IMPROVING THE FUEL ECONOMY BY USING HYDRAULIC HYBRID POWERTRAIN IN PASSENGER CARS

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Abstract: *The hydraulic hybrid is alternative powertrain that offers an efficient way to recover braking energy and designed to enable a boost effect that would normally be offered only by complex electric drives. All vehicle manufacturers, in the stages of vehicle development, apply Vehicle simulation software for calculation of driving performance, fuel consumption and emissions of toxic gases. In order to investigate the potential possibilities of application of hydraulic hybrid drive in passenger cars in the urban environment during standard cycle UDC, NEDC, a modeling of the potential hybrid vehicle based on the platform of Yugo Florida is performed. Results show that it can achieve significant savings in fuel consumption, especially in case of vehicle motion purely based on hydraulic drive.*

Keywords: HYDRAULIC HYBRID, VEHICLE SIMULATION, FUEL ECONOMY

1. Introduction

Hydraulic hybrid drive has already found considerable use in utility vehicles (garbage truck), but that's not all the possibilities offered by this type of powertrain technology. Due to its simplicity and robustness, and proven effects in fuel consumption reducing, the use of hydraulic hybrid system is suitable for all vehicles used in urban areas with frequent start-stop driving regime [1,2].

The hydraulic hybrid is alternative powertrain that offers an efficient way to recover braking energy and designed to enable a boost effect that would normally be offered only by complex electric drives. Here, a conventional internal-combustion engine combines with hydraulic units and an accompanying nitrogen pressure accumulator to provide a brief boost to acceleration. The hybrid system is able to support gasoline and diesel engines in ranges where they do not work at optimum efficiency. The hybrid system makes use of energy that would normally go to waste. Braking, for instance, quickly fills up the hydraulic accumulator: the kinetic energy captured during braking is converted into hydraulic energy and stored in the pressure accumulator. Normally, this energy would go to waste, turning into heat in the friction linings of the brakes. The advantages of a hybrid powertrain are equally evident when the vehicle is travelling at a constant speed. Here, the engine can be run within an efficient range while also filling the hydraulic energy accumulator.

2. Current status of hydraulic hybrid technology

The hydraulic full-hybrid powertrain technology, which Bosch is developing in collaboration with PSA Peugeot Citroën (Fig.1), is clear in its aims: to supply a hydraulic hybrid powertrain that will significantly reduce fuel consumption and CO_2 emissions in compact cars [5].

The hydraulic hybrid is designed to enable a boost effect that would normally be offered only by complex electric drives. Here, a conventional internal-combustion engine (ICE) combines with hydraulic units and an accompanying nitrogen pressure accumulator to provide a brief boost to acceleration. The hybrid system is able to support gasoline and diesel engines in ranges where they do not work at optimum efficiency.

The power-split concept permits various drive options. For short journeys, stored energy can be used to run exclusively on hydraulically generated power, with the internal-combustion engine remaining inactive and the vehicle producing zero emissions (ZEV). For longer journeys, or when driving at higher speeds, acceleration force is provided by the internal-combustion engine. Alternatively, the two types of powertrain can also be combined. In this case, the energy stored in the hydraulic system and the fuel burned in the internal-combustion engine work together to drive the vehicle, which also provides a brief boost effect. The smart control system adapts the operating mode to the driver's command and optimises energy efficiency in three different modes.

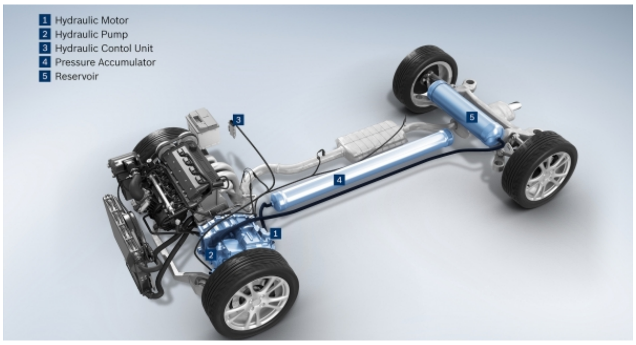

Fig. 1 *PSA hydraulic hybrid.*

According to the reports issued by manufacturers, in the New European Driving Cycle (NEDC), it has the capacity to reduce fuel consumption by up to 30% when compared to a conventional internal-combustion engine.

3. Modeling of vehicle

All vehicle manufacturers, in the stages of vehicle development, apply software for calculation of driving performance, fuel consumption and emissions of toxic gases. AVL CRUISE [4] is Vehicle simulation platform basically developed for optimization of vehicle and vehicle components (fuel economy, vehicle performance).

Its modular concept enables efficient and quick evaluation of new vehicle concepts (eg, hybrid electric vehicle, fuel cell). AVL CRUISE is used to perform vehicle simulation and powertrain analysis. It is designed to develop and optimize low emission engines, reliable powertrains, and sophisticated control systems of engines, cooling, and transmission systems. CRUISE supports the engineer during the whole engine and vehicle development process in standard applications, such as fuel economy and full load acceleration tests, hill climbing performance and traction diagrams, as well as computational concept studies including the mechanical, electrical, thermal, and control system. This integrated solution makes simultaneous engineering in the development process possible, which is the basis for reducing development times and costs. properties of selected powder materials.

In order to investigate the potential possibilities of application of hydraulic hybrid drive in passenger cars in the urban environment during standard cycle UDC, NEDC, a modeling of the potential hybrid vehicle based on the platform of Yugo Florida is performed. Basic features of the car are: engine displacement 1116 cm^3, power rating 45 kW at 6000 rpm, curb vehicle weight 910 kg and gross vehicle weight 1310 kg.

Taking into account the fact that it is a subsequent installation of the hydraulic drive device for research purposes, a separate configuration of driving units was chosen, where the hydraulic system is attached to the rear axle of the vehicle. This solution, in addition to the practical side, has the advantage of better front/rear axle load distribution, which is used in some hybrid vehicles (e.g. Volvo). It is also easier to solve management system when there is only one of the two drives (ICE, hydraulic unit). The downside of this solution is doubling the differential mechanism and driving shafts, although the measurements of these elements are considerably smaller due to the lower values of torque generated by hydromotor.

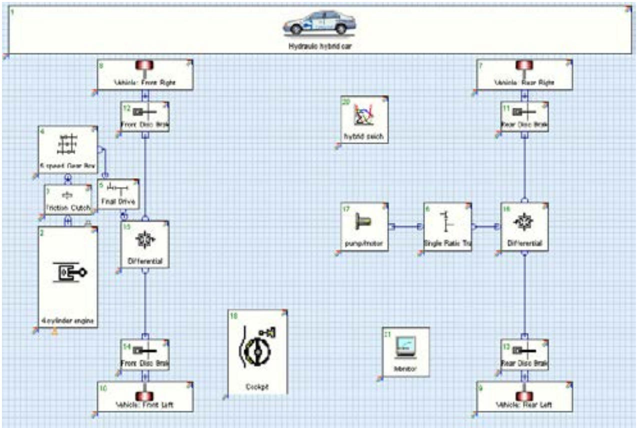

Fig. 2 *Hydraulic hybrid model develop by CRUISE*

With the wide use of the opportunities provided by the CRUISE simulation software, an upgrade of the standard FWD model as applied to vehicle Florida is performed, with a powertrain consisting of a rear differential gear and the main gear, and a module which performs the function of variable hydraulic motor/pump. Of course, the vehicle model is supplemented with the control unit (hybrid swich) that performs actuation of the hydraulic system based on parameters obtained from the cockpit [3]. Input parameters for the hydraulic control unit are: acceleration pedal travel, brake pressure, vehicle velocity (speed pump/motor), accumulator SOC and vehicle acceleretion during travel. Operating range of hydraulic drive is within the range of 1-50 km/h.

Dimensioning of the hydraulic system was based on the declared maximum acceleration, i.e. deceleration in the UDC cycle located within the limits + / - 1 m/s^2. These system performances can be achieved by using a variable axial motor with the nominal displacement of 10 cm^3, with a rated speed 3600 rpm and maximum torque of 42 Nm at 250 bar. Mass of the motor is 8 kg. Accumulator capacity is a value directly relevant to the autonomous motion of the vehicle on hydraulic drive, and for this purpose the selected unit of 10 liters which enables autonomous motion within a UDC cycle. Accumulated energy of 0.25 MJ at nominal pressure is enough for the vehicle chosen for the simulation. Of course, with the increase of the capacity of accumulators (e.g. PSA), a better autonomy of the vehicle can be achieved without using the ICE, although it should be noted that this will be followed with the increase of the vehicle mass, which ultimately may compromise the energy efficiency of the whole project. In general, vehicle operating mode is dominant for the selection of optimal characteristics of the elements of the hydraulic system.

Figure 2 shows a simulation model of a car used to examine the effects of the application of hydraulic hybrid system with special emphasis on energy efficiency and emission of toxic gases. It is a standard FWD manual scheme, with the friction clutch and five-speed gearbox. The optional start-stop function is available, with which the effects of the hybrid would be undoubtedly higher, since it enables the acceleration of the vehicle up to a certain speed with the engine off. In this case it is possible to reduce the fuel consumption for a few extra percents.

4. Comparative analysis of fuel consumption

Figure 3 shows the distribution of the drive torque at UDC cycle, where it is evident that the departure of vehicle is supported with ICE, and the hydraulic drive is engaged when the hydro-motor speed exceeds 10 rpm. The reason for that is the reduced efficiency values at low engine revs. The same principle is applied when the hydraulic system works in the pump mode, ie. decelerates the vehicle, where the vehicle may stop with the assistance of the service brake.

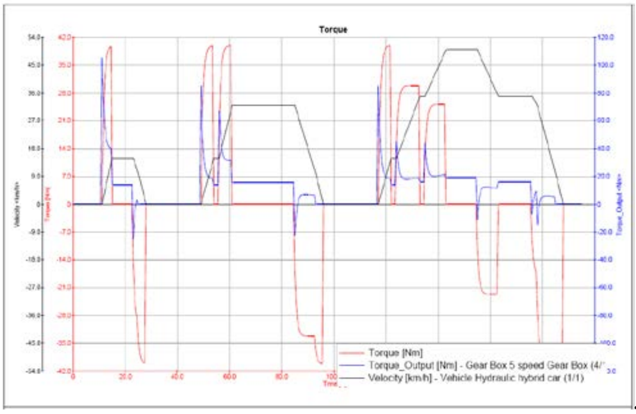

Fig. 3 *Torque from engine and hydraulic unit on UDC*

For the purpose of comparative analysis, Figure 5 shows a variation of the torque and the introduction of the service brake in case of the lack of hydraulic system assistance (motion of the base vehicle under UDC cycle) with the remarkable increase of energy used by ICE and longer braking.

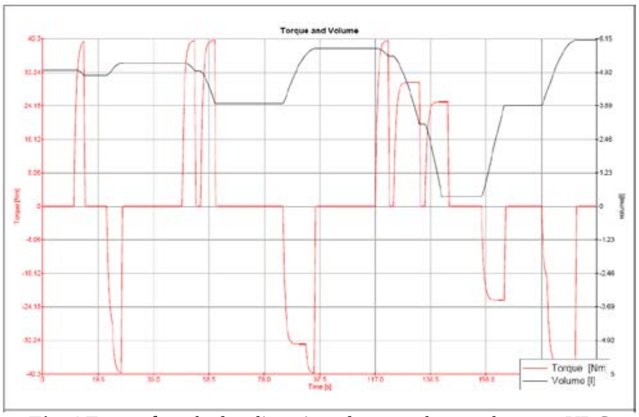

Fig. 4 *Torque from hydraulic unit and accumulator volume on UDC*

Figure 4 describes a flow of volume variation in hydro-accumulator during the UDC cycle, where at the end there is the increase in volume of about 1l, as a result of somewhat greater use of ICE for vehicle acceleration, relative to the influence of regenerating braking in case of vehicle deceleration.

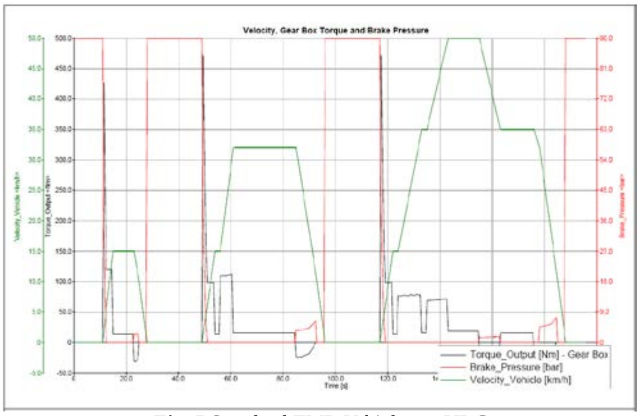

Fig. 5 *Standard FWD Vehicle on UDC*

Table 1 shows the fuel consumption during UDC for standard FWD car and hydraulic hybrid car for different operating conditions. Significant reduction (12%) of fuel consumption during vehicle use in urban conditions is evident.

***Table 1** Fuel consumption in UDC*

Vehicle type		standard FWD	hydraulic hybrid	reduction
Fuel consumption (kg) for the following operating conditions:	Overall	0.0489	0.0429	12.3%
	Engine idle	0.0099	0.0099	-
	Acceleration	0.0154	0.0091	40.9%
	Const. drive	0.0170	0.0170	-
	Deceleration	0.0066	0.0068	-

In any case, the control module (hybrid swich) is the unit which maintains the necessary power reserve in the accumulator, depending on the desired effect. If the goal is to perform the entire UDC drive cycle solely on hydraulic drive (for which it is necessary to have a fully recharged accumulator), it is possible to use ICE in optimal regime, to refill it to the required level. Figure 6 shows a variation of torque from the hydraulic in the process of refilling the accumulator up to the full capacity, which is performed during the vehicle at a constant speed. The control system is designed to fully charge the accumulator during the one UDC cycle, which is shown in the same Figure through the increase of the fluid volume in the accumulator.

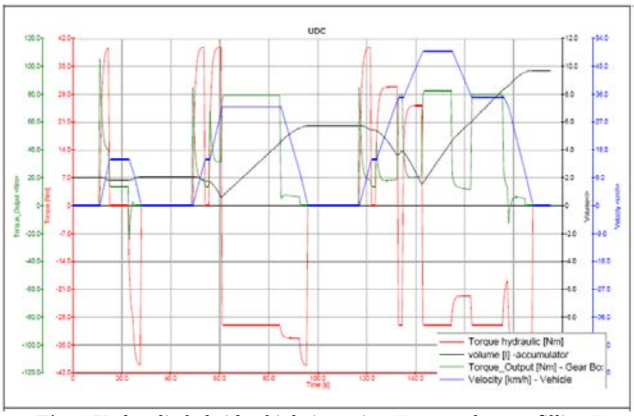

***Fig. 6** Hydraulic hybrid vehicle in regime "accumulator refilling "*

With this operation mode it is easily possible to perform one UDC cycle with the help of ICE, and the following can be done using the energy stored in the accumulator, which dramatically reduces fuel consumption. Table 2 shows the fuel consumption during this cycle (the next one can be performed exclusively by use of hidro-drive) compared to the fuel consumption during the dual UDC cycle when using the combined drive. The achieved overall savings are at the level of the results declared by the PSA.

***Table 2** Fuel consumption in dual UDC cycle*

Operation mode of the system		2x Combined drive	Combined drive with restore function + Solely hydro-drive	reduction
Fuel consumption (kg) for the following operating conditions:	Overall	0.0858	0.0595	30.6%
	Engine idle	0.0198	0.0099	50.0%
	Acceleration	0.0182	0.0089	51.1%
	Const. drive	0.0340	0.0332	2.3%
	Deceleration	0.0136	0.0074	45.6%

Table 3 shows the comparative fuel consumption of the basic vehicle and hydraulic hybrid vehicle in the NEDC, which consists of four UDC and EUDC cycles. As expected, the effects of the application of hybrid drive are decreasing at speeds over 50 km / h due to the lack of the assistance of the hydraulic unit. Yet the cost savings achieved by the use of this kind of hybrid technology in passenger vehicles is evident.

***Table 3** Fuel consumption in NEDC*

Vehicle type		standard FWD	hydraulic hybrid	reduction
Fuel consumption (kg) for the following operating conditions:	Overall	0.3885	0.3608	7.1%
	Engine idle	0.0457	0.0460	-
	Acceleration	0.1460	0.1153	21.0%
	Const. drive	0.1615	0.1619	-
	Deceleration	0.0353	0.0376	-

5. Conclusions

• This paper shows the potential benefits gained from the use of Hydraulic hybrid system for passenger car, on a NEDC and especially during the UDC cycle, where the reduction of fuel consumption of approximately 30% is expected.

• Engine can be run within an efficient range when the vehicle is travelling at a constant speed while refilling the hydraulic energy accumulator at the same time.

• Depending on the capacity of the accumulator, the stored energy can be used to run the vehicle exclusively on hydraulically generated power, thus providing the vehicle producing zero emissions (ZEV).

• Hybrid systems are highly beneficial in a frequent stop-start (urban) driving regimes.

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