Speed control of dog clutch during mode switch for noise and wear reduction

CEVT

This paper deals with mode switch when the vehicle is shifted from electric vehicle/ series hybrid mode to parallel hybrid driving mode at high vehicle speeds. The schematic view of powertrain is shown in Figure 1a.

When the vehicle is in EV/series hybrid mode the P1 motor will be acting as a generator and will be charging the battery with engine power. The battery will provide the traction power to the wheels by P3 motor. The dog clutch will be open as shown in Figure 1a.

Figure 1b shows the mechanical view of the dog clutch. The primary side of the dog clutch is connected with P1 motor and the secondary side is connected to the P3 motor. The velocity at primary side is dented by ω_p and velocity at secondary side is denoted by ω_s.

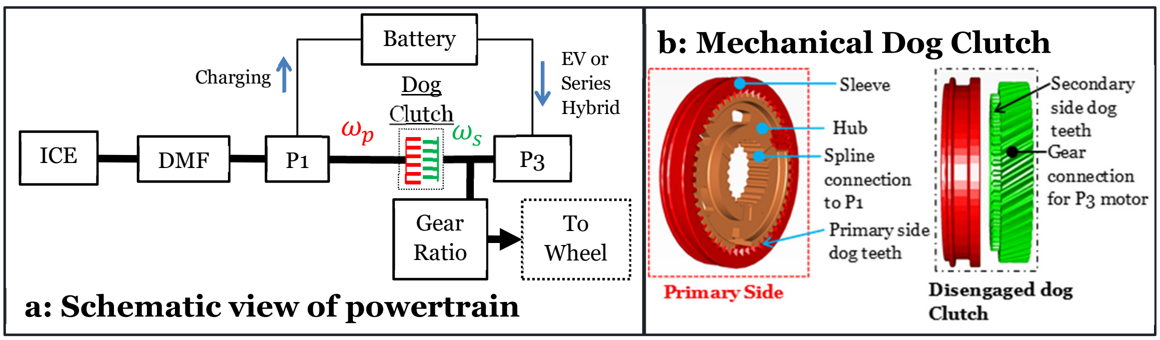

Figure 1 Schematic view of the powertrain and mechanical dog clutch

The traction effort curve of vehicle is shown in Figure 2. When the vehicle is in pure EV or series hybrid mode, below a certain speed v_1 kph, the internal combustion engine (ICE) will be running at the operating point shown by the red dot in Figure 2a.

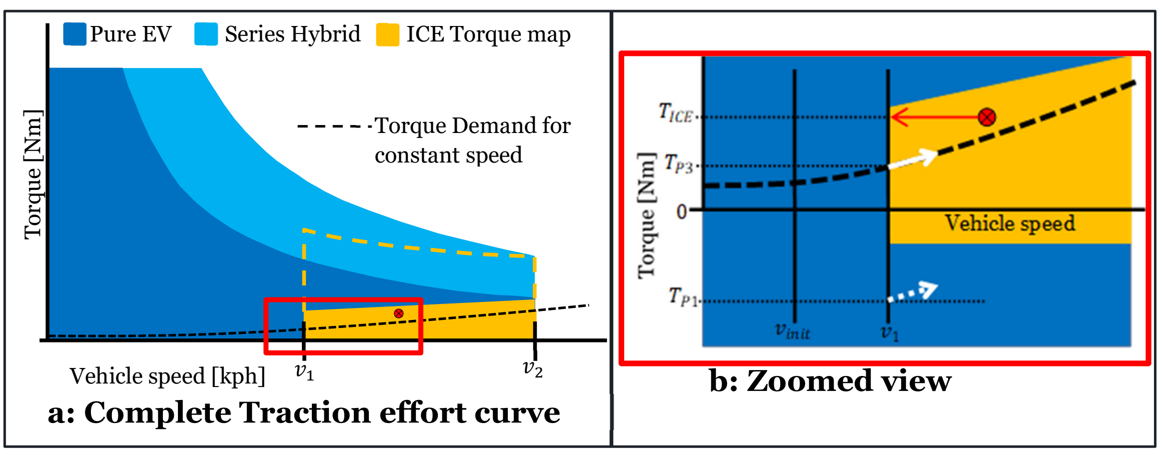

Figure 2 Traction effort curve

When the vehicle reaches the speed $v_1$kph, for efficiency in driving the vehicle must be in the parallel driving mode. Figure 2b shows the part of the traction curve marked by red square in Figure 2a. When the vehicle reaches a calibratable speed v_{init}, the P1 motor starts applying a breaking torque on the engine, hence decreasing the engine velocity as shown by the red line in Figure 2b. Meanwhile the torque demand at wheels is fulfilled by P3 electric motor by supplying the torque T_{P3}

When the vehicle velocity reaches v_1 kph, the dog clutch in Figure 1 can be closed and then engine and P1 motor will be connected to wheels. At this point the P1 breaking torque can be reduced as shown by the dotted white line in Figure 2b and as a result the traction torque at the wheels will increase as shown by the solid white line in Figure 2b

To ensure minimum noise and wear during the mode switch the velocity difference ω_{diff} between primary side of dog clutch ω_p and the secondary side ω_s must be kept minimum. To see the limits of ω_{diff}, tests at the lab were performed on the powertrain, the results are shown in

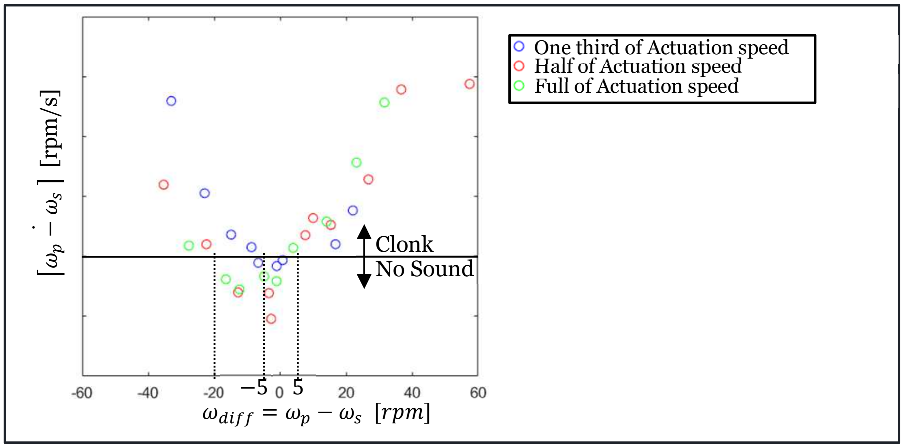

Figure 3 Lab results showing limits for ω_{diff} at dog clutch engagement

As shown in Figure 3, the dog clutch was engaged for 3 different actuator velocities. From test results it can be concluded that if ω_{diff} is between +5 and -20 rpm, the clonk noise is not observed.

Then the control objective in this paper is to design a controller that can provide breaking torque request T_{P1} to the P1 electric motor shown in Figure 2b, such that the primary side velocity ω_p comes within the beforementioned limits of the secondary side velocity ω_s. The time limit for this speed synchronization is defined by the time it takes for the vehicle to reach velocity v_1 kph from v_{init} kph. In this paper this time limit is defined as 2 seconds.

Since the controller is operating on the primary side by applying the torque T_{P1} and controlling the primary side velocity ω_{P1}, the physical model will contain ICE, DMF and P1 motor as shown in Figure 4.

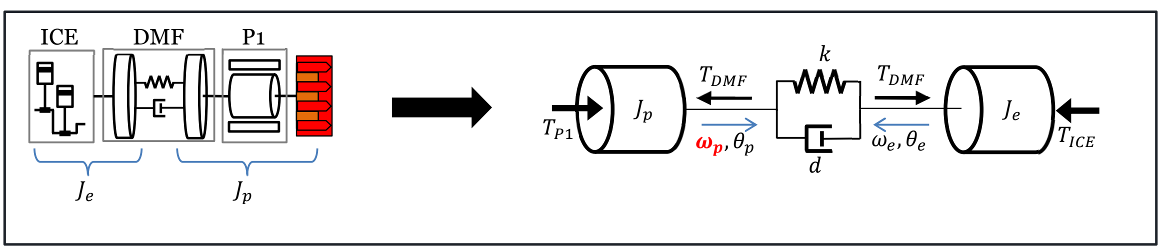

Figure 4 Physical plant model

Since the system is under constant disturbances of the engine combustion torque T_{ICE}, a Linear Quadratic Integral (LQI) controller is implemented as shown in Figure 5.

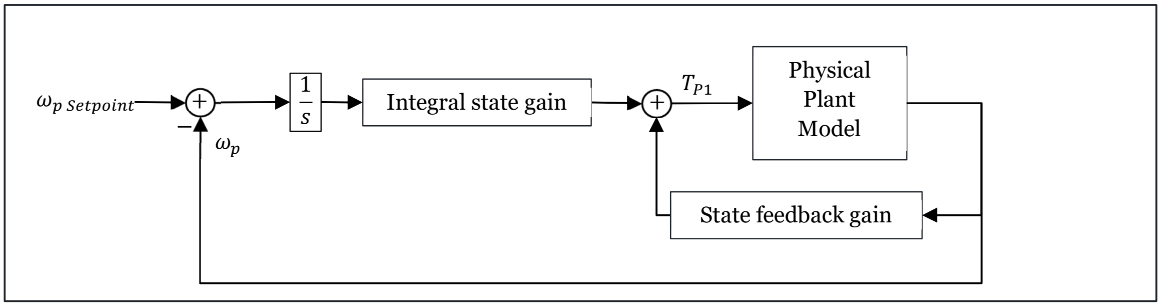

Figure 5 Feedback control

The optimal performance of LQI control depends on the elements of weighting matrices. Normally these weighting matrices are chosen by a trial-and-error approach which is time consuming and requires many simulations. In this paper, the weighting matrices are selected by using a novel algebraic approach. The input to the weighting matrices selection algorithm is the desired response time and the output is state feedback and integral state gain in Figure 5. This new approach decreases the simulations required quite a lot.

In this paper the controller that fulfils the response time of 2 seconds was achieved after just 2 simulations.

The controller simulation result is shown in Figure 6

S

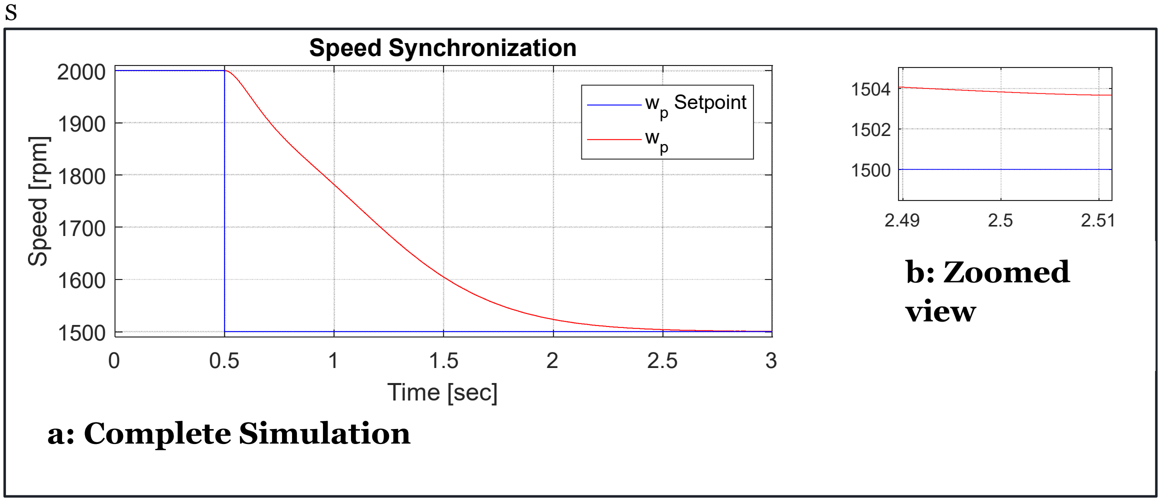

Figure 6 Simulation result

In Figure 6a, at time 0.5 seconds the primary velocity setpoint $\omega_{p\ Setpoint}$ is changed from 2000 rpm to 1500 rpm. Referring to Figure 2b, 0.5 seconds is the time when the vehicle speed reached v_{int} kph. The setpoint change also implies that the vehicle velocity will be reaching v_1 kph in 2 seconds so the primary side velocity must be close to ω_s = 1500 rpm.

So the feedback controller in Figure 5 starts decreasing the primary side velocity ω_p. After 2 seconds the primary side velocity is within the limits of ω_s as shown in Figure 6b, hence the dog clutch can be closed without noise and wear.

China Euro Vehicle Technology AB
中欧汽车技术中心
Theres Svenssons gata 7
SE-417 55, Göteborg, Sweden
Org. nr: 556922-7639
+46 (0)31-309 75 70
info@cevt.se
www.cevt.se