Modal Analysis of Composite Materials- A Review

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Abstract- *A single isotropic material cannot be used at all sorts of industrial applications. It may have some limitations in usage. So there is a need for new materials which has the ability to suit to the particular applications. Hence composite material plays a vital role in most of the applications especially in aerospace and automotive industries. Since it is a new material, there is a necessity to know its dynamic behavior at design stage itself. Through the modal analysis the vibration characteristics of a material like natural frequencies, mode shapes and damping properties can be predicted. This review paper explores the dynamic characteristics of various composite materials in details.*

Keywords- MMCs, Modal Analysis, FEA, FFT analyser, Dynamic Characteristics.

I. INTRODUCTION

Three major types of composites are widely used in industries namely Polymer Matrix Composites (PMC), Metal Matrix Composites (MMC) and Ceramic Matrix Composites (CMC) [1]. Apart from this composites are also made from bio-degradable natural materials. Day by day the industries are preferring composites instead of monolithic material due to its tailor made properties. Hence the usage of composites in industries is extended from aerospace, automobile, marine applications and even in medical field also [2]. It encourages the researchers and scientists to introduce a new material to the world in recent decays. Concern with the technical details, still issues are there to solve [3]. Prediction of dynamic characteristics is a serious issue encountered in the rotating components. Since composites are widely used in very sensitive areas like aerospace industries the components should undergo thorough investigation on its dynamic characteristics. Modal analysis helps us to study the complete dynamic behavior of the material. Vibration characteristics of a material depends on its mechanical properties and size [4]. Through modal analysis the natural frequencies, damping ratio, damping factor and mode shapes can be predicted [5]. It is possible to do the modal analysis in three ways such as analytical method, FEA and experimental testing. In analytical method, the natural frequencies are predicted using Eigen values. ANSYS software is a renowned FEA package to do analysis. Accelerometer, impact hammer and FFT analyzer set up is used to study the dynamic characteristics by experimentally [6]. This review a gives detailed study on the dynamic characteristics of composite materials. The research works of many authors have been condensed and presented in this paper.

II. LITERATURE REVIEW

Frantisek Klimenda and Josef Soukup [7] had done a modal analysis on a thin aluminium plate to find out the natural frequencies and modes shapes. First the derivation on theory of modal analysis was made and the Eigen values of natural frequencies and mode shapes of the plate were found. For solving the natural frequencies and mode shapes Finite Element Method is used. Solution for this modal analysis is found by using ANSYS software. The first ten frequencies and mode shapes are studied and plotted in table 1.

Table1. Natural frequencies of Al plate

Modes	Frequency[Hz]
1	1744.4
2	3545.3
3	3545.3
4	5210.3
5	6324.9
6	6356.6
7	7907.3
8	7907.3
9	10059.0
10	10059.0

Steven Leuridan et al.[8] have performed experimental study on determining the properties of the composite replicate bone model based on vibration approach. Three composite models such as femur, tibia and cylinder were tested experimentally. Experimental modal analysis of specimen was performed to find the initial material properties like young’s modulus, poison’s ratio, density etc and also found that experimental frequency is in range of 50-2750 Hz. The isotropic and transversely isotropic FE (finite element) models of the specimen are also created using Mimics and MSC Patron software. With the help of initial material properties and first eight resonance frequencies between experiment and model the FE model was updated. From the result they interpreted that updated isotropic material FE modal gives excess error. But, when looked up an updated transversely isotropic model, its assumed error is reduced to 2.84%. Thus desired material properties are obtained while transversely isotropic material model is used.

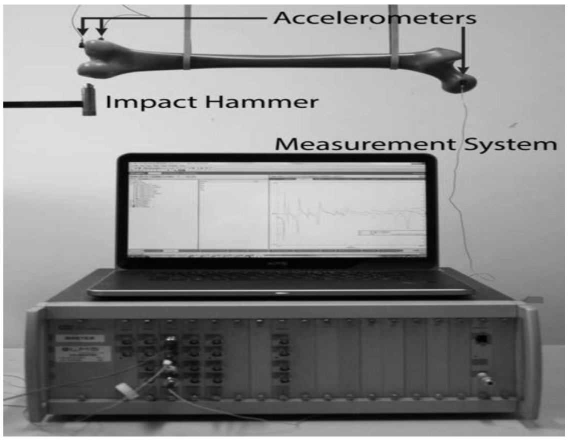

Fig.1 Experimental setup

The specimen was suspended in free-free conditions. Impaction was applied perpendicular to the specimen surface using impact hammer. The response was recorded in all other perpendicular directions.

F.M. Santos et al.[9] have studied the dynamic behavior of the fast patrol boat. Most fast patrol boats have small length/depth ratios of 4.6 which causes problem of inaccuracy in result obtained by beam theory. So, a three dimensional finite element analysis was developed for solving complex problems. Modal analysis have been made and compared the natural frequencies and mode shapes with values obtained by three dimensional finite element analysis. The equation of motion of ship structure was presented by evaluating fluid interactions over the ship hull and also analysed two dimensional non uniform beam model by Prohl-Myklestad method. They also developed two three dimensional geometry (beam and plate) and obtained natural frequencies and mode shapes by ANSYS. While comparing natural frequencies of all the three models they found that 3D plate gives lower natural frequencies than 2D and 3D beam model. It is found that variation of result between all the models is due to small length/depth ratio and discontinuities in ship structure such as deck openings etc thus caused modeling problems.

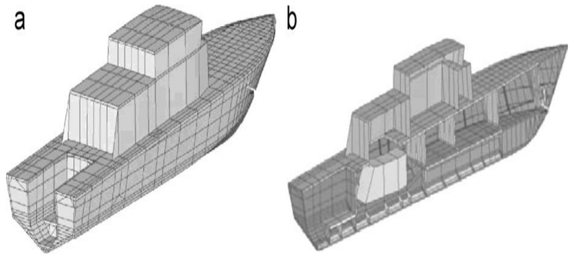

Fig.2. Finite Element Model

Sourabha Havaldar et al.[10] have performed analytical and experimental study for estimation of damping ratios of different composite materials. Glass fiber reinforced plastics [GFRP] as face sheets and Polyurethane foams [PUF], natural cork as core material are used in this study. Polyurethane foams of densities 65 kg/m3 [PUF65] and 400 kg/m3 [PUF400] are used for three different monolithic sandwich panel fabrication. Similarly PUF and cork of 300 kg/m3 density [CORK300] are used to fabricate six different hybrid sandwich panels. First Elastic constants are determined by Gibson equation (for monolithic material) and by series combinations rule of mixture in order to find shear modulus. Pure materials and nine different combinations were tested experimentally with the help of FFT analyser to find the experimental damping ratio. Also Analytical expression is made for predicting the damping ratio of these materials. Predicted and experimental damping value shows that PUF with low density and cork gives high damping capacity. Thus for determination of damping ratio, density and shear modulus plays important role.

Husain Mehdi et al.[11] have performed a modal analysis on composite beams with and without Cracks. Composite beam is made of aluminium and fibers (nylon and glass fiber reinforced plastic). Composite beam used here is chosen as cantilever beam Model of uniform cross section. First mechanical properties of aluminium, nylon and GFRP are measured using universal testing machine. Then modal analysis is done on ANSYS 14 by feeding the already measured mechanical properties of material inorder to determine the natural frequencies and mode shapes. From the result it is found that for pure materials of aluminium composite with nylon gives less deflection rather than using GFRP and also deflection increases for increase in cracks. But in case of natural frequencies, it is larger for pure materials (nylon and GFRP) than composite beams and also natural frequencies decreases as number of cracks increases. Also Finite element values made a good agreement with analytical values.

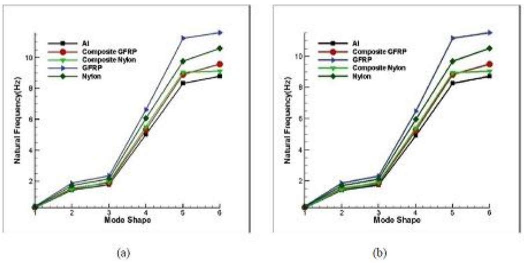

Fig.3.Variation between Natural frequency and Mode Shape (a) 0 Crack (b) 9 Cracks

Shiwei Niu[12] have done an modal analysis of cylindrical gear based on finite element model. In this analysis Pro/E software is used for creating a solid cylindrical model and is analysed in finite element software. Three kinds of materials such as cast iron, 40 Cr and 20CrMo are analysed individually for cylindrical gear model in order to find out the natural frequency. It is found that natural frequency increases with increase of elastic modulus. Modal analysis of gear with web type is also performed. Here the influence of gear structure on natural frequencies was studied and found that natural frequencies are much smaller in web type than compared to solid type gear. This shows that there is relation between structure and natural frequency. This method will be very useful for gear design parameters and analysis of gears.

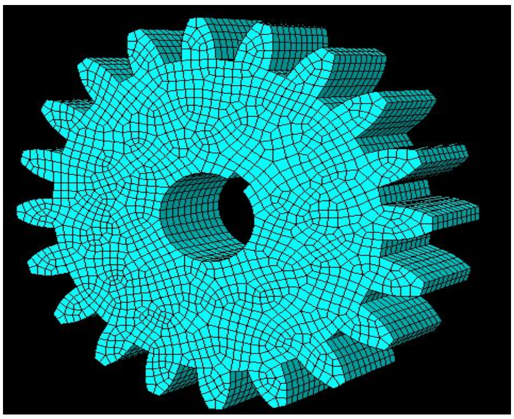

Fig.4. Meshed view of the gear

M.S.Patil et al.[13] have analysed vibration of a gearbox casing of tata indigo cs vehicle with the help of finite element analysis. Natural frequency of casing is determined by ANSYS software. First solid model is made in PRO E and meshed with hyper mesh. Then stress analysis is done to determine the theoretical natural frequencies for first 12 mode in free free condition. Also Fast Fourier Transformer (FFT) analyser is used to calculate experimental natural frequencies. Finally theoretical and experimental values of natural frequencies are compared. The comparison shows good agreement between these values. Hence a methodology of vibration based techniques have been presented for condition monitoring in geared box casing to avoid effect of vibration failure in their working life.

Table.2. ANSYS and Experimental results

Modes	ANSYS Frequency (Hz)	Experimental Frequency (Hz)	Error (%)
1	709.19	717.52	0.84
2	950.97	961.27	1.04
3	1543.8	1559.03	1.60
4	1899.5	1914.91	1.50
5	2297.6	2312.62	1.90
6	2742.1	2756.12	1.50

Nilofar H Pathan et al [14] have discussed the design and modal analysis of spur gear along with its experimental verification. The analysis is done in both analytical method and with the use of software. In the analytical the natural frequency of the gear material (EN9) is calculated with the help of the torsional theory. The modal analysis is done by the software called nastran and the values obtained from the FEM is compared with the analytical values of natural frequency. Analysis are made by changing the material (EN19B and EN353) to improve its performance. It is found that frequency of the gear is increased by changing the material (EN353) and it is suitable for spur gear .The experimental verification is made with the help of vibration test using FFT analyzer and accelerometer.

Manjunath N Kenchraddi et al [15**]** have investigated the dynamic behavior of hybrid Aluminium metal matrix composites. In this paper the dynamic behavior of various composition of composite material (tungsten carbide and fly ash) along with the aluminium alloy (LM 6) is studied. The analysis made both experimentally and numerically. The below table shows the various composition of elements taken into consideration.

Table.3. Composition of materials

Specimen 1	Specimen 2	Specimen 3	Specimen 4	Specimen 5
Base Alloy (Aluminium LM 6)	LM 6 + 1% WC + 2% fly ash	LM 6 + 2% WC + 4% fly ash	LM 6 + 3% WC + 6% fly ash	LM 6 + 4% WC + 8% fly ash

The experimental analysis is made with the help of FFT analyser and the modal test results are obtained for both cantilever and free-free plates of all the specimens. The obtained natural frequency of the specimen is compared with the results of natural frequency obtained from the numerical analysis .It is found that by adding the composite material the frequency of the specimen is changed to certain extent and its behavior is also changed based on the requirement different composites can be used for different purpose.

Christian A .Geweth et al [16] have intended to detect the damage on reinforced composite structures using experimental modal analysis. In order to obtain the information about the production process nondestructive testing method is used on the specimens. Five multilayer fibre-reinforced specimens are tested in order to detect the change in frequency due to the defects.

Table.4. Defect description

Specimens	Defect
Pr 1 OK	Produced without artificial damage
Pr 2 OK	Produced without artificial damage
Del 10 mm	10 mm area of artificial delamination
Del 25 mm	25 mm area of artificial delamination
Pressure	Incomplete infiltration of resin due to insufficient pressure during manufacturing

The measurement is done with the help of LSV where the frequency range is split into two series which differs in the method of excitation and number of measurement points. The results are obtained and it is further examined with the modal analysis done on ME' scope VESTM .The obtained modes were sorted by their mode shapes, the comparison of different mode numbers are given below.

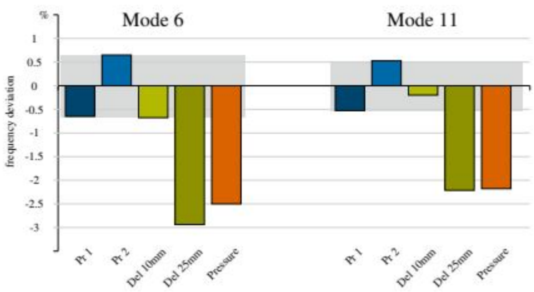

Fig.5. Natural frequencies of the sixth and eleventh mode.

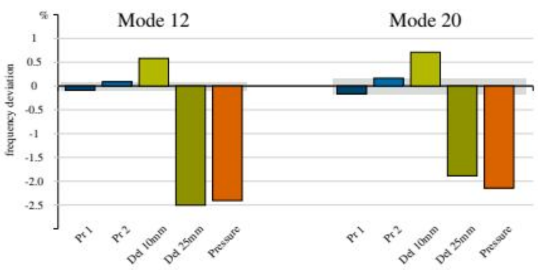

Fig. 6. Natural frequencies of the 12th and 20th mode

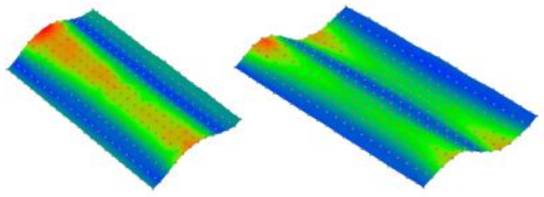

Fig.7. Mode shape of the sixth (left) and eleventh (right) mode

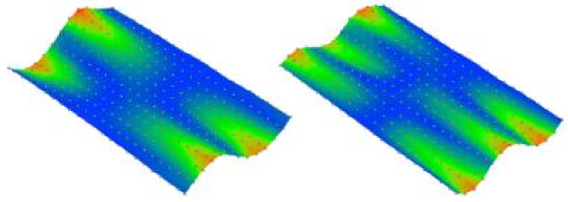

Fig. 8. Mode shape of the 12th (left) and 20th (right) mode

The fig shows that the defected specimens have low natural frequency than the other specimen, it is due to the decrease in the stiffness of the specimen. It is found that same behaviour could not be observed for increase of nodal lines and loops over the length of the specimen the possible reason would be the position of the PTFE-layer. Finally, with the help of this analysis there is also a possibility of finding the position of the defect.

Amreen Taj et al [17] have investigated the variations in the fundamental frequencies of aluminium graphite specimen due to its geometric structures. The dynamic behaviour is evaluated by its density, natural frequencies of the structure, mode shapes and damping factors. The specimen is formed by taking the various compositions of Al-graphite mixture and its young's modulus is calculated using the rule of mixture.

$$EC_1=EF_1V_F+EM_1V_M$$

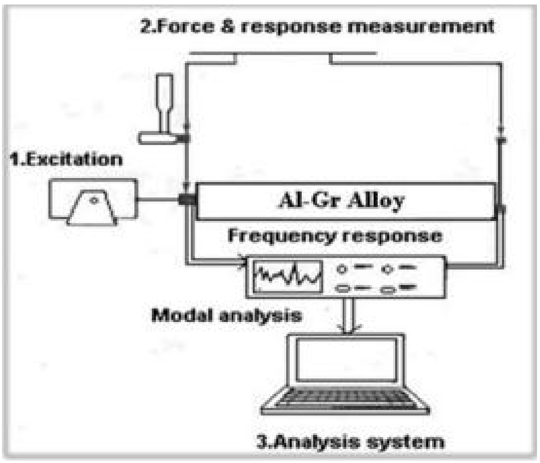

Fig. 9. FFT analyser set up

The experimental analysis is done with the help of FFT analyser along with the accelerometer to measure the vibration and the output is displayed in the analyzer screen with the help of the software. Along with that the result of modal damping is also obtained from the experimental analysis. The modal analysis is carried out with the help of ANSYS 11 software and results of natural frequencies are obtained. The damping ratio is found by using logarithmic decrement. The results of experimental and modal analysis are compared and it is found that the increase in percentage of graphite increases the natural frequency of the specimen.

III. CONCLUSION

From the literature review it is clear that the vibrational characteristics of a material is entirely depends on its mechanical properties and size. Through vibration signature the present condition of the component can be predicted. Vibration analysis is used at condition monitoring also.

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