Study on Energy Efficient Flywheel Design

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Abstract— Flywheel is used where the input power is fluctuated in order to store the energy and deliver the energy when it is required. In present investigation a mathematical analysis has been carried out to optimize Total Storage Energy (TSE) per unit mass. Material is taken same in all the flywheels because the Total Energy Storage (TES) ratio has been calculated which is independent of density that is property of material. The material mass also is taken as constant of all flywheels. Through this a mathematical study is done. Finally through taking all minimum assumptions objective function is derived in terms of slope of varying width of flywheel. It has been found that higher the value of n lesser the scope of increment of TSE by observation of graph between objective function and n (slope of variation of width). One more observation is seen that with increment on slope of width variation the inner width of flywheel reduced. That is also a critical parameter to design because with stress will increase highly at minimum cross – section. It is found that as the slope of variation of width in flywheel increased then rate of increment of Total Storage Energy (TSE) is decreased.

Key words: Flywheel, Total Storage Energy (TSE)

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 not 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.

Composite flywheels are being currently being developed for energy storage. The energy storage in the flywheel can be used to supply power for electrical drive machinery. To satisfy the high performance and low-weight constraints, high-strength carbon fiber composites has been the materials of choice for flywheel construction. Recently, several composite flywheels have been developed for commercial power generation and vehicles, such as buses, trains and all automotive industry, missile and airplane to give direction through gyroscopes. In the government sector, NASA, ISRO intend to have composite flywheels in the space station for energy storage. Flywheels have also been proposed for satellite direction and altitude control. There had been many investigations of hybrid and all-electric combat vehicles and weapons. Composite flywheels are important components of the mechanical systems. There had been numerous R&D programs on composite flywheels in the past. Several programs have been conducted in national laboratories for nuclear applications to increase the performance. Some long term programs had been performed in academics and industries. With many efforts, there are few successful composite flywheels built and used in practical applications. The shortcomings that hinder the use of composite materials in flywheel applications are also here. The inertial stresses in a flywheel during operation (high-speed rotation) are dominant in the circumferential direction and consequently, composite flywheel rotors are usually analyzed by many organizations. However, tensile stress is also developed in the radial direction due to mismatches in the growth of the rotor as well as Poisson effects. An elastic thick-walled composite cylinder analysis was developed to determine the stress and strain profiles in a flywheel.

One of the biggest applications of flywheel is automobile industry. The most common cycle used in automobile is two stroke and four stroke engines with combination of petrol and diesel engine. The most common pattern in these types of engines is variable output from system. In order to run system a constant and continuous output is required but it is not possible due to some constraints of mechanical system.

Apart from internal combustion engines the place where reciprocating motion is converted into rotating motion the flywheel becomes important to make sure for constant and continuous power. Flywheel energy storage systems with mechanical transmissions allow braking and power augmentation during acceleration in automotive vehicles. The development of this technology is being driven by rising fuel costs and restricting emission legislation. In recent years the issue of climate change has generated great scientific and public interest in the effect of human activity on the production of greenhouse gasses has been linked with global temperature rises, and in the light of reports such as the Stern Review on the economic impact of climate change a general consensus appears to have been reached on the need to limit such emissions. Road vehicles account for a large proportion of the total world energy use and energy-related CO_2 emissions, and stabilization of atmospheric concentrations is likely to require continuous improvements in vehicle efficiency over the next 40 years as mapped out by the IEA. Many fuel saving technologies are currently available, but the associated increase in vehicle cost appears to be limiting widespread implementation. Continuously variable transmissions are required to achieve the continuous range of output-to-input speed ratios necessary for flywheel energy storage systems. This can be achieved using mechanisms such as toroid and push-belt drives. While these types of continuously variable transmissions are limited by the range of gear ratios that can be spanned, they can be used as direct transmissions in flywheel energy storage systems such as the commercialized system.

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 software. 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) a 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.

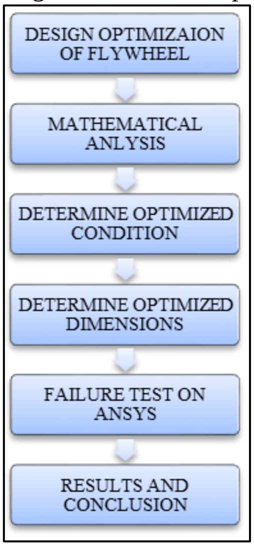
Jerome Tzeng, Ryan Emerson, Paul Moy made the research paper for flywheel of composites. As the concept says the mass is one of the key to improve performance of flywheel. The mass is related to density. Using different composites the experiment is shown. Composite properties are such a way that can 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.

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).

II. METHODOLOGY

In flywheel optimization technique different flywheels are taken. The objective function is specified as Total Storage Energy (TSE) which is derived mathematically along with certain assumptions. These assumptions are:

1) Outer and inner radius of flywheel is taken as constant for all flywheels.
2) The width of flywheel is taken as linearly varying from inner radius to outer radius of flywheel.
3) The mean angular speed is taken as constant.
4) Coefficient of fluctuation of speed is taken as constant.
5) Material of flywheels is taken constant.
6) Material is homogeneous and isotropic.



The flywheel can be different type and there are number of ways to analyze. The geometry of flywheel is one of the important criteria on which the flywheel Total Storage Energy (TSE) can be improved. In this investigation the geometrical analysis is based on mathematical analysis. Above given assumptions are important to investigate and to formulate our objective function in terms of slope index.

The flywheel is optimized by varying the width of flywheel taking inner and outer diameter of flywheel same for all. This consideration gives a fixed space or system where the study is to be done. The linear variation of width has been considered. This gives more scope to analyze the flywheel with taking different type of variation of width in flywheel such as exponential, parabolic, hyperbolic etc.

The mass of flywheel is taken same for all flywheels that give more simplified solution in mathematical terms. The assumption that the material is same gives the volume of flywheels is same. So a mathematical term is found out for outer width of flywheel is given by-

$$a_r = B + \frac{(a - B)r}{r_f}$$

The volume is compared of base flywheel and system flywheel. An expression for inner width of flywheel is derived is given by-

$$B = \frac{(r_f^2 - r_s^2) * B_1}{2\left\{\frac{(r_f^2 - r_s^2)}{2} + \frac{(n-1)(r_f^3 - r_s^3)}{3r_f}\right\}}$$

Finally in order to calculate the Total Storage Energy (TSE) the assumption of coefficient of fluctuation of speed and mean angular velocity of shaft are taken as constant. This consideration decides the TSE is directly proportional to moment of inertia of flywheel (MOI). Finally the objective is to increase the MOI to obtain increased TSE. The MOI is calculated in terms of slope index and calculated. The graph is drawn with all values between MOI and slope index (n).

III. RESULTS & DISCUSSIONS

The final expression in between inner width (B_2) and slope index (n) is obtained. The graph is drawn in these variables shown in figure. This graph gives clearly indication that if slope index (n) of flywheel is increased then inner width of flywheel decreases which is not good for flywheel because stress induced in critical section is increased.

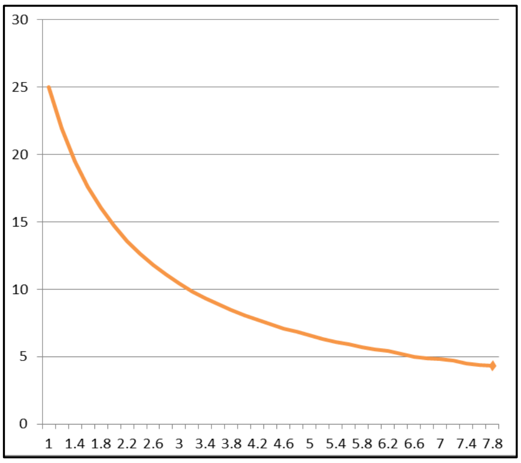


Fig. 1: Graph between Inner Widths of the Flywheel & Slope Index after Volume Analysis

The second expression is for Total Storage Energy (TSE) and slope index (n). The MOI is considered as TSE because they are directly proportional. The graph is shown below in which the value of TSE is increasing monotonically. But one more observation is taken that the rate of increment in TSE is decreasing.

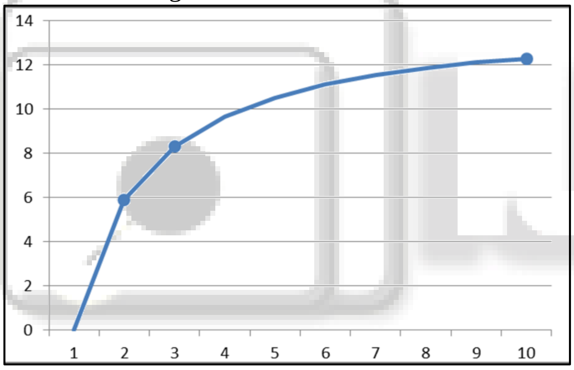


Fig. 2: Graph between Percentage Increment in TSE & slope index of the Flywheel after Mathematical Analysis

The next graph is in between rate of increment in TSE and slope index (n). It gives decreasing nature over slope index.

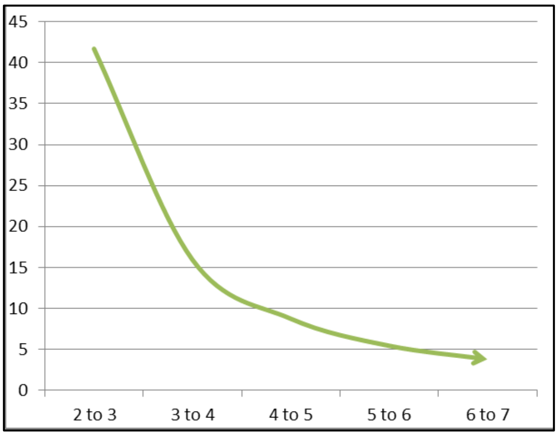


Fig. 3: Graph between Changes in Percentage Increment in Tse & Slope Index of the Flywheel after Mathematical Analysis.

IV. Conclusions

It is seen that with increment on slope of width variation the inner width of flywheel reduced. That is also a critical parameter to design because with stress will increase highly at minimum cross – section. It is found that as the slope of variation of width in flywheel increased then rate of increment of Total Storage Energy (TSE) is decreased.

After mathematical calculation the optimized slope index (n) comes out with n = 1, 2, 3 where n is slope index and n = 1 is base flywheel.

The geometrical dimensions of optimized flywheel have been calculated then total storage energy has been calculated. It was found that the Total Energy Storage of flywheel 2 increased by 5.88% with respect to base flywheel. It was found that the Total Energy Storage of flywheel 3 increased by 8.33% with respect to base flywheel. This gives the overall material saving for same TSE.

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