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Design of High Performance Vehicle Composite Flywheel

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Abstract: Flywheels have been in use for a very long time, however, there is need to continuously improve the existing ones or develop new ones. The design of a functional high performance vehicle composite flywheel is presented. The component materials include aluminium hub, cast iron friction surface and alloy gear rim. Since the stored energy in a flywheel is proportional to the square of its rotational speed, the obvious method for maximizing stored energy is to push the speed of the flywheel. There is a limiting speed, which is set by the stresses developed within the wheel due to inertia loads that are also proportional to the square of rotational speed. A composite wheel of this nature weighs less than the conventional whole cast iron or steel alloy wheel and hence, develops lower inertia loads at a given speed. The combination of high strength and low weight enables extremely high tip speeds related to conventional flywheels. A C++ computer programme was developed for the computation of the major parameters of the composite flywheel. The design drawings for the isotropic disc- and rim-type flywheel, components of the composite flywheel and the assembly were also presented. The components were assembled using high strength fasteners. The conventional automobile flywheel designed for cast iron material weigh about 9.0 kg and that for steel alloy weigh about 9.4 kg. However, the composite wheel design for components of cast iron, steel alloy and aluminium alloy weigh a total of 4.8 kg and is lighter. This means it can be made lean ad compact. Experimental study of the mechanical properties, heat treatment, vibration analysis and dynamic balancing proved the performance of the composite flywheel as test results conforms to standards. Freeing up so much rotating mass from the engine with a lighter flywheel makes it very responsive. It revs up much more quickly and low speed acceleration is improved.

Key words: High performance, flywheel, design, cost iron, components, Nigeria

INTRODUCTION

The flywheel stores kinetic energy by mechanically confining motion of a mass to a circular trajectory. The functional elements of the flywheel are the mass storing the energy, the mechanism supporting the rotating assembly and the means through which energy is deposited in the flywheel or retrieved from it.

Flywheels are found in internal combustion engines where they damp out torque pulses caused by periodic firing of cylinders. In this application, energy is stored very briefly before it is used: for less than one revolution of the wheel itself.

The evolution of flywheel materials and components and a systemic approach to design, has led to the choice of flywheel materials which depends largely on the design requirements and on a velocity constraints. If there is no constraint on the peripheral velocity, the main feature is the specific strength of the material. The energy density is proportional to the ratio between the maximum stress the material can withstand and its density. In this respect, modern high-strength composite materials can be considered the optimum choice (McLallin *et al*., 2001).

The choices of materials for composite flywheels are Aluminium alloy, cast iron and steel alloy. The specific strengths of these materials are similar, at least so far as static uniaxial strength is concerned and the choice between them is mainly a matter of cost. This research is aimed at the development and application of light-weight composite flywheel in automobile and energy industries as an energy storage system.

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Composite vehicle flywheel design calculation: The development design approach is used to size the necessary parameters of the flywheel. The real work in designing the flywheel comes in the determination of the shapes and sizes of the hub, rim and arm or web. This includes the analysis of the operating forces and determining the working dimensions. However, the most relevant dimensions are the rim diameter, rim thickness and the hub (Herbst *et al.*, 2002). Current solids modeling CAD systems make the steps of design easy by computing these parameters automatically for the dimensions.

Programme flywheel calculation: The basic equations required for flywheel design are well documented (Norton, 1999; Genta, 1985; Shigley and Charles, 2001; Khurmi and Gupta, 2004; Genesan, 1996; Khurmi and Gupta, 2004; Flywheel Basic Tutorial, 2001). The major parameters of the composite flywheel were, however determined by writing a C++ computer programme. The programme was executed on a Dell personal computer.

/*This Programme Computes the Design Parameters for a Composite Flywheel: A list of Variable Description is as follows:-

DE = Maximum fluctuation of Energy, MAE = Max. Energy, MIE = Min. Energy,
v = Peripheral velocity of the flywheel in m/s, Q1 = Hoop Stress,
D = Mean diameter of the Flywheel
CS = Total fluctuation of speed, m = Mass of flywheel rim, p = Density

t = Thickness of the rim in meters, b = Width in meters

PT = Power transmitted, T_{mean} = Mean torque

wpds = Work done during the power stroke

T_{max} = Maximum torque, T_{excess} = Maximum torque,

E = Energy stored by the flywheel

Erim = Energy stored by the flywheel rim

I = Mass moment of inertia of the flywheel in Kg/sq. m

Qt = Centrifugal stress

Dh = diameter of Hub, Ds = Diameter of Shaft, L = length of Shaft,
Tm = Maximum torque acting on the shaft

```
*/
#include <iostream.h>
#include <math.h>
double pow (double base, double exponent);
double Foo (double Dia1, double Dia2, double Hie)
{
    double pie = 3.142;
    double Dia12 = pow(Dia1,2);
    double Dia22 = pow(Dia2,2);
    double Foo = pie* (Dia12 – Dia22) *Hie/4;
    return Foo;
}
double Foo2 (double DD1, double DD2, double Hie)
```

```
{
      double pie = 3.142;
      double DD12 = pow (DD1,2);
      double Foo2 = pie * DD12 * DD2 * Hie/4;
      return Foo2;
}
double Foo3 (double DDD1, double DDD2)
{
      double pie = 3.142;
      double Foo3 = pie * DDD1 * DDD2;
      return Foo3;


}
double Foo4 {double Di1, double Di2)
{
double pie = 3.142;
double Di12 = pow(Di1,2);
double Di22 = pow(Di2,2);
double Foo4 = pie* (Di12 – Di22) /4;
      return Foo4;
}
double main (void)
{
double MIE, MAE, DE, v, E, Q1;
/ /Energy computation
      MIE = 1043.2, MAE = 192.9;
      DE = (MIE + MAE) * 0.087;
      Cout << "Max. fluctuation of Energy = " << DE << '\n';
/ /Mean diameter of the flywheel
      double p = 7800;
      Q1 = 6000000;
      double vv = Q1 /p;
      v = pow (vv, 0.5);
      double pie = 3.142;
      double N = 1825;
double D = v*60/ (pie*N);
cout << "The Mean diameter of the flywheel is" << D << "m"<< '\n';
D = D * 1000;
cout << "The Mean diameter of the flywheel in mm = " << D << "mm"<<' \n';
/ /Mass of flywheel rim
      double w = 2*pie*N/60;
      double R = 0.145;
      double CS = 0.02;
      double R2 = pow (R, 2);
      double w2 = pow (w,2);
      double m = DE/ (R2*w2*CS);
      cout << "Mass of flywheel Rim =" << m << ' \n';
/ /Cross-section of the Flywheel Rim
      double t2, t, b;
      t2 = m/ (2*pie *7 *p *R);
      t = pow (t2, 0.5) * 1000;
```

```
        b = 7 * t;
        cout << “Thickness of the Rim in mm =” << t << ‘ \n’;
        cout << “Width of the Rim in mm =” << b << ‘ \n’;
/ /Mean Torque
        int PT = 9060;
        double Tmean = double (PT) /w;
        cout << “The mean Torque in N/m = “ << Tmean << ‘\n’;
/ /Work done per cycle
        double wd = Tmean * 4 * pie;
        cout << “The work done per cycle in N/m = “ << wd << ‘ \n’;
/ /Work done during the power stroke
        double wdps = wd + (wd *0.33);
        double Tmax = wdps * 2 / pie;
        cout << “The work done during the power stroke = “ <<wdps << ‘ \n’;
        cout << “The maximum torque =” << Tmax << ‘ \n’;
/ /Excess Torque
        double Texcess = Tmax – Tmean;
        cout << “The excess torque =” << Texcess << ‘ \n’;
/ /Energy stored by the flywheel (E)
        E = DE / (2 * CS);
        Cout << “Energy stored by the flywheel =” << E << ‘ \n’;
/ / Energy stored by the flywheel rim (Erim)
        double Erim = E * 15 / 16;
        cout << “Energy stored by the flywheel rim =” << Erim << ‘ \n’;
/ / Mass moment of inertia of the flywheel
        w2 = pow (191, 2);
        double I = DE / (w2 * CS);
/ /Centrifugal Stress
        double Qt = p * vv;
        cout << “The centrifugal stress =” <<Qt << ‘ \n’;
/ /Diameter and Length of hub
        // Ts = Allowable shear stress of cast steel material = 31
        double Tm = 2 * Tmean;
        double ds2 = (Tm * 1000 * 64) / (pie * 31);
        double ds = pow (ds2, 0.33);
            int Dh = 2 * 55;
            if (ds > 35) {
            cout << *Diameter of the shaft =” << ds << “say 55mm” << ‘ \n ‘;
            }
        cout << “Diameter of hub in mm =” <<Dh << ‘ \n’ ;
        cout << “Length of hub in mm = 83” << ‘ \n’;
/ / ____________________________________________________________________
/ /Moment of inertia of composite flywheel
        double Tmass = MAA2 + MFS + MSAR;
        double ICF = Tmass * pow (0.290, 2) /1000;
        cout << “The total volume of composite flywheel = “<<Tmass<<”g,    I for
aluminium alloy = “<<ICF<<”kg/sq.m” << ‘\n’ ;
/ /Energy stored in the cast iron flywheel
        double MICI = 0.757;               / /mass moment of inertia of the cast iron
flywheel in Kg/sq.m
        double w22 = 191;                          / /Angular speed of the flywheel in rad/s
        double ESCI = 0.5 * MICI * w22;
```

```
        cout << “Energy stored in the cast iron flywheel = “<<ESCI<<”N/m “<<’ \n’ ;
/ /Energy stored in the steel flywheel
      double MIS = 0.791;              / /mass moment of inertia of the steel flywheel in Kg/sq.m
      double ESS = 0.5 * MIS * w22;
      cout << “Energy stored in the steel flywheel = “<<ESS<<”N/m “<<’ \n ‘ ;
/ /Energy stored in the aluminium alloy flywheel
      double MIAA = 0.278;             / /mass moment of inertia of the aluminium
alloy flywheel in Kg/sq.m
      double ESAA = 0.5 * MIAA * w22;
      cout << “Energy stored in the aluminium alloy flywheel =
“<<ESAA<<”N/m” << ‘\n’ ;
/ /Energy stored in the composite flywheel
      double MIC = 0.404;              / /mass moment of inertia of the composite flywheel in Kg/sq.m
      double ESC = 0.5 * MIC * w22;
cout << “Energy stored in the composite flywheel = “<<ESC<<”N/m” <<’ \n ‘ ;
return 1;
}
```

RESULTS

Max. Fluctuation of Energy = 107.541
The Mean diameter of the flywheel is 0.290209m
The Mean diameter of the flywheel in mm = 290.209 mm
Mass of flywheel Rim = 7.00021
Thickness of the Rim in mm = 11.862
Width of the Rim in mm = 83.0339
The mean Torque in $N\ m^{-1}$ = 47.4002
The work done per cycle in $N\ m^{-1}$ = 595.726
The work done during the power stroke = 792.316
The maximum torque = 504.338
The excess torque = 456.938
Energy stored by the flywheel = 2688.52
Energy stored by the flywheel rim = 2520.49
The centrifugal stress = 6e + 006
Diameter of the shaft = 38.2085 say 55 mm
Diameter of hub in mm = 110
Length of hub in mm = 83
Energy stored in the cast iron flywheel = 13808.059 $N\ m^{-1}$
Energy stored in the steel flywheel = 14428.236 $N\ m^{-1}$
Energy stored in the aluminium alloy flywheel = 5070.859 $N\ m^{-1}$
Energy stored in the composite flywheel = 7369.16 $N\ m^{-1}$
Energy Density = 5.5KJ kg^{-1}.

A typical isotropic disc- and rim-type vehicle flywheel is shown in Fig. 1. The high performance composite flywheel is designed to maximize the specific energy, where the mass is concentrated in the rim, at the largest possible spin radius. The high performance flywheel composite comprises of aluminium alloy hub, cast iron friction surface and steel alloy gear rim as shown in Fig. 2.

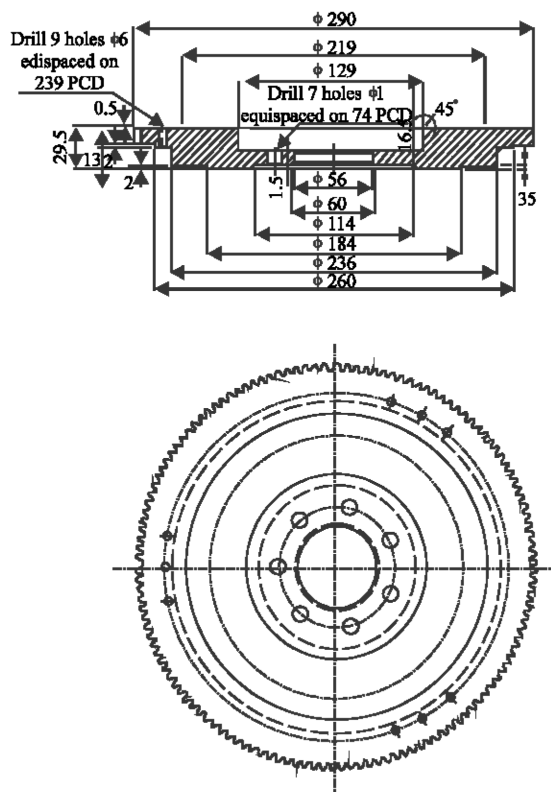


Fig. 1: An isotropic disc- and rim-type flywheel

- Aluminium alloy hub; the flywheel utilize lightweight aluminium alloy hub connecting the cast iron friction surface and the geared steel alloy rim.
- Cast iron friction surface.
- Steel alloy rim; the steel alloy rim is geared to couple with the pinion.

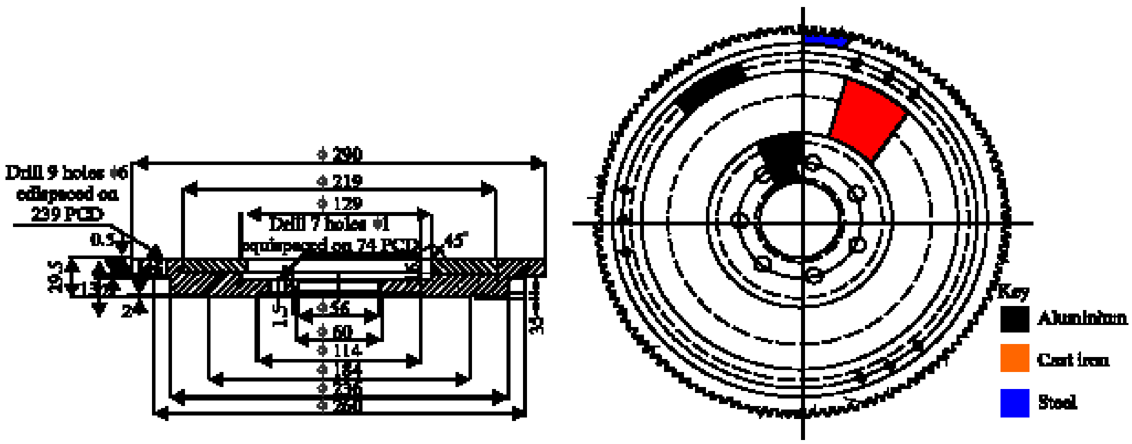


Fig. 2: The designed disc- and rim-type composite flywheel

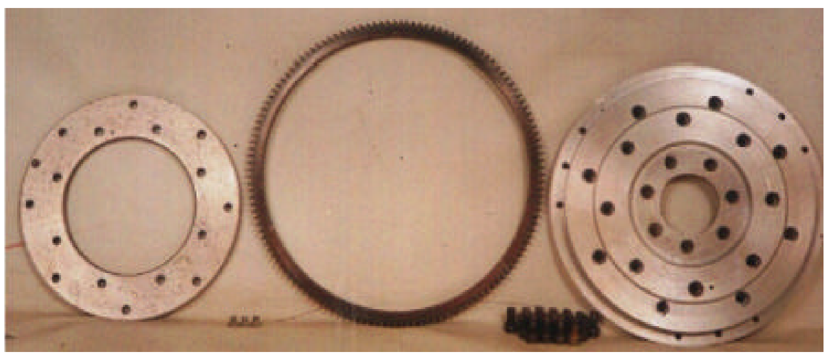
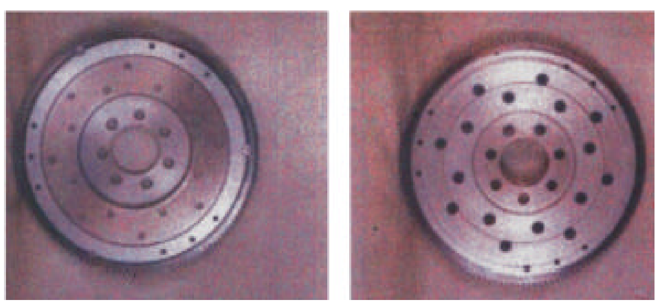


Plate 1: Machined flywheel components and screws before assembly



Front

Back

Plate 2: Assembled composite flywheel

This assembly is compact, lightweight and has high energy density. Finished components of the composite flywheel are presented Plate 1 and the assembly of the composite wheel is also shown in Plate 2. The stored energy in a flywheel is proportional to the square of its rotational speed and the obvious method for maximizing stored energy is to push the speed of the flywheel. This design have a limiting speed, which is set by the stresses developed within the wheel due to inertial loads that are also proportional to the square of rotational speed (The Electric Universe Project, 2003).

CONCLUSION

A composite flywheel was developed. The development and analysis of the parameters and characteristics for an energy storage flywheel was developed using a C++ computer programme for the computation of the major parameters and energy characteristics of the composite wheel. The design drawings for the components of the composite flywheel and the assembly were also presented. The composite combines an aluminium hub, cast iron friction surface and alloy steel gear rim. High-strength composites are the most competitive materials for production of high performance flywheels, since the mass energy storage capacity is proportional to the ratio of ultimate allowable stresses in the material to its density. This category of flywheel can be efficient in applications like automobile, electrical systems and mechanical working machines.

Energy storage capacity is similar to the conventional hardware, however the weight have been reduced by about half. The C++ Programme is easy to operate and the advantages to be gained from it include:

- Flywheel parameters and energy characteristics may be easily and rapidly estimated saving time and costs.
- The Programme may be used to analyze existing systems and will show the effect of modifying them.
- A record of the systems is kept, so that vehicle flywheel design becomes more systematic.
- A comprehensive technical manual is provided to develop the understanding of the principles of good practice.

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