Literature Review of Flywheel Design

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Abstract— In present investigation a literature review is taken from different research papers. The whole idea is concentrated about the optimized design of flywheel, for which many research have been taken into account. Basically the flywheel bears fluctuating torque by which some dynamic fluctuating loads are exerted. Those dynamic loads can be analyzed by number of methods. Modern era is for software where today mechanical loads can be computed. In this research paper all such methods are taken into account and try to find out the different material used for flywheel designing and the best performance. Also many trends are analyzed followed with optimization.

Key words: Flywheel

I. INTRODUCTION

Flywheel is a mechanical device which is manufactured with the shaft (i.e. shaft and flywheel is same link). When engine runs there is no continuous constant output. These outputs vary with intra-cycle. When shaft receives the varying output the whole mechanical system becomes unstable and shaft will no be able to perform. In order to ensure the constant output flywheel is attached with same link of shaft. Whenever shaft receives power higher than the average value then it is received and stored by flywheel for a moment. This power is disbursed when shaft receives power less than the average power. Usually the power, energy and velocity all are taken analogously with each other. Flywheel absorbs kinetic energy through its inertial mean. The storing power of kinetic energy depends upon density, volume and distribution of mass about the axis. Many papers are reviewed in this with conventional and software method (i.e. 3-D modeling).

Due to number of models of engine and their performance in between cycles the flywheel designed today in such a way so that the total storage capacity of flywheel can be increased for given constraints. In modern days the compactness is also a one of the basic need of life that enhances the system appearance.

II. LITERATURE SURVEY

Sushama G Bawane, A P Ninawe and S K Choudhary research paper published in IJMERR is the sample of analyzing the flywheel with 3-D modeling using CATIA software and finally tested in ANSYS. This scrutinizes mainly the dimensions of flywheel with different material related to their uniform performance. With the CATIA software the same size and dimensions of flywheel is analyzed with taking Gray Cast Iron, Aluminum alloy and SAE111. In this finally 20% of material is saved through deduction from periphery.

Sung Kyu Ha, Dong-Jin Kim, Tae-Hyun Sung gave optimum design in multi-ring composite flywheel rotor using a modified generalized plane strain assumption. This research paper using established MGPS method, three dimensional finite element method (3-D FEM) and assumptions of plane stress (PSS) objective function is secured. Total Store Energy (TSE), stress and strength distribution ratio, distribution of mass radially and life of flywheel for given material can be taken as the objective function. In this the modern way to analyze the load on flywheel is best option this fact is revealed.

Jerome Tzeng, Ryan Emerson, Paul Moy made the research paper for flywheel of composites. As the concept says the mass is one of the key to improve performance of flywheel. The mass is related to density. Using different composites the experiment is shown. Composite properties are such a way that can be selected to most desiring form and having many excellent properties that make it different from other pure metal or alloyed metal. Not only physical property but also chemical properties also should be selected to fulfill criteria of design. This research paper also introduces the application of flywheel. According to this in modern days composite flywheel is being developed which is used in space application and satellites for altitude controlling and energy storage.

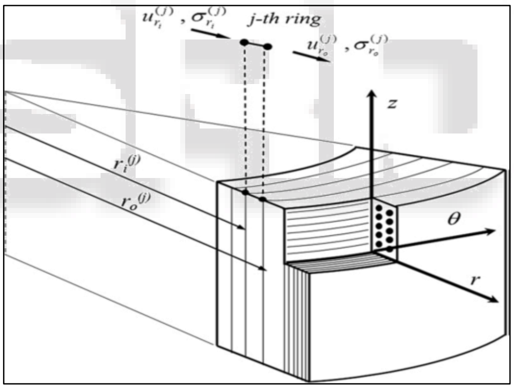

Fig. 1: Flywheel design

Shaobo Wena, Shuyun Jiang emphasis on optimum design of hybrid composite multi-ring flywheel rotor based on displacement method. Here scope of multi ring in flywheel is searched which is again composites plays roll. Four types of the optimal schemes of energy storage capacity, energy per unit mass (EPM), energy per unit volume (EPV), energy per unit cost (EPC) and energy per unit mass and cost (EPMC) are proposed to satisfy the needs of different applications and optimal designs are carried out by using a sequential quadratic programming (SQP).

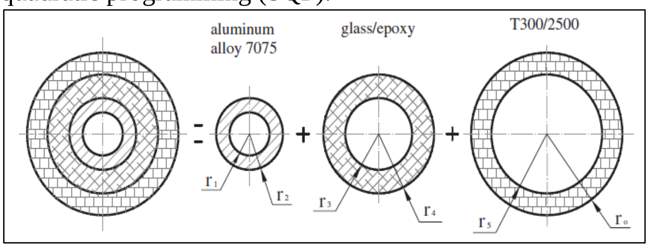

Fig. 2: Schematic Diagram of Hybrid Composite Flywheel Structure

Optimal design of press-fitted filament wound composite flywheel rotors is done by Andrew C. Arvin, Charles E. Bakis. This research is based on different from others on simulated annealing. This is the one based on production engineering where the factors analyzed are comparable specific energy (energy per unit mass) and superior specific power (power per unit mass), charge/ discharge behavior, efficiency, temperature range, and cycle life.

Such research based on broad area of flywheel where with the application of flywheel this becomes such an important. We have seen the research follows three broad methods are Conventional method, Computational method, Production method.

All method consist their own advantages as well as disadvantages. The conventional method is reasonable method where all basic engineering, geometry, calculus and other area of mathematics are applied on it which will give an analyzed approach. There is also so many assumptions which are not possible in practical manner and application. This makes some error in results and final solutions.

Computational method is based on software technique. This is best approach. It has many advantages such as less time consuming, effective use, highly interactive, fastest method, least error etc. In this many software have been developed to analyze the given material with given constraints and given loads. Mainly used software is CATIA and ANSYS.

Production method is oldest method to analyze the part. This method gives direct communication to material. The given job is made in many variables and they are analyzed in testing machine. In this the wastage of material is higher that leads to high cost. This approach is basic and used in various testing machine. But this is suitable only for simple loading. Any complex loading cannot be tested directly on the machine.

III. Method

The main requirements in a flywheel design are to store the maximum amount of kinetic energy per unit mass and ensure against premature failure due to fatigue or brittle fracture. If the failure is due to fatigue, the performance index would be σ limit/ρ (where σ limit is the fatigue limit of the material and ρ is the material density). This signifies that the higher the value of σ limit/ρ, the lower the weight of the material for a given fatigue strength and consequently, the kinetic energy per unit mass of the flywheel would be higher. For failure due to brittle fracture, fracture toughness (KIC) of the material would be the performance measure. If the flywheel breaks into small pieces at final failure, the hazard would be much reduced. Thus, from the safety point of view, fragment ability of the flywheel material is an important property. Jee and Kang considered four criteria, i.e. fatigue limit (σ limit/ρ), fracture toughness (KIC/ρ), price per unit mass and fragment ability, among which fatigue limit, fracture toughness and fragment ability are beneficial criteria, and price/mass is a non-beneficial criterion.

To analyze for given torque fluctuation (i.e. power fluctuation) many methods are used. In research paper review most used methods are following-CATIA, ANSYS, Multi objective optimization on the basis of ratio analysis (MOORA) method, Displacement method, Press fitted production method, Theory of failure, Theory of dynamic loading etc.

All these type of research papers are reviewed in this literature review. Where the objective is to find most used method in past for optimization and getting the most practical solutions. The article is subjected to many book theories with the modifications and simplifications. The research paper reviewed from following organizations-

- IJMERR
- Springer Link
- Engineering Structures
- Composite Structures
- Energy Procedia
- Composites Science and Technology
- Composites Science and Technology
- Material and Design
- Composites Part B: engineering
- Advances in Engineering Software
- International Journal of Mechanical Sciences
- UCRL Lawrence Livermore National Laboratory

With same input all results are compared and given the focus on best and optimized strategy and technique suitable to scholars that must be used for different objective function and different method.

IV. Results

The main analysis is based on Sushama G Bawane, A P Ninawe and S K Choudhary on which the model is totally analyzed on ANSYS software through 3- D modeling by taking a model of flywheel of Maruti Suzuki Omni with capacity of 796 cc. All basic data are given on the article but dimensions are not given. The flywheel is analyzed through different material and targeted to material saving which leads to cost saving and compact system. Based on the consideration of rotational deformations in the flywheel, the element Soilid72, a 3-D 4-node tetrahedral structural solid with rotations, is used to model meshes. Grey cast iron and Aluminum alloy both material are tested through which it is found that At last through the software for reduction of 1kg weight 20% material can be removed from the periphery of the flywheel.

Quantity	Gray Cast iron	Aluminium Alloy
Equivalent (von-mises) stress, MPa	0.02189	0.02164
Normal stress, MPa	0.003073	0.003591
Shear stress, MPa	0.001474	0.001556
Total deformation, mm	1.419×10^{-5} mm	2.24×10^{-5} mm

Table 1: Comparison of Result by ANSYS

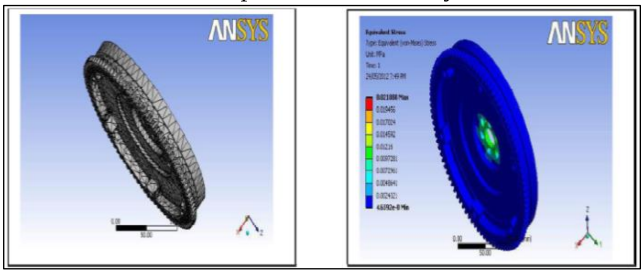

Fig. 3: Meshing and Equivalent Stresses in Flywheel

The above analysis makes a strong question mark that which material has good impact on performance of flywheel. In this analysis the performance of flywheel is function of properties of material. The objective function may be cost, total storage energy, mass of material, turning moment variation, inertia etc. all these can be optimized by any method. In this analysis the material is saved which shows for same performance by opting different material the overall weight of material and unbalancing can be decreased.

Yonjie Han et al. illustrate flywheel rotor design process and its influence factor. The process included requirements analysis, rotor type option, general design, optimum design, and performance evaluation. Goals of general design is to determinate geometric parameters of flywheel depending upon the limiting factor, a very large number of conditions and factors must be considered, such as general configuration of flywheel energy storage device, the stored energy, operation speed, material behavior, moment of inertia, rotor dynamics, flywheel rotor mass, structural manufacturability. Maximum outer radius, Stress analysis, Flywheel rotor components, Failure criteria selection, Maximum outer radius calculation and finally through this Geometric parameters of flywheel rotor is analyzed. In geometric parameters of flywheel rotor the polar moment of inertia, Distributed moment of inertia, Geometric parameters of flywheel is calculated by which finally suitable flywheel rotor dimensions are calculated which satisfies the entire design criterion.

It was applied to determine flywheel rotor parameters of 600Wh flywheel energy storage system in developing. They have proved to be a practical method. The maximum outer radii were calculated by depending upon the Tresca stress failure criterion. It suited to the steel flywheel or metallic hub of composite flywheel, which was made of the isotropic & ductile materials.

The maximum stress is always at the inner radius of the flywheel rotor, the maximum outer diameter decrease as inner diameter is increased. The steel flywheel or metallic hub of composite flywheel was made of materials that had the better strength and low density, such as aluminum and Alloy steel.

Design requirement was taken as a 600Wh class FESS with the operating speed range of 5,000~15,000rpm, η=90%. Respectively and general geometric parameters of steel flywheel rotor and composite flywheel rotor is determined. The cheap material 40Cr had been taken which is easy to manufacture. Finally result came out as inner diameter respectively is 300 mm, 200 mm and 50 mm, the material Al 7050, Carbon steel 45, and alloy AISI 4340, the maximum outer diameter can be diameter are calculated from equations and Table The maximum outer diameter decrease as inner diameter are increased, there are the larger outer diameter with better strength and low density materials. So we select that the metallic hub of composite flywheel is made of aluminum 7050, and the steel flywheel is made of alloy steel AISI 4340.

The density of composite rim is 1800 kg·m-3, its thickness is selected from 30mm to 60mm. The geometric parameters of flywheel had been calculated from many design equations. The results are listed in Table 2 for the steel flywheel and Table 3 for the composite flywheel. The detail design of the flywheel rotor will begin after determining the general parameters, three dimensional (3-D) flywheel rotor is constructed and modified slightly, thus the flywheel rotor design will be finished.

Item	Aluminium 7050			Carbon steel 45			Alloy steel AISI 4340		
Density ρ ($kg \cdot m^{-3}$)	2810			7850			7900		
Yield stress [σ] (Pa)	455			355			835		
Poisson's ratio μ	0.33			0.28			0.28		
Inner diameter d_1 (m)	0.05	0.20	0.30	0.05	0.20	0.30	0.05	0.20	0.30
Outer diameter d_2 (m)	0.561	0.554	0.545	0.298	0.284	0.264	0.457	0.447	0.435

Table 1: Maximum outer diameter and material behavior

d (m)	h (m)	d_1 (m)	d_2 (m)	H (m)	m_w (kg)	J_d/J_p
0.07	0.035	0.38	0.42	0.204	79.2	0.66

Table 2: The geometric parameter of steel flywheel

d [m]	h [m]	d_1 [m]	d_2 [m]	D [m]	H [m]	m_w [kg]	J_d/J_p
0.07	0.05	0.30	0.38	0.48	0.227	72.1	0.705

Table 3: The geometric parameters of composite flywheel

S. Wen et al. used displacement method and find out some useful graphs. The graph found in between circumferential stress on flywheel versus radius which gives a trend to finalize the radius of composite flywheel. Aluminum, glass fiber and carbon fiber are analyzed. For all three materials the slope comes out negative showing as radius will decrease the circumferential stress increases. But most negative slope in the graph is aluminum. Where carbon fiber shows least negative and glass fiber is showing in between of aluminum and carbon fiber. This gives clear indication that aluminum cannot be used directly for bigger flywheel. Here glass fiber or carbon fiber will be best suited.

Stress distribution of optimal flywheel based on EPM at a constant rotational speed of 58114 rpm: (a) circumferential stress; (b) radial stress

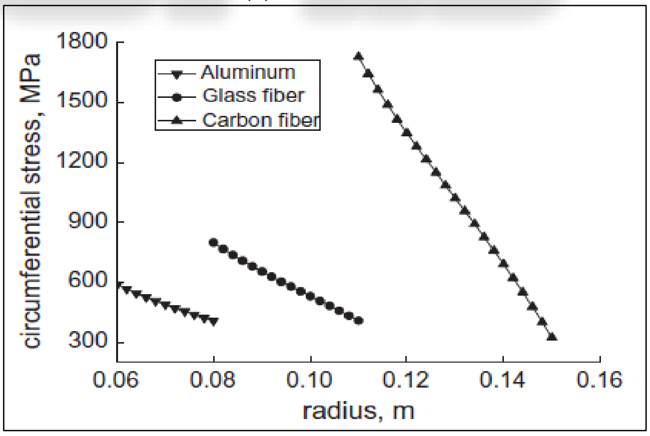

Fig. 4: Circumferential Stress

In another graph the abscissa is taken as radius and ordinate is taken as radial stress. In this again same trend is seen. The aluminum at outer radius goes for higher radial stresses whereas other two material glass fiber and carbon fiber are subjected to lesser radial stress when comparing to the aluminum material.

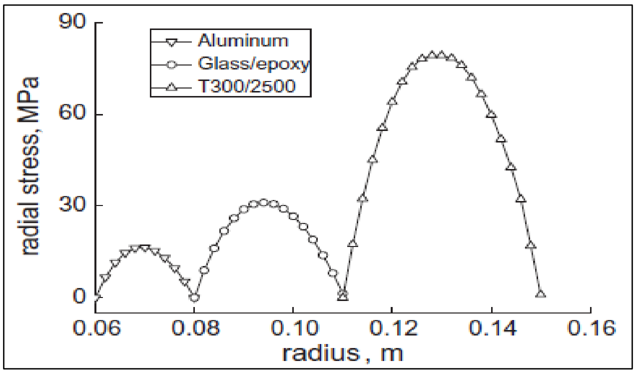

Fig. 5: Radial Stress

V. CONCLUSIONS

Many methods had been used to optimize the geometric parameter and material for flywheel. Here one thing is noticed that many parameters at a time can be taken for a flywheel designing. In practical situation all parameters and factors are applied simultaneously. Single method is taking factor at a time which gives some error to practical basis that leads to premature failure of flywheel. But most common and strong factor which must come to our calculation is cost and total energy storage capacity of flywheel. The cost is encountered with both how much material is saved and how cheap material can be used. In research paper review both factor for optimization of flywheel had been considered.

Total storage energy capacity of flywheel helps in giving uniformity of speed for varying loads. This factor had been taken into account by most of authors. The total storage energy is key point for scope of flywheel.

For optimization flywheel parameter many methods had been use by authors. Many author used conventional method which is accurate by analysis purpose but make some error by practical application. Modern methods give best solution with less time consuming. Modern method is far away advance from conventional. Although all rules and equations are followed by conventional and theory but is more systematic than the conventional.

One more conclusion can be drawn on the literature review that the creep effect had not been taken into account for analysis of flywheel. Creep is also one of parameter which affects flywheel life. Its effect on performance of flywheel is negligible.

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