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Motor-Assisted AMT System driven by Supercapacitors and Disturbance Observer-based Controller

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Abstract

Motor-assisted AMT is basically a highly efficient transmission system. This system requires the electric motor attached on the endshaft of transmission to generate driving torque when the neutral gear or clutch is pressed while shifting. Therefore continuous acceleration can be provided as well as other conventional automatic transmissions. In this system, the required very large torque should be generated quickly, but it is enough to be applied for a short time. Therefore, super capacitor is the most suitable energy storage device for this aim. This paper proposes a novel control technique of motor torque and capacitor voltage based on engine torque observer. This control offers continuous acceleration and energy management without any additional sensors.

Keywords: controller, EDLC, HEV, transmission

1 Introduction

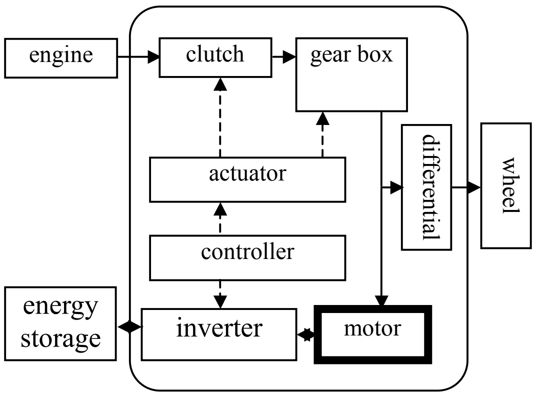


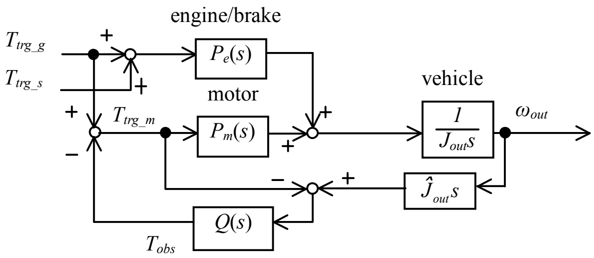
Figure 1: Configuration of motor-assisted AMT

Motor-assisted AMT system is basically a more efficient transmission system than the other conventional automatic transmissions. It does not require oil pumped devices except one clutch like a torque converter or plural clutches which courses friction loss on general transmissions. The concept of these systems is shown in Figure 1. This system is based on manual transmissions that change the gear through single clutch. But this system requires the electric motor attached on the end shaft of transmission that generates driving torque when the neutral gear or clutch is pressed while shifting. Therefore continuous acceleration can be provided as well as other conventional automatic transmissions. In addition, the kinetic energy is regenaratable to the energy storage on the deceleration through the motor.

On this system, the required very large torque should be generated quickly, but it is enough to be applied for a short time. Therefore, super capacitor is the most suitable energy storage device for this aim.

2 Torque Control Strategy

The configuration of the proposed torque controller is shown as Figure 2. There are two torque commands.



$Q(s)$: Low pass filter
$P_e(s)$: Transfer function of engine/brake
$P_m(s)$: Transfer function of electric motor
J_{out}: Nominal inertia moment of vehicle

Figure 2: Calculation block of requested torque

The first input T_{trg_g} is the torque request from the driver. This value is calculated from the acceleration and brake pedal positions and the vehicle velocity. It should be fit with the driver's intension.

Another input T_{trg_s} means the torque request from the energy storage device. This is calculated based on the control error in v_c (terminal voltage of capacitors) from its reference v_{trg_c}. The stored energy in capacitors is proportionate to v_C^2.

Here, we determine v_{trg_c} as is shown in Fig. 3 as the function of ω_{out}, the vehicle speed, because of the two reasons as follows.

(i)At lower speed, the transmission is expected to work frequently. Therefore we should store more energy to capacitors than that at higher speed.

(ii)At higher speed, the electric motor regenerates more electrical energy before it stops than at low speed. Therefore capacitors should be discharged to absorb this energy.

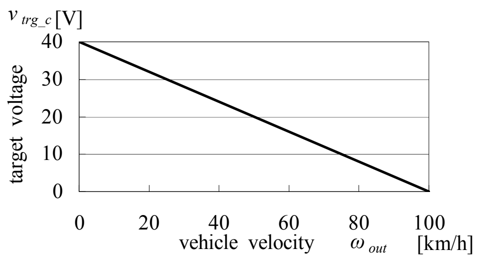


Figure 3: Relation between target voltage and vehicle velocity

To realize both torque requests and to operate this system smoothly, we propose a control technique of motor torque and capacitor voltage based on engine torque observer, which estimates the engine torque as the disturbance. Only the motor torque and the vehicle speed are used as shown in Figure 2.

The transfer function from the torque commands, T_{trg_g} and T_{trg_s} to the vehicle acceleration, ω_{out}, is described as (1).

$$\dot{\omega}_{out} = \frac{P_m + (1-Q)P_e}{J_{out}(1-Q) + \hat{J}_{out}QP_m} T_{trg\_g} + \frac{(1-Q)P_e}{J_{out}(1-Q) + \hat{J}_{out}QP_m} T_{trg\_s} \qquad \ldots(1)$$

While the clutch is released, P_e can be regarded as 0 because the engine torque never transfers to the vehicle body. So it is transcribed as (2) on shifting.

$$\dot{\omega}_{out} = \frac{P_m}{J_{out}(1-Q) + \hat{J}_{out}QP_m} T_{trg\_g} \qquad \ldots(2)$$

This equation means the acceleration of vehicle follows the torque command T_{trg_g}. In other words, It enables to control the output shaft torque to follow T_{trg_g} without any additional sensors like a clutch stroke sensor and so on because the motor compensates for any kinds of torque fluctuation on driving, whether the engine is clutched or not.

The equation (1) can be also described as (3).

$$\dot{\omega}_{out} = \frac{P_m}{J_{out}(1-Q) + \hat{J}_{out}QP_m} T_{trg\_g} + \frac{(1-Q)}{J_{out}(1-Q) + \hat{J}_{out}QP_m} P_e(T_{trg\_s} + T_{trg\_g}) \qquad \ldots(3)$$

This expression shows that the torque vibration of real engine torque that is described as $P_e(T_{trg\_s}+T_{trg\_g})$, is and not transferred to the vehicle acceleration at low frequency because the high pass filter shuts out. This fact implies that the vehicle vibration derived from the engine is also improved.

3 Simulation and Results

This torque-assisted AMT system is superior to the other HEV systems on the point of its small weight. Therefore on this paper, simulation is carried out to apply this to a lightweight vehicle shown as Figure 4. As the first step, we construct a simulation model adjusted to the lightweight vehicle on MATLAB and examine if this system could be valid to drive.

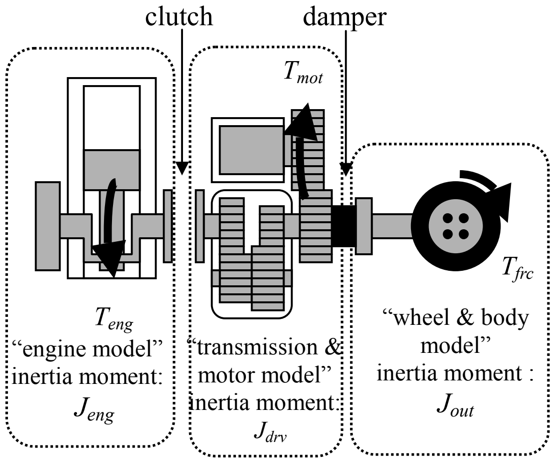


Figure 4: Vehicle physical model.

The vehicle is modeled on three blocks as Figure 5.

To simulate vibration of the engine torque practically, the engine torque T_{eng} is modeled with first order lag element and circular function as (4).

$$T_{eng} = \frac{e^{-s\tau_{0eng}}\overline{T}_{eng}}{1+s\tau_{1eng}} \begin{cases} (1+\sin\theta_{eng}) & (0 \le \theta_{eng} < 2\pi) \\ 1 & (2\pi \le \theta_{eng} < 4\pi) \end{cases}$$

$\overline{T_{eng}}$:average torque of engine

…(4)

Figure 5 is the example of the simulated engine torque.

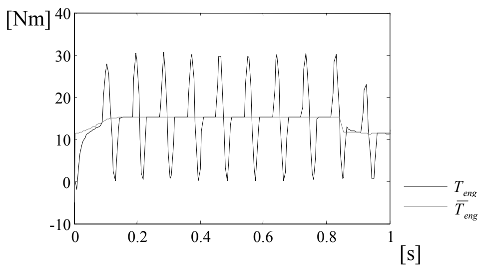


Figure 5: Example of simulated engine torque

Table 1 is the major specification of those simulations. These parameters are determined assumed as lightweight HEV.

Table 1. Simulation condition.

Max Engine Power	5.5[kW]	r_C	0.1[Ω]
Weight	565[kg]	r_m	0.07[Ω]
Tire radius	0.235 [m]	L_m	0.37[mH]
C	0.25[F]	Φ_0	0.07[Wb]

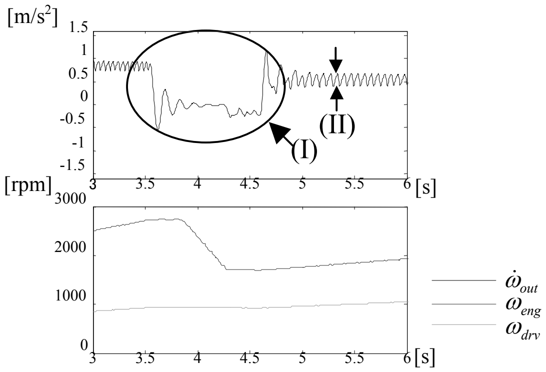


Figure 6: Simulation result of acceleration (without motor-assist)

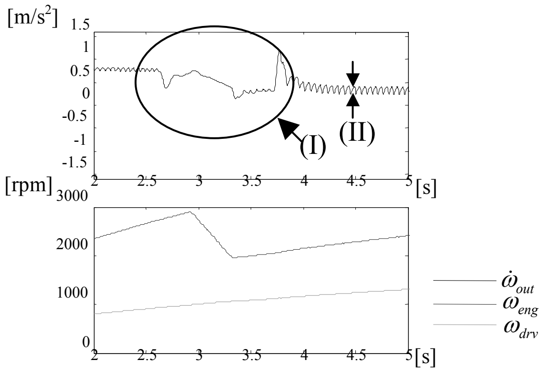


Figure 7: Simulation result of acceleration (with motor-assist)

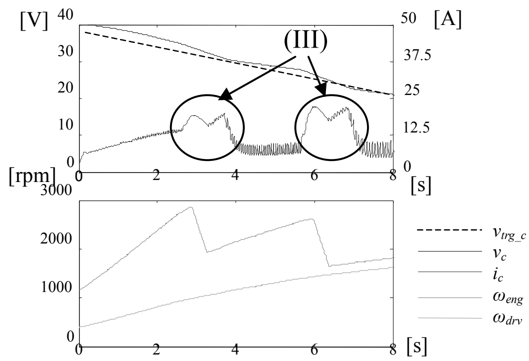


Figure 8: Simulation result of electric current on acceleration

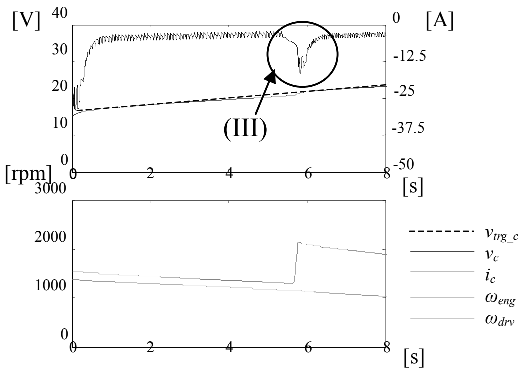


Figure 9: Simulation result of electric current on deceleration

Figure 6 shows the simulation result on acceleration without torque assist. Figure 7 shows with torque assist. The line of acceleration circled as (I) on Figure 7 was not decrease compared with that on Figure 6. This deference shows that by this motor-assisted AMT system with proposed controller, smooth gearshift operations can be achieved.

And the oscillation circled as (I) on Figure 7 reduced to 73% of that on Figure 8. This shows that the vibration is also reduced as it expected.

Figure 8 and Figure 9 are figures focusing on the stored energy. These figures showed the voltage of capacitor; v_c gradually followed the target voltage v_{c_trg} both on acceleration and on deceleration. This result shows that energy storage management can be realized at the same time.

In addition, the electric current i_c in circle (III) suddenly rose. Those are evidence of the power consumption coursed form the torque assist on gearshift.

4 Page and Column Dimensions

Through the results of simulations, we showed the 3 suggestions as the following.

(i) Using the proposed control algorism applied with disturbance observer-based controller, smooth gearshift operations can be achieved without any additional sensors.

(ii)The energy storage management can be realized by this control at the same time.

(iii)By this control, the vibration derived from engine torque is also improved even though shift change does not occur.

Based those simulation results, we are producing the test vehicle and going to verify to evaluate its potential and fuel-efficiency

References

[1] Sasaki: "Development of Capacitor Hybrid System for Urban Buses (Second Report) : Characteristics and Possibility of Capacitor Hybrid System", Transactions of the Society of Automotive Engineers of Japan, Vol.33, No.3 (20020715) pp. 179-184

[2] Soga: "Development of a Motor-Type Automated Manual Transmission", Journal of Society of Automotive Engineers of Japan, Vol.58, No.9 (20040901) pp. 62-67

[3] H.D. Lee: "Advanced Gear Shifting and Clutching Strategy for a Parallel Hybrid Vehicle", IEEE Industry Applications Magazine, Nov. /Dec., 2000.

[4] Fujii: "Charging and Driving Force Control of Motor-Assisted AMT with Super Capacitor", JIASC08, 2008/Aug

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