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Study on Active Suppression Control of Drivetrain Oscillations in an Electric Vehicle

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Abstract. Due to the low damping in a central driven electric vehicle and lack of passive damping mechanisms as compared with a conventional vehicle, the vehicle may endure torsional vibrations which may deteriorates the vehicle's drivability. Thus active damping control strategy is required to reduce the undesirable oscillations in an EV. In this paper, the origin of the vibration and the design of a damping control method to suppress such oscillations to improve the drivability of an EV are studied. The traction motor torque that is given by the vehicle controller is adjusted according to the acceleration rate of the motor speed to attenuate the resonant frequency. Simulations and experiments are performed to validate the system. The results show that the proposed control system can effectively suppress oscillations and hence improve drivability.

1. Introduction

The research of electric vehicles (EVs) to achieve green transportation is increasing in recent years [1]. In an EV, the high voltage battery storages energy, the integration of the motor and transmission system configuring the powertrain provides the ability of driving. In addition, a highly coordinated electronic control unit (ECU) is used for torque control, speed control and power distribution to meet the vehicle requirement.

Conventional none EV vehicle drivetrain system mainly consists of diesel engine, transmission system, driveshaft, clutch, half shafts, differential, and wheels, etc. The existence of the clutch and the driveline system's elastic nature performs a passive way of damping the oscillations in conventional vehicles. In a central driven pure EV, no clutches is present and the overall system configuration is less elastic inherently due to the fact that the motor and the transmission system are direct mechanical coupled. This configuration has little passive damping effect that can dampen disturbances and avoid oscillations, which are mostly noticeable during low speed range. Therefore, due to the low damping in an EV and lack of passive damping hardware as compared with a conventional vehicle, a damping control strategy is needed to minimize the drivetrain oscillations.

Active damping approach using a control strategy that can be implemented as software is more preferable than passive ones most of which need extra hardware to dampen oscillations. Several methods and configurations to minimize the oscillation have been studied [2-4]. Some of them introduce certain notch filter to attenuate the resonant poles by cancelling the resonant poles of the system transfer function to produce poles that are located in a more well-damped position in the splane left part. Such kind of method may be useful and effective, but the drawback of heavy computational burden makes it not easy to implement in real-time applications. The suppression of the oscillations in an EV is achieved by an easy-to-implement active damping torque control strategy in this paper. The origin of the vibration and the design of a damping control method to suppress such oscillations to improve the drivability of an EV are studied. The drive motor torque that is given by the ECU is adjusted according to the acceleration rate of the motor speed to attenuate the resonant frequency [5,6]. The proposed control strategy is validated by simulation and experimental tests. The results clearly show that the proposed approach is easy to implement and effective in suppressing the oscillations in an EV.

2. Oscillations in central driven EV

Several factors can contributed to the oscillation of EV, especially noticeable in low speed range. However, the deep reason is that the whole EV drivetrain system is an under-damping system. When the motor speed go across the inherent resonant frequency, oscillation will be inevitable if no damping is added to the system.

It is shown from the Figure 1 that the most sever vehicle oscillation happens when the speed of the drive motor is around 80-100 rpm, and the vehicle resonant frequency is about 5~6Hz. Figure 2 showed the drive motor current waveform during the oscillation

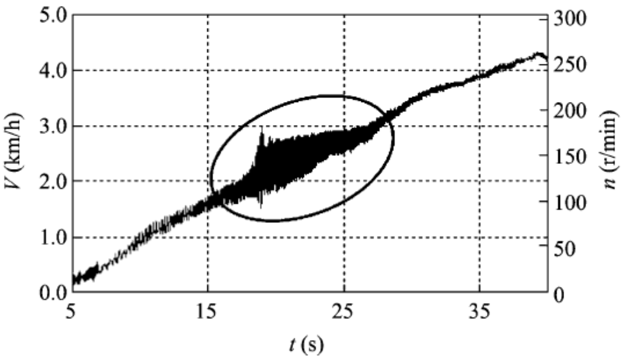

Figure 1. Acceleration oscillation of a certain EV.

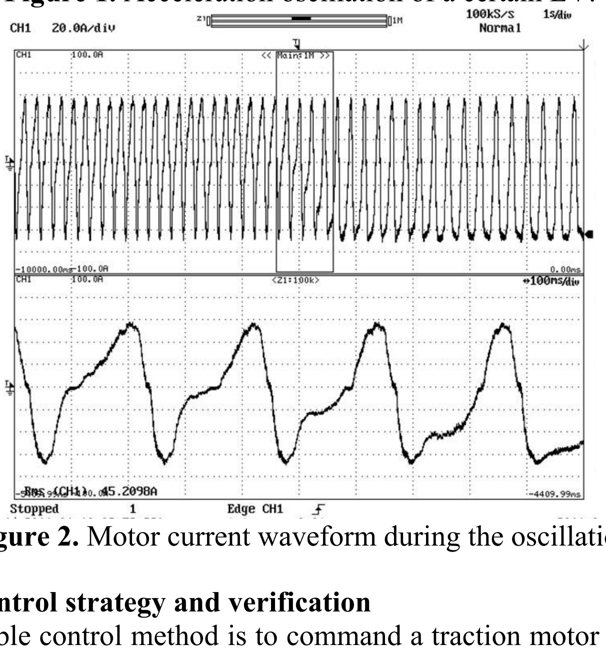

Figure 2. Motor current waveform during the oscillation

3. Active suppression control strategy and verification

The active-damping-capable control method is to command a traction motor with a provisional torque being adjusted by a proportion-differential control based on the difference between the measured motor speed and the calculated vehicle speed. This difference is proportion to the acceleration rate of the motor speed by further analysis. The calculated vehicle speed is based on an average of wheel

speed signals through a low pass filter. Unlike other active damping controllers that use wheel speed input to perform the active damping functionality, only two parameters are needed in this method.
The target torque is generated based on the differential of measured motor speed. The target torque is filtered then to attenuate the drivetrain resonant frequency as discussed before. Actually this method is a proportion plus derivative (PD) control with the input to the controller the calculation of drivetrain oscillation. For the drivetrain system, the proportional control of speed difference will introduce additional damping effect to the whole system.
The feasibility of the above proposed method is verified both by simulation and experiments. Figure 3 showed the simulation model for the proposed damping control method. Figure 4 showed the simulation result of speed acceleration of motor speed without and with vibration damping with the upper plot without damping and lower plot with damping. Figure 5 showed the comparison of experimental result of torque and speed of the drive motor for the effectiveness of the proposed method in mitigating drivetrain oscillations at low vehicle speed with the upper plot without damping and lower plot with damping. Figure 5 showed the comparison of experimental result of vehicle response to throttle tip-in/tip-out without and with vibration damping.

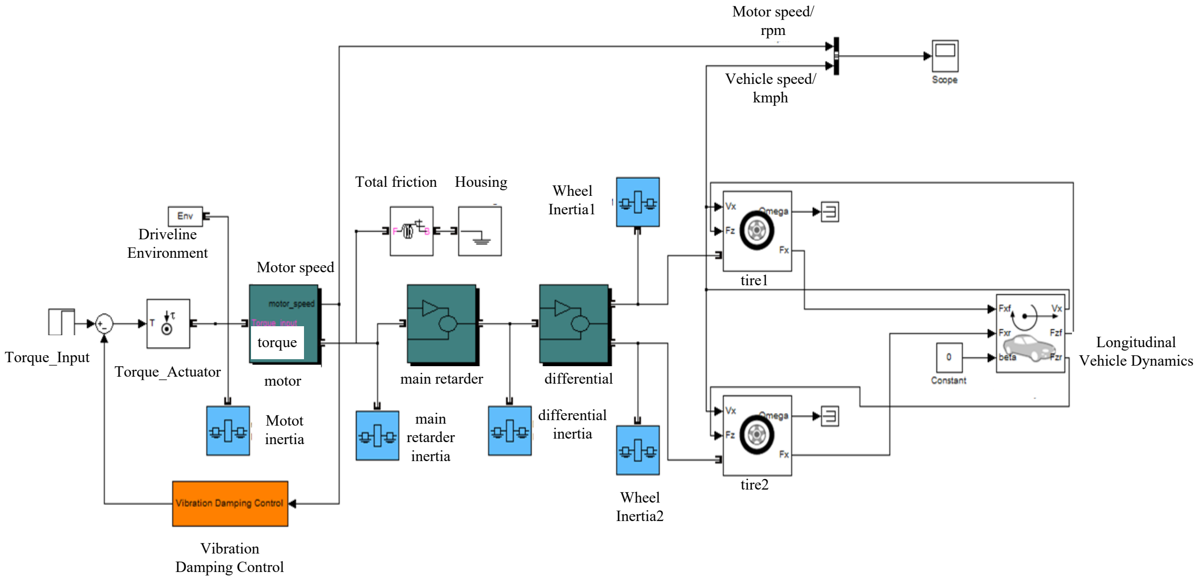

Figure 3. Simulation model for the proposed damping control method.

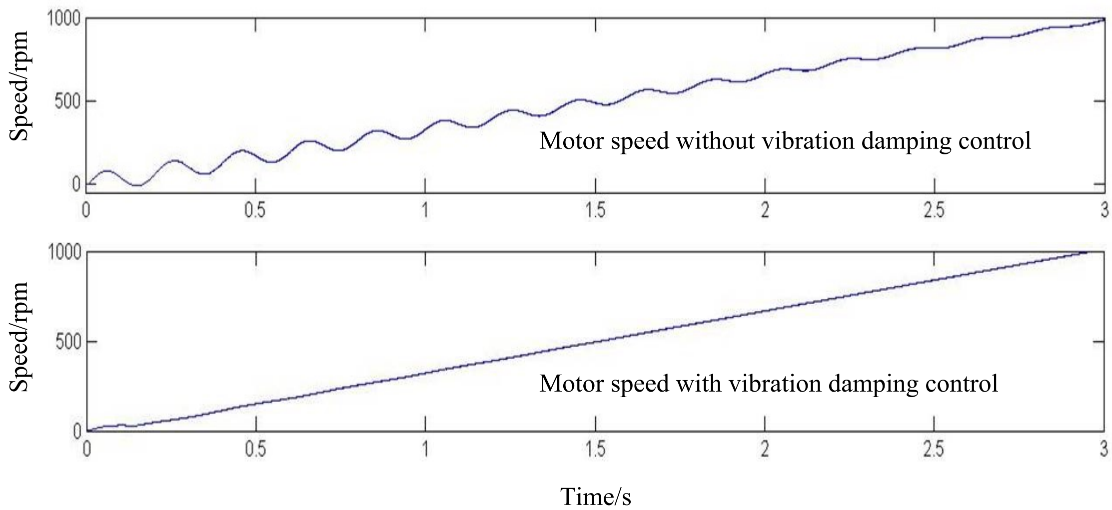

Figure 4. Simulation result of speed acceleration of motor speed without and with vibration damping (upper plot: without damping, lower plot: with damping).

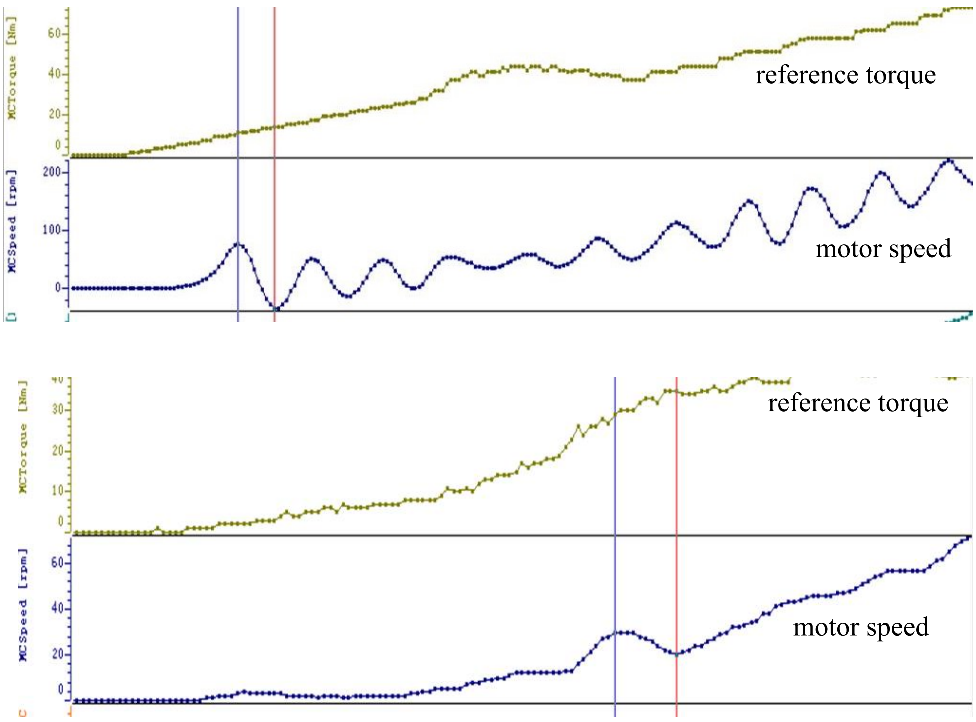

Figure 5. Comparison of experimental result of torque and speed of the drive motor for the effectiveness of the proposed method in mitigating drivetrain oscillations at low vehicle speed (upper plot: without damping, lower plot: with damping).

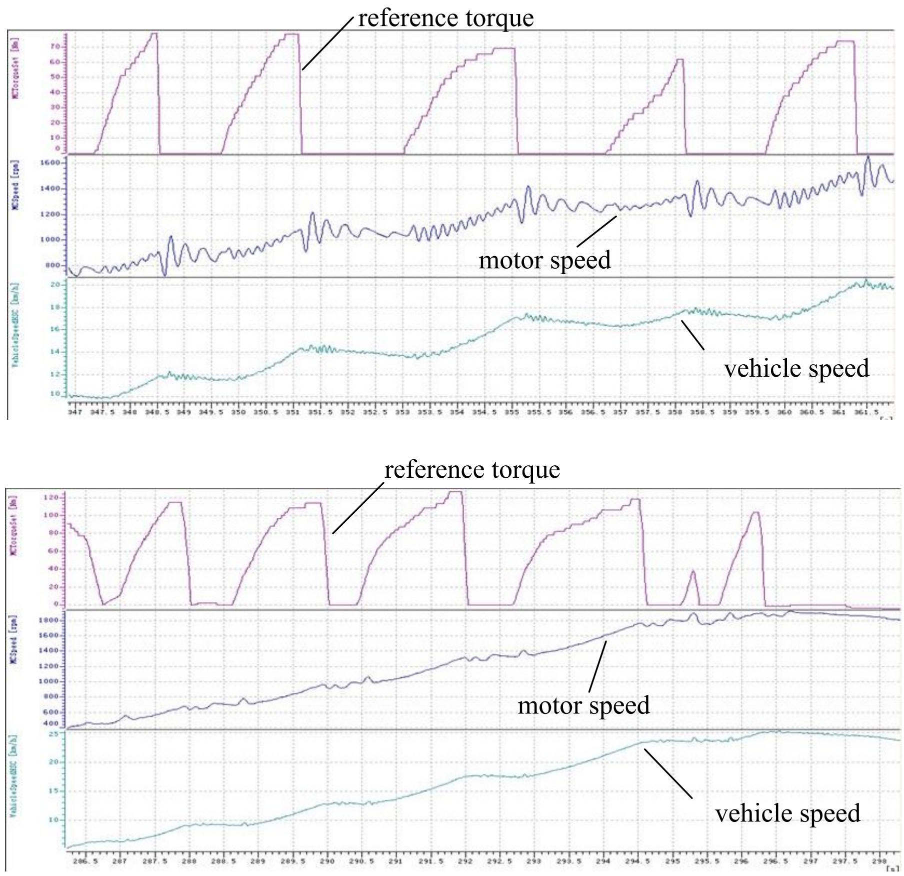

Figure 6. Comparison of experimental result of vehicle response to throttle tip-in/tip-out without and with vibration damping (upper: without damping, lower: with damping).

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4. Conclusion

This paper has proposed a simple yet effective approach to actively damping the oscillation of EV powertrain, which can improve drivability and customer satisfaction.. The acceleration of speed of the drive motor is used to form a PD controller to compensate the damping. This active damping controller was verified by simulation and experimental results. The results showed that the proposed damping control method can improve the performance of the vehicle by reducing the resonance component that inducing driveline oscillations.

Acknowledgments

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