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Review Article

A Review on Automotive Powertrain Parameter Optimization

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Abstract

Automotive industry is producing vehicles that are more fuel efficient and lower in emissions due to stricter regulations and evolving environmental concerns.This can be achieved by optimization of automotive Powertrain. This paper presents the study of different trends in powertrain optimization which includes tackling the major problem of friction, improving functioning of alternative or hybrid powertrains, clutch engagement control in mechanical powertrains as well as study of the case study of efficiency improvement on powertrain design done by VOLVO involving Super truck.

Keywords: *Friction reduction, alternative powertrains, and clutch engagement control, efficiency improvement, Volvo Super truck.*

1. Introduction

Over the past 100 years, vehicles have changed our lives; they have provided mobility which we exploit in all our commercial activities around the globe and they have also provided millions of us with new opportunities afforded by personal transportation. The automobile technology is undergoing a fast evolution as manufacturers strive to meet high targets to reduce global greenhouse gas emissions and average fleet fuel usage. Recent trends in energy supply and use are patently unsustainable – economically, environmentally and socially. Without decisive action, energy-related emissions of carbon dioxide (CO2) will be nearly double by 2050 and increased oil demand will heighten concerns over the security of supplies. Over the past 100 years, vehicles have changed our lives; they have provided mobility which we exploit in all our commercial activities around the globe and they have also provided millions of us with new opportunities afforded by personal transportation.

At the very heart of vehicle design is the powertrain system; it is the engineering of the powertrain system which provides the driving force behind the mobility. The output from the power source – to date, dominated by the internal combustion (IC) engine – is controlled by a transmission system and driveline to deliver tractive effort to the wheels. And all these components, collectively referred to as the powertrain system, are controlled by the driver. Drivers, who are also viewed as discerning customers by the vehicle manufacturers, have a range of performance criteria: acceleration, top speed, fuel economy, gradeability, and towing capacity are some of the more obvious quantitative features. But subjective judgments such as driveability, fun to drive, refinement and driving pleasure play a huge part in the commercial success of vehicles.

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2. Powertrain Components

The following components are subject to relentless efforts in order to improve their performance-efficiency, emissions control, overall cost effectiveness. The most recent trends are,

Engine

- Stratified charge combustion
- Lean burn combustion
- HCCI (homogeneous charge compression ignition)combustion
- Variable valve timing
- Supercharging or twin-charging (when coupled with a downsized engine)
- Turbocharged direct injection diesel engines
- Gasoline direct injection petrol engines
- Common rail diesel engines, Variable geometry turbocharging.

Transmission

- Lower-friction lubricants (engine oil, transmission fluid, axle fluid)
- Locking torque converters in automatic transmissions to reduce slip and power losses in the converter

- Continuously variable transmission (CVT)
- Automated manual gearbox
- Dual clutch gearbox
- Increase in the number of gearbox ratios in manual or automatic gearboxes

Vehicle structure

- Reducing vehicle weight by using materials such as aluminum, fiberglass, plastic, high-strength steel and carbon fibre instead of mild steel and iron.
- Using lighter materials for moving parts such as pistons, crankshaft, gears and alloy wheels.
- Replacing tyres with low rolling resistance models.

Systems operation

- Automatically shutting off engine when vehicle is stopped.
- Recapturing wasted energy while braking (regenerative braking).
- Augmenting a downsized engine with an electric drive system and battery (mild hybrid vehicles).
- Improved control of water-based cooling systems so that engines reach their efficient operating temperature sooner.

But nowadays for satisfying the criteria of reduced fuel consumption, alternative or hybrid powertrain are being developed on a considerable scale. Electric powertrain which includes battery electric vehicles (BEVs) which are powered by 100% electric energy, various hybrid-electric vehicles (HEVs), and plug-in hybrid electric vehicles (PHEVs).

Hybrid Electric Vehicle (HEV)

A hybrid electric vehicle (HEV) operates on two energy sources, usually an internal combustion engine and an electric battery and motor/generator.

In a Series Hybrid there is a single path to power the wheels of the vehicle, however it has two energy sources. The fuel tank feeds an engine which is coupled to a generator to charge the battery which provides electrical energy to a motor/generator to power the wheels through a transmission although a direct coupling can also be used. The motor/generator is also used to recharge the battery during deceleration and braking.

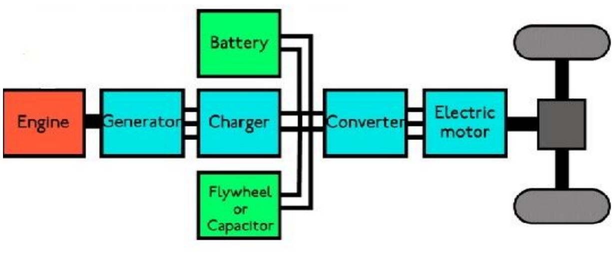

Figure 1 Schematic of Series Hybrid Powertrain

Parallel Electric Vehicles (Hybrid)

In a Parallel Hybrid, there are basically two parallel paths which provide power to the wheels of the vehicle: an engine path and an electrical path. The transmission couples the motor/generator and the engine, allowing either, or both, to power the wheels. Control of a Parallel Hybrid is much more complex that for a Series Hybrid because of the need to efficiently couple the motor/generator and engine in a way that maintains driveability and performance.

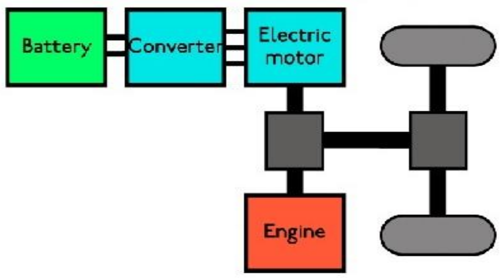

Figure 2 Scematic of Parallel Hybrid Powertrain

3. Literature Survey

Case 1:- Reduction in powertrain efficiency through friction (JohannesBeulshausen, Johannes Geiger, Prof. Dr.-Ing.StefanPischinger-Rwth Aachen University And TuMÜnchen, Germany)

Within the framework of the Low Friction Powertrain research cluster, a simulation model for an entire vehicle powertrain was developed at RWTH Aachen University and TU München for the virtual representation of relevant energy flow rates within a thermal management system, including a detailed description of a thermal gearbox model, for the purpose of evaluating measures to reduce powertrain friction.

The temperature distribution in the engine and gearbox – particularly in system warm-up – is of very importance. As part of a holistic approach covering the entire powertrain, engine and gearbox system, states may be influenced through thermal management. Optimization measures are evaluated and quantified for a petrol-powered powertrain representative of an upper medium-sized class vehicle with a manual six-speed gearbox. This is carried out in the simulation environment GT-Suite. By several measures, aoverall friction reduction of approximately 30 % can be achieved, which corresponds to a fuel consumption reduction of roughly 12 %. The results of the simulation showed that only about 16 % of the total fuel energy is converted into mechanical energy. The energy to heat up the warm up system consists of combustion chamber heat and engine friction, which makes up roughly one quarter of the entire warm-up energy. Apart from the reduction in the losses caused by the internal combustion engine, the aim of the research cluster was to lower the frictional losses of the gearbox. The focus of several projects within the cluster was the optimization of the power loss of bearings and gears.

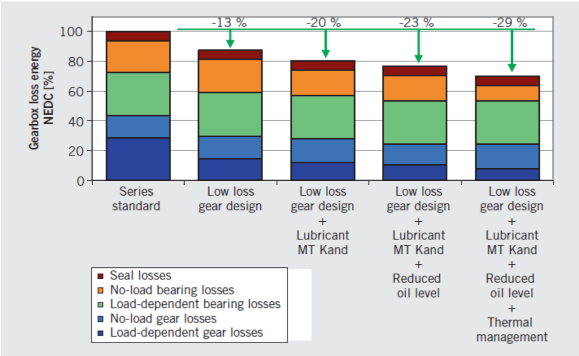

Figure 3 Overview of the Gearbox Power loss Savings

Other sub-projects of the Low Friction Powertrain research project were aimed at minimize the combinations of friction. In particular, piston friction and the friction of the main and connecting rod bearings were investigated. Concerning piston friction, both measurements and simulations were performed.

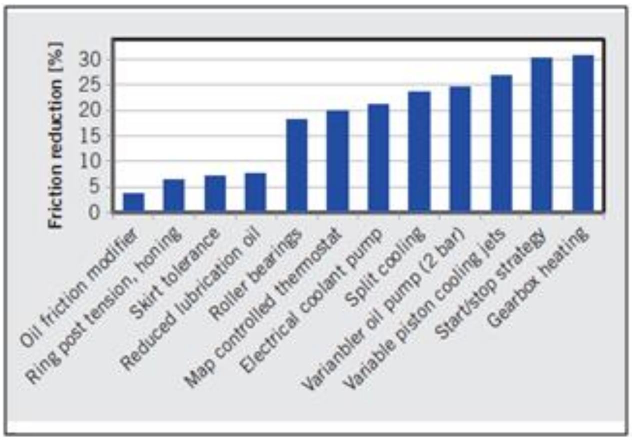

Figure 4 Evolution in friction reduction due to optimization measures

Camshafts (Thyssenkrupp)

Camshafts generally has two areas of contact with their environment which are susceptible to friction: bearings and the cams. Cam friction contact is preferably optimized by involving sliding contact e.g. bucket tappets.

This is coated with layers which consists of amorphous carbon (diamond like carbon, DLC). This coating reduces friction torque by around 30% over wide speed ranges.ThyssenKrupp has further developed its assembly technology so that pre-ground cams which are coated prior to assembly can also be joined using the standard press and form fit process.

Case 2:- Fast and smooth clutch engagement control for a mechanical hybrid powertrain (Koos van Berkel, Student Member, IEEE, FransVeldpaus, Theo Hofman,Bas Vroemen, and Maarten Steinbuch, Senior Member, IEEE).

Automatically controlled clutches are basically used in advanced automotive powertrains to transmit a demanded torque while synchronizing the rotational speeds of the shafts. The two objectives of the clutch engagement controller are a fast clutch engagement which reduces the frictional losses and thermal load also, and a smooth clutch engagement to accurately track the demanded torque without a noticeable torque dip. Meanwhile, the controller is subjected to standard constraints such as model uncertainty and limited sensor information. The controller is elaborated for a mechanical hybrid powertrain that uses a flywheel as a secondary power source and a continuously variable transmission.

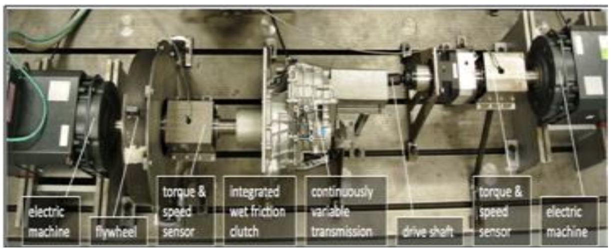

Figure 5 Overview of the Experimental Setup

The controller is based on the relevant actuator dynamics and the clutch slip dynamics. The clutch slip dynamics is controlled using the standard speed sensors such that the desired slip acceleration is achieved at the time of clutch engagement. The desired slip acceleration is useful as the calibration parameter to choose the tradeoff between fast and smooth clutch engagement. Simulations show that generic controller is effective for driving and braking situation.

A parameter variation study is performed to show how the calibration parameter and the uncertainty in the variator time constant influence the clutch engagement performance. For uncertain time constants of the actuator, smooth clutch engagement can still be achieved, but at the cost of a conservative clutch engagement time. Test rig experiments validate the effectiveness of this relatively simple controller and its robustness against realistic modeling errors and measurement noise.

Case 3:- Source of primary energy efficiency in alternative powertrains **(**Max Ahman, Energy 26 2001)

A comparative assessment was performed which showed that there are chances to double the primary energy efficiency using electric drivetrains in vehicles, such as BEVs, HEVs or FCEVs, compared with present ICEVs. All vehicles with an alternative powertrain have the potential for higher primary energy efficiency than vehicles with an improved conventional powertrain.

Table 1 Future Powertrain Efficiencies

Powertrain efficiency	Primary engine %	5-speed transmission %	Electric drivetrain %	Total efficiency %
Battery powered	-	-	65	65
hybrid parallel	36	92	68	30
Hybrid series	40	-	72	29
Fuel cell methanol fuelled	40	-	72	29
Fuel cell hydrogen fuelled	47	-	72	34
Conventional developed	24	92	-	22
Conventional today	18	92	-	16

Case 4:- Volvo Supertruck **(DEER 2012)**

Volvo is carrying out a project to build a supertruck which has following objectives:

- Improve freight efficiency by 50%
- Demonstrate a 55% brake thermal efficiency concept

Volvo is successful in using simulations to

- Minimize predicted increase in brake energy for concept trucks
- Design advanced control strategies e.g. using 'look ahead' and terrain based torque controls
- Quantify potential fuel savings with various concepts
- Pre size components and systems for the new concepts

Figure 7 Lightweight intelligent efficient drivetrain

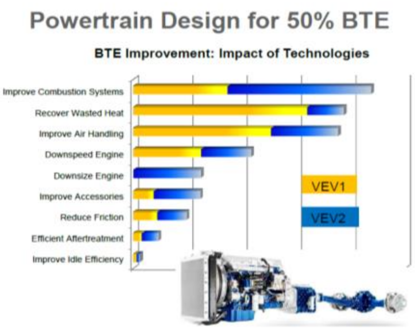

Figure 8 Powertrain design specifications for 50% BTE

Case 5:- Study on dynamic analysis of powertrains and optimization of coupling stiffness **(**Wenji Qin, Dandan Dong, Beijing Institute of Technology, China)

The structure design of the power and transmission system is performed at different stages, and matching of them is usually focused on the operation performance. So it is important to analyze and refine the structure dynamic characteristics of the two systems as a whole. The powertrain investigated in this paper is a hydro-mechanical system. According to the hydraulic mode, the powertrain can be thought as two vibration systems because of the vibration isolation of the torque converter. So only the mechanical gears in which the converter is locked are concerned and the dynamics of the whole structure is studied in this paper.

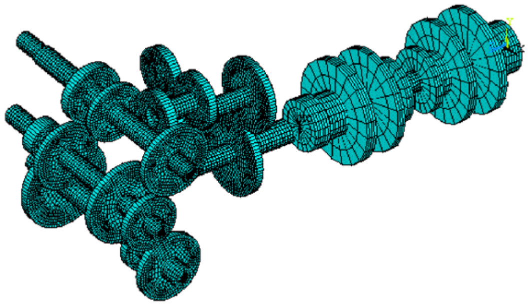

Figure 9 Finite element model of Powertrain

At the engine speed of 800r/min, the stresses of the engine and the transmission of the mechanical gears (three) vs. coupling stiffness are shown in Figure 10. Depending on the transmission, the results highlight that in the lower coupling stiffness range (less than 0.2 MN-m/rad) the stresses decrease greatly with the reduction of the stiffness, while when the stiffness is greater than 0.2MN·m/rad, the changes of the stresses become much smaller. On the other hand for the engine, the stresses are much lower and the curves are relatively smoothly (in the range of 31~33MPa). It indicates that the effect of the coupling stiffness on the stress response of the engine is relatively slight.

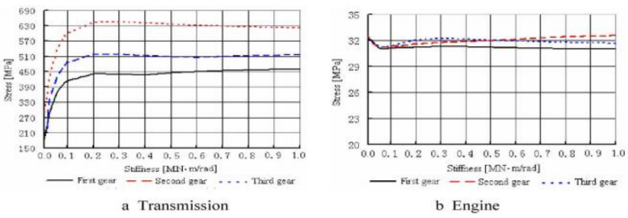

Figure 10 Maximum effects of transmission and engine on coupling stiffness

The Analysis on finite element model is applied to the dynamics analysis of one vehicle powertrain. Its natural frequencies of three mechanical gears are obtained and the frequencies sensitive to the coupling stiffness are selected. Then the stress responses at different engine speeds of different gears are calculated through the transient dynamics analysis, and the gear and engine speed at which the highest stress response occurred are calculated. Based on these results, the coupling stiffness optimization model with the goal of reduction the stress response is established.

The optimal results show that the maximum stresses of each mechanical gear decrease drastically with the known coupling stiffness.

Conclusion

Hybridization instead of full electrification is the most likely path for vehicle technology in the medium term, keeping gasoline and diesel internal combustion engines, still in use. By resorting to methods for optimization of conventional as well as alternative drivetrains can help us in achieving fuel economy. This paper presents a theoretical study of the literature regarding recent trends in powertrain technology which, if developed further, will boost the automobile industry on a positive scale.

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