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Control of Electric Power Steering Systems From State of Art to Future Challenges

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1. INTRODUCTION

Electric power steering (EPS) systems are about to find their way into premium cars. As a result not only the hardware requirements but also functional requirements for EPS systems are increasing. These functional requirements concern performance in conjunction with vehicle level control algorithms as well as road feedback. The paper summarizes the essential functional requirements for state of the art steering systems. It gives an overview of control concepts as implemented in typical EPS systems today and outlines challenges for future approaches from an industrial point of view. These challenges cut down to practical design of controllers and estimators with coarsely quantized measurements and short-word-length on the target hardware.

2. STATE OF ART STEERING FEEL

The functional quality level of a steering system, i.e. the steering feel, considerably contributes to the driving behavior and thus to driving satisfaction and safety. In order to describe the steering feel several criteria are commonly used. These criteria can be divided into two categories.

The first category concerns the steering system itself. Here most obvious is the level of steering torque, i.e. torque needed to operate the steering wheel. Drivers consider a high torque level as sportive while a lower level is considered to be more comfort oriented. Regarding torque build up a sufficiently small delay between driver command and assist torque is needed. Especially at higher vehicle speeds a well developed on-center feeling, i.e. the gradient of steering torque vs. steering angle around the center, contributes to a good steering feel. Friction is an inherent issue of mechanical systems. For EPS systems friction e.g. prevents the steering wheel from aligning to the exact center position. To achieve best self centering quality, active return functions are used. Today these functions are combined with active damping functions and have evolved to a functional level well beyond that of HPS systems, i.e. they do not only over come friction issues but provide added value.

This steering system oriented category of criteria is complemented by a second category which considers the steering system as a part of the vehicle. In this case focus is on the fact that the driver is connected to the road via the steering system. Hence the steering system is the fundamental channel to give information about forces at the tire/road interface to the driver. This comprises two main issues. First the texture of the road surface, e.g. asphalt should feel different than cobblestone, second the vehicle state, e.g. over- or understeer. Both criteria must be enforced by appropriate design of the steering controller.

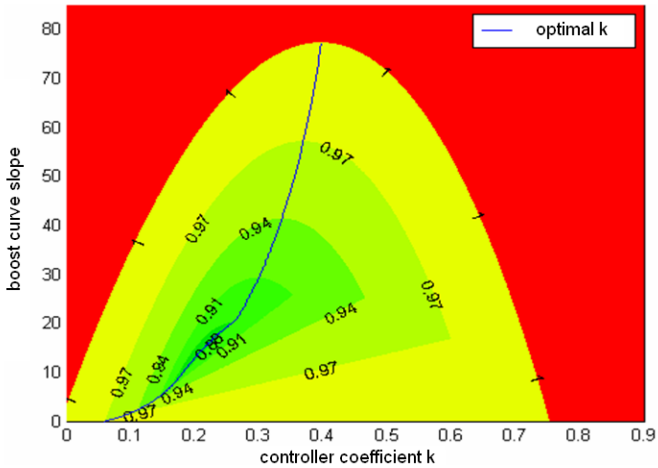

Fig. 1. Controller coefficient gain scheduling on basis of boost curve slope.

3. PRESENT CONTROL CONCEPTS

The functional structure of EPS control concepts found in today's systems aim at copying traditional hydraulic power steering systems (HPS) as described in the following. The system structure may be decomposed into two main elements. The first element is the boost curve. A torsion bar measures the torque which is then transformed into a corresponding assist torque. The boost curve which is the relationship between measured torque and assist torque is static while dynamics are addressed by the second element of the system structure, the dynamic compensator. The compensator realizes the balance between agility, stability and robustness of the whole steering system.

For HPS the properties of boost curve and compensator are adapted by suitable hydraulic design elements and additional damping measures. In EPS systems both components are realized as software functions. While the design of the boost curve is straight forward the design of the compensator has additional degrees of freedom compared to HPS. These degrees of freedom are used to improve the balance between agility, stability and robustness.

One possibility is the use of a gain scheduled phase adaptation to ensure controller stability at any level of assist. Fig. 1 shows the basis of such a gain scheduled phase adaptation. The color codes the spectral radius of the closed loop transition matrix, from left to right a controller coefficient k is shown which is scheduled against the slope of the boost curve increasing from bottom to top. The curve emanating from the origin is the line of optimal controller coefficients regarding robustness in terms of distance to spectral radius one. An approximation of this curve is then used in the actual ECU implementation. Promptness of assist is achieved by a high performance motor torque controller. The steering feel produced by these software components is further enhanced by the use of an active return algorithm as well as friction and inertia compensation.

4. TRENDS FOR FUTURE EPS SYSTEMS

The current EPS control concepts, as the one presented in the previous section, focus on the basic function of EPS, i.e. stable and robust provision of assist torque according to driver demand.

In the future EPS will play a key role in a variety of high-level functions aiming at increased comfort, e.g. automated parking, safety, e.g. vehicle stability control as well as combined functions increasing comfort and safety at the same time, e.g. automatic lane keeping. These functions imply that the assist torque is not only generated by the driver demand but also by high-level functions. Hence the EPS controller needs not only to be stable and robust as a stand alone system but also integrated in the closed loop with high-level functions. These requirements are beyond the capabilities of boost-curve plus compensator architectures. As a consequence a new generation of controllers (see e.g. Niessen and Henrichfreise (2002)) is needed that is able to realize the EPS basic function and external assist torque demands at the same time.

Besides this the basic function of EPS needs to be further enhanced to give the driver a good level of road feel. This comprises two issues: feedback on the lateral forces at the tire/road interface and emphasized tactility of the straight running direction in critical driving situations. Both issues can be directly realized if assist torque is no longer generated on basis of the driver demand but on basis of the forces acting at the tire/road interface. The desired road feel is then computed from the forces at the tire/road interface as reference value for the driver torque by a pseudo-inverse boost curve.

In addition to that the reference value for the driver torque can be augmented with driver torque requests from external functions. This offers a clear interface to the EPS for high-level functions such as e.g. driver steering recommendations which is not available in the classical boost-curve plus compensator architectures.

5. CHALLENGES FOR MODEL BASED EPS CONTROL CONCEPTS

To realize these new requirements in terms of performance and robustness ad hoc tuning of controllers is outdated. The dynamic capabilities of the specific EPS need to be utilized in the controller design. This is achieved by the use of suitable models of the EPS. Hence requirements regarding robustness gain in importance. Typical issues for robustness are actuator non-idealities as well as sensor non-idealities. Furthermore the controller must operate at any driving and environmental conditions. Insufficient robustness will turn out as unwanted hum or even shimmy at the steering wheel in certain circumstances.

A variety of discrete time controller design methods yielding robust controllers exist. However these methods are not capable to handle coarse quantization of sensor signals in a transparent way. Coarse quantization in this context means quantization intervals Δ of the sensors of 2 times and even more above the needed control accuracy. These coarse quantization was introduced to cut down costs in the classical boost-curve plus compensator architectures just as the use of inexpensive integer-only controll units, thus asking for a short-word-length realization of the control-algorithms.

Despite the fact that the same limitations apply to the estimation of forces at the tire/road interface on basis of EPS internal signals the advantages of this approach in contrast to the use of chassis signals such as yaw-rate and lateral acceleration is discussed next.

As described in the previous section the use of the pseudo-inverse boost curve requires the knowledge of the lateral force at the tire/road interface. These forces are not directly measurable and hence they need to be estimated in real time. Since this force is supported by the rack which in turn is balanced by the assist torque and the driver torque it is the EPS system that is first influenced by changes in the lateral force. Hence the EPS system is the key to estimation of lateral tire/road forces. Any estimation process relies on a model of the EPS system and hence the quality of the model significantly contributes to the quality of the estimated force at the tire/road interface.

The controller and estimator design is further complicated by safety requirements. These safety requirements may be cut down to simply requiring that any unintended steering actions must be detected and suitable counteractions have to be taken. In order to fulfill this requirement a realtime supervision of the computed control actions is needed togehter with a validation of the used input signals. As high availability of the steering system is a crucial requirement the supervision must not be conservative yet detect all relevant mal functions of the EPS system.

In summary the key challenge for model based EPS control from a controller-design-method point of view is to provide the practitioner with transparent design methods. These design methods must ensure performance and robustness in presence of quantized measurements and short-word-length control units while at the same time the resulting controllers need to be supervised.

REFERENCES

H. Niessen and H. Henrichfreise. Vehicle steering system for controlling a steering or steering lock angle of at least one wheel of a vehicle, 2002. EP 1 373 051 B1, 21.02.2002.