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DESIGN ANALYSIS AND WEIGHT REDUCTION OF CAR FLYWHEEL BY USING FEA- A REVIEW PAPER

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Abstract *- Flywheel is a rotatng mechanical device that is used to store rotational energy. Flywheels have a significant moment of inertia and thus resist change in rotational speed. Flywheel development has been dominated by mobile application where minimizing mass is critical. The main problem with flywheel is its higher weight which results in lower rotational speed. The main objective of this work is to study various researches done in past to reduce weight of flywheel by changing design and materials.*

Keywords: *Flywheel, Design, Composite, FEA.*

I. INTRODUCTION

Flywheels serve as a kinetic energy storage and retrieval device that stores twisting or spinning motion and then release it as rotational kinetic energy to provide motion when the requirement of the energy is more than supply. The amount of energy stored in a flywheel is proportional to square of its rotational speed. The main function of flywheel is to smoothen out variation in the speed of a shaft caused by torque fluctuation [10]. Flywheels are typically made of steel and rotate on conventional bearings having a higher weight. These are generally limited to a revolution rate of a few thousand RPM. As it is necessary to modify or design advanced flywheel having a lighter weight and less fracture possibilities with composite material. For that stress analysis are carried out to flywheel for different composite materials [13].

II. LITERATURE REVIEW

Christos .c chamis et al. (1976) [1] in this paper elementary relations are used to determine the material utilization efficiency of thin wall composite flywheel compared with other configuration. An algorithm was generated for the automatic selection of the optimum composite material for given thin wall flywheel environment. Subsequently computer programme NASTRAN (NAsa STRuctural ANalysis) was used to perform a detail stress and vibrational analysis of both single and multi rim thin wall composite flywheel for a specific application. The hoop wound thin wall cylindrical rim is most weight efficient basic element flywheel configuration for carbon fibre composite. Multirim flywheels combine both weight efficient and volume efficient rims to optimize the total energy capacity for single flywheel installation. NASTRAN can be used for stress and structural dynamic analysis of both single and multi rim flywheel.

J.D.Herbst, et al. (2000) [2] Published Paper describes the design, fabrication, and spin testing of two 10 MJ composite flywheel energy storage rotors. To achieve the demonstrated energy density of greater than 310 kJ/kg in a volume of less than 0.05 m^3, the rotors utilize flexible composite arbors made up of Toray T700, Toray M30S and S2 glass to connect a composite rim to a metallic shaft, resulting in compact, lightweight, high energy density structures. The paper also describes the finite element stress and rotor dynamics analyses, along with a description of the fabrication and assembly techniques used in the construction of the rotor. A description of the experimental setup and a discussion of spin testing of the rotors up to 45,000 rpm are also presented. In the 1^{st} spin test at 39300 rpm speed radial growth of rotor is 1.46 mm while predicted value is 1.40 mm in which difference between two values is more hence geometry changes at rim/arbor interface are done in spin test 2. In the 2^{nd} spin test at 45000 rpm speed radial growth is 1.80 mm while predicated value is 1.81mm which is nearer and there is no further increment in vibration level.

G.R. Kress et al. (2000) [3] this paper deals with finding the best thickness distribution along the radius of a centrally bored flywheel under the objective of reaching an even stress distribution. A global numerical shape optimization procedure is used, employing a two-dimensional Finite -Element-Method (FEM) model, and a one-dimensional analytical model based on simplified mechanical considerations and inspired by Stodola's solution for an evenly stressed turbine disk without central bore. Both models are presented in detail and the results compared. According to the simplified model, an even-stress shape design does not exist for bore radii greater than the square root of one-third of the radius of the flywheel. The optimum-shape predictions of both models agree well if the radius of the bore does not exceed approximately one third of the radius of the disk. The stress level in the optimized design is approximately only one third of the maximum circumferential stress at edge of the bore in a flywheel of constant thickness.

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Mofid Mahdi et al. (2011) [4] this paper considered three solid flywheel disk profiles that are constructed using functions of cubic splines. Using FEM, the cubic splines parameters are analyzed systematically to seek a maximum stored kinetic energy per unite mass. All FEM computations were carried out using ANSYS. Three flywheels thickness profiles were analyzed based on cubic splines functions. The study concluded that: (1) A more cases of flywheel disk thickness functions should be analyzed, (2) case 2 and case 3 shows that thinner flywheel disk has a higher capability of kinetic energy storing respectively KE/Ma (KJ/kg) = 31.5 and 33.2, and (3) the corresponding maximum effective stresses are found near the centre of flywheels where thickness should be maximum.

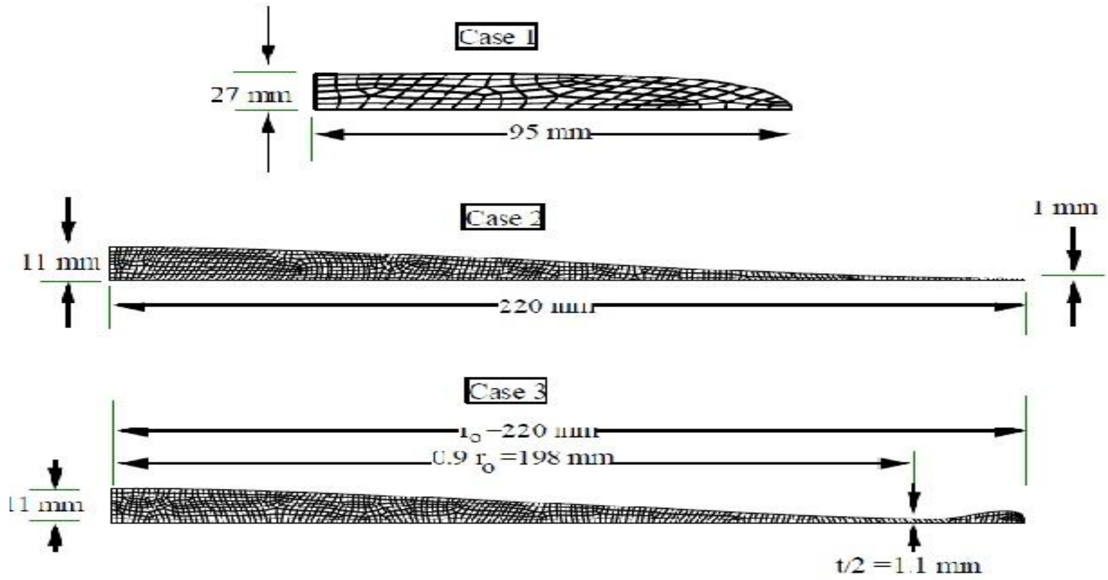

Figure 1.Optimized cases shapes

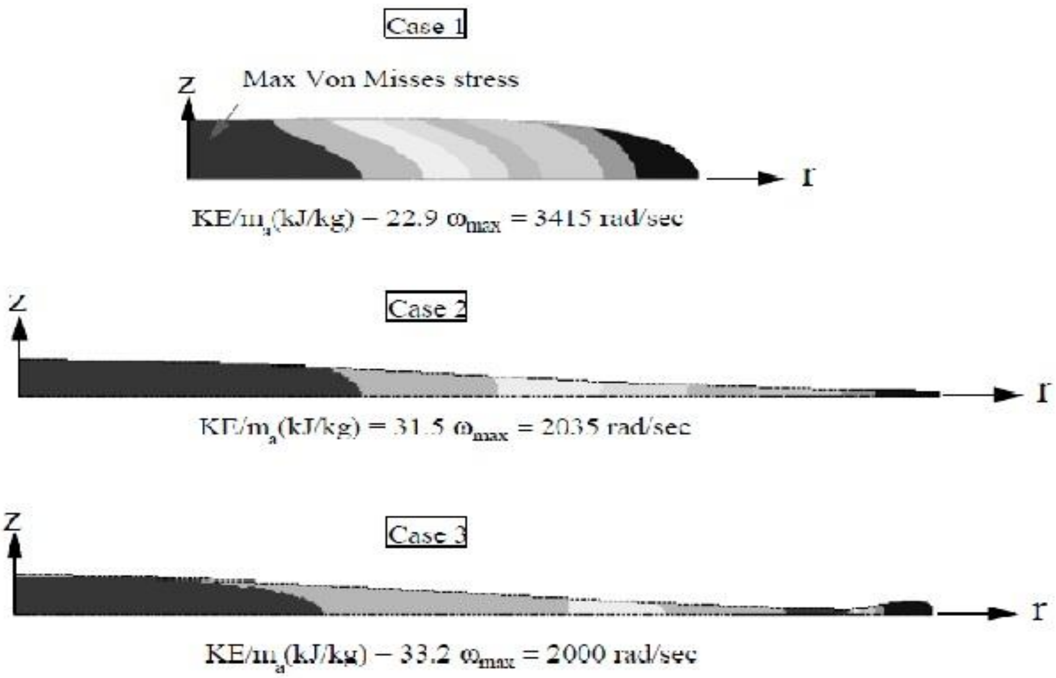

Figure 2. Capability and stress state of flywheel optimized cases

K.Hayat et al. (2011) [5] this paper describes a hybrid composite flywheel rotor designed to store 50 kWh (Kilo Watt hour) energy at maximum rotational speed of 17,000 rpm.Design optimization and stress analysis were carried out by

FEA to acquire a hybrid composite dome-type hub geometry. Both the rotor and dome type hub were then fabricated by filament winding process using glass and carbon fibre reinforced composites to provide required stiffness to match radial growth and axial contraction during high rotational speed. As shown in figure below the hub and rotor were assembled by press-fitting technique to apply the necessary compression at the composite rotor inner surface, resulting in lowering of undesired radial tensile stress. The performance of the hybrid composite dome-type hub was verified by conducting a successful spin test of the flywheel rotor up to the target test speed of 17,000 rpm. Result shows that at 17000 rpm speed vibration level reduced at 14 to 44%. It also exhibits sufficient stiffness to apply required compression at the rotor inner surface to prevent the separation and to overcome the problem of excessive vibration at high speed rotation. The designed hybrid composite flywheel rotor with dome type hub is a successful step towards the development of high speed, high energy storage capacity composite flywheel.

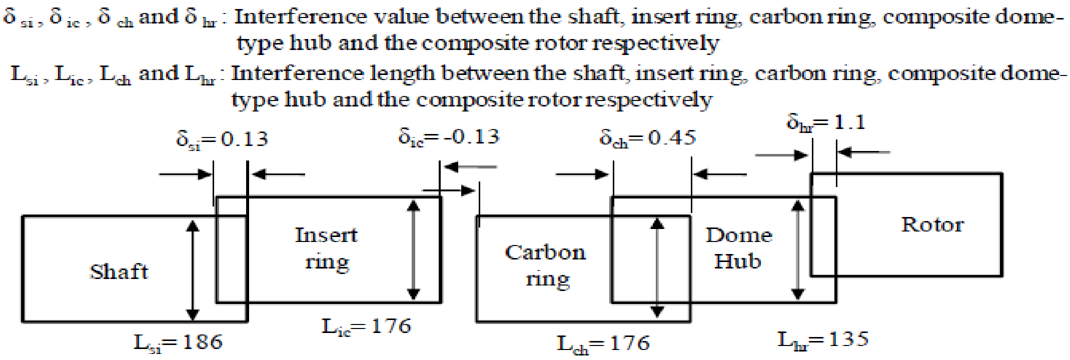

Figure 3. Interference values for press-fit assembly of the composite flywheel rotor

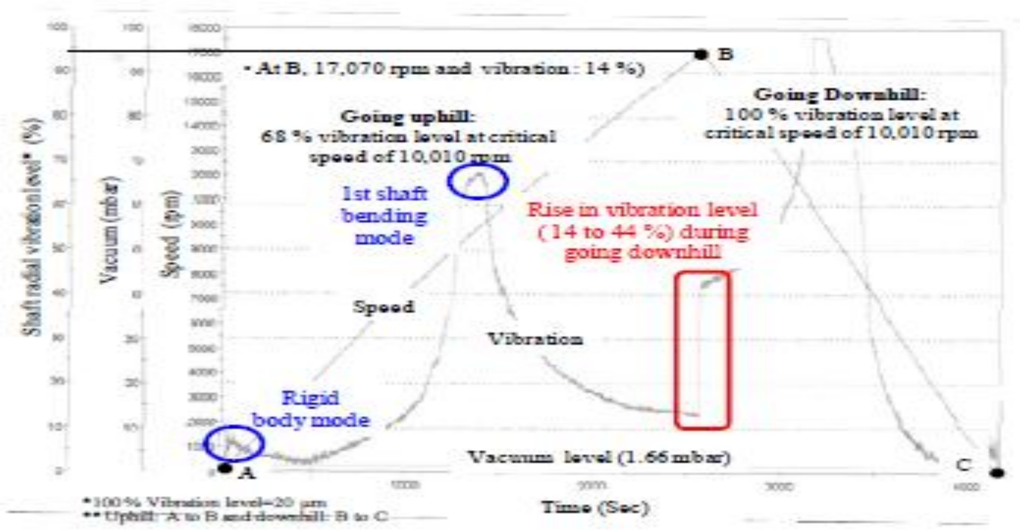

Figure 4. Spin test result

Sushama G Bawane et al. (2012) [6] had proposed flywheel design, and analysis the material selection process. The Gray cast iron, ASTM 30.SAE 111 was selected for the flywheel of MARUTI SUZUKI OMNI. The FEA model is described by using CATIA software to achieve a better understanding of the mesh type, mesh size and boundary conditions applied to complete an effective FEA model. Gray cast iron model was compared with aluminium alloy. After analysis the total deformation of Gray cast iron including equivalent stress Mpa, Normal stress Mpa and shear stress Mpa was 0.00001419 mm while in aluminium alloy the total deformation was 0.0000224 mm. Hence Gray cast iron can be used to reduce stress and weight of flywheel.

Table 1. Comparison of result by ANSYS

Quantity	Gray cast iron	Aluminium alloy
Equivalent stress (von-misses stress) , Mpa	0.02189	0.02164

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Normal stress, Mpa	0.003073	0.003591
Shear stress, Mpa	0.001474	0.001556
Total deformation	0.00001419 mm	0.0000224 mm

S. M. Dhengle, et al. (2012) [7] in this paper evaluation of stresses in the rim and arm are studied using finite element method and results are validated by analytical calculations .The models of flywheel having four, six and eight no. arms are made up of Gray cast iron developed for FE analysis. The FE analysis is carried out for different cases of loading applied on the flywheel and the maximum Von misses stresses and deflection in the rim are determined. From this analysis it is found that (1) Maximum stresses induced are in the rim and arm junction. Due to tangential forces, maximum bending stresses occurs near the hub end of the arm. (2) For low angular velocity the effect gravity on stresses and deflection of rim and arm is predominant. (3) As the number of arms increases from 4to 8, the stresses in the arms goes on reducing. This may be due to sharing of load by larger no. of arms. (4) With increase in angular velocity the stresses are increasing. This is due to larger centrifugal forces acting on the flywheel rim. (5) When the gravity effect along with angular velocity is considered, it is observed that the stresses at the junction of rim and arms are more than that of neglecting gravity effect. Thus the gravity effect contributes to rise in the stresses in flywheel rim. (6) As the fillet size goes on increasing the stresses are reducing considerably thus suitable fillet size is recommended for lower stress value.

Mauleeswaran senthil kumar et al. (2012) [8] had put forward discussion of composite flywheel design. Based on analytical approach for calculating stresses in flywheel using genetic algorithm. The problem was solved for a sample flywheel with varying materials. Minimum mass required is found out for different value of energy storage and corresponding other parameters are found out for five different materials cast iron, aluminium alloy, marging steel, carbon fiber composite and E Glass fiber epoxy . Finally, from the analysis, it is clear that, among five materials carbon fibre composites have lowest mass 0.001 kg and highest angular velocity 354 rad/sec for 500 j energy storage. It can be also used in high speed applications, as the values of angular velocities obtained are higher than that of other materials.

Table 2. Materials and functional values

Material	Energy storage	Mass (m) kg	Radius (r)	Angular velocity(ω) rad/sec
Cast iron	100	0.0033	0.829	208.91
	200	0.0066	1.039	166.67
	300	0.0100	1.089	159.00
	400	0.0130	1.109	156.16
	500	0.0166	1.128	153.42
Aluminium alloy	100	6.7E-4	1.065	361.46
	200	0.00130	1.423	270.48
	300	0.0020	1.488	258.59
	400	0.0027	1.510	254.87
	500	0.0033	1.528	251.95
Maraging steel	100	8.88E-4	1.009	332.26
	200	0.0017	1.344	249.58
	300	0.0026	1.406	238.59
	400	0.0035	1.427	235.04
	500	0.0044	1.444	232.28
Carbon fiber composite (40% epoxy)	100	2.06E-4	1.319	499.99
	200	4.13E-4	1.836	378.91
	300	6.20E-4	1.919	362.41
	400	8.26E-4	1.945	357.66
	500	0.001	1.964	354.15
E glass fiber (40 % epoxy)	100	7.6E-4	1.040	348.62
	200	0.0015	1.388	261.31
	300	0.0028	1.452	249.80
	400	0.0030	1.474	246.12
	500	0.0038	1.491	243.31

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Akshay P. Punde, et al. (2013) [9] has presented the investigation of a flywheel, A flywheel model is prepared by CATIA software, and analyzed by using Finite Element Analysis method. Further it is used to calculate the Stresses inside the flywheel by ANSYS; finally the comparison study between the Design and analysis with existing flywheel is carried out. The total deformation in Gray cast iron is 1.0484 x 10^{-3} while in S Glass epoxy total deformation is 5,3399 x 10^{-3}. Hence s glass epoxy can be used in flywheel to store higher energy with less mass.

Sudipta Saha et al. (2013) [10] have Proposed Computer aided analysis by using FEA and ANSYS for five different geometries (two straight geometry, concave triangular and convex) of flywheel as shown in figure. Optimization procedure results show that smart design of flywheel geometry could both have a significant effect on the Specific Energy performance and reduce the operational loads exerted on the Shaft/bearings due to reduced mass at high rotational speeds. The performance of case 5 is 50% better than case2. Case 5 exerts lowest shaft load than others as it has smallest mass.

Table 3. Comparison of result

	Case 1	Case 2	Case 3	Case 4	Case 5
Mass rotational seed (rpm)	19325	13198	24002	27225	31640
Mass (kg)	26.798	13.8296	16.0268	10.035	3.2923
Kinetic energy(J)	533.780	210437	403501	256418	110892
Max σmax = σy (MPa)	290	290	290	290	290
EK/ mass(kJ/ kg)	21.725	15.043	25.38	25.54	33.2

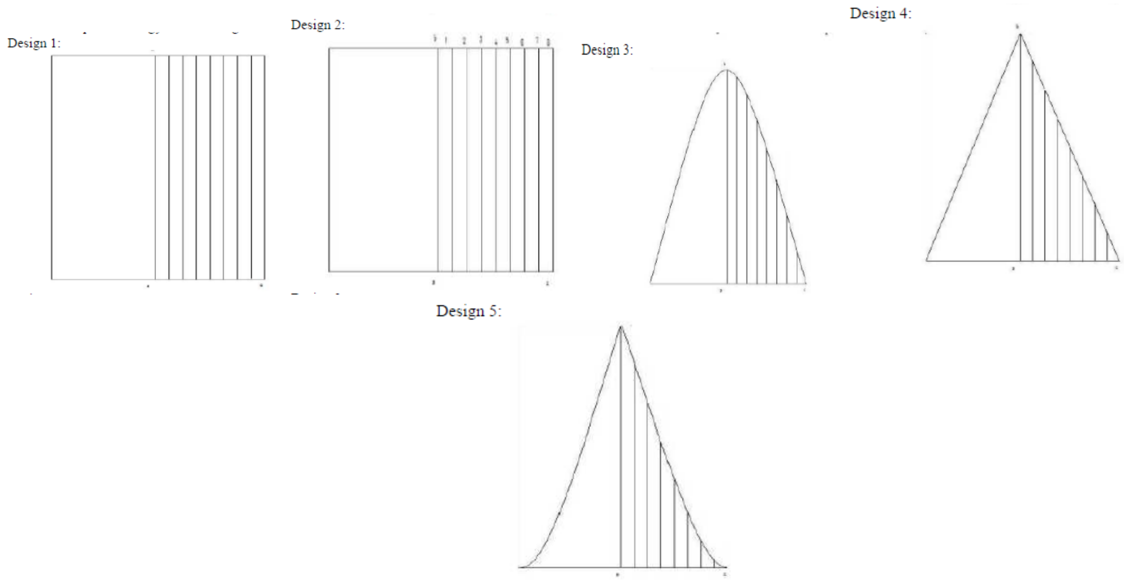

Figure 5. Flywheel geometries

M.lavakumar et al. (2013) [11] this paper involves the design and analysis of flywheel to minimize the fluctuation in torque, the flywheel is subjected to a constant rpm. The objective of present work is to design and optimize the flywheel for the best material. The flywheel is modelled with solid 95 (3-D element), the modelled analyses using free mesh. The FEM mesh is refined subject to convergence criteria. Preconditioned conjugate gradient method is adopted during the solution and for deflections. Von-misses stress for both materials (mild steel and mild steel alloy) is compared. The flywheel is modelled with solid elements. To reduce stress and deflection flywheel 40% titanium element is added as alloying element to the mild steel. The maximum deflection of mild steel alloy is 0.444E-05 meters which is less than maximum deflection of mild steel which is found to be 0.369E-03 meters. Thus mild steel alloy is best, from rigidity point of view. Maximum von-misses stress in flywheel is 332288 N/m^2 for mild steel alloy which is less than the maximum von-misses stress of flywheel which is found to be 352405 N/m^2. Hence design is much safe based on strength point of view for mild steel alloy than for mild steel.

Kishor D. Farde et al. (2014) [12] the main objective of this research is to reduce weight of automobile by using composite material. In this research Work taking Flywheel as an Automobile component and applying FEA analysis using ANSYS to optimize weight and strength of flywheel. Here Performing Analysis on metal flywheel, carbon fibre

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flywheel and composite i.e. metal and carbon fibre flywheel. By using ANSYS stresses obtained & compared with analytical calculations, also weight is compared. A composite material allows a higher rotational speed and this result in flywheel rotors with high specific energy and light in weight. Composite materials are therefore a better choice than metals when designing flywheel rotors. The theoretical specific energy of composite rotors is around five times higher than metallic ones. Composite materials also have safety advantage over metallic material.

III. CONCLUSION

- A composite flywheel has a lighter weight.
- Thus composite material allows a higher rotational speed and this result in flywheel rotors with high specific energy.
- Stresses are more at flywheel disk centre where thickness should be more.
- Composite flywheel has lesser stress and deformation.
- Chances of failure in composite flywheel are less at higher Angular velocity .
- Hence composite materials are better choice when designing flywheel.

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