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A Case Study on Design of a Flywheel for Punching Press Operation

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***Abstract—** A flywheel is the heavy rotating mass which is placed between the power source and the driven machine to act as a reservoir of energy. It is used to store the energy when the demand of energy of energy is less and deliver it when the demand of energy is high. The current paper is focused on the analytical design of arm type of flywheel which is used for punching press operation. Now in regard to the design of flywheel it is required to decide the mean diameter of the flywheel rim, which depends upon two factors such as availability of space and the limiting value of peripheral velocity of the fly wheel. However the current design problem is formulated for punching machine which has to be make holes of 30 holes/minute in a steel plate of 18mm thickness with space limitation that is the diameter of flywheel should not exceed 1000mm, hence it can be observed that the design of the flywheel is to be carried out (based) on the availability of space limitation and accordingly the fluctuation of energy, dimensions of the flywheel, stresses induced in the flywheel are determined. Finally after detail analysis it is observed that the induced diameter of the flywheel is less than the allowable/permissible diameter and hence it can be concluded that the design is safe from availability of space point of view.*

***Keywords-** Flywheel, peripheral velocity, fluctuation of energy, stresses, stored energy.*

I INTRODUCTION

Several hundred years ago pure mechanical flywheels where used solely to keep machines running smoothly from cycle to cycle, thereby render possible the industrial revolution. During that time several shapes and designs where implemented, but it took until the early 20th century before flywheel rotor shapes and rotational stress were thoroughly analyzed [1].Later in the 1970s flywheel energy storage was proposed as a primary objective for electric vehicles and stationary power backup. At the same time fiber composite rotors where built, and in the 1980s magnetic bearings started to appear [2]. Thus the potential for using flywheels as electric energy storage has long been established by extensive research. More recent improvements in material, magnetic bearings and power electronics make flywheels a competitive choice for a number of energy storage applications.

One of the major advantages of flywheels is the ability to handle high power levels. This is a desirable quality in e.g. a vehicle, where a large peak power is necessary during acceleration and, if electrical breaks are used, a large amount of power is generated for a short while when breaking, which implies a more efficient use of energy, resulting in lower fuel consumption.

Individual flywheels are capable of storing up to 500MJ and peak power ranges from kilowatts to gigawatts, with the higher powers aimed at pulsed power applications.

Stress analysis is the complete and comprehensive study of stress distribution in the specimen under study. To improve the quality of the product and in order to have safe and reliable design, it is necessary to investigate the stresses induced in the component during working condition. Flywheel is an inertial storage device which acts as reservoir of energy. When the flywheel rotates, centrifugal forces acts on the flywheel due to which tensile and bending stress are induced in a rim of flywheel.

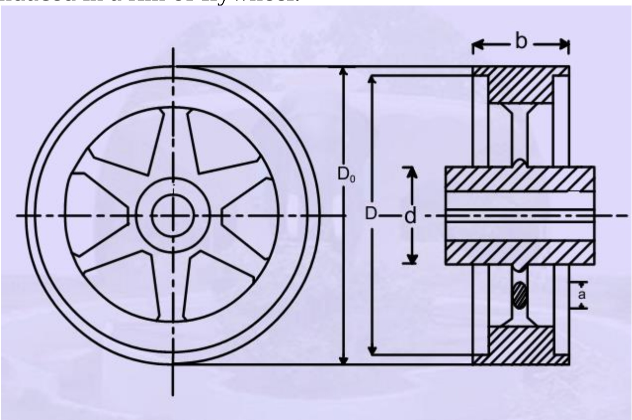

Fig.1.1Arm type of flywheel

The current paper is focused on the analytical design of arm type of flywheel which is used for punching press operation. Now in regard to the design of flywheel it is required to decide the mean diameter of the flywheel rim, which depends upon two factors such as availability of space and the limiting value of peripheral velocity of the fly wheel. However the current design problem is formulated for punching machine which has to be make holes of 30 holes/minute in a steel plate of 18mm thickness with space limitation that is the diameter of flywheel should not exceed 1000mm, hence it can be observed that the design of the flywheel is to be carried out (based) on the availability of space limitation.

II. PRESENT THEORIES AND PRACTICES

A literature review of some relevant research work was conducted in related with the current study as stated below

Akshay P. Punde, G.K.Gattani (2013) has presented the investigation of a flywheel, to counter the requirement of smoothing out the large oscillations in velocity during a cycle of an I.C. Engine, a flywheel is designed, and analyzed by using Finite Element Analysis method.

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Further it is used to calculate the Stresses inside the flywheel; finally the comparison study between the Design and analysis with existing flywheel is carried out. [1]
Bjorn Bolund, Hans Bernhoff, Mats Leijon (2007) The early models where purely mechanical consisting of only a stone wheel attached to an axle. Nowadays flywheels are complex constructions where energy is stored mechanically and transferred to and from the flywheel by an integrated motor/generator. The stone wheel has been replaced by a steel or composite. Rotor and magnetic bearings have been introduced. Today flywheels are used as supplementary UPS storage at several industries world over. Future applications span a wide range including electric vehicles, intermediate storage for renewable energy generation and direct grid applications from power quality issues to offering an alternative to strengthening transmission. One of the key issues for viable flywheel construction is a high overall efficiency, hence a reduction of the total losses. By increasing the voltage, current losses are decreased and otherwise necessary transformer steps become redundant. So far flywheels over 10kV have not been constructed, mainly due to isolation problems associated with high voltage, but also because of limitations in the power electronics. Recent progress in semi-conductor technology enables faster switching and lower costs.The predominant part of prior studies has been directed towards optimizing mechanical issues whereas the electro technical part now seems to show great potential for improvement. An overview of flywheel technology and previous projects are presented and moreover a 200kW flywheel using high voltage technology is simulated. [2]
Sudipta Saha, Abhik Bose, G. Sai Tejesh, S.P. Srikanth(2013) the performance of a flywheel can be attributed to three factors, i.e., material strength, geometry (cross-section) and rotational speed. While material strength directly determines kinetic energy level that could be produced safely combined (coupled) with rotor speed, this study solely focuses on exploring the effects of flywheel geometry on its energy storage/deliver capability per unit mass, further defined as Specific Energy. Proposed Computer aided analysis and 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. This paper specifically studies the most common five different geometries (i.e., straight/concave or convex shaped2D). [3]
M.lavakumar, R .prasanna srinivas (2013) 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 modeled with solid 95 (3-D element), the modeled 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) are compared, the best material is suggested for manufacture of flywheel. [4] Sushama G Bawane , A. P. Ninawe and S. K. Choudhary(2012) By using optimization technique various parameter like material, cost for flywheel can be optimized and by applying an approach for modification of various working parameter like efficiency, output, energy storing capacity, we can compare the result with existing flywheel result. Based on the dynamic functions, specifications of the system the main features of the flywheel are initially determined; the detail design study of flywheel is done. Then FEA ANALYSIS for more and more designs in diverse areas of engineering is being analyzed through the software. FEA provides the ability to analyze the stresses and displacements of a part or assembly, as well as the reaction forces other elements are to impose. This thesis guides the path through flywheel design, and analysis the material selection process. The FEA model is described to achieve a better understanding of the mesh type, mesh size and boundary conditions applied to complete an effective FEA model. At last the design objective could be simply to minimize cost of flywheel by reducing material. [5]
Mofid Mahdi (2011) the consumption of energy is increasing drastically. The available resources of energy are limited therefore; the search of new sources is a vital issue. This has to be done with efficient energy consumption and saving. A flywheel may provide a mechanical storage of kinetic energy. A capable flywheel must have a very high rotational speed which may lead to a high stresses. The stress state relies on the flywheel material properties, geometry and rotational speed. On the other hand, the stored kinetic energy relies on the mass moment of inertia and rotational speed. 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. Subjected to maximum permissible effective stress, favorable flywheel disk profiles were achieved. All FEM computations were carried out using ANSYS. [6] S. M. Dhengle, Dr. D. V. Bhope, S. D. Khamankar (2012) there is many causes of flywheel failure. Among them, maximum tensile and bending stresses induced in the rim and tensile stresses induced in the arm under the action of centrifugal forces are the main causes of flywheel failure. Hence in this work 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 developed for FE analysis. The FE analysis is carried out for different cases of loading applied on the flywheel and the maximum Von mises stresses and deflection in the rim are determined. From this analysis it is found that 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. It is also observed that for low angular velocity the effect gravity on stresses and deflection of rim and arm is predominant. [7] D.Y. Shahare, S. M. Choudhary (2013) This study solely focuses on exploring the effects of flywheel geometry on its energy storage/deliver capability per unit mass, further defined as specific energy. In this paper we have studied various profiles of flywheel and the stored kinetic energy is calculated for the respective flywheel .various profiles designed are solid disk, disk rim ,webbed/section cut, arm/spoke flywheel. It shows 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.

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Efficient flywheel design used to maximize the inertia of moment for minimum material used and guarantee high reliability and long life. FE analysis is carried out for different cases of loading on the flywheel and maximum von-mises stresses and total deformation are determined. [8]

III. PROBLEM DEFINITION

The design of arm type flywheel is to be carried out for punching press machine with the consideration of space requirement or with the condition that the diameter of flywheel should not exceed than 1000mm. The fly wheel is to de design which is used to punch 30 holes/minute on a steel plate of 18 mm thickness. In concern this geometrical dimension, material, and function values of flywheel as stated below

- Geometrical Dimensions and material condition:
  - ✓ Flywheel should not exceed the diameter of 1000mm
  - ✓ Coefficient of fluctuation of speed :0.1
  - ✓ Mean speed of flywheel : 270 rpm
  - ✓ Mass of flywheel : 254 kg
  - ✓ Material of flywheel : Grey cast iron with density 7100kg/m3
- Functional values of flywheel:
  - ✓ The following table shows the details about flywheel design parameters.

Flywheel	Total energy (N-M)	Fluctuation of energy (N-M)	Rim velocity (m/s)
Arm type	3592.6	3233.3	11.3

Table 1.1 Flywheel Parameters

IV. METHODOLOGY

The method adopted for the design of flywheel for punching machine is Analytical method. Now let us determine the various parameters in regard with flywheel design.

- ✓ Mean speed of flywheel N= 9 Number of strokes/min =9×30=270rpm
- ✓ Maximum shear stress required to punch a hole
  =Shear strength ×resisting area
  $=f_{s\times}\ \pi\ dt$
  $=\frac{240\times\pi\times25\times18}{1000}$
  =339.3kN
- ✓ Energy required to punch one hole
  =average force × distance travelled by punch
  =0.5×339.3× 18=3053.7N
- ✓ Since mechanical efficiency is less than 100%, assuming as 85% ,therefore
  Total energy required, E=3053.7/0.85
  =3592.6N-m
- ✓ Actual punching operation lasts for the $1/10^{th}$ of the cycle period. Therefore, during remaining period $9/10^{th}$ of the cycle period, the energy is stored by the flywheel. Thus fluctuation of energy =9/10× E= 3233.3Nm
- ✓ Maximum space available is 100mm,therefore considering as D=800mm to carry out design
- ✓ Rim Velocity= $\frac{\pi\times 0.8\times270}{60}$
  =11.3m/s…which is less than the maximum permissible velocity for grey cast iron
- ✓ Mass of flywheel, m= $\frac{\text{fluctuation of energy}}{V^2\times C_s}$
  $=\frac{3233.3}{11.3^2\times0.1}$ = 253.3 Kg
- ✓ Assuming mass of rim as 90%of total mass,
  m_{rim} =0.9×253.2=227.88Kg
- ✓ $m_{rim}= \pi Dhp$ ….used to determine dimensions of rim
  Where, p=7100kg/m^{3}for C.I.
  Therefore, h=90mm, b=150mm
- ✓ Outer diameter of flywheel=D_o=D+h=0.89m, which is less than the maximum space of 1m, hence the design dimensions are within limit.
- ✓ *To* determine Shaft diameter
- ✓ Bending moment M =weight of flywheel× overhang =253.2×9.81× 0.2=496.78N-m
- ✓ Average torque = $\frac{\text{Energy required/min}}{2\pi N}$
  $=\frac{107778}{2\pi\times270}$
  =63.53N-m
- ✓ Assuming suddenly applied load condition with shock and fatigue factor of 1.5 and 2
- ✓ Equivalent torque =((Cm×M)2 +(Ct× T)2)1/2
  =755.92N-m
- ✓ Shaft is made of medium carbon steel, with shear strength 360N-mm2, Factor of safety is 4,therefore shaft diameter can be determined by using torsion equation
- ✓ Shaft diameter,ds =34.96 say=40mm
- ✓ Hub diameter, dh= 2ds=80mm
- ✓ Length of hub, lh = 2.5 ds=100mm
- ✓ To determine the Stresses in the rim of flywheel
- ✓ Stresses in unstrained rim = pv2
  = 7100×11.32 =0.9066MN/m2
- ✓ Stresses in restrained rim = pv2(2πR2/ i2h)
  =4.97 MN/m2
- ✓ Total Stress in the rim ,
- ✓ = 0.75 Stresses in unstrained rim+0.25 Stresses in restrained rim
- ✓ =1.922 MN/m2….which is less than the allowable strength of C.I, hence design of rim is safe
- ✓ To determine stress in arm of flywheel
  Considering arm type flywheel of four arms
  Bending stress in the arm =10N/mm2
  $=\frac{T(D-dh)}{iDz}$
  Where, Z=modulus of elasticity=1429.4mm3
  i=numbers of arms=4
- ✓ Direct stress due to centrifugal force =pv2=0.9066N/mm2
- ✓ Total stress = Bending stress+ Direct stress =10+0.9066=10.9066N/mm2
- ✓ Total stress is less than the allowable strength 20N/mm2, hence the design of the arms are safe.

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V. CONCLUSIONS

- ✓ It can be conclude that in case of flywheel design it is first important to know the design requirement such as material, type, application, desired speed (peripheral velocity), availability of space, and dimensions of the flywheel.
- ✓ The peripheral velocity of the flywheel is governed by allowable strength of the flywheel material, generally for grey cast iron it should be less than or greater than 25m/s.
- ✓ In case of arm type of flywheel the numbers of arms selection depends upon the diameter of the flywheel, generally four numbers of arms are selected for diameter of flywheel which should be less than 0.75m.
- ✓ As the current problem is related to the design of flywheel with consideration(limitation) of the space availability that is maximum space should be less than 1m, but after carrying out design the outer diameter of flywheel obtained is of 0.89m which is less than the required condition, hence can be concluded as design is safe.

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