FEATURES OF THE HYBRID VEHICLES WORK MODE CONTROL STRATEGY

Post-graduate student Tonkov G.
Department of Transport Equipment, Todor Kableshkov University of Transport
Geo Milev str. 158, 1574 Sofia, Bulgaria
tonkov.smolyan@gmail.com

Abstract: The transmissions of HEVs or so-called hybrid transmissions (HT) are essentially power split transmissions, which almost always require planetary gears to split or sum up power. An essential prerequisite for reading and studying hybrid transmissions is the knowledge of planetary gear function and calculation. For example, the Toyota hybrid system can only be clarified using the principles of the planetary mechanism. In addition to Toyota’s decision, there are two modes of transmission (BMW, Daimler and GM) and many patent applications with similar ideas. Technically speaking, these solutions are power split transmissions that turn into a hybrid system by adding an electric motor (EM), an electric generator (EG) and an electric storage battery (SB). These transmissions perform the functions required for vehicles with an internal combustion engine, such as the HEV. These functions are launching, torque and speed conversion, reverse gear, and rapid gear-shifts in ascending or descending order. In addition, the requirements for HT are realized with the help of electronic control. For parallel HEV, a conventional gearbox plus EM is used. The automatic transmissions used in the mixed HEVs are designed with planetary gearboxes and are also known as automatic HTs.

This article discuss the features of planetary gearboxes used in HEVs transmissions.

Keywords: HEV, WORKING MODE, STRATEGY

Automotive sensors and actuators are widely used in modern vehicle control systems [1]. It is important to understand and design management programs and also be able to use tools and software to generate such programs. [3].

Modern cars are subject to even tougher requirements regarding power, torque, fuel economy and environmental performance [4]. In all high-tech systems of modern cars a CAN protocol is used for communication between individual controllers [2]. The reliability of the entire vehicle control system is determined by the reliability of the most vulnerable components [5].

The HEV control strategy is essentially an algorithm that defines the operating points of the HEV drive components [6]. The main purpose of the control strategy is to ensure that the driver's demand is met and the efficiency of the power system optimized. The main inputs of the control controller are the vehicle speed and pedal inputs. The secondary inputs for traffic information, traffic and GPS can also be used in more controllers. Controller outputs are command signals for powertrain components, such as torque control of internal combustion engine (ICE) and EM, and commands for switching on/off certain components.

The charge state (SOC) of the SB or energy storage system should also be maintained within levels that prolong the SB resource. The control strategy determines when and how much the energy storage system will allow a deep dilution of the SB in order to meet the driver’s requirement. In addition, the kinetic energy of the vehicle can be restored and stored in the energy storage system using regenerative braking when the HEV stop command is set by the driver.

Additional targets targeting the control strategy algorithm include all or some of the following: Increasing drive efficiency and/or fuel economy, reducing emissions and maintaining good manageability. Improving fuel efficiency and reducing emissions is an increased requirement; an optimization algorithm can be used to determine the best operating points of the ICE and EM. User-friendliness is also a key parameter for HA’s market demand; the controller must ensure that the driver's feel is almost the same as that of the conventional ICE car. Changes in the management of the various drive components must be carefully coordinated to maintain the high quality of HEV control. Convenience can be measured in terms of gear shifting and drive vibration.

The deterministic, rule-based method of the management strategy is further developed with the help of mixed HEV entities. Mixed components with two EDs and one ICE can be implemented either by means of a planetary mechanical control device or using modal (electronic) control. The strategies for choosing the mode of operation of split (series-parallel) HEV are discussed below.

1. Operating modes with mechanical control of torque distribution

The mechanically-controlled mixed-mode hybrid drive uses a Planetary Power Distribution Device (PPDD) without clutches in the drive. The concept of power distribution using a set of planetary gears was first introduced by TRW [7,8]. The gearbox, which is connected to the PPDD, offers uninterrupted variations in torque (CVT) and power, while allowing three drive components to be mounted in one transmission. Mechanical power distribution management has quickly become the choice of design for hybrid sedans, light trucks and SUVs. The mechanical design offers compactness and ease of assembly with EM, EG and ICE mounted in one transmission.

The scheme for driving a mixed HEV with the PPDD similar to Toyota Prius is shown in Figure 1 [6]. The PPDD has three gears: an ring wheel, a sun wheel and an arm. The crankshaft of the ICE is connected to the arm of the PPDD. The mechanical power is transmitted to the main transmission (end-drive) from the ICE and EM via the ring wheel. There is no direct link between the ICE and the final drive. The EG is connected to the sun wheel; EM along with the drive wheels is connected to the ring wheel. The power of the ICE can be divided and part of it transferred to the final drive and the wheels and thence through the sun wheel to EG for producing electric power. ICE drives EG, which loads SB or feeds EM or performs both. The work of EG produces resistance torque on the waterline to which the crankshaft of the ICE is connected. EM can add torque to the sun wheel to provide additional power to the drive wheels. The EG can also operate in EM mode during peak acceleration to add torque to the PPDD which is then transmitted to the drive wheels via the solar wheel. Both electric machines can operate either in engine mode or in generator mode. During regenerative braking, EM acts as EG for the use of kinetic energy at regenerative braking, which is converted into electrical energy and stored in SB. Several
possible modes of operation are described in more detail by linking the PPDD and the reversible modes of operation of the EM and EG [9].

Fig.1. Location of the power components of mixed HEV with the PPDD [6]

The power ratio of HEV is the sum of the capacities of the ICE and EM [1] and is given by the dependence (1):

\[ P_{engine} = P_{engine_torqing} + P_{engine to sun} = T_p \omega_p = \frac{r_s \omega_s}{r_{s+T_s}} T_p + \frac{r_{s+T_s}}{r_{s+T_s}} T_p \]

(1)

The directions of rotation shown in Figure 1 for the three PPDD gears associated with the three drive components are assumed to be a positive direction of rotation.

1.1 Mode of operation with EM (low speeds, reversing, battery charging)

In this mode, the internal combustion engine is switched off and the wire is stationary, ie, \( \omega = 0 \). The generator that performs the function and the starter rotate freely in idle conditions in the opposite direction. The speed relationship between EG and EM is given by an expression (2):

\[ r_s \omega_s = -r_o \omega_o \]

(2)

The electric drive driven by the SB energy provides the traction force of the drive wheels as shown in Figure 2. No power is transmitted through the PPDD. The accelerator pedal position (set by the driver) and the vehicle speed determine the set current value of the EM (3):

\[ I_{motor} = \frac{r_{s+T_s} I_p}{r_{s+T_s}} \]

(3)

The SB can be recharged using regenerative braking control strategy, with the EM operating in EG mode when HEV is running in inertia or stops while the ICE is off.

1.2 Starting the ICE and low speeds

To run an internal combustion engine it is necessary to work in the engine (starter) mode. The starter mode is activated by a command from the driver, where EG rotates in the opposite direction and draws power from the SB for the purpose of running the ICE. The starting of the HEV can be accomplished with the power provided by the EM. The energy source during the start of the ICE and the start of the HEV is SB.

1.3 Parallel Mode (Peak Acceleration)

The drive operates in parallel peak acceleration mode, which may be required during acceleration of the HEV. Simultaneously the ICE, EG and EM participate in this short-term process. The power flow in the parallel mode is shown in Figure 3.

Fig.3. Parallel operation of electrical and mechanical components from power transmission[6]

The power of EG, using equation (1), is obtained from:

\[ P_{sun_torqing} = \frac{r_s \omega_s}{r_{s+T_s}} T_p \]

(4)

The sun wheel rotates in the opposite direction, i.e. in an anticlockwise direction viewed from the shaft of EG, that is, \( \omega_s < 0 \). The reverse rotation of the solar wheel increases the torque of the internal combustion engine, allowing EG to produce the power for the EM, which is transmitted to the final drive. The input of EG in this case is an SB power supply.

1.4 Power distribution mode (smooth running, low acceleration)

In this mode, the internal combustion engine power is divided between EG and EM, as shown in Figure 4. ICE assists the EM by adding more torque to the differential input shaft of the final drive. At the same time, some power of the EM can be diverted to the solar gear to bring EG into the generator mode to charge SB. EG rotates forward.
The power flow of the ICE to EG, and hence to the SB, is regulated by controlling the engine speed, since the percentage of the torque of the EM shifted to EG is mechanically fixed. The required power of AB determines the current of EG, and hence its torque (5).

\[ I_{\text{gen}} = \frac{T_s}{r_s + r_p} \]  

(5)

This torque on the sun wheel of the PPDD, in turn, fixes the torque T of the EM; therefore, ICE must be speed controlled.

1.5 Engine Brake Mode

In this mode, an ICE runs idle and draws some energy. EM rotates freely (I = 0). EG rotates in the opposite direction and generates electrical energy. The power flow in this mode is shown in Figure 5.

1.6 Regenerative braking mode (SB charging)

In this mode, the shaft of EG rotates freely (I = 0). EM is driven by the kinetic energy of HEV and restores (recharges) SB. The power flow in this mode is shown in Figure 6.

3. Modal control strategies

Modal control algorithms use driver commands and system feedback inputs to meet the requirements, while optimizing drive efficiency and minimizing emissions. SOC of the SB is also maintained in a predefined range to meet performance requirements without damaging the system.

The control algorithms within the modal control strategy define the best reference points for the energy converters and the best transmission ratio for the transmission. Management algorithms can be generated based on an optimization algorithm, where the cost function, which is fuel economy, emissions, efficiency, or SB resource, is minimized. Global optimization to achieve the best fuel efficiency depends on the prior knowledge of energy consumption and driving conditions, which is only possible in simulation. Global optimization based on fixed driving cycles can be used to define real-time flow management rules. In real-life scenarios, a management strategy based on real-time optimization can be developed [10,11].

For this, an instantaneous cost function, defined as real-time variables, applicable to such an optimization strategy is used. Drive subsystems place limits on maximum continuous and peak power that can be provided in individual operating modes.

However, the modal control algorithms share general calculations to determine the maximum power that the ICE, EM, and EG can provide. The calculations are based on the maximum load values of transmission devices, temperature, current of the current bus, the velocity of the HEV and other parameters that determine the operating point limits for each subsystem. For example, the power limitation of the EM can be achieved as a function of the reduction of the bus voltage. The voltage of the bus depends on the stored energy in the SB. The purpose of reducing the DC power for reduced voltages is to ensure acceptable control by eliminating the sudden reduction of acceleration if the EM enters the shutdown mode when the SB is depleted. The power limitation for the EM also depends on the temperature. The nominal voltage values of the EM are reduced for the increased operating temperatures.

Conclusion

Single, parallel, and mixed HEV modes require different management algorithms. Optimization methods, if used, for different modal control strategies are also different. It should be noted that the modal control strategies discussed in this article are just examples; there may be various other ways to implement a modal control strategy depending on the size of the available components of the power aggregates and the desired optimization strategy.

ACKNOWLEDGEMENT

Authors would like also to acknowledge the Todor Kableshkov University of Transport for funding the project agreement № 131/25.04.2019.

References:

https://ieeexplore.ieee.org/document/8447126

[3] Евелина Пирчева, Ивайло Иванов, Велислав Стаменов, Микита Андреев, Ростислав Лозов, Теодора Цветкова, доц. д-р инж. Славчо Божков, Генериране на управляваща програма за стенд САВ-1 за автоматизирано управление на автомобилни горивни дюзи за впрыскване на бензин, Младежки научен форум ―Аз знам и мога―2018‖, Научно списание ―Механика, транспорт, комуникации‖, Раздел Млад форум, ISSN 2367-6558 (print), ISSN 2367-6612 (online), том 7, брой 1, 2018 г., статия № 1587, стр.VI-36-VI-41, БТУ „Тодор Каблешков‖, София, 2018


