

## Active Damping of Drive Train Oscillations for an Electrically Driven Vehicle

Norker Amann, Joachim Böcker, and Franz Premer

**Abstract**—A problem encountered with electrically driven vehicles are resonances in the drive train caused by elasticity and gear play. Disadvantageous effects caused by this are noticeable vibrations and high mechanical stresses due to torque oscillations. The oscillations can be damped using a control structure consisting of a nonlinear observer to estimate the torque in the gear and a controller, which computes a damping torque signal that is added to the driver's demand. The control algorithm was implemented in the existing motor control unit without any additional hardware cost. The controller was successfully tested in a test vehicle. The resonances can essentially be eliminated. The controller copes satisfactorily with the backlash problem.

**Index Terms**—Active damping, drive train oscillations, electrical vehicle.

### I. INTRODUCTION AND PROBLEM STATEMENT

Electrical drives are of increasing interest for road vehicles, either as a sole propulsion engine that is fed by a battery or a fuel cell, or in combination with a combustion engine as a hybrid drive. This paper, however, deals with a pure electrical drive system (Fig. 1) that was experimentally fitted to a Mercedes-Benz A-Class vehicle (Fig. 2). The induction motor of 50 kW rated power is fed by a voltage source converter with a Zebra battery supply allowing 140-km operation range.

The paper focuses on the particular problem of drive train oscillations. Torsional oscillations in drive trains of electrically driven vehicles are a common but annoying problem. However, the problem is more awkward with electrical drives than with combustion engines. Unlike drive trains with combustion engines, which are usually equipped with dampers due to the high torque pulsation of the engine (at engine firing frequency), electrically driven trains are rather weakly damped. Dampers seem not to be necessary due to the smooth torque of electric motors. But not surprisingly, any unevenness of the driver's demand or, more evident, of the load from the disturbances of the road-wheel-contact will then excite mechanical resonances (at low driveline oscillation frequency). Typically, the motor controller does not provide any damping of the oscillations, because it is usually designed in a way to produce the demanded torque independently of the mechanical state of the system.

Drive train oscillations are undesired due to the high material stress but also due to poor riding comfort because the oscillations can cause, particularly at low speeds, that the whole vehicle shudders quite unpleasantly. Corrective measures are necessary in order to improve the riding comfort and to lessen mechanical stress.

In this paper, a control scheme for active oscillation damping is described. The controller determines a small corrective signal, which is added to the torque demanded by the driver such that the oscillations in the drive train are reduced. A special problem the control design had to deal with was the backlash of the gear and of the cardan shafts that introduces nonlinearities in the control loop. If the controller were not able to cope with that, the backlash could, of course, be minimized using more precise, but also more expensive mechanical components.

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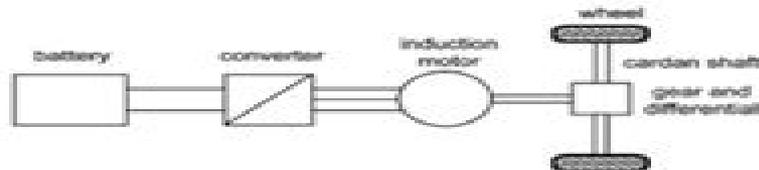


Fig. 1. Drive system structure.

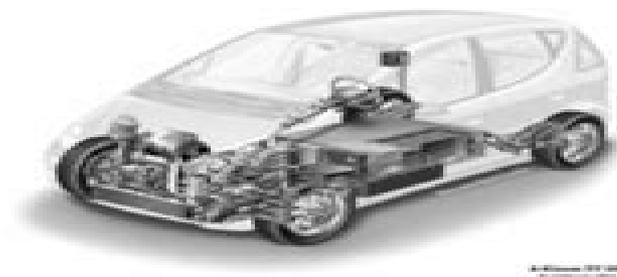


Fig. 2. A-Class electrical vehicle.

So it is appreciated that the developed controller can indeed operate sufficiently with a considerable backlash.

The control approach was realized without any additional hardware cost within the existing motor control unit (MCU). The computational effort is moderate. The approach was applied for a Mercedes-Benz A-Class vehicle with electrical drive. Results of vehicle tests are shown.

### II. STATE OF THE ART

Active damping of oscillations with electrical drives has been a subject of many publications. A possible road are frequency-domain approaches like introducing filters with certain frequency characteristics in the control loop in order to compensate for the mechanical resonances [9]. Another strategy is the emulation of physical behavior of a damper by the controller [10]. State-space methods have advantages particularly for oscillating systems of higher order [6]. Some proposals assume the speed as control objective and cannot be used for torque control. The choice of method also depends on the available measured signals that are mostly motor and/or load speed. Another distinguishing feature is the consideration of nonlinearities of the system, particularly nonlinear friction or backlash [4]. Vehicle shuddering is also subject of vehicles with conventional combustion engines [8]. Good surveys can be found in [2] and [7].

The contribution of the paper is a control algorithm to improve the mechanical properties of an electric drive train. A challenging restriction is to use only existing sensors and motor controller hardware. A combined approach of a nonlinear state-space observer and a frequency-domain controller meets the requirements perfectly as shown below.

### III. DRIVE TRAIN MODEL

Drive train oscillations may always appear, in principle, if there exist any elasticity and inertia. Elastic elements are the shafts, the gear, the

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