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Design and Analysis of Automotive Powertrain Using Static, Model, Thermal and Transient Structure Analysis Techniques

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Abstract: ***The term powertrain describes the main components that generate power and deliver it to the road surface, water, or air. This includes the engine, transmission, drive shafts, differentials, and the final drive (drive wheels, continuous track as in military tanks or caterpillar tractors, propeller, etc.). Sometimes "powertrain" is used to refer to simply the engine and transmission, including the other components only if they are integral to the transmission. In a carriage or wagon, running gear designates the wheels and axles in distinction from the body. The project was aimed to design and analysis of powertrain by designing its subassembly such as flywheel, clutch with axial force 10.96KN and gear box having different speeds and gear ratio with 6 Forward speeds and 1 reverse speeds using model, structure, transient and thermal analysis techniques. The modeling and analysis is done by SOLIDWORKS and ANSYS.***

Keywords: Powertrain, Clutch, Gear box, Flywheel, Transient analysis.

1. Introduction

A motor vehicle's driveline or drivetrain consists of the parts of the powertrain excluding the engine and transmission. It is the portion of a vehicle, after the transmission, that changes depending on whether a vehicle is front-wheel, rear-wheel, or four-wheel drive, or less-common six-wheel or eight-wheel drive. In a wider sense, the power-train includes all of its components used to transform stored energy into kinetic energy for propulsion purposes. Early transmissions included the right-angle drives and other gearing in windmills, horse-powered devices, and steam engines, in support of pumping, milling, and hoisting.
Most modern gearboxes are used to increase torque while reducing the speed of a prime mover output shaft (e.g. a motor crankshaft). This means that the output shaft of a gearbox rotates at a slower rate than the input shaft, and this reduction in speed produces a mechanical advantage, increasing torque. A gearbox can be set up to do the opposite and provide an increase in shaft speed with a reduction of torque. Some of the simplest gearboxes merely change the physical rotational direction of power transmission.

Many typical automobile transmissions include the ability to select one of several different gear ratios. In this case, most of the gear ratios (often simply called "gears") are used to slow down the output speed of the engine and increase torque. However, the highest gears may be "overdrive" types that increase the output speed.

2. Design of Flywheel

A flywheel is a rotating mechanical device that is used to store rotational energy. Flywheels have a significant moment of inertia and thus resist changes in rotational speed. The amount of energy stored in a flywheel is proportional to the square of its rotational speed. Energy is transferred to a flywheel by applying torque to it, thereby increasing its rotational speed, and hence its stored energy. Conversely, a flywheel releases stored energy by applying torque to a mechanical load, thereby decreasing the flywheel's rotational speed. For flywheel material is taken as steel with mass density 7900kg/m^3, maximum torque T_{max} = 1500N-m, minimum torque T_{min} = 500N-m through 720^0 rotation of driving shaft, thichness of flywheel t= 50mm, coefficient of friction μ = 0.3, C_s is .030, N_1 = 500rev/min, N_2= 5000rev/min,

$\omega_1 = 2\pi N_1 = 2\pi(500/60) = 52.35$rad/sec,
$\omega_2 = 2\pi N_2 = 2\pi(5000/60) = 523.59$rad/sec,
$\omega = (\omega_1 + \omega_2)/2 = (52.35+523.59)/2 = 287.97$rad/sec,
$\Phi = (\omega_2 - \omega_1)/2 = 1.63$
Mean Torque $T_m = ((500+1500)/2 \times 4\pi)/2 = 2000$Nm,
$U_0 = ((1500-1000)(2\pi-\pi))/2 = 250\pi$ Nm.
$I = U_0/\omega^2 C_s = (250\pi)/(287.97^2 \times .03) = 0.315$kg/m^2 ,
$I = (\pi/2) \times \rho \times t \times R^4$,
$R^4 = (2 \times I)/(\pi \times \rho \times t) = (2 \times 0.315 \times 1000)/(\pi \times 7900 \times 50)$,
R = 0.150m = 150mm, D = 300mm,
diameter of flywheel is 300mm.

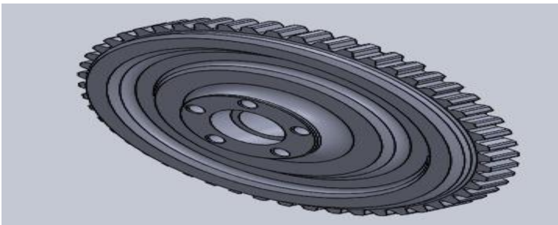


Figure 1: Flywheel isometric view

3. Design of Clutch

A clutch is a mechanical device that engages and disengages the power transmission, especially from driving shaft to driven shaft. Clutches are used whenever the transmission of power or motion must be controlled either in amount or over time (e.g., electric screwdrivers limit how much torque is transmitted through use of a clutch; clutches control whether automobiles transmit engine power to the wheels).In the simplest application, clutches connect and disconnect two rotating shafts (drive shafts or line shafts). In these devices, one shaft is typically attached to an engine or other power

unit (the driving member) while the other shaft (the driven member) provides output power for work. While typically the motions involved are rotary, linear clutches are also possible. For clutch design maximum torque T = 850Nm, External diameter of clutch plate is 10 times its internal diameter, maximum pressure intensity for the clutch facing Pi = 2000 KPa, coefficient of friction μ= 0.3. Assume uniform wear. R_i and R_0 is inner and outer diameter of clutch facing in mm.
$R= (R_i + Ro)/2 = (R_i + 10x\ Ri)/2 = 5.5R_i$,
$PR = P_i R_i = P_o Ro$ = constant. So $PR = 2x R_{i.}$,
$W = 2 \times \pi \times PR \times (Ro – R_i)$,
$W= 2 \times \pi \times 2 \times Ri \times 9 \times Ri = 113.09\ Ri^2$
$T= 2 \times \mu \times W \times R = 2 \times 0.3 \times 113.09\ Ri^2 \times Ri = 373.197\ Ri^3$
$850 \times 1000 = 373.197\ Ri^3$, Ri = 13.15mm, Ro = 131.5mm, and $W = 2 \times \pi \times PR \times (Ro – R_i) = 11.96$KN

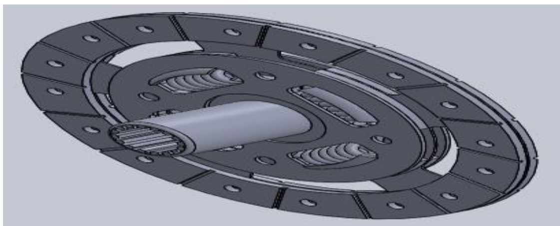


Figure 2: Clutch isometric view

4. Design of Gearbox

A machine consists of a power source and a power transmission system, which provides controlled application of the power. Merriam-Webster defines *transmission* as an assembly of parts including the speed-changing gears and the propeller shaft by which the power is transmitted from an engine to a live axle. Often transmission refers simply to the gearbox that uses gears and gear trains to provide speed and torque conversions from a rotating power source to another device. In British English, the term *transmission* refers to the whole drivetrain, including clutch, gearbox, prop shaft (for rear-wheel drive), differential, and final drive shafts. In American English, however, the term refers more specifically to the gearbox alone, and the usage details are different.
Take $T_A = 32$, $T_B = 36$,
Assumed gear ratio is G1 = 3.60, G2 = 2.063, G3 = 1.432, G4 = 0.956, G5 = 0.855, G6 = 0.660, G7 = 4.030.
$G1 = N_A/N_C = (T_B/T_A) X (T_C/T_D)$, $3.6 = (36/32) X (T_C/T_D)$, $T_C = 3.20\ T_D$, $T_A + T_B = T_C + T_D = 68$, $T_C = 52$, $T_D =16$.
Using same process, we have $T_E = 44$, $T_F = 24$, $T_G = 38$, $T_H = 30$, $T_I = 32$, $T_J = 36$, $T_K = 30$, $T_L =38$, $T_M = 26$, $T_N = 42$, $T_0 = 54$, $T_{P=P1=P2} = 14$,

Now find actual gear ratio with help of calculated values,

$G_1 = N_A/N_C = (T_B/T_A) X (T_C/T_D) = (36/32) X (52/16) = 3.656$,
$G_2 = N_A/N_E = (T_B/T_A) X (T_E/T_F) = (36/32) X (44/24) = 2.062$,
$G_3 = N_A/N_G = (T_B/T_A) X (T_G/T_H) = (36/32) X (38/30) = 1.425$,
$G_4 = N_A/N_I = (T_B/T_A) X (T_I/T_J) = (36/32) X (32/36) = 1.0$,
$G_5 = N_A/N_K = (T_B/T_A) X (T_K/T_L) = (36/32) X (30/38) = 0.888$,
$G_6 = N_A/N_M = (T_B/T_A) X (T_M/T_N) = (36/32) X (26/42) = 0.696$,
$G_7 = N_A/N_O = (T_B/T_A) X (T_O/T_P) = (36/32) X (54/14) = 4.339$,

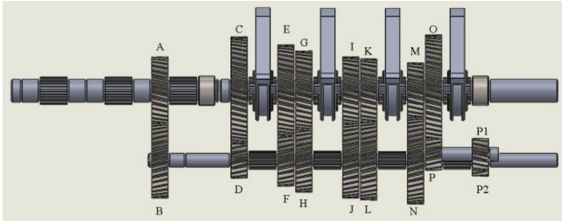


Figure 3: Gear box side view

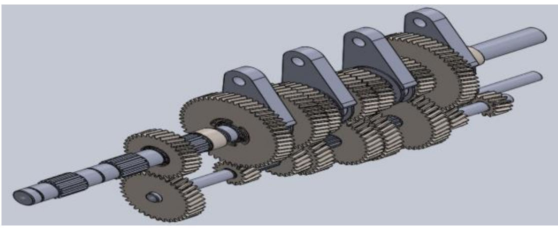


Figure 4: Assembly of gearbox isometric view

5. Powertrain Specification

Type of transmission: 6 Forward speeds and 1 reverse speed gear box

Gear ratio: 3.656, 2.062, 1.425, 1.0, 0.888, 0.696(Top), 4.339(reverse)

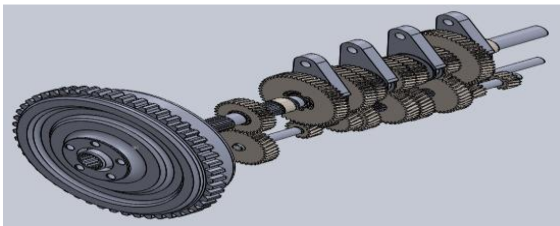


Figure 5: Assembly of powertrain isometric view

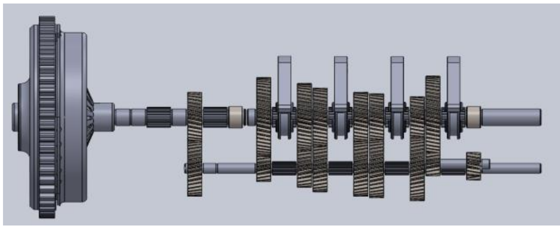
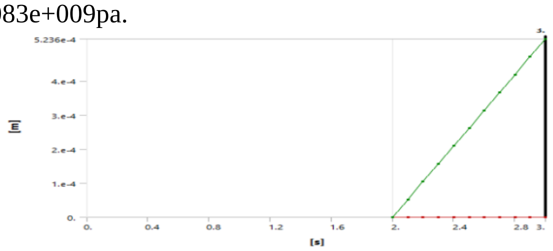


Figure 6: Assembly of powertrain side view

6. Static Structure Analysis

A structure refers to a body or system of connected parts used to support a load. Important examples related to branches of engineering, ship and aircraft frames, tanks, pressure vessels, mechanical systems, and electrical supporting structures are important. In order to design a structure, one must serve a specified function for public use, the engineer must account for its safety, aesthetics, and serviceability, while taking into consideration economic and environmental constraints. Other branches of engineering work on a wide variety of nonbuilding structures. Structural analysis is the determination of the effects of loads on physical structures and their components. Structures subject to this type of analysis include all that must withstand loads, such as buildings, bridges, vehicles, machinery, furniture, attire, soil strata, prostheses and biological tissue. Structural analysis incorporates the fields of applied mechanics, materials science and applied mathematics to compute a structure's deformations, internal forces, stresses, support reactions, accelerations, and stability. The results of the analysis are used to verify a structure's fitness for use, often saving physical tests. Structural analysis is thus a key part of the engineering design of structures.

In case of Flywheel density is 7900kg m^-3, Coefficient of Thermal Expansion is 1.2e-005 C^-1, Specific Heat 434 J kg^-1 C^-1, Thermal Conductivity 60.5 W m^-1 C^-1, Resistivity 1.7e-007 ohm m. And total deformation varies from 0 to 5.236e-004m; equivalent stress varies from 0 to 1.2083e+009pa.



Graph 1: Total deformation vs. time

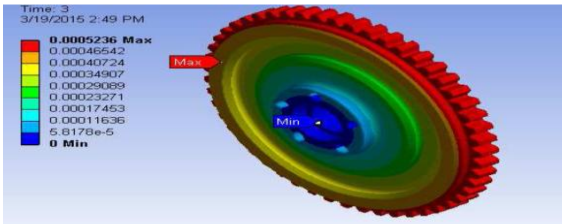
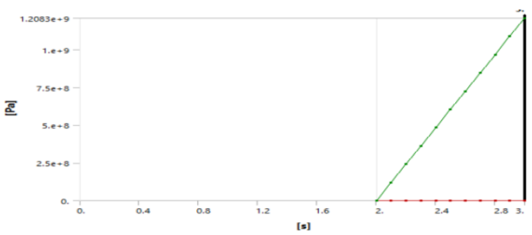


Figure 7: Total deformation



Graph 2: Equivalent stress vs. time

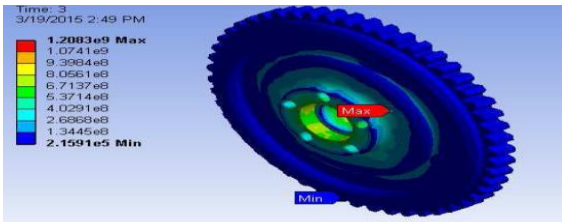
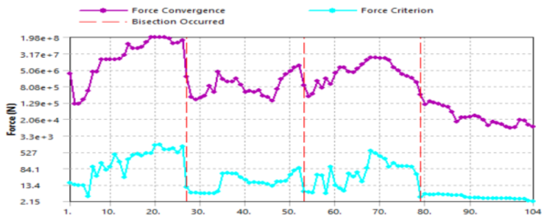


Figure 8: Equivalent stress

In case of clutch total deformation varies from 6.51e-009 m to .00105 m and equivalent stress varies from 7.9276e-003 MPa to 6231.6 MPa



Graph 3: Force convergence

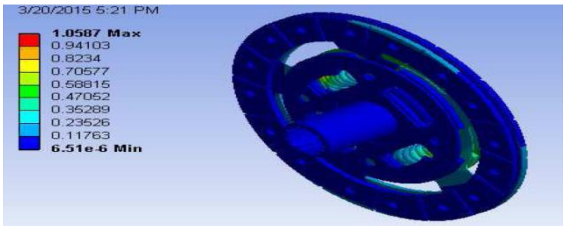


Figure 9: Total deformation

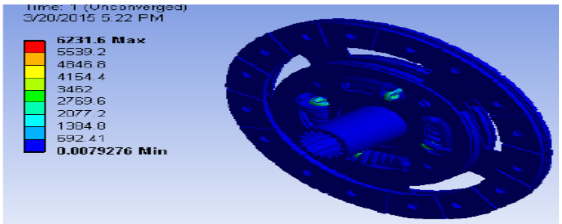


Figure10: Equivalent stress

In case of gear box assembly total maximum deformation is 5.7329e-007m, maximum *directional deformation* 5.502e-007m, maximum *equivalent stress is* 8.9371e+006 Pa, maximum *normal stress is* 5.3154e+006 Pa.

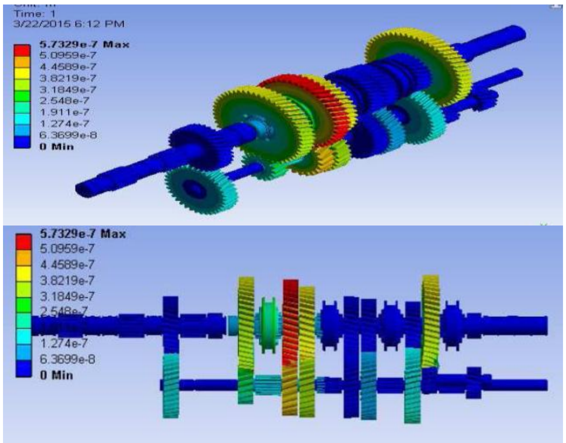
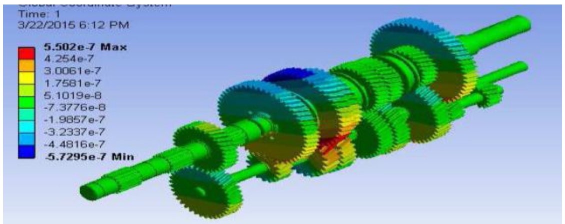


Figure11: Maximum total deformation



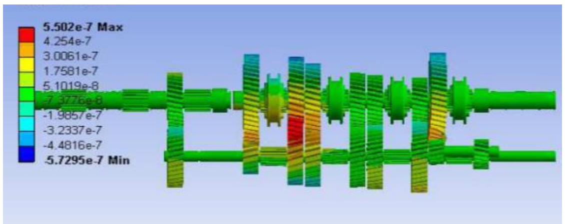


Figure12: Maximum directional deformation

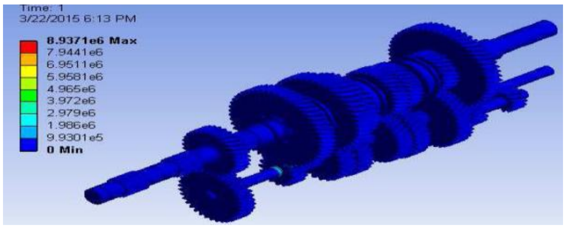


Figure13: Maximum equivalent stress

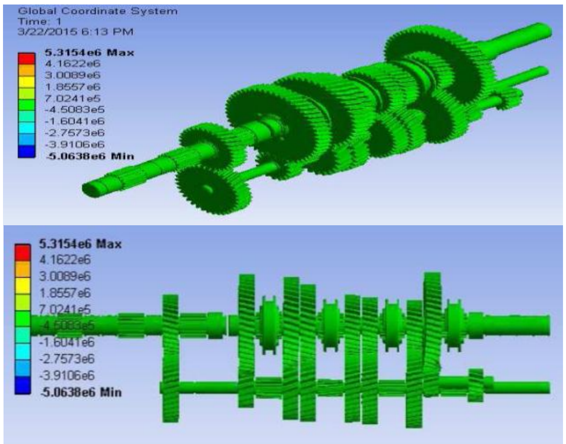
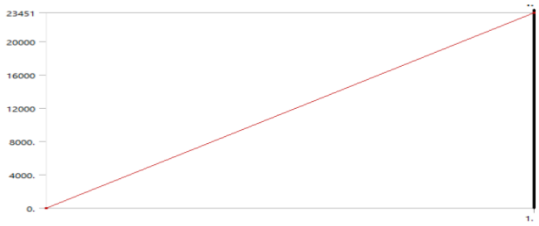


Figure14: Maximum normal Stress

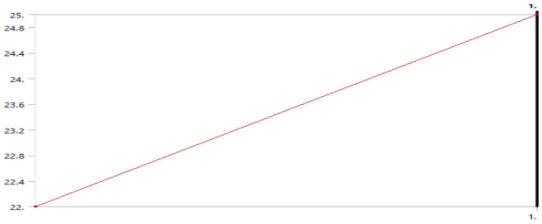
7. Thermal Analysis

Thermal analysis is a branch of materials science where the properties of materials are studied as they change with temperature. Simultaneous Thermal Analysis (STA) generally refers to the simultaneous application of Thermogravimetry (TGA) and differential scanning calorimetry (DSC) to one and the same sample in a single instrument. The test conditions are perfectly identical for the TGA and DSC signals (same atmosphere, gas flow rate, vapor pressure of the sample, heating rate, thermal contact to the sample crucible and sensor, radiation effect, etc.). The information gathered can even be enhanced by coupling the STA instrument to an Evolved Gas Analyzer (EGA) like Fourier transform infrared spectroscopy (FTIR) or mass spectrometry (MS).

For flywheel *Heat Flux* = 23451 W/m², *Convection* film Coefficient = 250. W/m²·°C, ambient temperature = 22°C, *Radiation* ambient temperature = 25 °C, so maximum steady thermal temperature = 33.54°C, maximum total heat flux = 24465 W/m², maximum *directional heat flux* = 19892 W/m²,



Graph 4: Heat flux vs. time



Graph 5: Radiation vs. time

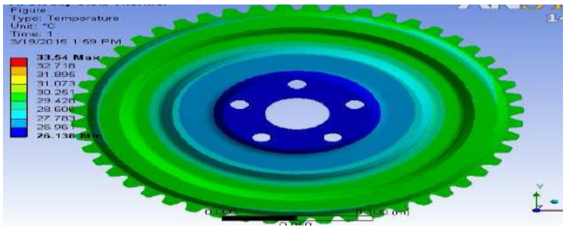


Figure 15: Steady state thermal temperature

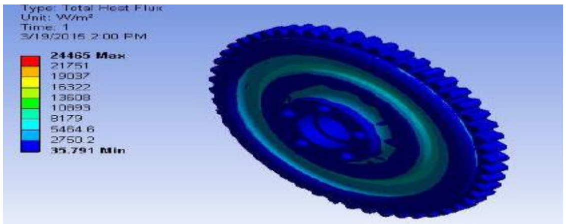


Figure 16: Total heat flux

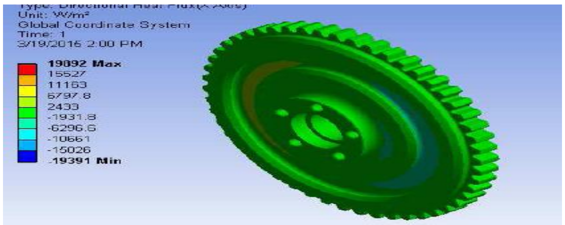
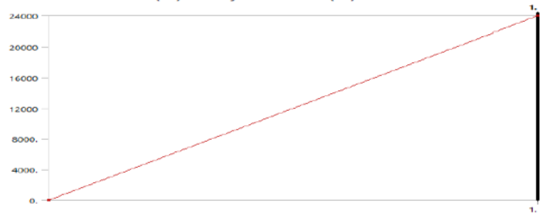
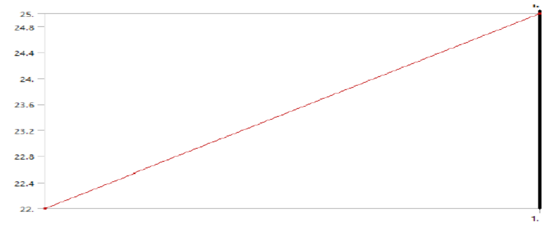


Figure 17: Directional heat flow

For clutch film coefficient is 250. W/m²·°C and 24000W for heat flow, ambient temperature 25°C for convection and radiation, so result for maximum *temperature is* 760.13 °C and maximum total heat flux is 4.2539e+006 W/m².



Graph 6: Heat flow vs. time



Graph 7: Radiation vs. time

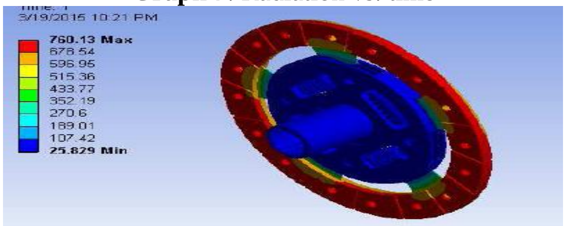


Figure 18: Steady state thermal temperature

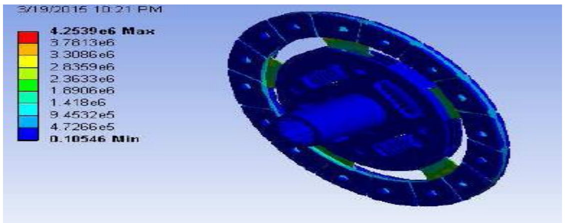
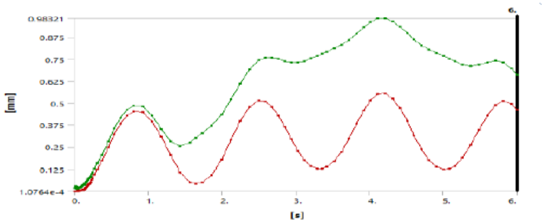


Figure 19: Total heat flux

8. Transient Structure Analysis:

In mechanical engineering, a transient response or natural response is the response of a system to a change from equilibrium. The transient response is not necessarily tied to "on/off" events but to any event that affects the equilibrium of the system. The impulse response and step response are transient responses to a specific input (an impulse and a step, respectively). In case of flywheel 6 frequency mode is taken with frequency 0 to 2.2784e-003, *rotational velocity* is 4500rpm, so calculated maximum *total deformation is* 0.00066 m and maximum *equivalent stress is* 59.93 MPa,



Graph 8: Total deformation vs. time

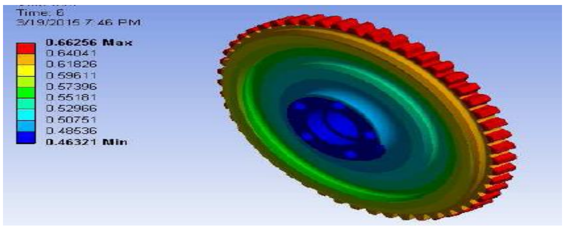
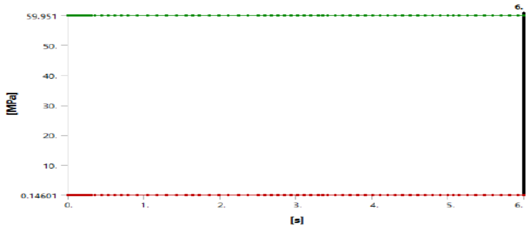


Figure 20: Total deformation



Graph 9: Equivalent stress vs. time

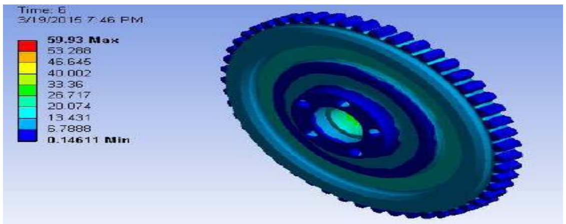
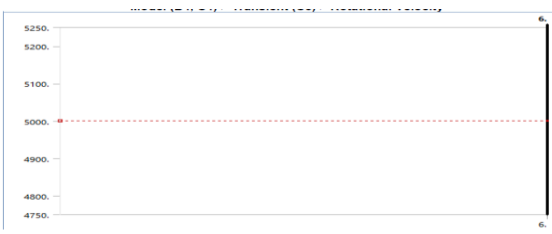
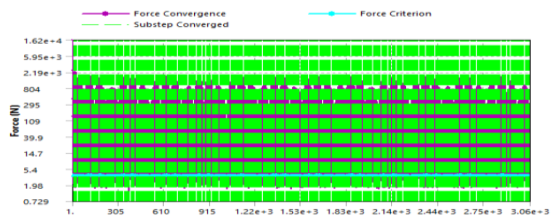


Figure 21: Equivalent stress

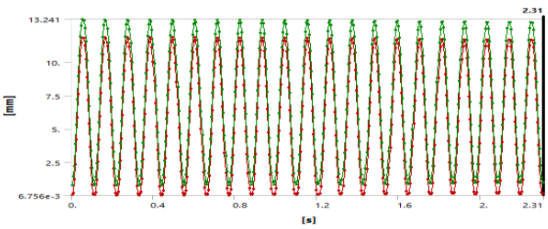
For flywheel 6 frequency mode is taken with frequency 0 to 8.2262, Rotational Velocity 5000rpm, *Standard Earth Gravity* 9.806m/s², maximum *Total Deformation* = 00.01324m, maximum *Equivalent Stress* = 199.81 MPa



Graph10: Rotational velocity vs. time



Graph11: Force convergence



Graph12: Total deformation vs. time

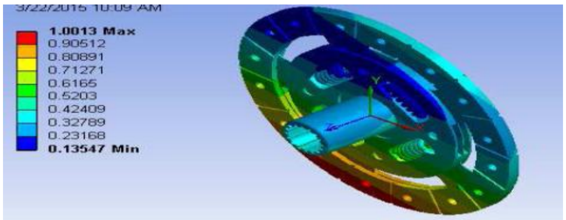
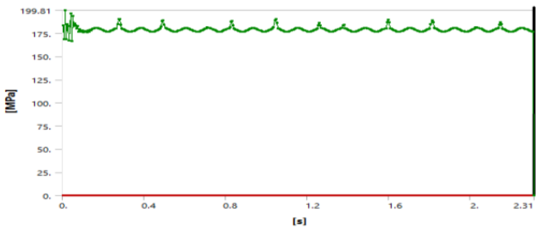


Figure22: Total deformation



Graph13: Equivalent stress vs. time

9. Model Analysis

The purpose of modal analysis in structural mechanics is to resolve the natural mode frequencies and shapes of a design or structure during free vibration. It is general to use the finite element method (FEM) to execute this analysis because, like other computation using the FEM, the object being analyzed can have arbitrary shape and the results of the calculations are satisfactory and acceptable. The classifications of equations which emerge from modal analysis are those seen in Eigen systems. The physical interpretation of the Eigen and Eigen vectors which come from solving the system are that they represent the frequencies and corresponding mode shapes. Sometimes, the only desired modes are the lowest frequencies because they can be the most prominent modes at which the object will vibrate, control all the higher frequency modes.

In case of powertrain 6 frequency mode is taken varies from 455.41 to 629.09Hz, maximum total deformation 1.6957m

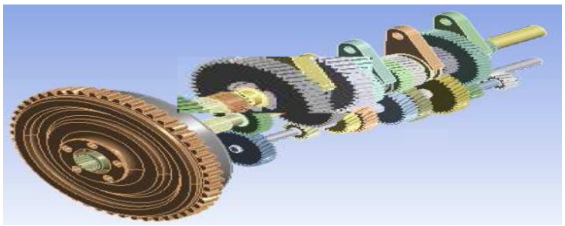


Figure23: Isometric view of powertrain

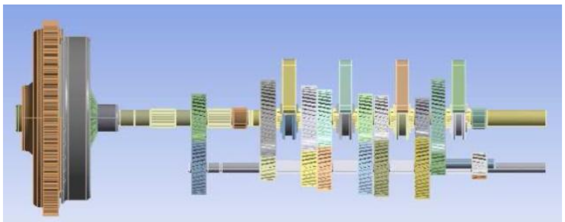


Figure23: Side view of powertrain

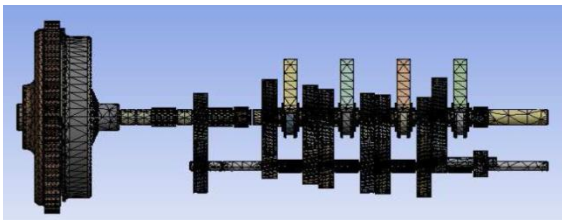
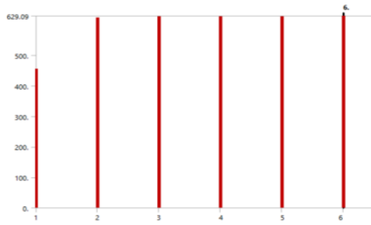


Figure24: Powertrain mesh view



Mode	Frequency [Hz]
1.	455.41
2.	623.66
3.	627.24
4.	627.52
5.	627.62
6.	629.09

Graph14: Frequency mode

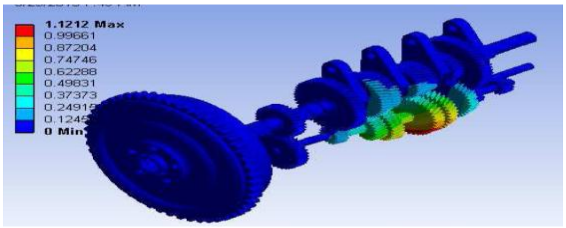


Figure23: Total deformation view of powertrain

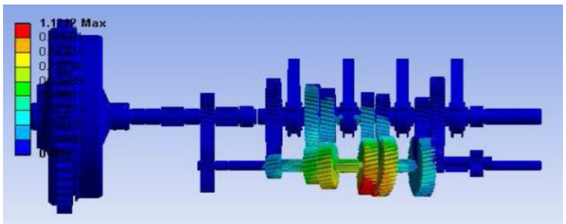


Figure25: Total deformation frequency mode 1

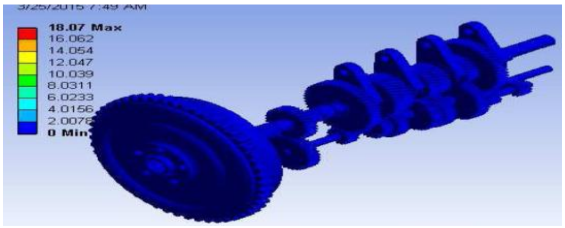


Figure26: Total deformation frequency mode 2

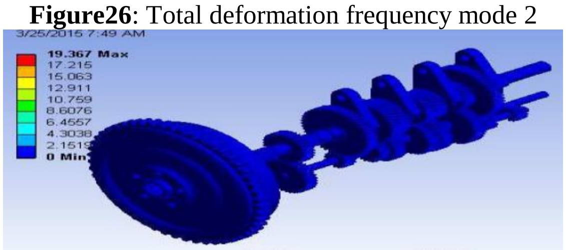


Figure27: Total deformation frequency mode 3

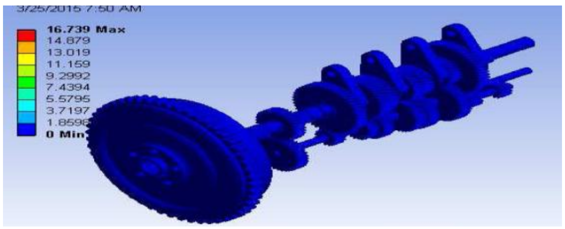


Figure28: Total deformation frequency mode 4

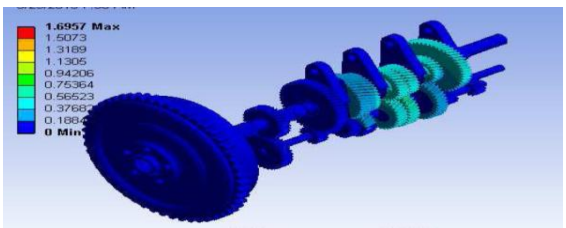


Figure 29: Total deformation frequency mode 5

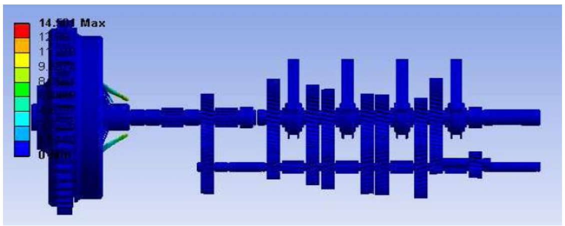


Figure 30: Total deformation frequency mode 6

It is also possible to test a physical object to determine its natural frequencies and mode shapes. This is called an Experimental Modal Analysis. The results of the physical test can be used to calibrate a finite element model to determine if the underlying assumptions made were correct.

10. Conclusion

Here is the complete design of automotive powertrain. And we have effective result data of design using different techniques and approaches. And it provides a unique design solution with effective concept; require less space, validate dimension by applying high force and rotational speed. And model and structure analysis is part of the data control theory. SOLIDWORKD and ANSYS software is used for this purpose. And the graph and plots of velocity magnitude with time define the variety of conditions and results.

11. Further Possible Work

There is many more method that can use to formulate to know about whether design and mechanism will work properly or not such as six-sigma, optimization techniques with vibration, linear and nonlinear buckling and fatigue analysis etc. So these methods can be used to improve the other factors of car powertrain.

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