Design of Torque Enhancer for Hybrid Vehicles using Planetary Gear

E Vijayaragavan, Aditya Vatsa, Adil Hossain, Agam Dubey

Abstract: ***This work presents the development of an alternate powertrain for hybrid vehicle called the 'Torque Enhancer'. It is a planetary gear system with a sun gear, an internal ring gear, three planet gears, a planet carrier and an outer ring casing. The primary inputs from the electric motor (EM) and an internal combustion (IC) engine were connected to the sun gear and the planet carrier respectively. The ring casing provides the necessary output. The sun gear and the planet carrier were coupled to generate higher torque and higher rpm at the output. The 3D modelling and simulation for dynamic motion were performed in SOLIDWORKS 2018. The results showed that a higher rpm and a higher torque were achieved on the output ring casing. For design optimization, a Nonlinear- Dynamic Study was performed to check for different analysis like the Stress, Displacement, Strain and velocity for different designs of carrier plates. The Stress, Strain and velocity decreases with the thickness, the displacement is found to be almost constant around 25mm and the velocity decreases with increase in thickness. A ribbed carrier plate of thickness 4mm is chosen to be the most optimized carrier plate..***

Index Terms**: *Parallel Hybrid Vehicle; Planetary Gear Drive; Torque Enhancer; Planet Carrier.***

I. INTRODUCTION

Traditional vehicles having IC Engine provides long distance operating range by the combustion of petrol. Electric vehicles (EV) have advantage over other vehicles such as cutting costs and no emissions. Hybrid electric vehicles (HEV), has two power sources, thermal power and electric power. HEV have the characteristics of both thermal and electric power, and also improve their limitations. HEV are of four major types: series, parallel, a combination of series and parallel and complex hybrid.

Honda Accord hybrid 2017 [2] is one such example of a parallel hybrid vehicle. It has two inputs of power, the IC Engine and the EM. It operates in following modes:

(i) Electric mode: When the power requirement is low and the battery is charged, the vehicle is then operated by the EM only. In this case the IC Engine remains turned off

(ii) Engine mode: During long distance travelling and when power requirement is high, the vehicle is driven by IC Engine only. The EM remains idle.

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(iii) Hybrid mode: When power requirement is very high, the vehicle uses both the IC engine and the EM to deliver power to the transmission.

This work is specialized in parallel hybrid vehicles whose system architecture is depicted in Fig. 1 [1].

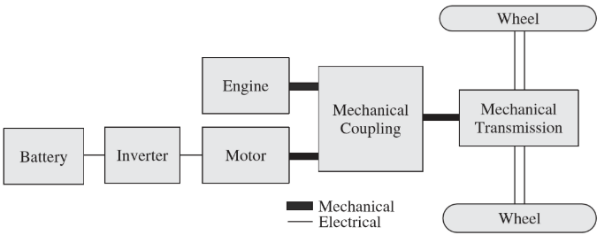

Fig. 1. The architecture of a parallel HEV

II. METHODOLOGY

In hybrid drive the engine runs the generator to power the motor which runs the motor gear. Thus, power is transferred to the mechanical transmission though only one gear (motor gear or the engine gear).

Fig. 2 shows the configuration of the three modes- EV drive, Engine drive and Hybrid drive. In this configuration, either the motor (EV drive and Hybrid drive) or the engine gear (Engine Drive) runs the mechanical transmission [3].

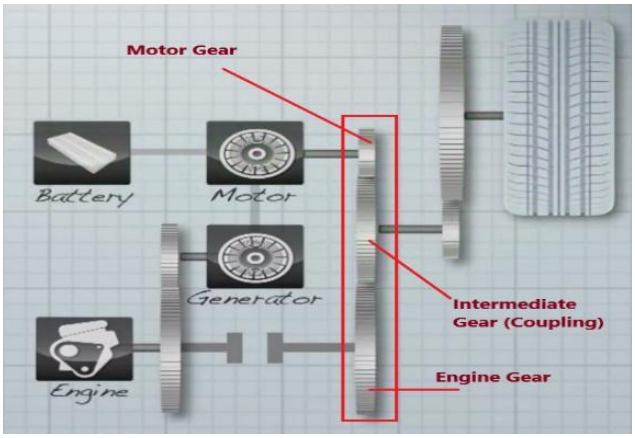

Fig. 2. Powertrain of Honda Accord Hybrid 2017

This paper focuses on development of an alternative powertrain in which both the motor gear and the engine gears are running simultaneously to transfer power to the mechanical transmission. This is achieved by developing a planetary gear system. Thus, both the Sun gear and the Planet gears transfer power to the internal ring gear simultaneously.

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The design of the planetary gear set is inspired from the Power Split Device (PSD) [4] used in Toyota Prius drivetrain. The module is taken as 3 mm based on calculations. The no. of teeth on the gears are calculated as 16, 29 and 61 on the sun gear, the planet gears and the internal ring gear respectively. 3D Modelling is done by using Solidworks 2018 Student Edition. The gears and the bearings are taken from the Toolbox Library. The carrier plate and the ring casing are designed as per requirements.

Motion Analysis is done to verify the output rpm by using Solidworks Motion Analysis. The sun gear and the IC Engine are connected with rotary motor with different rpms and the results are tabulated to check the output rpm which is shown in tables 3, 4 and 5.

An optimization is carried out by making three different designs of carrier plate and varying each carrier plate with thickness of 2mm, 3mm and 4 mm respectively. A nonlinear Dynamic study was performed to check different analysis such as Stress, Strain, Velocity, Acceleration and Reaction forces for each thickness of carrier plate and each design respectively to check for safety of the setup. The best among these is chosen based on the results.

III. TORQUE ENHANCER

It is a powertrain designed to add the torque and the rpm of the two inputs and thus produce an output that suits our requirement for higher torque or higher rpm. This powertrain is based on planetary gear system. The EM and the IC Engine is connected to the mechanical transmission by meshed gears.

Figure 3 shows the assembly of the Torque Enhancer. The IC Engine is connected to the system at the planet carrier by a shaft. The sun gear is a hollow spur gear of type B having a hub diameter of 30mm. The sun gear placed on the planet carrier shaft is held in place by roller bearing to allow free movement of sun gear as well as planet carrier shaft. The sun gear and the internal ring gear is meshed with the three planet gears with a gear ratio of 29:16 and 61:16 respectively. The output is taken form the ring casing which is bonded to the internal ring gear. The gears and the ring casing are made up of material C45 and the planet carrier is made up of Aluminum (6061 Alloy).

The 3D modelling of the torque enhancer was done using Solidworks 2018 Student Edition. The Ring casing has an outer diameter of 230 mm and inner diameter of 200 mm. The components like Sun gear, Planet gears, internal ring gear, sun shaft bearings, planet gear bearings are taken from the Toolbox- Design library. The spur gears are taken form the ANSI Metric library. The bearings are taken from the SKF library- Radial Roller Bearings. The dimensions of various components in the system is listed in Table I.

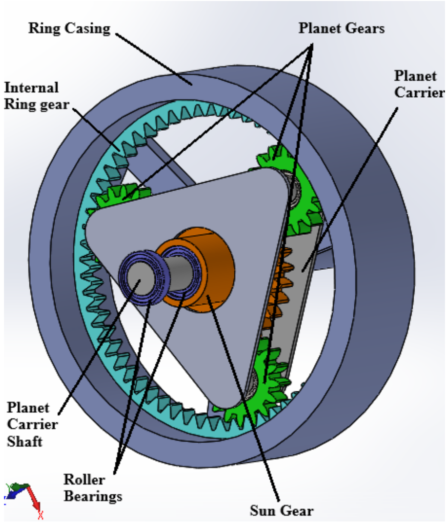

Fig. 3. Custom View of the Torque Enhancer

Table I – Dimensions of torque enhancer

Parameters	Sun Gear	Planet Gears	Internal Ring Gear
Module	3 mm		
No of Teeth	29	16	61
Pressure Angle	20 °		
Face Width	12 mm		
Hub Style	Type B	-	-
Hub Dia. (mm)	40	-	-
Overall Length (mm)	40	-	-
Outside Dia. (mm)	93	54	200
Nominal Shaft Dia. (mm)	30	24	-

IV. MOTION STUDY

The purpose of an alternate drivetrain is to get an output rpm and torque which is higher. Thus, in order to verify the same, a motion study is carried out using Solidworks Motion Analysis. Motors are added to simulate the power given by the EM at the sun gear and the IC Engine at the planet carrier. Two input rpm are given to the sun gear in clockwise direction and the planet carrier in anticlockwise direction respectively. The output rpm is checked at the ring casing and the results are tabulated.

Table II and Table III shows the relation between the input rpm and the output rpm. (E+C) Input rpm is summation of the rpms of the Carrier Plate shaft and the EM shaft.

In Table II, both the carrier plate shaft and the electric motor shaft are same. The output rpm is constant i.e. 97.5% of the total input rpm (E+C). In Table III, O2 output rpm is calculated when the EM shaft rpm is kept constant at 100

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rpm and carrier plate shaft rpm is varied form 100-500 rpm. The output O2 shows that when the carrier plate shaft rpm is increased, the output O2 rpm increased linearly and the output % also increased continuously. In Table III, O2 output rpm is calculated when the carrier plate shaft rpm is kept constant at 100 rpm and the EM shaft rpm is varied form 100-500 rpm. The output O2 shows that when the EM shaft rpm is increased, the output O2 rpm increased linearly but the output % decreased continuously.

Table II – Output rpm for common input speed

(C)- Carrier Plate Shaft (rpm)	100	150	200	250	300
(E) Electric Motor Shaft (rpm)	100	150	200	250	300
(E+C) Input (rpm)	200	300	400	500	600
O1- Output (rpm)	195	292	390	487	585
% Output	97.5	97.5	97.5	97.5	97.5

Table III – Output rpm for constant Electric motor speed

Case	Case 1		Case 2	
(E+C) Input (rpm)	O2 at E = 100	%	O3 at C = 100	%
200	195	97.5	195	97.5
300	342	114	242	81
400	490	122	290	73
500	637	127	338	67.6
600	785	130	385	64

Fig. 4 shows the comparison of three cases in which different input rpm are taken for carrier plate shaft and EM shaft respectively. In case 1 i.e. when the EM shaft rpm is same as carrier plate shaft rpm, the output rpm is shown by the blue line. In case 2, the EM shaft is kept constant at 100 rpm and the carrier plate shaft rpm in increased. The output rpm is shown by the orange line. Similarly, in case 3, the carrier plate rpm is kept constant at 100 rpm and the EM shaft rpm is increased. The output rpm is shown by the grey line.

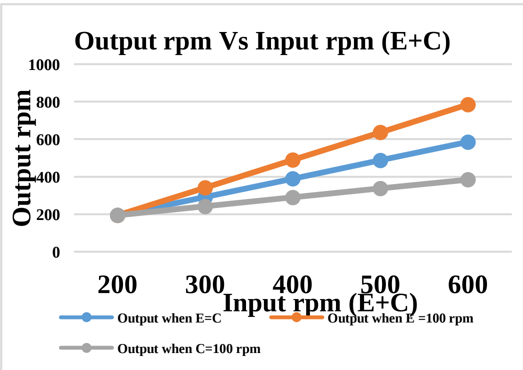
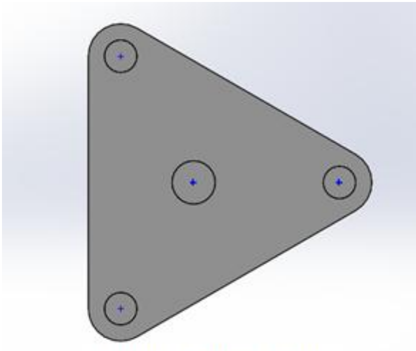


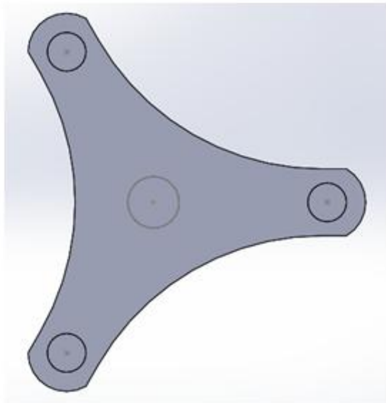
Fig. 4 Graph showing relation between the output rpm and the input rpms (E+C).

V. RESULTS AND DISCUSSIONS

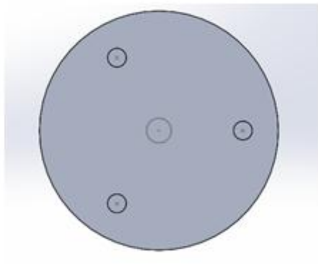
A design optimization is carried out for the specification of each component- planet carrier plate, outer ring box, etc. The thickness of the carrier plate is changed and studied for different thickness. The Study is carried out using SOLIDWORKS Simulation to check the Stress, Displacement, Strain and Velocity. The analysis type is Nonlinear – Dynamic. The mesh type is Solid Mesh. Solver type used is Large problem Direct Sparse. Iterative technique is NR (Newton-Raphson). Integration method is Newmark. Fig. 5 shows the design of triangular, ribbed and circular carrier plates whose thickness is taken as as 2mm, 3mm and 4mm for each analysis.



a. Triangular carrier



b. Ribbed carrier



c. Circular carrier

Fig. 5. Profiles of Carrier plate

The motion analysis results including stress (σ), strain (ξ), displacement (y), velocity (v), reaction force (F) for the different carrier plates with thickness (t) is listed in Table III.

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Table III – Results of motion analysis

Profile	t mm	σ N/mm²	ξ 10^{-3}	y mm	V 0.01 m/s	F (N)
Circular	2	1728	3.87	25.97	2.38	0.16
	3	1491	3.42	25.62	1.85	0.22
	4	1471	3.47	25.81	2.03	0.37
Triangular	2	1888	3.74	25.93	2.45	0.35
	3	1590	3.46	26.37	1.25	0.46
	4	1655	6.22	26.34	2.76	0.29
Rib	2	1617	6.03	25.69	1.77	0.25
	3	1445	5.77	25.28	1.11	0.24
	4	1258	2.96	25.21	0.81	0.25

The triangular carrier plate of thickness 4 mm is chosen as the optimum thickness with stress of 1655 N/mm2, strain of 0.00622, displacement of 26.34 mm, velocity of 0.0276 m/sec and reaction force of 0.29. It has the highest velocity and other factors are comparable. A highest strain of 0.00622 is neglected as it is very low.

VI. CONCLUSION

The conceptual design of the torque enhancer is developed for adding up the torque as well as rpm for variable input from engine and motor in different cases. The given results of the simulation carried out by SOLIDWORKS. The analytical and simulation result of the 4mm thickness triangular plate are within the acceptable limits. Hence the conceptual coupling designed can be used in light as well as heavy hybrid vehicles.

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