 2 peak values that indicates the damage at both fixed end and also towards lateral edge. But as the amount of damage is lesser the amplitude of peak is also less compared to 80 percent and 50 percent damaged cases.

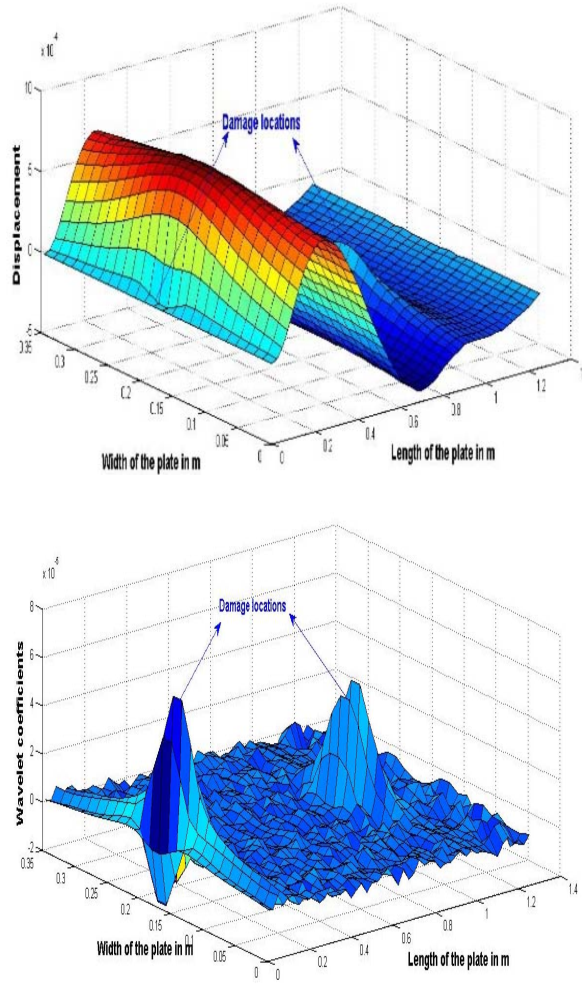

Figure-7. (a) Difference of undamaged and damaged mode shapes for second mode with 50% reduction in thickness case (b): Difference of undamaged and damaged wavelet coefficients for 50% reduction in thickness case.

The Figure-7 (a) indicating the mode shape difference between undamaged and 10 percent damaged cases at second mode is giving good peaks at 2 locations. Figure-7(b) indicating the difference of wavelet coefficients between undamaged and damaged cases is showing 2 peak values that indicates the damage at both fixed end and also towards lateral edge. It is observed that there are unnecessary peaks at adjacent elements of damage.

By repeating the same procedure for lesser damage cases it is observed that as the adjacent elements at damage are giving unnecessary peaks. It is concluded that this process is sensitive up to 10 percent damage case.

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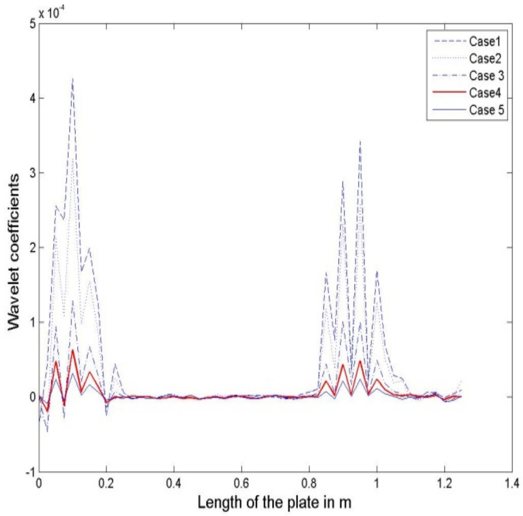

Figure-8. 2D plot indicating comparison of intensities of wavelet coefficient difference plots with 80, 50, and 20,10,5 % reduction in thickness, respectively.

Figure-8 is a 2D plot showing difference of wavelet coefficients between undamaged and damaged cases with 80, 50, 20, 10, 5 percent reduction in thickness respectively. Mid plane along the width of the plate is projected along the length of the plate. It is observed that the amplitude of the peak at damage location is proportional to the amount of damage. Highest amplitude is observed in case of 80 percent damage.

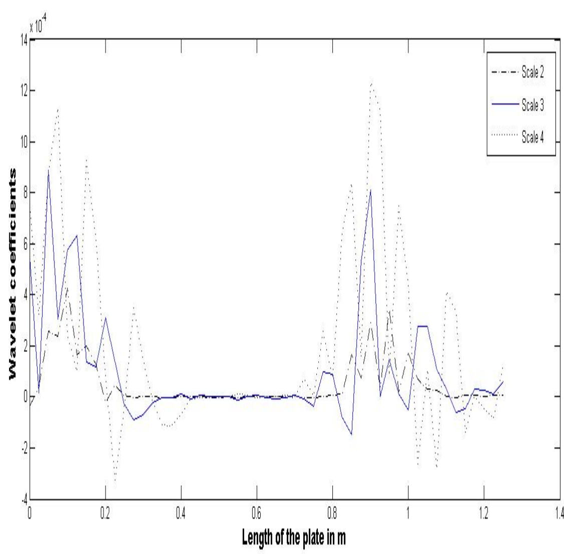

Figure-9. 2D plot plate along the length for 80% damaged case at different scale values in DB6 wavlet.

Daubechies wavelet with different scale values is tested for accuracy in locating the damage. Figure-9 shown below is the 2D plot of the mid section of plate width along the length at 80 percent damage case for different scale values.It is observed from the figure that the scale 4 (s=4) is showing good peaks but not accuratly as the adjacent elements are showing unncessary peaks. Scale 3 (s=3) is showing the good peaks with accuracy. Scale 2 (s=2) is not giving peaks at damage. So Scale 3 is used for all the above wavelets shown.

To proceed further, in future, damaged and undamaged models of steam turbine blade are made using glass fiber composites. By performing hammering test the natural frequencies and mode shapes of both models are tested and compared to verify this project practically.

CONCLUSIONS

This paper presents the technique of damage detection and localization in the plate model by using Daubechies wavelet transform. Finite elements method is used to analyze the cantilever structure as application of future steam turbine model concept. Damage was created at known elements by reducing percentile of thickness. As the mode shape data difference of undamaged and damaged cases could not locate the damage. The same data processed through signal processing technique like Daubechies wavelet transform along its length and width with wavelet coefficients values as three dimensional coordinates, gives the damage localization results. The location and severity of the damage are successfully detected. This research work proved that continuous wavelet transform method is a promising technique in the field of structural condition monitoring.

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