Spin Test of Flywheel with Layered Composites Three-Dimensional Model to Determine Shear Stresses with Different Hub Angle

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***Abstract* — The analysis has presented the effect of shear Stress with different profiles of the flywheel with different layered (0.5mm, 1mm, 1.5mm) and different Hub angle (4˚, 5˚, 6˚) the natural frequency and modes of different materials and shear stress effects were analyzed on different profile and materials of flywheel and distribution along the flywheel was studied. The natural frequency along the flywheel profile is found to be maximum of the T1000G material profile with multi rim flywheel and different hub angle. The shear stress distribution along the multi rim flywheel is maximum for T300-POM and minimum for T300-T1000G of a flywheel with different profiles. The magnitude of frequency is minimum in the case of T300-POM material profile with 4˚ hub angle. The nature of the natural frequency is maximum near its end in 3rd, 4th and 6th mode. The nature of the shear stress is minimum near its hub of flywheel with 0.5mm multi rim of T300-T1000G and 4˚ inclined hub angle.**

Keywords— Fly Wheel, Shear Stress, Hub Angle, Composites

I INTRODUCTION

Composite materials are produced basically by combining two heterogeneous materials into a new material that may be better suited for a particular application than either of the original materials alone. The most common example of a composite material is the fibre glass-reinforced plastic commonly used in household goods and in many industrial applications. The plastic alone is relatively weak and has a low and elastic modulus, that is, It bend and stretches easily. However, it is very stable chemically and constitutes an excellent matrix for the composite. The glass fibre provides the strength and stiffness; their modulus of elasticity may be 50 times greater than that of the plastic. Since the glass fibre can withstand a much higher tensile stress before strain or yielding occurs, they take most of the load when the composite is stressed. Many of our modern technologies require material with unusual combinations of properties that cannot be found out by the conventional metal alloys, ceramics and polymeric materials. This is especially true for materials that are needed for aerospace, underwater and transportation applications. Metals, glasses, ceramics, cement and polymers can also be combined in composite materials to produce unique characteristic such as stiffness, toughness and high temperature strength. Portland cement concrete, simple asphalt concrete and similar type of materials are considered as aggregate composites, whereas reinforced and prestressed concrete can be regarded as a first prototype of modern composite materials. Many of the composite materials are mainly composed of just two phases; one is known as matrix, which is continuous and surrounds the other phase, often called dispersed phase. Conventional monolithic materials means a large block of stone have limitations in achieving good combination of strength, stiffness, toughness and density. To overcome all these shortcomings and to meet the basic ever increasing demand of modern and recent day technology, composites are most hopeful and promising materials of recent interest. Metal matrix composites (MMCs) belongs particularly enhanced properties including high specific strength; damping capacity, specific modulus and also good wear resistance compared to unreinforced alloys. There has been an increasing interest in composites containing low density and low cost reinforcements.

II TRIBOLOGICAL EFFECTS

Mechanical properties of some of the composites are affected by the size, shape and volume fraction of the reinforcement, matrix material and reaction at the interface. The interface between some of the matrix and reinforcement plays an important role in determining the properties of MMCs. Stiffening and Strengthening rely on load transfer across the interface. Toughness is basically influenced by the crack deflection at the interface and ductility is affected by the relaxation of peak stress near the interface Extensive studies on the tribological type of characteristics of Al MMCs containing reinforcements such as Sic and Al2O3 is available in the literatures. Metal matrix composites (MMCs) are under consideration as potential candidate materials for a variety of structural type of applications such as those in the aeronautical and aerospace industries, transportation, defence and sports industries because of the range of mechanical properties they possess. There is however problems mainly associated with the production of reinforced composites, one of significance being the difficulty of getting a homogeneous distribution of reinforcement in the matrix, essential for optimum mechanical properties. T300 and T1000G is basically a baseline carbon fibre used in aerospace applications with intermediate modulus, world's highest tensile strength fibre. Suitable for light weight, tensile strength critical applications such as pressure vessels for aerospace.

Epoxy is either any of the basic components or the cured end products of epoxy resins, as well as a colloquial name for the epoxide functional group. Epoxy resins, also known as polyepoxides, are a class of reactive prepolymers and polymers which

contain epoxide groups. Epoxy has a wide range of applications, including metal coatings, use in electronics / electrical components/LED, high tension electrical insulators, paint brushes manufacturing, fiber-reinforced plastic materials and structural adhesives.
Polyplastic (POM), also known as acetyl, polyacetal and polyformaldehyde, is an engineering thermoplastic used in precision parts requiring high stiffness, low friction, and excellent dimensional stability. As with many other synthetic polymers, it is produced by different chemical firms with slightly different formulas and sold variously by such names as Delrin, Celcon, Ramtal, Duracon, Kepital and Hostaform.

Typical applications for injection-molded POM include high-performance engineering components such as small gear wheels, eyeglass frames, ball bearings, ski bindings, fasteners, guns, knife handles, and lock systems. The material is widely used in the automotive and consumer electronics industry.

III CLASSIFICATION OF METAL MATRIX COMPOSITES

Composites are either categorised as- Fibre, particulate and laminar based on shape of the reinforcement or as- polymer matrix, metal matrix, ceramic matrix and carbon matrix based on the matrix material.

The various matrix materials are

1. Polymers
2. Metals
3. Ceramics and glasses
4. Fibre reinforced plastics

IV APPLICATIONS

- Carbon reinforced plastics are used for pressure vessels.
- Carbon reinforced plastics are used extensively in aerospace applications, including struts for the space shuttle.
- Carbon reinforced plastics are used in aircraft wing panels.
- Copper based alloys reinforced with SiC fibres are used for producing high strength propellers for ships.
- Titanium reinforced with SiC fibres are considered for turbine blades and discs.
- Super alloys reinforced with tungsten maintain their strength at high temperatures. They are used in jet engines and turbine blades.
- Carbon reinforced plastics are also used in helicopter
- Components and in casing of rocket motors.

Table 4.1: Properties of Material

Material	Mass density (kg/m^3)	Longitudinal elastic modulus (GPa)	Poisson's ratio (μ)	Tensile strength (MPa)
T300	1760	230	0.31	3530
T1000G	1800	294	0.31	6370
EPOXY	1250	3.4	0.36	NA
POM	1400	2.5	0.35	63

Objective of the Work

The main objective of the current work is

- Validation of the ANSYS models by comparing the present simulated results with the experimental result by N. Hiroshima.
- To predict shear stress effects for different layered flywheel (0.5mm, 1mm, 1.5mm) and different Hub angle (4˚, 5˚, 6˚) on the flywheel.
- To simulate the flywheel of the different layered flywheel (0.5mm, 1mm, 1.5mm) and different Hub angle (4˚, 5˚, 6˚) on the flywheel for variable modes and same RPM.
- Parameter sensitivity study of flywheel.
- To define natural frequency effects and shear stress effects for the flywheel of different layered and different hub angle and constant angular velocity of 35900rpm.
- To predict frequency distribution along the flywheel.

Problem Formulation

The study of various literatures we find the natural frequency is lower as compared to present study. The purpose of this study is to predict shear stress with different layered and hub angle in the flywheel at constant angular velocity of 35900 rpm. Thus chosen (0.5mm, 1mm, 1.5mm) layered and Hub angle (4˚, 5˚, 6˚) profiled flywheel for analysis.

V LITERATURE REVIEW

Sara Caprioli et al. [1], in this paper Thermal cracking of railway wheel treads is investigated using a combined experimental and numerical approach. Results from control break rig tests of repeated stop braking cycles for a common railway wheel in rolling contact with a name called rail wheel is presented. Test conditions are then numerically analysed using finite element (FE) simulations that basically account for the thermo mechanical loading of the wheel tread. For the studied wheel braking case, thermal cracks are found in the wheel tread after few brake cycles. Results from thermal imaging shows a frictionally excited thermo elastic instability pattern basically called "banding" where the contact between brake block and wheel takes place only over a fraction of the block width

A. Rupp et al. [2], the introduction of flywheel energy storage device in a light rail transit train is analyzed. Mathematically operated models of the train, driving cycle pattern and mainly flywheel energy storage systems are developed. These type of models are required to study the energy use and consumption and the operating and running cost of a light rail transit train with and without flywheel

energy storage capacity. Results tell that maximum energy savings of 31% can be obtained using flywheel energy storage systems with the help of energy and power capacity of 2.9 kWh and 725 kW systematically. Cost savings of 11% can be possessed by utilizing different flywheel energy storage systems with power rating of 1.2 kWh and 360 kW. The basic introduction of flywheel energy storage systems in a light rail transit train can basically result in substantial energy and cost savings.

Xujun lyu et al. [3], Energy storage flywheels helps on active magnetic bearings (AMBs) have attracted much attention both in the academia and in the industry due to many of their advantageous features, such as short charging time, high specific energy, no pollution and long lifespan. Feedback controlling is essential in the operation of AMB support systems. However, actual types of AMB suspended energy storage flywheels are not widely available for research on feedback control design. To deliver an economic and efficient platform for the study of AMB supported energy storage flywheels, which includes research on the design of their feedback controllers, we propose in this paper to match or emulate the operation of such flywheels on a rotor AMB test rig we recently constructed

Daniel Jung et al. [4], the crankshaft angular velocity measured and calculated at the flywheel is a commonly used signal for engine misfire detection. However, flywheel manufacturing errors or defects result in vehicle-to-vehicle change or variations in the measurements and have a diverse impact on the misfiring detection performance. A misfiring detection algorithm must be able to compensate for this type of vehicle-to-vehicle changing if it is being used in production cars to assure that legislations are satiated. It is shown that flywheel angular variations between vehicles in the magnitude of 0.05° have a prominent impact on the measured or calculated angular velocity and should be compensated for to make the misfire detection algorithm robust. A misfire detection algorithm is basically proposed with the flywheel error adaptation in order to increase robustness and decrease the number of mis-classifications

Makbul A.M. Ramli et al. [5], this paper analyzes a hybrid energy system performance with photovoltaic (PV) as well as diesel systems as the main energy sources. The hybrid energy system is equipped with flywheel to store excess energy from the PV. HOMER software was employed to study the basic economic and important environmental benefits of the particular system with flywheels energy storage for Makkah, Saudi Arabia. The analysis focused on the impact of utilizing flywheel on the power generation, total energy cost, and the net present cost for certain configurations of the hybrid system. Analyses on fuel consumption and carbon emission reductions for the system configurations were also presented in this paper

Zanjhi Wei et al. [6], the micro vibrations generated by flywheels running at full speed onboard high precision spacecrafts will affect stability of the spacecraft bus and further degrade the pointing correctness of the payload. A passive vibration isolation type of platform comprised of multi-segment zigzag beams is proposed to isolate disturbances of the flywheel. By presuming the flywheel and the platform as an integral and undivided system with some gyroscopic effects, an equivalent dynamic model is developed and verified through eigen value and frequency response analysis. The critical speeds of the system are concluded and expressed as functions of some system parameters.

VI MODELING AND ANALYSIS

5.1 Procedure for finite element analysis

Consider the example of an automobile piston. A piston during the operation of I.C Engine is subjected to various types of loads like impact load, friction force, reaction from cylinder wall due to thermal expansion of piston etc. Due to these loads, a non-uniform stress distribution may take in the piston body. This nature of stress distribution can be determined using finite element analysis approach, in which the entire body of the piston is divided into smaller elements called finite elements. These elements may be square, cuboidal, tetrahedral, prism or hexahedral elements. These elements are connected to each other at corner vertices (or nodes). Element matrices are defined to find the value of stresses at these nodes. Then a global stress matrix is defined which represents the stress distribution in entire body of the piston. Once the stress distribution in the entire body of piston is known, design improvements can be made by increasing wall thickness in the region of higher stress accumulation. Finite element method is a numerical analysis technique and is used to find variables. These field variables may be vector quantities like displacement, stress, etc. or scalar quantities like distance, temperature etc.

Any analysis to be performed by using finite element method can be divided into following steps:

1. Discretization
2. Choosing the solution approximations.
3. Forming the element matrix and equations.
4. Assembling the matrices.
5. Finding the unknowns.
6. Interpreting the results

Preprocessing: Finite element modelling

1. Generating nodes
2. Defining elements
3. Mesh generation
4. Defining load and material properties.

Processing: Finite element analysis

1. Forming element materials
2. Assembling element materials
3. Applying boundary conditions
4. Finding the unknowns

Postprocessing:

1. Interpreting the results.

To use the FEA packages properly, the following points are significant:

1. Which elements are to be used for solving the problem in hand.
2. How to discritize to get good results.
3. How to introduce boundary conditions properly.
4. How the element properties are developed and what are their limitations.
5. How the displays are developed in pre and post processor to understand their limitations.
6. To understand the difficulties involved in the development of FEA programs and hence the need for checking the commercially available packages with the result of standard cases.
7. Field variables: In engineering problems there are some basic unknowns. If they are found the behaviour of the entire structure can be predicted. These unknowns are called field variables in FEA. Displacements in structural mechanics, temperature in heat flow processes, velocities in fluid mechanics, electric and magnetic potentials in electrical engineering.
8. In a continuum, these unknowns are infinite.

9. The finite element process reduces the unknowns to a finite number by dividing the solution region into small parts called elements.
10. In FE procedure the unknown field variables are expressed in terms of assumed approximating functions within each element. The approximating functions are defined in terms of field variables of specified points called nodal points.
11. This function which relates the field variable at any point within the element to the field variables of nodal points is called shape function.

VII RESULT AND DISCUSSION

6.1 Shear Stress and Natural Frequency along the Flywheel with Different Layered Materials and Different Inclined Hub Angles.

A Structural and Modal - analysis was carried out to analyze shear stress of Flywheel with different Layered material and different inclined hub angle relation between natural frequency and spin speed four types of materials of T300, T1000G, EPOXY, POM, with flywheel to determine the frequency distribution along the Flywheel. Frequency distribution contours in case of flywheel are shown in **Figure**, and the effect of different materials on Flywheel profile on the frequency and modes distribution for various materials are represented in the Figure.

7.1.1 Shear stress of 0.5mm layer flywheel

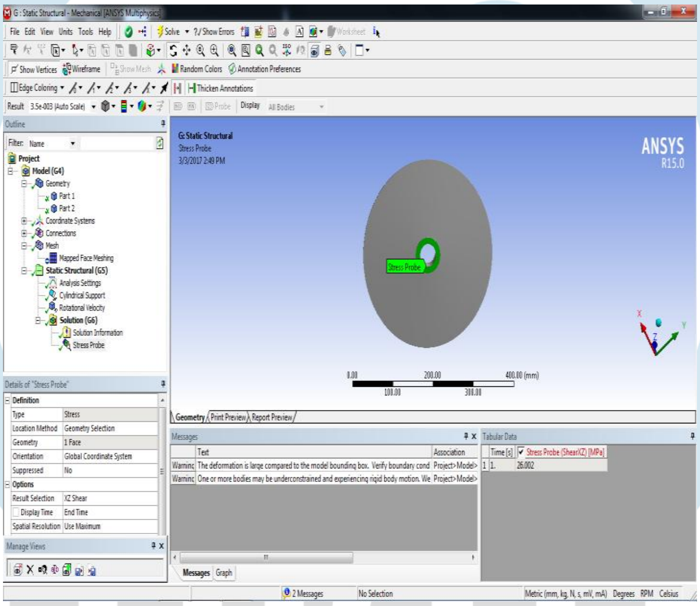

Figure : 7.1 Shear stress of 0.5mm layer flywheel of (T300-T1000G) material.

7.1.2 Shear stress of 1mm layer flywheel

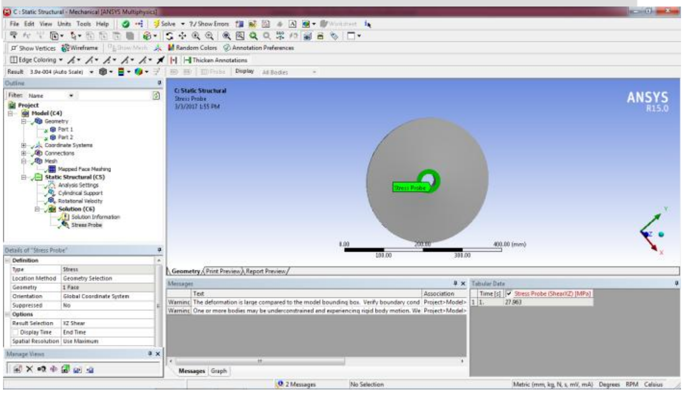

Figure : 7.2 Shear stress of 1mm layer flywheel of (T300-T1000G) material

7.1.3 Shear stress of 1.5mm layer flywheel

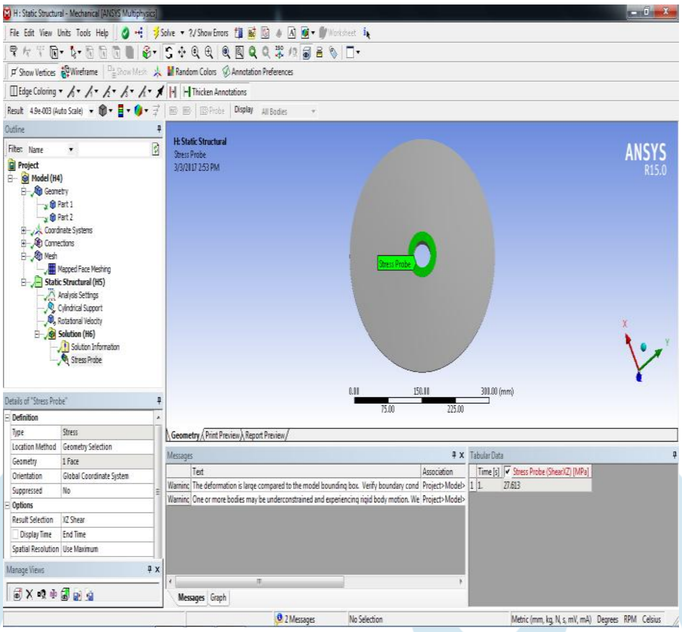

Figure : 7.3 Shear stress of 1.5mm layer flywheel of (T300-T1000G)

7.2 Different Layers shear stress in (T300-EPOXY)

7.2.1 Shear stress of 0.5mm layer flywheel

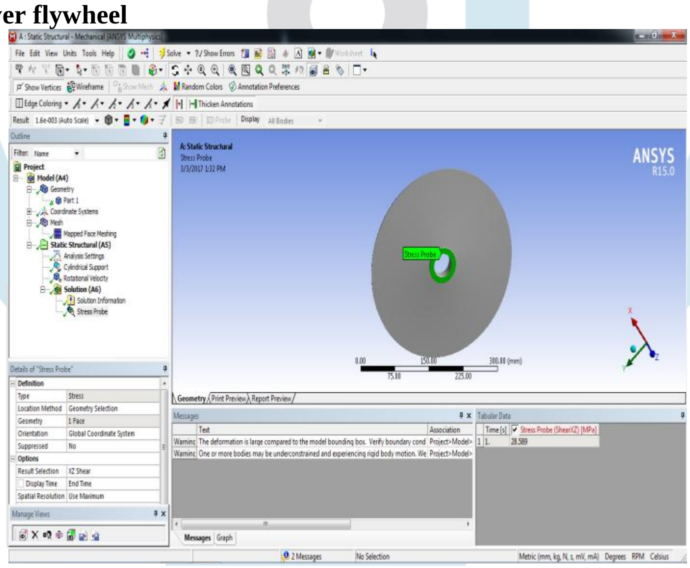

Figure: 7.4 Shear stress of 0.5mm layer flywheel of (T300-EPOXY)material

7.2.2 Shear stress of 1mm layer flywheel

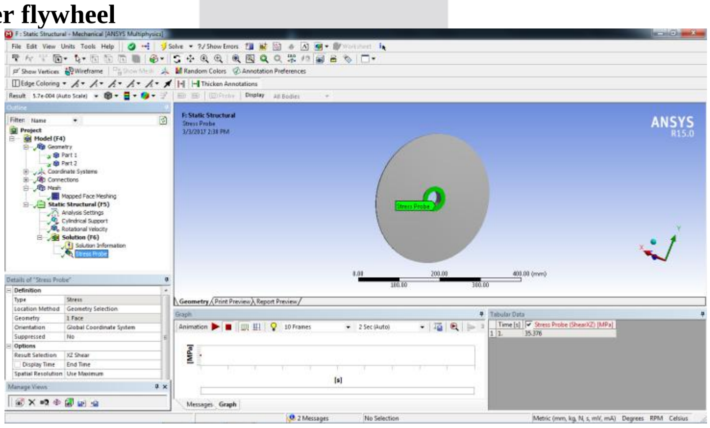

Figure: 7.5 Shear stress of 1mm layer flywheel of (T300-EPOXY) material

7.2.3 Shear stress of 1.5mm layer flywheel

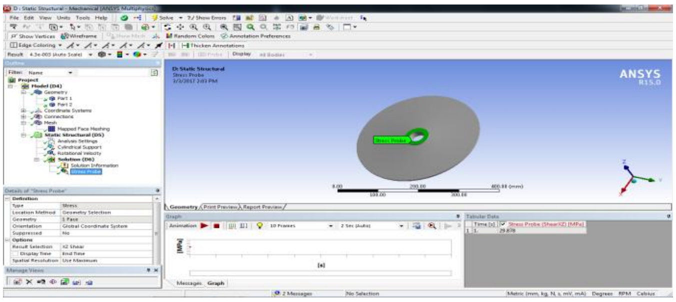

Figure: 7.6 Shear stress of 1.5mm layer flywheel of (T300-EPOXY) material

7.3 Different Layers shear stress in (T300-POM)

7.3.1 Shear stress of 0.5mm layer flywheel

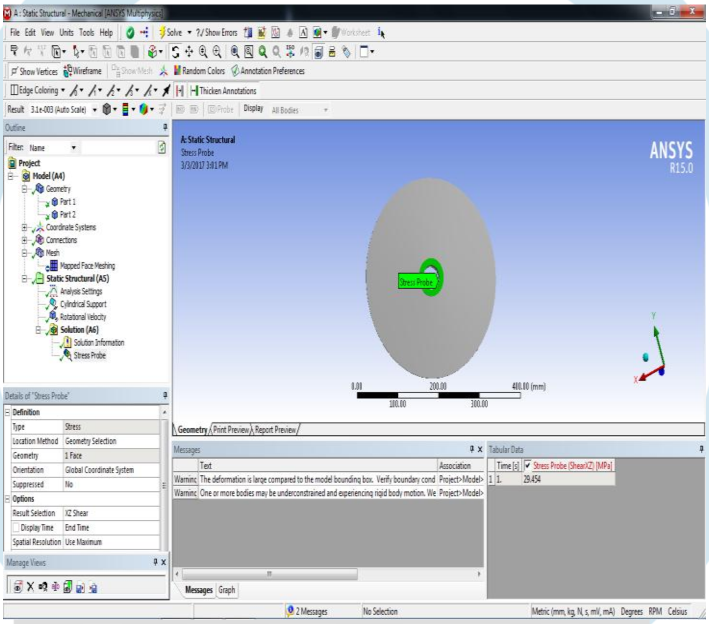

Figure: 7.7 Shear stress of 0.5mm layer flywheel of (T300-POM) material

7.3.2 Shear stress of 1mm layer flywheel

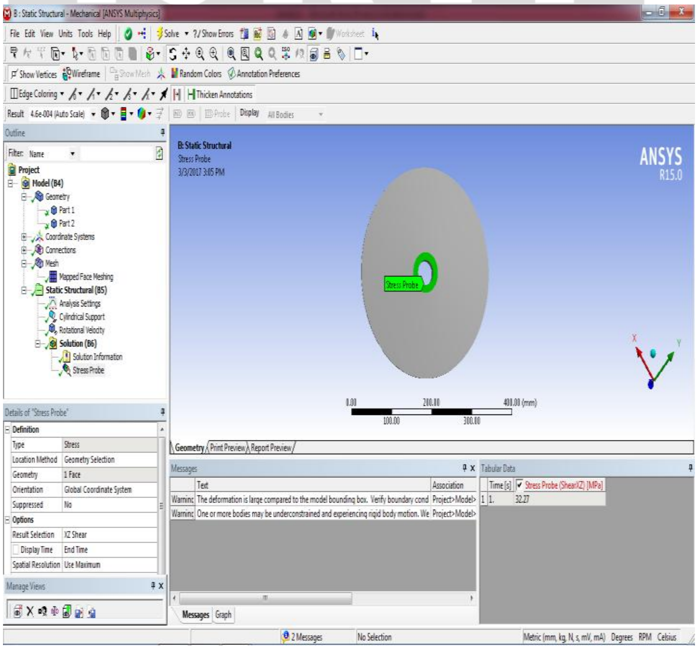

Figure: 7.8 Shear stress of 1mm layer flywheel of (T300-POM)material

7.3.3 Shear stress of 1.5mm layer flywheel

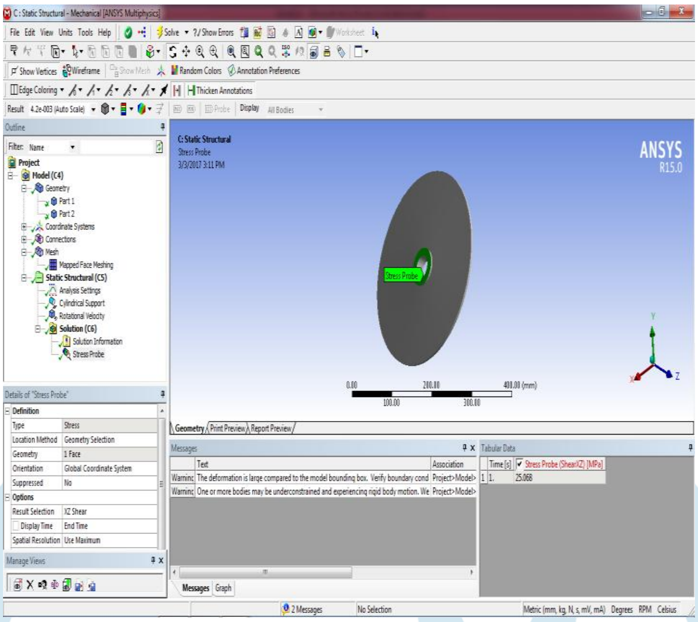

Figure : 7.9 Shear stress of 1.5mm layer flywheel of (T300-POM) material.

Table: 7.1.1 Shear stresses on different layer materials of flywheel.

Combine material	0.5 mm Layer	1 mm Layer	1.5 mm Layer
T300-T1000G	26.002	27.963	27.613
T300-EPOXY	28.589	35.376	29.878
T300-POM	29.454	32.27	25.068

Table: 7.1.2 Shear stresses on different inclined angles and materials of flywheel

Materials	4˚ Angle	5˚ Angle	6˚ Angle
T300	2.5534	3.1272	3.2962
T1000G	2.2065	2.3735	2.3789
EPOXY	3.2624	3.353	3.2011
POM	2.8107	2.6201	2.6255

7.4 Contour Plots of Natural Frequency of T300 non layer Flywheel with their Different Modes

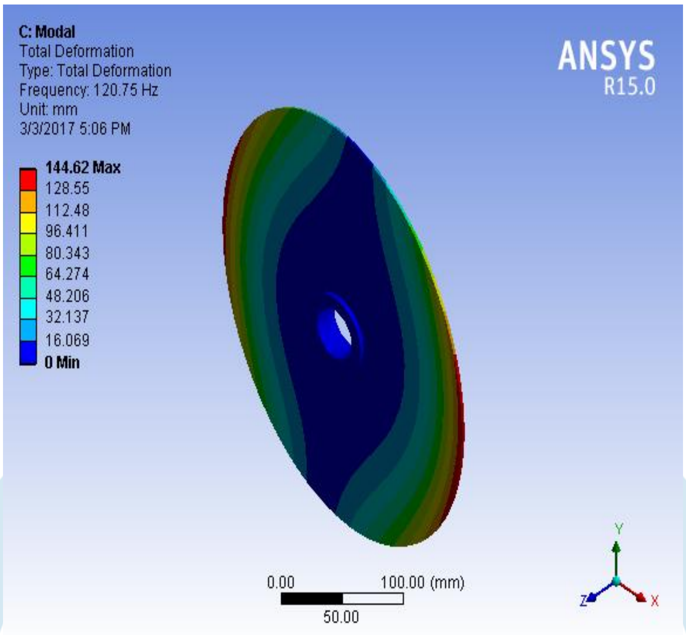

Figure:7.10 First mode frequency of T300 non- layer flywheel

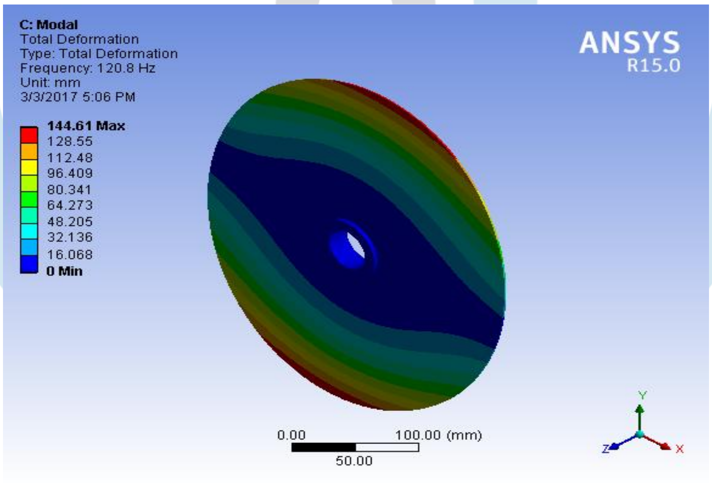

Figure: 7.11 Second mode frequency of T300 non- layer flywheel

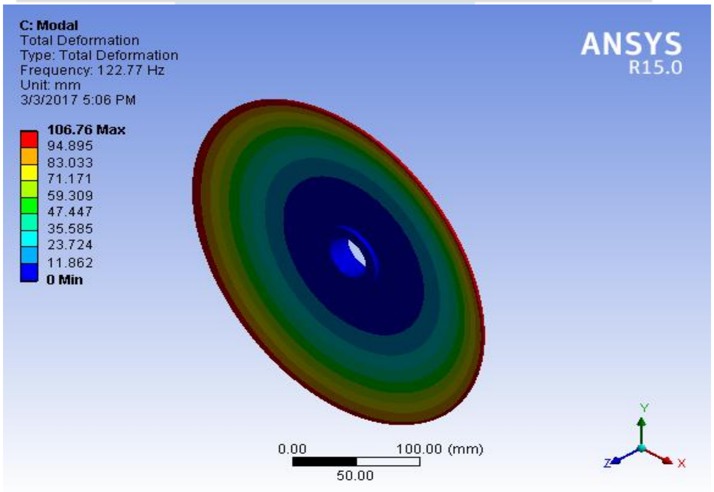

Figure: 7.12 Third mode frequency of T300 non- layer flywheel

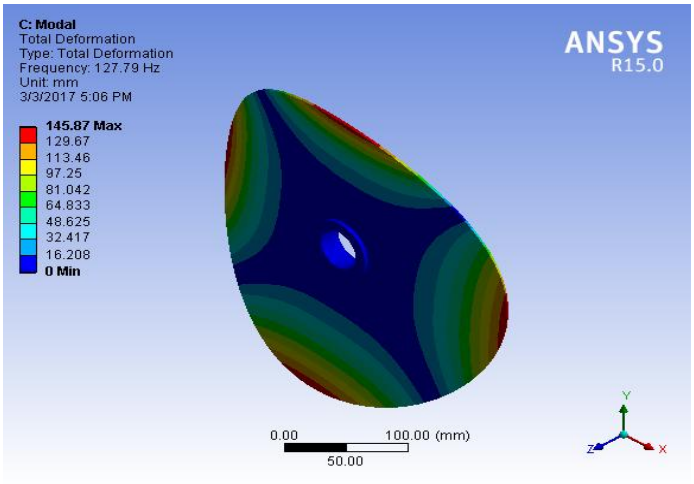

Figure: 7.13 Forth mode frequency of T300 non- layer flywheel

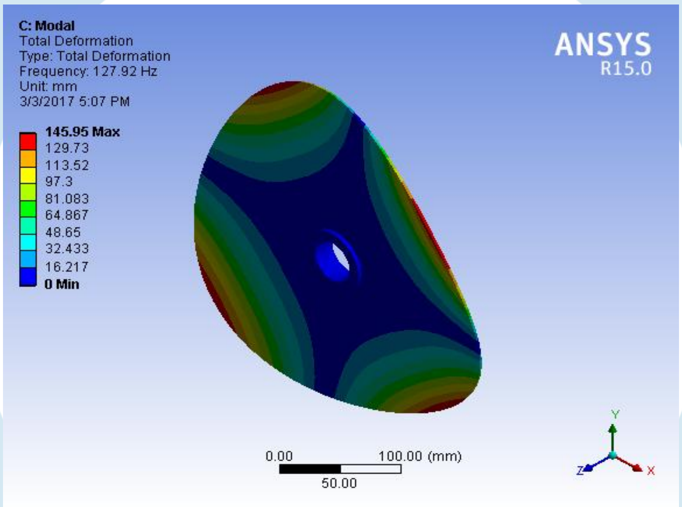

Figure: 7.14 Fifth mode frequency of T300 non- layer flywheel

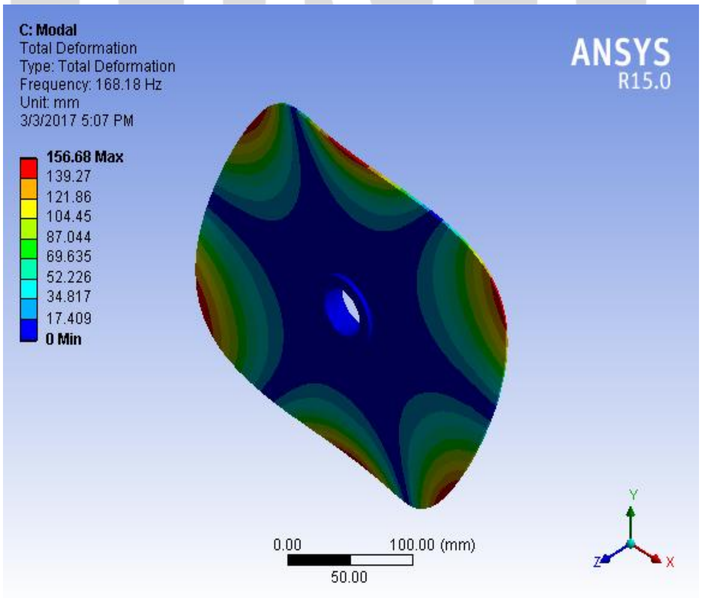

Figure: 7.15 Sixth mode frequency of T300 non- layer flywheel

Table 7.1.3: Shows natural frequency values w.r.t modes of non layered material.

Non Layer				
Modes	T300	T1000G	EPOXY	POM
1	120.75	135.00	127.79	144.16
2	120.80	135.06	179.04	144.24
3	122.77	137.25	183.32	147.47
4	127.79	142.86	185.21	149.87
5	127.92	143.01	185.40	150.04
6	168.18	143.01	242.16	196.18

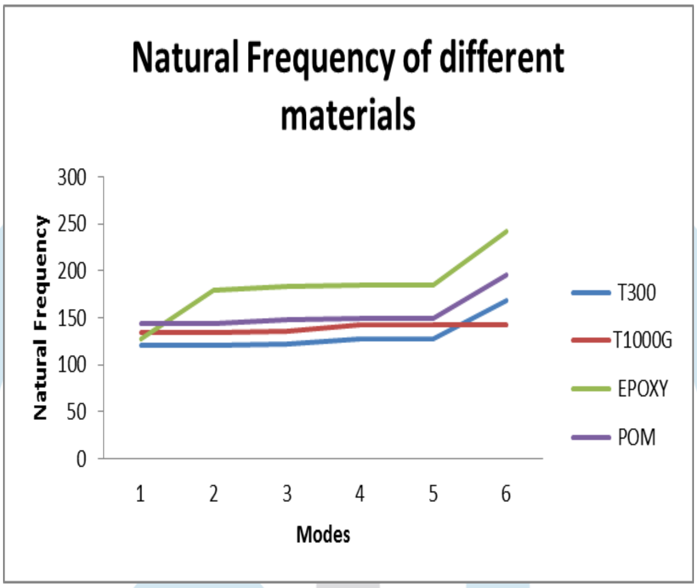

Figure 7.16: Natural frequency of POM, T1000G, EPOXY, T300

VIII CONCLUSION

The current analysis has presented a study of natural frequency characteristics of a flywheel of different profiles. Structural analysis was carried out on T300, T1000G, EPOXY, POM system. The effect of shear Stress with different profiles of the flywheel with different layered(0.5mm, 1mm, 1.5mm) and different Hub angle (4˚, 5˚, 6˚) the natural frequency and modes of different materials and shear stress effects were analyzed on different profile and materials of flywheel and distribution along the flywheel was studied. From the analysis of the results, following conclusions can be drawn.

8.1 Influence of different flywheel profiles

The natural frequency along the flywheel profile is found to be maximum of the T1000G material profile with multi rim flywheel and different hub angle. The shear stress distribution along the multi rim flywheel is maximum for T300-POM and minimum for T300-T1000G of a flywheel with different profiles.

The magnitude of frequency is minimum in the case of T300-POM material profile with 4˚ hub angle. The nature of the natural frequency is maximum near its end in 3rd and 4th, 6th mode.

The nature of the shear stress is minimum near its hub of flywheel with 0.5mm multi rim of T300-T1000G and 4˚ inclined hub angle for the same RPM and different modes of natural frequency.

Future Scope

- Solid Flywheel and thicker Flywheel could be used to analyze Shear stresses for different Hub angle.
- Different materials can be used for analyzing frequency and Shear stress for different types of Flywheel.
- Different Hub angle be also analyzed for different RPM to predict Shear stresses for Flywheel for save design.

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