

A Model Based Approach for Electric Steering Tuning to Meet Vehicle Steering Performance Targets

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ABSTRACT

Subjective steering feel tuning and objective verification tests are conducted on vehicle prototypes that are a subset of the total number of buildable combinations of body style, drivetrain and tires. Limited development time, high prototype vehicle cost, and hence limited number of available prototypes are factors that affect the ability to tune and verify all the possible configurations. A new model-based process and a toolset have been developed to enhance the existing steering development process such that steering tuning efficiency and performance robustness can be improved. The innovative method utilizes the existing vehicle dynamics simulation and/or physical test data in conjunction with steering system control models, and provides users with simple interfaces which can be used by either CAE or development engineers to perform virtual tuning of the vehicle steering feel to meet performance targets. The process can be used not only in early phases of vehicle programs before prototypes are available, but also in parallel to prototype tuning for objectively evaluating vehicle configurations that might otherwise be only assessed subjectively due to limited prototype availability.

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1. INTRODUCTION

Today's steering feel development relies on engineers' experience to subjectively tune hardware on prototypes, which are then validated with objective measurements. Steering tuning and physical tests are conducted on selected vehicle configurations and at discrete vehicle speed levels in the existing development process due to time and cost constraints. These constraints make it challenging to tune steering feel parameters for all vehicle configurations.

Using models for developing steering control systems is common in the industry. Though steering tuning still largely depends upon subjective experiences with prototypes, model-based approaches find more applications as seen in publications.

Camuffo, et al [1] reported that Fiat Auto has developed a numerical-experimental procedure in order to support on-road development and fine tuning of a new car with electric power steering. This procedure involved integration of an electric power steering model provided by a supplier in a full vehicle model in order to objectively evaluate steering feel. The procedure has allowed improving vehicle performance in term of steering feel and reduces on-road development time. Cianetti and Ambrogi [3] present detailed steering mechanical modelling with friction identification. The model, integrated with an analytical vehicle model and a tunable black-box

ECU model, is used for steering performance target settings. Ljungberg's thesis [5] describes a complete process from setting up the simulation environment to developing the optimization process of the parameters. The supplier's steering system model in Simulink is co-simulated with a vehicle model in CarMaker. Schick [7] shows how model-based development methods, which have been established in the powertrain domain for years, can be used for chassis/vehicle dynamics validation and calibration. A tuning tool presented by Takamatsu and Tomita [8] uses a simple simulation function with initial design and database to check the effect of changing parameters. A so-called tuning help function can be used by less-experienced engineers by translating steering feel requirements to tuning terms. Additional applications of model-based approaches can be found in numerous papers such as [4, 9, 10, and 12].

The keys to successful adoption of the model-base approaches in steering tuning are model quality and a streamlined process with easy user interfaces so that engineers without modelling experience can implement the approach. This paper introduces a new model-based process with a toolset to support and supplement in-car tuning processes such that steering performance can be tuned and evaluated at more vehicle speed levels and for a wider array of vehicle configurations than would normally be tested.

The new process was developed in a project with the following objectives:

- Implementing/automating standard tests in Simulink-based models with steering controls to evaluate steering feel performance
- Developing methods & process capable of evaluating steering feel metrics at different vehicle speed levels, and for varying vehicle loading & tire fitment
- Simplifying the tool such that it can be used by both CAE engineers and by development engineers who are not trained in CAE disciplines.

2. METHODS

Process Concept

The mode-based process requires high fidelity models and efficient simulation environment to allow large sized DOE's for performance optimization. Suppliers' collaboration ensures the required quality of steering control models. For vehicle modeling, existing ADAMS™ steering event simulations or measurements from vehicle tests are used to generate rack force input-output models with respect to rack displacements. Since the simulations use the measured or pre-calculated rack force model, it is assumed that the same maneuver parameters are used from which the rack force models are derived, and that the EPAS tuning changes don't affect the tie rod forces. Rack force models for system test were described by Wang and Esser in [11].

Figure 1 illustrates this concept, which enables efficient simulation with high fidelity vehicle dynamics. In addition, this concept eliminates the use of a specialized vehicle dynamics simulation package (e.g. ADAMS™ or CarSim™) to provide rack loads to steering systems, since using a vehicle dynamics simulation package is usually limited to vehicle dynamics CAE specialists. Therefore implementing the concept in the model-based process with an integrated toolset enables engineers to conduct steering tuning studies with minimal additional workload while achieving many benefits that will be discussed later in this paper.

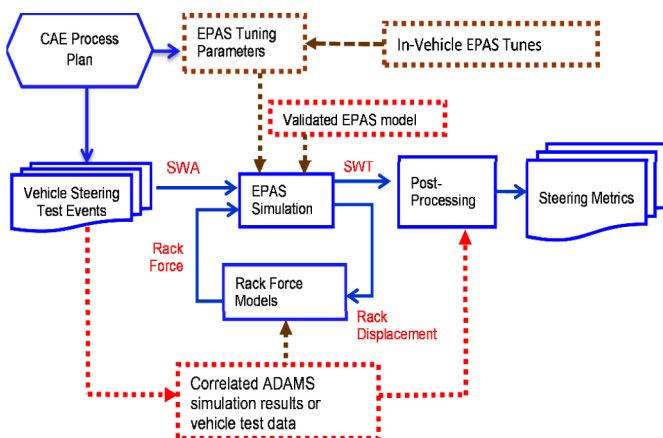


Figure 1. Process Concept

Steering Modelling

The steering system is modelled in Simulink and consists of a control model block and a mechanical model block. Both blocks are Simulink choice blocks so that they can be easily replaced for different designs or configurations. An agreement among model providers regarding model or sub-model interfaces can greatly simplify model building process. The standardized model interfaces can also make it possible to automate the model building and model check, enabling users without Simulink modeling experiences to execute the model-based process.

EPAS steering mechanical model should have at least the following components:

- Steering wheel model as shown in Figure 2
- Torsion bar, modelled as a spring and damper
- Intermediate shaft velocity variation, which is determined by the relationship between gear input angle with column angle

$$\theta_{pinion} = \Delta\theta \sin(2\theta_{column})$$
, where $\Delta\theta$ is angle variation amplitude.
- Intermediate shaft compliance
- Gear ratios
- Gear friction
- Motor with rack housing or motor with column

For an off-center rack EPAS, the rack and motor dynamic equation, described below, uses motor angle θ as the independent coordinate.

$$J_{em}\ddot{\theta} + C_{em}\dot{\theta} = T_{em} + (F_{LTR} + F_{RTR})r - F_{ric}r,$$

where,

J_{em} is total moment of inertia [Kgm²]

C_{em} is effective damping [Nms/rad]

F_{LTR} and F_{RTR} are left and right tie rod forces [N]

F_{ric} is total gear friction [N]

T_{em} is motor torque from the steering control model [Nm]

r is gear ratio [m/rad]

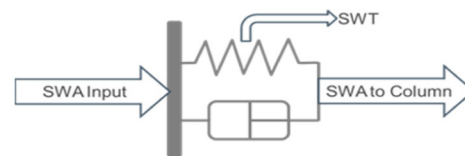


Figure 2. Steering Wheel Model to Calculate Steering Torque from Steering Wheel Angle Input