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Application Research of Hydraulic Hybrid Technology to Heavy Vehicles

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Abstract: The hybrid technology is widely recognized as the most effective measure to solve the energy problem. Hydraulic accumulators have relatively higher power density and energy conversion efficiency than batteries and supercapacitors, therefore it is well suited for frequent acceleration and deceleration under city duty of heavy vehicles. The design of the hybrid powertrain should follow the strategy that the powertrain must first guarantee the drivability to sustain the operating performance and then design optimal match to reduce the cost and enhance the fuel economy. This study designs the parameters of main units of the HHV, selects appropriate control strategy and duty cycles, then creates the system simulation model of HHV in AMESim. The simulation results show that it is very prominent in saving energy and reducing harmful emissions.

Key words: Hydraulic hybrid propulsion, parameter design, power performance

INTRODUCTION

With the problems of energy shortage and air-pollution have become more critical, energy saving in automobiles is a very important subject. Heavy vehicles such as city bus have the characteristics of frequent starts/stops and significant amounts of braking energy which needs to find a more efficient way to store and reuse the high power flow in the hybrid configurations (Taghavipour *et al*., 2012).

Currently, hybrid technology is widely recognized as the most effective measure to solve the energy problem and there are two kinds of hybrid technologies for vehicles, the hydraulic hybrids and the electric hybrids. As an important branch of hybrid technology, hydraulic hybrid vehicles have increasingly aroused the attention of the research institutions and automotive manufacturers. Hydraulic Hybrid Vehicles (HHV) employ hydrostatic transmission as against the traditional mechanical transmission, hence it can eliminate some mechanical connection between the engine and the driving wheels (Taghavipour *et al*., 2012). After the introduction of hydraulic accumulator, the engine is decoupled from the automobile load thus always operated in high efficiency region. Hydraulic accumulators have relatively higher power density and energy transfer efficiency than batteries and supercapacitors and can accept the high rates and high frequencies of charging and discharging, therefore it is well suited for frequent acceleration and deceleration under city duty of sportutility vehicles and heavy vehicles. (Matheson and Stecki, 2003).

OPERATING PRINCIPLES OF HYDRAULIC HYBRID VEHICLE

The research results indicate that hybrid powertrains can greatly improve fuel efficiency of the hybrid vehicles. Considering the performance and cost, the series powertrain is currently the best configuration for hybrid vehicles (Sun *et al*., 2009). The new type of configuration for series hydraulic hybrid vehicle mainly includes an engine, a accumulator, a variable displacement hydraulic pump and a variable displacement hydraulic pump/motor unit, clutch, final drive and differential. The hydraulic pump/motor and hydraulic pump are coupled to the propeller shaft and clutch respectively. In the configuration, the engine does not drive the vehicle directly.

During normal driving, the pump/motor provides torque for the moderate acceleration and decelerations. During deceleration, the hydraulic pump/motor decelerates the vehicle while operating as a pump to capture the energy normally lost to friction brakes in a conventional vehicle. Also, when the vehicle brake is applied, the hydraulic pump/motor uses the braking energy to charge the hydraulic fluid into a accumulator, increasing the pressure of the nitrogen gas in the accumulator. In the process of vehicle starting and accelerating, the pump/motor work in motor condition and

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provides the driving power for the vehicle using the regenerative energy, realizes the recycle of energy (Triet Kyoung, 2012). Hydraulic pump/motor is designed and sized to capture energy from normal, moderate braking events, if braking torques provided by hydraulics are not enough it is supplemented by the frictional brake.

BASIC PARAMETERS OF THE HYDRAULIC HYBRID BUS

The basic parameters of HHV are as follows: Vehicle mass: 15000 *kg*. Rolling resistance coefficient: 0.014. Body aerodynamic drag coefficient: 0.6714. Vehicle front area: 6.7704 m^2. Wheel radius: 0.462 m. Final drive ratio: 4.875. Maximum speed: >85 km h^{-1}. Gradeability: $\alpha = 25\%$ at the speed of $u = 15$ km h^{-1}.

SIZING OF HYDRAULIC HYBRID SYSTEM

The design of the hybrid powertrain should follow the strategy that the powertrain must first guarantee the drivability to sustain the operating performance and then design optimal match to reduce the cost and enhance the fuel economy.

Rating power of engine: For the series configuration, the ICE will not be influenced by the fluctuations of the load due to its specific configuration. The ICE can be controlled to work on a constant working point to supply the average power. So it is easy to determine the rating power and type of the ICE. (Sun and Jing, 2010).

Hydraulic accumulator: The hydraulic accumulator contains the hydraulic fluid and inert gas such as Nitrogen, separated by a bladder is used for energy storage in HHV. As the pump transfers the hydraulic fluid into the accumulator, the pressure of the gas sealed inside of it increases, thus storing energy. When discharging, fluid flows out through the motor and into the reservoir. Hydraulic accumulator is designed to have adequate capacity for storing the braking energy of loader. The volume of hydraulic accumulator may be expressed as: (Lin *et al*., 2010).

$$V_0 = \frac{Vx(p_1/p_0)^{\frac{1}{n}}}{1-(p1-p_2)^{\frac{1}{n}}} \tag{1}$$

Where:

V_0 = Accumulator total volume m^3
V_x = Working volume of accumulator, $V_x = 0.036$ (m^3)
p_0 = Initial charging pressure of accumulator (MPα)
p_2 = The minimum working pressure of accumulator (MPa)
n = The maximum working pressure of accumulator (MPa)
n = Poly-index of accumulator gas

Hydraulic pump: According to the maximum torque of engine the theoretical displacement of the hydraulic pump can be calculated as follows: (Wang *et al.,* 2009).

$$V_p = \frac{2\times\pi\times T_{emax}\times\eta_{tp}}{\Delta p} \tag{2}$$

Where:

Temax = The maximum torque of engine (N.m)
η_{to} = Total efficiency of hydraulic pump
Δp = The pressure difference between the import and export of hydraulic pump (MPa)
V_p = The theoretical displacement of the hydraulic pump (ml/r)

Hydraulic pump/motor: The driving system of HHV is an axial piston pump/motor with variable displacement, whose displacement is adjusted by inclination of the swash plate to absorb or to produce desired torque. While starting or accelerating, hydraulic pump/motor provides the total propulsion power. Accordingly, hydraulic pump/motor displacement is determined by the following equations (Xin *et al*., 2011).

According to the requirement of maximum climbing slope:

$$T_m = \frac{r\left(mgf\cos(\alpha)+mg\sin(\alpha)+\frac{C_D A u^2}{21.15}\right)}{i_0\times\eta_{tm}\times\eta_m} \tag{3}$$

Where:

η_{tm} = Total efficiency of hydraulic motors,0.9
η_m = Efficiency of the final drive

According to requirement of acceleration performance:

$$T_m = \frac{r\left(mgf+\frac{C_D A u^2}{21.15}+\delta ma\right)}{i_0\times\eta_{tm}\times\eta_m} \tag{4}$$

According to requirement of maximum vehicle speed:

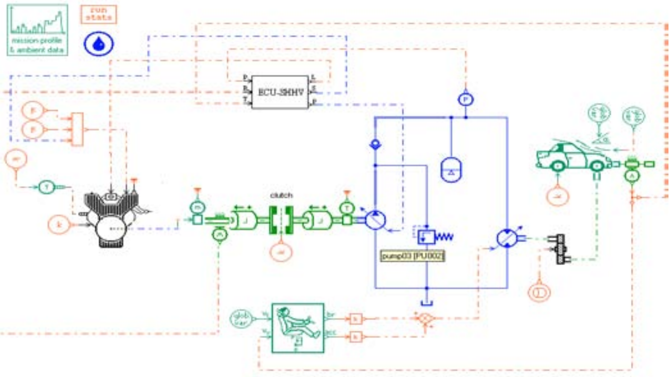

Fig. 1: Simulation model of hydraulic hybrid vehicle

$$T_m = \frac{r\left(\frac{mgfu_{max}}{3600} + \frac{C_D A u_{max}^3}{76140}\right)}{i_0 \times \eta_{tm} \times \eta_m} \qquad (5)$$

Select maximum torque to calculate the displacement and speed of the motor.

The displacement of secondary element could be determined by the driving torque of the secondary components:

$$T_m = \frac{i p_A q_{tm} \eta_{tm}}{\omega} \qquad (6)$$

Where:

p_A = System working pressure, Mpa
I = Final drive ratio
q_m = Displacement of hydraulic motors

SYSTEM MODEL OF THE HHV

The ICE modeling: DRVICE01A is a submodel of Internal Combustion Engine (ICE) at cold or hot start. It calculates the torque, the emissions and the fuel consumption. It also computes the exhaust gas flow rate and the combustion thermal losses. The maximum and minimum torques are read in a multi-1D data file, function of the rate: it can be defined either by a torque data file or by a BMEP data file. Friction losses are read in a multi-1D data file, function of the engine speed and of the engine temperature.

Vehicle load: TRVEH0A is a simple dynamic submodel of a vehicle load used to calculate the longitudinal acceleration, velocity and displacement of the car body. There is provision for viscous friction, road slope in percent and windage. There is no mass transfer during acceleration and braking that can change the vertical load. That is to say the car body model is a 1D model.

Control strategy: In the series HHV, the power flow control can be illustrated by four operating modes. During startup, normal driving or acceleration of the series HHV, both the engine (via the pump) and accumulator deliver hydraulic energy to the power converter so as to drive the motor and the wheels via the final drive. At light load, the engine output is greater than that required power to drive the wheels, so the generated hydraulic energy is converted to charge the accumulator until the accumulator pressure reaches a proper level. During braking or declivity, the motor acts as a pump which transforms the kinetic energy of the wheels into hydraulic energy to charges the accumulation (Sun and Jing, 2010).

Duty cycles: According to previous work on duty cycles for city bus, the New European Driving Cycle (NEDC) is adopted. It's the MVEG-A cycle but idling period of 40s has been eliminated: engine starts at 0s and the emission sampling begins at the same time. The duration of the cycle is 1180 s.

Simulation parameters setting: The simulation model of the HHV is created in AMESim as shown in Fig. 1. The AMERun standard integrator performs integration in a series of discrete steps. At each step an iterative process is started and this process must converge. When the iterations do converge, an error test is applied to determine if the results are accurate enough. By setting the run parameters to define the characteristics of the run and running the simulation, the simulation results of the HHV are shown in following Fig. 1.

ANALYSIS ON SIMULATION RESULTS

As shown in Fig. 2, the vehicle speed is almost the same as NEDC duty cycles. Working pressure of

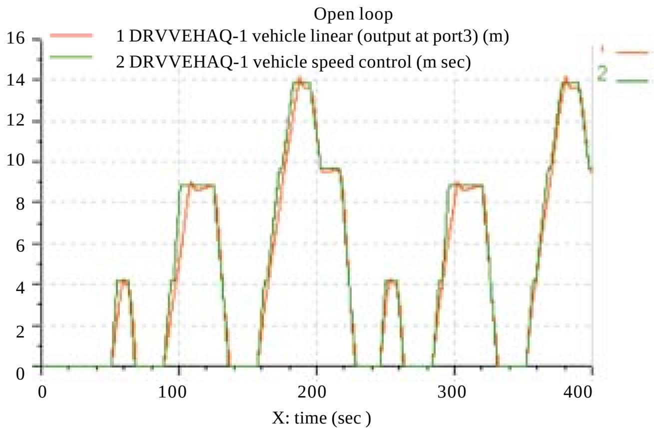

Fig. 2: Hydraulic hybrid vehicle speed

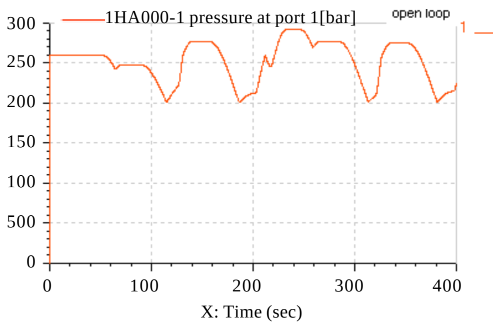

Fig. 3: Working pressure of accumulator

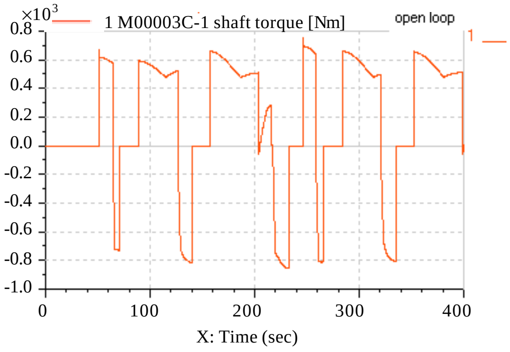

Fig. 4: Shaft torque of hydraulic motor

accumulator in Fig. 3 is characterized by large fluctuations due to high power flows through the system. When the pressure of hydraulic accumulator is higher than the minimum working pressure, the engine is turned off. While engine on, hydraulic pump regulate the engine load through filling pressure to accumulator. Fig. 4 indicates that output torque of hydraulic motor varies with vehicle operating conditions. On braking, the hydraulic pump/motor works in pump condition and regenerates the

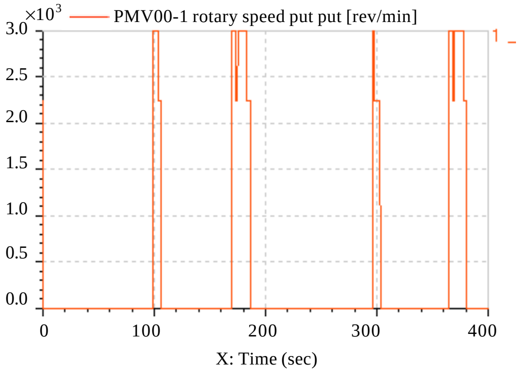

Fig. 5: Engine output speed

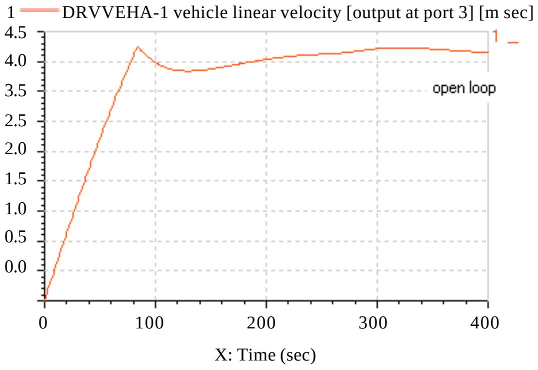

Fig. 6: Gradeability of HHV

vehicle braking energy. On starting and accelerating, the hydraulic pump/motor work in motor condition, provides the auxiliary power for the vehicle using the regenerative energy. Fig. 5 indicates that engine runs in speed of 1500-2000 rpm, which is within optimal operating speed range of engine, resulting in lower emissions and optimal fuel consumption. Fig. 6 shows that gradeability of HHV

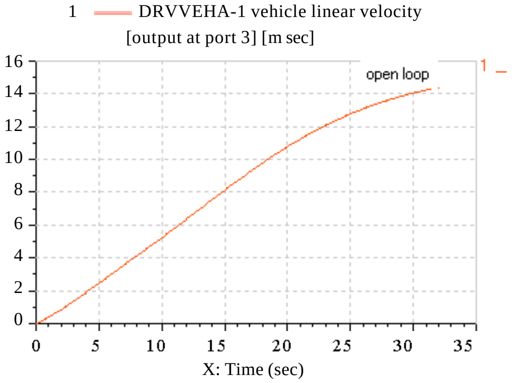

Fig. 7: Accelerating ability of HHV

meets the working requirements. Accelerating ability of HHV in Fig.7 shows that it takes about 28.3 s from standing start to 50 km h^{-1}. Compared with the traditional vehicle in the same duty cycle from simulation results, fuel economy of HHV is improved by 21%.

CONCLUSION

This study proposes a combined simulation and analysis on the performance of the HHV. It shows that the hybrid powertrains could optimize the working condition of the ICE and improve the fuel economy of the vehicle. The simulation results also show that the series system is currently more suitable for HHV due to its better fuel economy and lower cost. Therefore it is well suited for off-road vehicles and heavy-duty trucks. The multi-disciplinary design optimization method still need to be adopted for optimal matching system parameters.

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REFERENCES

Lin, T., Q. Wang, B. Hu and W. Gong, 2010. Research on the energy regeneration systems for hybrid hydraulic excavators. Automation Construction, 19: 1016-1026.

Matheson, P. and J. Stecki, 2003. Development and simulation of a hydraulic-hybrid powertrain for use in commercial heavy vehicles. SAE Trans., 112: 114-123.

Sun, H. and J. Jing, 2010. Research on the system configuration and energy control strategy for parallel hydraulic hybrid loader. Automation Construction, 19: 213-220.

Sun, H., J.H. Jiang and X. Wang, 2009. Torque control strategy for a parallel hydraulic hybrid vehicle. J. Terramechanics, 46: 259-265.

Taghavipour, A., M.S. Foumani and M. Boroushaki, 2012. Implementation of an optimal control strategy for a hydraulic hybrid vehicle using CMAC and RBF networks. Scientia Iranica, 19: 327-334.

Triet, H.H. and K.A. Kyoung, 2012. Design and control of a Closed-loop hydraulic Energy-regenerative system. Automation Construction, 22: 444-458.

Wang, D., C. Guan, S. Pan, M. Zhang and X. Lin, 2009. Performance analysis of hydraulic excavator powertrain hybridization. Automation Construction, 18: 24-257.

Xin, W.G., A.C. Yu and C.A. Wei, 2011. Optimal matching on driving system of hydraulic hybrid vehicle. Procedia Eng., 15: 5294-5298.