Modelling of Planetary Gear using EMR and Simdriveline for Hybrid Electric Vehicles

Special session "EMR and Other Description"

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ABSTRACT

The modelling of the planetary gear in series-parallel Hybrid Electric Vehicles (HEV) is a vital point because of its role in power distribution, efficiency and enhanced design. The series-parallel HEV has an architecture that is more diverse than the other types of hybrid electric vehicles as it joins the advantages of series HEV and parallel HEV. Due to this complex design, to get higher performance results from series-parallel HEV architecture is more complicated and costly. The driveline of the series-parallel HEV is dependent on the planetary gear. Two different models of the planetary gear have been implemented into Simdriveline and MATLAB-Simulink™ thanks to the EMR approach. These different models are then compared.

I INTRODUCTION

With a part estimated approximately at 20% of carbon dioxide (CO_2) global emissions, the transport sector is one of the main contributors to global warming [1]. In order to help lower carbon dioxide emissions and save energy to prevent global warming, one of the focuses has been on developing new technology and improvements in fuel efficiency. One such solution that emerged is what is known as the Hybrid Electric Vehicle (HEV), which is in between the thermal and electric vehicles [2].

Hybrid electric vehicles are able to be categorized with respect to propulsion-energy flow, as either series or parallel. In a series hybrid system, an engine powers a generator to charge a battery or provide electricity to a machine that in turn drives the wheels i.e. the engine power and the electrical machine power are in a series. Contrarily, in a parallel hybrid system, both the engine power and the machine power work in parallel to drive the wheels. A combination and utilization of both systems results in a series-parallel hybrid system. This system includes a series hybrid system with a parallel hybrid system that alternate according to driving circumstances in order to extract the benefits of both systems [3]. In order to optimize series-parallel HEV behaviour, global simulations are required to take into account the main components and their interactions with each other. Specific modelling has thus been suggested to simulate the whole system [4] [5].

The planetary gear is the core of the power split transmission for the series-parallel HEV and the means through which the engine torque splits resulting in a portion to the generator and a portion to the driveline. However, because of its dynamic behaviour, the modelling of the planetary gear is a sensitive issue as it is connected to the two electrical machines and an engine [6][7].

The aim of this paper is to gain an understanding of the critical factors involved in the planetary gear for the series-parallel HEV, both in terms of functional and the structural aspects. EMR (Energetic Macroscopic Representation) approach helps in functional modelling because it has the global modelling capabilities of energy flow. This approach is based on the physical causality (integral causality) which shows the graphical representation of energy flow for the planetary gear [8][9][10]. Simdriveline helps in structural modelling for the planetary gear which represents directly the physical components and their relationships with each other [11]. In this way, with these two (EMR and Simdriveline) and the use of MATLAB-Simulink[TM], give us the ability to compare the computation time, accuracy and complexity of the system.

II MODELLING OF PLANETARY GEAR

A. STUDIED SYSTEM

The studied structure consists of a planetary gear mounted with the shafts connected to the two electrical machines and an engine as shown in Figure 1.

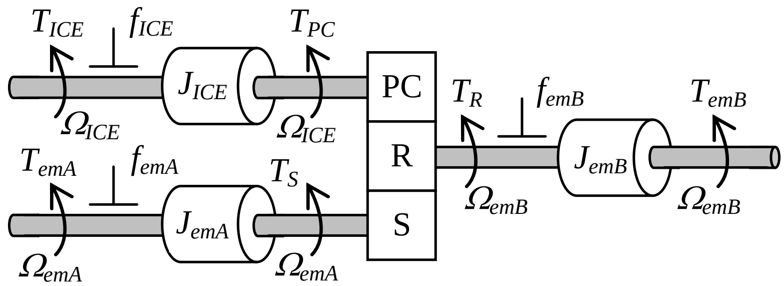

Figure 1 Transmission Scheme

The planetary gear trains are the mechanisms of several degrees of freedom. In its composition, one element of planetary gear has two rotational movements. In the above system, ICE drives the planetary carrier wheel, while the sun gear is connected to the electrical machine A (Motor/Generator) for allowing increased and / or decreased speed. The ring gear provides torque and is connected to the second electrical machine B (Motor/Generator) with an additional gear ratio. The ring gear output shaft transmits the summation power to the vehicle driveline.
The architecture of the planetary gear is depicted in a specific way (Figure 2) in order to deduce the other classical architectures.

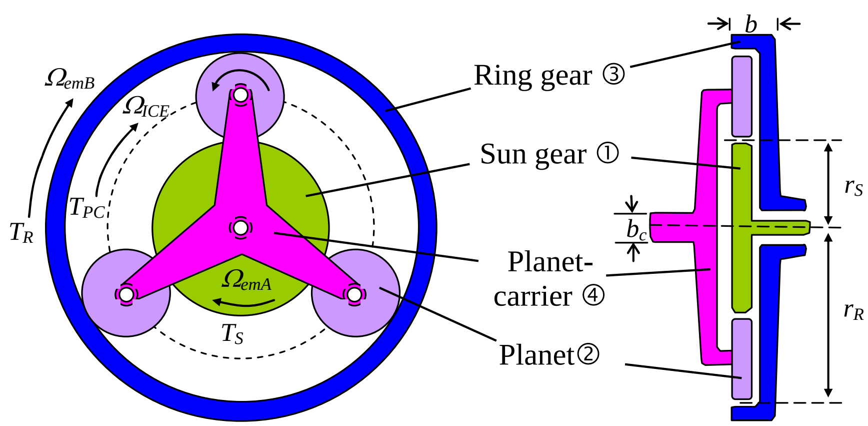

Figure 2 Planetary Gear Unit

B. Global modelling of the planetary gear

The fundamental equation (1) for planetary gearing is that the gear must rotate so as to maintain a fixed ratio of angular velocities relative to the carrier body. The fixed ratio n equals the radius of the ring r_R divided by the radius of the sun gear r_s. The negative sign shows the exterior epicyclic.

$$\frac{\Omega_{emA}-\Omega_{ICE}}{\Omega_{emB}-\Omega_{ICE}}=-\frac{r_R}{r_S}=-n \qquad (1)$$

$$\Omega_{emA}-n\Omega_{emB}+(n-1)\Omega_{ICE}=0 \qquad (2)$$

$$M_{Tot}=r_R^{\,2}b\pi\rho\left(\frac{1}{(n-1)^2}+\frac{3(n-2)^2}{4(n-1)^2}+(k_{R_o}-1)+\frac{b_C n^2}{4b(n-1)^2}\right) \qquad (3)$$

$$J_{Tot}=\frac{r_R^4\left((9b+b_C)n^2-36bn+52b\right)}{32(n-1)^4}\pi\rho \qquad (4)$$

After simplification, equation (1) reduces to the more general form shown in equation (2). Equation (2) shows the inherent speed summing the nature of the planetary gear and the reason it is used in the power split. The relationship shows the planetary gear particularly: among three speeds only two are independent, the third is deduced.

The equation (3) shows the total mass of the planetary gear train while equation (4) depicts the total moment of inertia. The variables ρ and k_{r_o} stands for the mass density of the gear and relation between outer and reference radii of ring gear, respectively. Further details about the relationships will be provided in the final paper.

C. Modelling with EMR

Energetic Macroscopic Representation (EMR) is based on an action-reaction principle whose structure is organized and simplified to highlight the exchange variables of the elements of an energetic conversion.

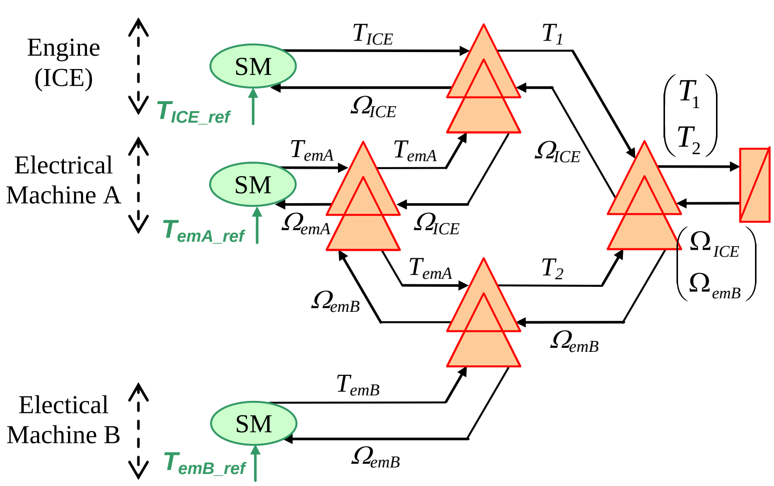

Figure 3 Planetary Gear Unit in EMR

In the full paper, the modelling of the planetary gear by EMR (Figure 3) will be detailed and simulated via MATLAB-Simulink^{TM}.

D. Modelling with SimDriveline

Simdriveline offers an efficient medium to construct driveline models within the Simulink environment. In this, we are able to choose a block-diagram network description representing the system. The blocks characterize such components as the sun gear; planet gears and planet carrier. The lines that connect the blocks represent rotating components of the system, such as the drive shaft.

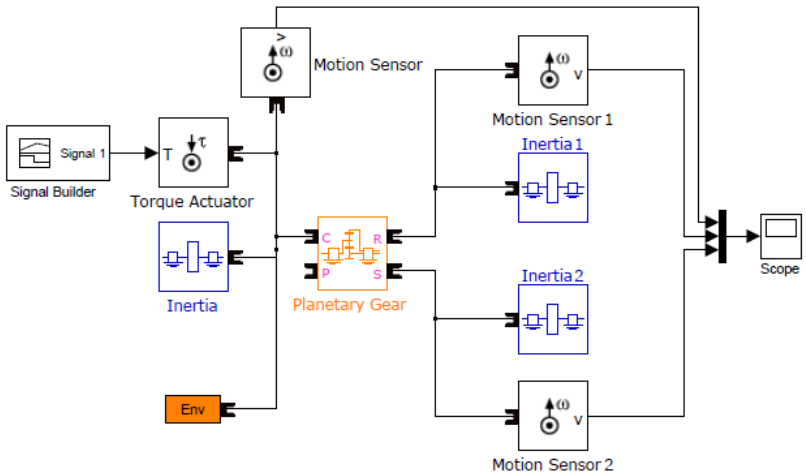

Figure 4 Planetary Gear in Simdriveline

In the full paper, the modelling with Simdriveline (Figure 4) of the planetary gear will be provided with its results.

E. Simulation Results

Simulation is carried on the Simdriveline software and the result with the following parameters:

$$n = 2 \qquad J_{ICE} = 0.15\ kg.m^2 \qquad J_{emA} = 0.1\ kg.m^2 \qquad J_{emB} = 0.1\ kg.m^2$$

The input torque is imposed such as in Figure 5(b) which results the rotation speed in Figure 5(a). The ring gear rotational speed is higher than sun and carrier gear speeds, which shows the summation of angular speeds of sun and carrier gears by the help of equation 2. The result (Figure 5(a)) verifies the equation 2 for global modelling of planetary gear. In the full paper the complete results will be provided with inertia, mass, torque and efficiency.

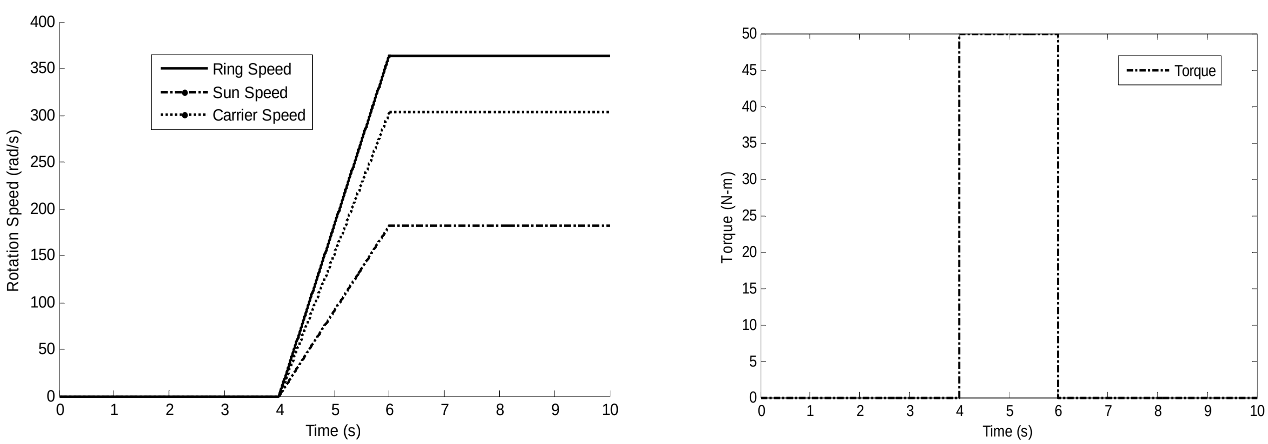

Figure 5 (a) Simulation Result from Simdriveline for rotational speed of Ring, Sun and Carrier. (b) Torque

IV Conclusion

To gain a complete and simple understanding of the planetary gear, it is advantageous to model with both Simdriveline and EMR as they are able to give information regarding the planetary gear in both structural and functional perspective, respectively. Using these two mediums, an improved design that increases the efficiency of the planetary gear with application to series-parallel HEV is able to recognize. In the final paper, some simulation results via MATLAB-Simulink™ will be provided and compared.

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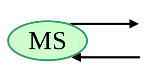
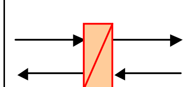
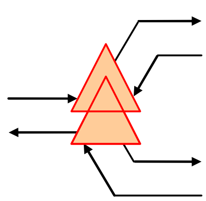
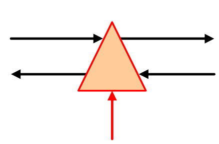
Appendix: Synoptic of Energetic Macroscopic Representation (EMR)

	Mechanical source of energy		Element with energy accumulation
	Mechanical coupling (distribution of mechanic energy)		Mechanical converter (without energy accumulation)