Determination of Natural Frequency for CFRP Composite Satellite Antenna Reflector using Vibration Analysis

Dhaval B. Shah, Kaushik M. Patel and Shashikant J. Joshi*

Mechanical Engineering Department, Institute of Technology, Nirma University, Ahmedabad.
**E-mail: s.j.joshi@nirmauni.ac.in*

***Abstract*— The reflector is required for high gain space antenna systems for telecommunication payloads. The carbon fibre reinforced polymer (CFRP) is broadly used in aerospace industries and space applications owing to their decent specific properties over pure metals and alloys. The frequency for a typical satellite antenna reflector is an important parameter for different types of payloads.**

In this article, parabolic reflectors have been fabricated with the autoclave process to attain great dimensional accuracy. The number of prepreg layers made from CFRP have been arranged at specific orientation on AISI 430 grade stainless steel mould. The mould - prepreg assembly as well as consolidation material has been vacuum bagged and cured in the autoclave machine. The high volume fraction can be achieved using the autoclave process in composite manufacturing. The natural frequency has been determined for reflector using FFT analyser in vibration measurement test setup. The volume fraction has been determined using scanning electron microscopic (SEM) technique. The effect of layup orientation and fiber volume fraction on natural frequency has been studied. As volume fraction increases, the natural frequency for the reflector decreases gradually.

***Index Terms*— Autoclave curing, Fiber volume fraction, Natural frequency, Reflector, Scanning electron microscopy.**

I. Introduction

Among all composite materials, CFRP are comprehensively employed in space applications and aerospace industries thanks to their terribly high specific strength and stiffness. The foremost common trendy applications of the paraboloid reflector are reflective and radio telescopes, satellite communication dishes, solar cookers, microphones, and lots of lighting devices like spotlights, automotive headlights, etc. The autoclave curing process is highly used for the manufacturing of complicated shape with high volume fraction [1-2]. An antenna is a device used for radiating and/or receiving electromagnetic waves. For deep space communication, reflector types of antennas are preferred due to better gain associated with it. Basically, a parabolic shape is preferred for an antenna, as the number of energy waves can be absorbed and transmitted within the same path [3].

Donthi et al. [4] estimated natural frequency for different configuration antenna reflector using the finite element approach. Ali et al. [5] studied the impact of volume fraction and mass magnitude on the natural frequency of functionally graded clamped plate connected with point mass. Belkov et al. [6] estimated stiffness for largely sized umbrella space reflectors using analytical and numerical approach. Darrow and Smith [7] thought-about spring-in effects on mould expansion, thickness cure shrinkage and fiber volume fraction gradients parameters. Kaushik et al. [8] considered the impact of the degree of cure, pressure and ramp rate on the friction coefficient within the autoclave method. Stefniak et al. [9] performed experimental work to compute the stress gradient and property gradient mechanisms with regard to their relative influence to composite part deformations.

In this article, parabolic reflectors made from CFRP have been fabricated by means of the autoclave manufacturing process to achieve nice dimensional accuracy. The AISI 430 grade chrome steel material has been identified for fabrication of paraboloid male mould. The layers of carbon fiber prepreg have been positioned at particular orientation on male mould. The release agent, peel ply, breather fabric, vacuum bag, etc. have been arranged in correct sequence on assembly of prepreg and mould. The natural frequency for all fabricated reflectors has been measured using FFT analyser in vibration measurement test apparatus. The different layup orientation i.e. unidirectional, balanced, cross and quasi-isotropic are used to prepare an antenna reflector. The fiber volume fraction has been determined from results of scanning electron microscopy. The effect of layup orientation and fiber volume fraction on natural frequency has been studied.

II. Antenna Reflector Manufacturing

The metallic mould and composite part interaction is the

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Dhaval B. Shah is an Assistant Professor in Mechanical Engineering Department, Institute of Technology, Nirma University, Ahmedabad 382481, Gujarat, India. (e-mail: dbshah@nirmauni.ac.in).

Kaushik M. Patel is a Professor in Mechanical Engineering Department, Institute of Technology, Nirma University, Ahmedabad 382481, Gujarat, India. (e-mail: kaushik.patel@nirmauni.ac.in).

Shashikant J. Joshi is a Professor in Mechanical Engineering Department, Institute of Technology, Nirma University, Ahmedabad 382481, Gujarat, India. (e-mail: s.j.joshi@nirmauni.ac.in).

crucial factor for process induced deformation of the finished products. The AISI 430 grade of stainless steel material has been identified as mould material because of the similarities in coefficient of thermal expansion (CTE) with composite material as well as ease of availability. The material properties for the selected grade of stainless steel material are summarized in table I.

TABLE I
MATERIAL PROPERTIES FOR STAINLESS STEEL BLOCK AS MOULD MATERIAL

Properties	Values
Specific Gravity (gm/cc)	7.8
Young's Modulus (GPa)	210
Yield Tensile Strength (MPa)	280
CTE (/°C)	$11.4*10^{-6}$
Thermal Conductivity (W/mK)	25

The stainless steel block AISI 430 Grade of 300 mm X 300mm X 70mm size is machined using 5-axis VMC machine as shown in figure 1. The high surface accuracy is achieved while machining to get proper dimensional control for the reflector.

Fig. 1. The paraboloid stainless steel mould

The carbon fiber epoxy prepreg of twill configuration has been procured. Hinpreg®A45 is a sophisticated epoxy prepreg developed to alter economic fabrication of different superior composite products. This prepreg consists outstanding mechanical properties and having superb surface finish. This prepreg has been withdraw the circular form of diameter 300 mm when marking. The peel ply, release agent, breather cloth, vacuum bag, etc. consolidation materials have been procured such that they resist high temperature while curing process. The aim of release film is to remove finished composite product from the mould whereas peel ply permits free passage of volatiles and excess matrix throughout the solidifying process. The breather cloth and peel ply have been cut identical to the prepreg. The layers of release agent has been applied on the curve surface of the mould. The numbers of layers with correct sequence of prepreg have been organized one over another. The sealant tape has been stick at the four corner of mould. The peel ply and breather cloth have also been stacked on the assembly within which breather cloth offers the means that to use the vacuum and assists removal of air and volatiles from the total assembly. The total setup has been vacuum bagged employing a vacuum film and within the centre location of the bag, a hole has been created to accommodate the vacuum valve. The hose pipe has been associated to the valve and pump at respective ends.

The complete air entrapped inside the bag has been taken out using a vacuum pump through the vacuum valve. This whole setup has been kept in laboratory scale autoclave machine as shown in figure 2 for curing of CFRP reflector. The curing cycle has been applied as per selected prepreg type in a controlled manner with constant ramp-up rate of 2 °C/min. The external pressure of 5 bar has been applied throughout the cycle. The vacuum pressure has been maintained to ensure no air inside the bag during the curing of the reflector in the autoclave.

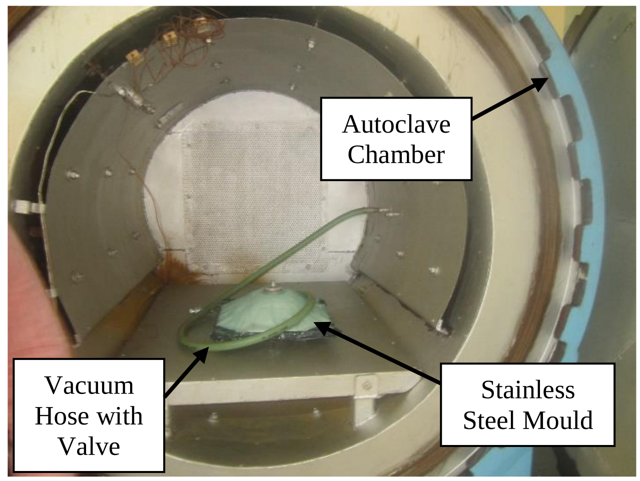

Fig. 2. Curing in autoclave machine

The entire assembly has been taken out from the autoclave curing process. The consolidation materials, as well as composite reflector, have been detached from the total assembly at atmospheric condition. The final cured composite reflector is shown in Fig. 3. The complete process has been repeated with other layup sequences to understand the result of layup sequence on natural frequency.

Fig. 3. Composite cured antenna reflector

III. MEASUREMENT OF NATURAL FREQUENCY

The natural frequency is measured for prepared composite reflectors using FFT analyser. The vibration test setup has been prepared as shown in figure 4. The accelerometer can be kept at end of composite component to measure its natural frequency. The signal from the accelerometer can be captured by a computer to get amplitude and frequency as shown in figure 5.

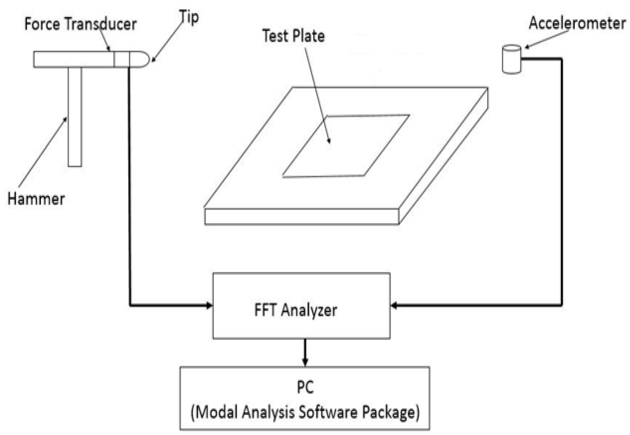

Fig. 4. Vibration testing setup

Fig. 5. Test set up for vibration testing

The natural frequency of composite reflector is found 12 Hz as shown in figure 6 to figure 8. The different g load acceleration i.e. 5.1 g, 2.7 g and 1.7 g have been applied during measurement for natural frequency. The acceleration vs. frequency graphs have been generated from software available with FFT analyser.

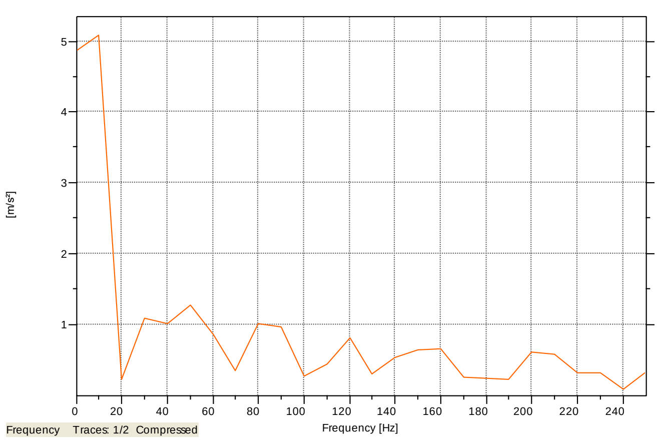

Fig. 6. First natural frequency – 12 Hz with 5.1 g acceleration

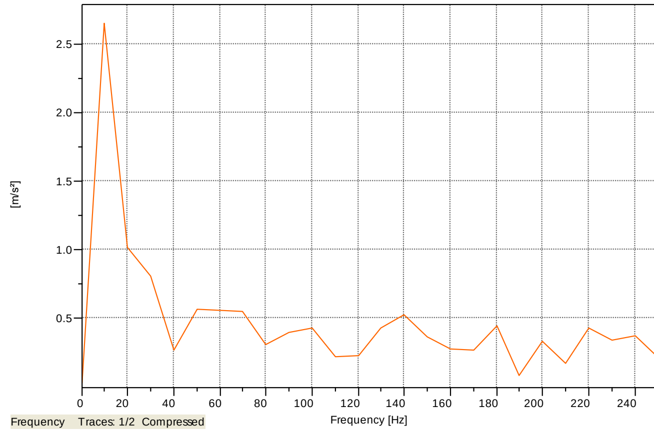

Fig. 7. First natural frequency – 12 Hz with 2.7 g acceleration

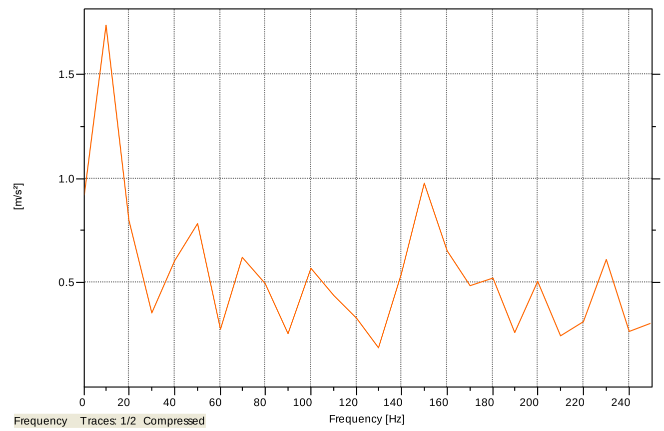

Fig. 8. First natural frequency – 12 Hz with 1.7 g acceleration

IV. Measurement of Fiber Volume Fraction

The composite manufactured reflectors have been analysed using scanning electron microscopy. The fiber volume fraction for each reflector has been measured from SEM images. The fiber volume fraction is that the magnitude relation of proportion of fiber volume within the entire volume of a fiber-reinforced part. The image for the SEM test with various magnification i.e. 500 X, 1000 X, and 2000 X are shown in figures 9 to 11. From this testing, fiber volume fraction is measured and in the range of 75% to 85% for the prepared composite reflector. The amount of fiber volume fraction has been varied in this small range because of the presence of different amount of moisture content in the prepreg due to relative humidity while manufacturing as well as the settlement of epoxy systems during the curing process. The image with higher magnification is clearer to measure this parameter compared to lower magnification images.

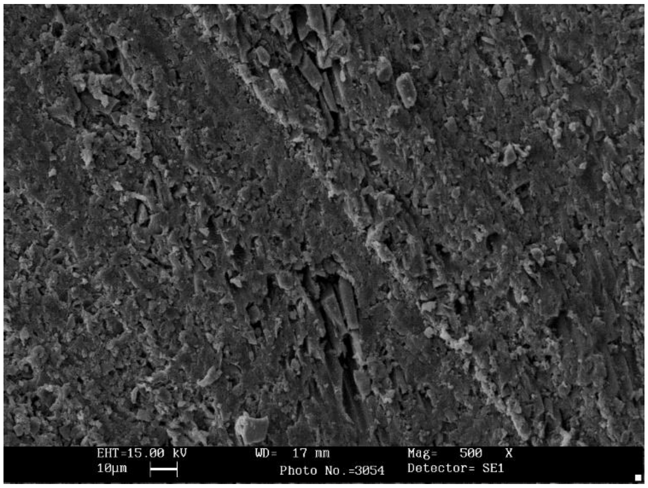

Fig. 9. SEM image with magnification 500 X

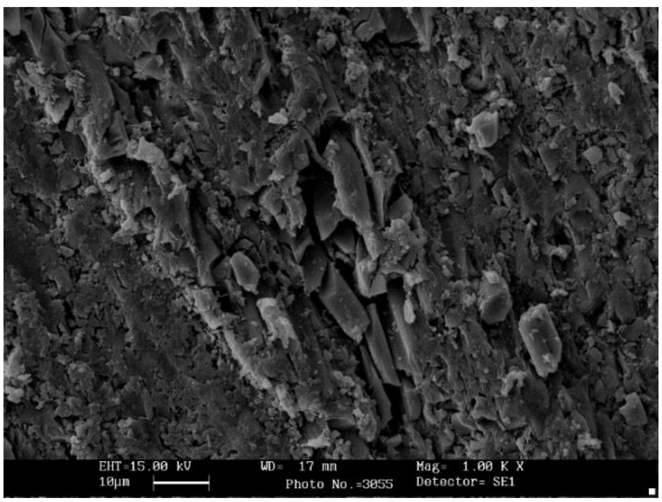

Fig. 10. SEM image with magnification 1000 X

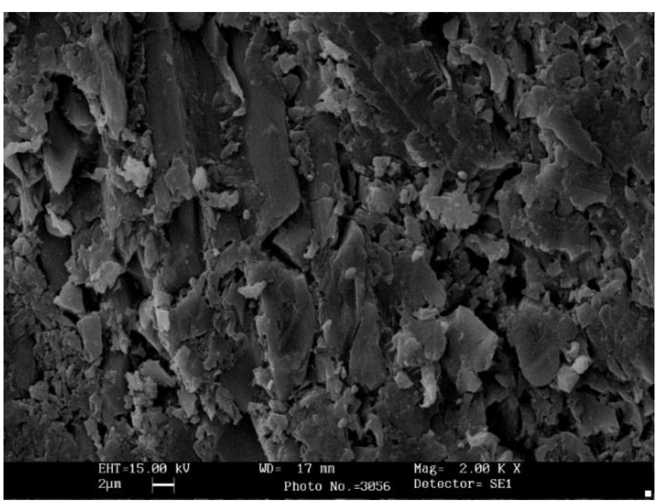

Fig. 11. SEM image with magnification 2000 X

The CFRP reflectors have been manufactured with different layup orientations. The fiber volume fraction for each reflector has been obtained in the range of 75 % to 85 %. For each volume fraction value, the corresponding natural frequencies have been determined and same has been plotted as shown in figure 12. As the fiber volume fraction increases, the natural frequency for the corresponding reflector decreases. The natural frequency is inversely proportional to the square root of the mass of the component.

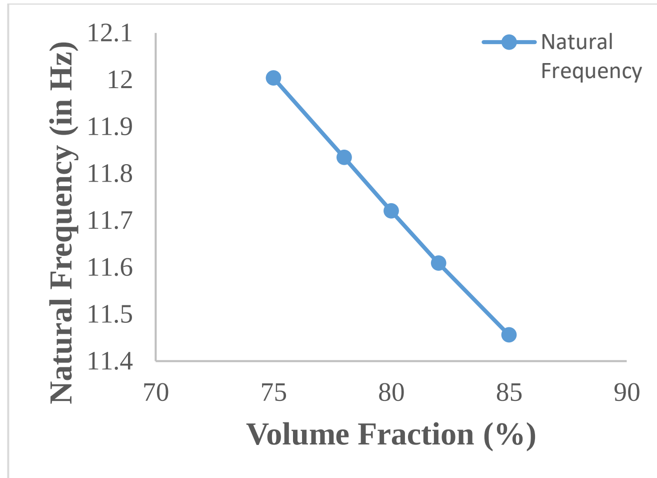

Fig. 12. Volume fraction vs. natural frequency

V. CONCLUSION

The CFRP reflectors have been manufactured using autoclave manufacturing process with stainless steel mould and Hinpreg A45 – twill prepreg tape to predict natural frequency. Consolidation materials have been organized in correct sequence on the mould. The different layup sequences i.e. uni-directional, cross-ply and balanced have been considered. The natural frequency has been determined for each configuration of reflectors using FFT analyser. This fundamental frequency has been found at 12 Hz. In order to optimize the mass, a balanced layup sequence with symmetric and quasi-isotropic layers are to be preferred. Finally, the better frequency can be achieved by optimized mass configuration. The volume fraction for manufactured reflectors has been determined using the scanning electron microscope technique. This amount of volume fraction for different reflectors have been found in the range of 75% to 85%. The effect of layup orientation and fiber volume fraction on natural frequency have been obtained.

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Dhaval B. Shah is currently working as an Assistant Professor in Mechanical Engineering Department, School of Engineering, Institute of Technology, Nirma University. He has received B. E. degree in Mechanical Engineering in the year 2007 from Gujarat University. He has obtained M. Tech degree specialization in CAD/CAM in the year 2009 and pursuing Ph. D. degree from Nirma University. He has an experience of more than 10 years in the field of teaching and research. He has presented/published more than 45 papers in International Journal, Conferences / Proceedings. He is actively associated with providing consultancy services to many industries. He has guided more than 25 PG dissertations. He has successfully completed two minor research projects funded by Nirma University. He is active member of various society like SAE, SSME and ISTE. Currently, he is working as a faculty advisor of SAE Nirma Collegiate Club.

Dr. Kaushik M. Patel obtained M.Tech. (Manufacturing Engineering) from IIT Bombay, Mumbai and Ph.D. from IIT Delhi, New Delhi. He also holds Postgraduate Diplomas in Marketing Management and Finance Management from IGNOU. He has about three years of professional experience in maintenance of heavy engineering equipment and machinery used in seamless tube manufacturing. He has about twenty years of academic experience of teaching at undergraduate and postgraduate level. His research interest includes analysis of various manufacturing processes namely welding, casting, and machining. He guided 37 major projects at M. Tech. (CAD/CAM) and M. Tech. (Computer Integrated Manufacturing) programmes. He guided 1 Ph.D. student and is presently guiding 7 Ph.D. students for their research work. He has published a number of papers in National & International conferences and journals. He has been working as a reviewer of International Journals like IJAMT, Materials and Design, Rapid Prototyping Journal, etc. He has rendered professional services to leading Universities at various capacities. He is also Principal Investigator and Co- Principal Investigator for the projects sponsored by SERB-DST, ISRO Respond and Nirma University. He is active member of ISTE.

Dr. Shashikant J. Joshi is currently working as a professor in Mechanical Engineering Department, School of Engineering, Institute of Technology, Nirma University. He has received B. E. degree in Production Engineering in the year 1998 from Dr. BAM University. He has obtained M. Tech degree specialization in Engineering Materials in the year 2001 from MANIT, Bhopal and Ph. D. degree in the year 2017 from RGPV Bhopal. He has an experience of more than 15 years in the field of teaching and research. He has presented/published more than 30 papers in International Journal, Conferences / Proceedings. He is actively associated with providing consultancy services to many industries. He has guided more than 40 PG dissertations. He has been working as a reviewer of many International and National Journals. He has rendered professional services to leading Universities at various capacities. He is also Principal Investigator and Co- Principal Investigator for the projects sponsored by ISRO Respond and Nirma University. He is active member of ISTE and SSME.