Preliminary study on Electronic Power Assistance Steering (EPAS) systems

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Abstract

According to the document **ANR 09 VTT VOLHAND Doc B**, presented on **October 2011**, the research team in Gipsa-Lab is involved into the task 5.2 (T5.2) for the design of the the amplification curves that can be adapted to disabled people. The typical architecture of an Electric Power Assistance Steering (EPAS) system includes a static map to provide the correct amplification to the driver's exerted torque. In literature, it is generally known as booster curve. This document concerns a preliminary study of the current methods diffused in literature to provide this amplification and is based on the results published in [6] and [11]. The basic concepts of the Electric Power Steering (EPS) systems with a realistic model for the friction contact, that acts on the wheels are discussed. A relation between the assistance and the driver's torque is provided, under the hypothesis of a position-oriented control of the movement and the Stevens' power law. Finally, the simulation results proposed at the end of this paper validate the shape of the booster curves and are in accord with the initial hypothesis.

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1 Introduction

The assistance provided by the electric motor of EPS systems reproduces the hysteresis cycle of the hydraulic valve, as shown in Fig. 1: the amplification torque U grows, according to the value of the driver's torque τ_v and the vehicle speed V, then saturates. If the driver's torque changes in direction, we have the downhill phase of the amplification torque. During this phase, the amplification torque decreases, until reaching the lower saturation values.

In literature, we can find many stationary models for the EPS system ([3], [4], [7], [17], [5],[13], [16], [2], [12]), where the hysteresis cycle is approximated by a single curve. Nevertheless, these investigations do not provide ground foundations (other than these curves reproduce the behaviour of the older power steering systems, based on hydraulic valves), neither evidence that they are optimal for the driver in any sense. To justify the optimality of these curves (or to develop new ones), we propose a model for the steering column and the assistance, by introducing a relationship between the assistance and the driver's exerted torque. This relationship is based on the Steven's power law. The simulations at the end of this report shows some assistance curves, that are very similar to those shown in literature.

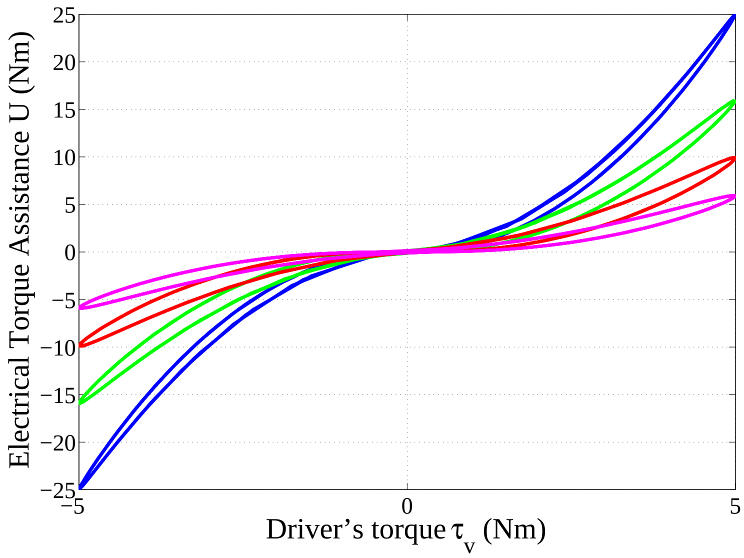

Figure 1: Example of the booster curve, provided by the EPAS system, reported in [3].

2 Torques acting on the EPS system

Works in [11] show that it is possible to compensate the torsion torque in the steering column with a inner control law. Under this hypothesis, it is possible to describe the dynamics of the EPS system, as follows:

$$J\ddot{\theta} + B\dot{\theta} + \frac{\tau_a}{N_1} = \tau_v + U \tag{1}$$

$J = J_v + J_T$ = total inertia at the steering wheel level

$B = B_v + N_2^2 B_m + \frac{\sigma_2}{N_1^2}$ = the total viscosity of the system at the steering wheel level

τ_a = friction torque

τ_v = driver's exerted torque

U = assistance torque

At stand still, the main force opposing to the driver's effort is the contact friction. In this situation, it is possible to assume that the assistance U acts to compensate, first of all, a part of the contribution of the load torque τ_a in Eq. (1). Indeed at steady-state conditions:

$$\frac{\tau_a}{N_1} = \tau_v + U \tag{2}$$

In order to design the assistance amplification, the hypothesis that the driver's perception of the load torque obeys to the *Stevens' power law* ([14, 8, 1]) is done:

$$\delta \left(\frac{\tau_a}{N_1}\right)^n = \tau_v \tag{3}$$

where:

δ = the intensity magnitude of the external stimulus

n = the rate of growth of the sensation of the stimulus and depends on the sensory modality of the driver (e.g. perception of force or perception of position).

The value of δ is tuned to obtain a realistic value of the amplification torque, while to choose the value of n, it is mandatory to refer to the literature, concerning some neuro-muscular studies. During the steering movement, some authors ([10, 15]), show that drivers prefer exerting their control, basing on the transfer function between the friction contact load and the steering angle (*position-oriented control*), rather than the transfer function between the friction torque and the steering torque (*torque-oriented control*). This can be explained by the fact that the neuro-muscular system is better suited to control the steering angle than the exerted torque, thanks to the gamma (γ) motor neurons, that adapt the length of the spindles according to the hand wheel angle [15]. Under the hypothesis of a control-oriented control, we will use $n < 1$.

3 Relation with the assistance torque

To obtain a relation between the assistance torque and the driver's torque in steady-state, Eq. (2) is substituted in Eq. (3), as follows:

$$\delta \left(\tau_v + U\right)^n = \tau_v \tag{4}$$

By solving for U, it is possible to obtain:

$$U = \sqrt[n]{\frac{\tau_v}{\delta}} - \tau_v \tag{5}$$

When the dynamic terms of inertia and viscosity are included, the same closed-form solution for the assistance U is not reachable, but it follows:

$$J\ddot{\theta} + B\dot{\theta} + \delta \left(\frac{\tau_a}{N_1}\right)^n = \tau_v \tag{6}$$

Let consider Eq. (1), we can express the assistance torque U, as the following difference:

$$U = \frac{\tau_a}{N_1} - \delta \left(\frac{\tau_a}{N_1}\right)^n \tag{7}$$

In this case, it is not possible to retrieve the corresponding value for the assistance torque in closed form, because it is necessary to solve Eq. (6) to obtain the corresponding values in Eq. (7). For this reason, it is necessary to introduce the optimization problem, shown in Section 4.

4 Problem formulation

Under the hypothesis of a position-oriented control of the movement, we propose an optimization problem, based on the minimization of the jerk [9] to find the optimal trajectories to substitute in Eq. (1) and Eq. (6), to obtain the corresponding driver's torque for different values of δ to substitute in Eq. (7) to obtain the amplification curves.

The considered movement consists into bringing the steering wheel from 0 rad to $\pi/2$ rad and returning it to its initial position. The problem is to find the optimal trajectory $\hat{\theta}$, that minimizes the cost index I:

$$I = \int_0^T \left(\frac{\mathrm{d}^3\theta}{\mathrm{d}t^3} \right)^2 \mathrm{d}t \tag{8}$$

under the constraint to have a driver's torque $\tau_v = 0$ at the beginning and at the end of the movement.

The optimization problem can be written as follows:

$$\min_{\hat{\theta}} \int_0^1 \left(\frac{\mathrm{d}^3\theta}{\mathrm{d}t^3} \right)^2 \mathrm{d}t \tag{9}$$

with the boundary conditions on the trajectory

$$\begin{array}{lll} \theta(0) = 0 & \theta(1) = 0 & \theta(0.5) = \pi/2 \\ \dot{\theta}(0) = 0 & \dot{\theta}(1) = 0 & \dot{\theta}(0.5) = 0 \\ \ddot{\theta}(0) = 0 & \ddot{\theta}(1) = 0 & \end{array} \tag{10}$$

and on the driver's torque

$$\tau_v(0) = 0 \quad \tau_v(1) = 0 \tag{11}$$

Details of this procedure can be found in the paper [6].

5 Simulation results

Fig. 2 shows the optimal trajectories obtained from the simulation. As expected from an optimization that minimizes the jerk, the optimal trajectories are smooths and regulars. Note that the angular trajectory is not symmetric in the last phase. This feature allows to obtain both the load and the driver's torques to be null at the final time. In Fig. 3, at steady-state the curve has an exponential behaviour. This characteristic is more accentuated, as the coefficient n diminishes. The amplification is almost negligible for driver's torques in the interval $-1 \leq \tau_v \leq +1$ N m, while it grows for more important values. The hysteresis effect is present when the optimization in transient state is carried out, due to the influence of the inertial and viscosity torques. Nevertheless, it is possible to conclude that the commonly used amplification curves correspond to the profile obtained with $n < 1$. This means that the Stevens' coefficient for the rate of growth of the stimulus corresponds to the hypothesis of the position-oriented control of the movement.

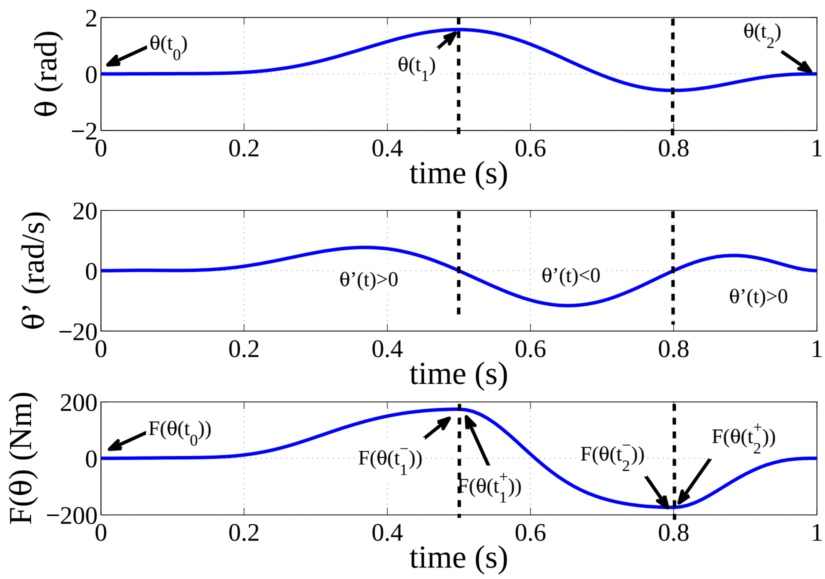

Figure 2: Evolution of the angular and speed profile used to evaluate the analytic solution of the contact friction model.

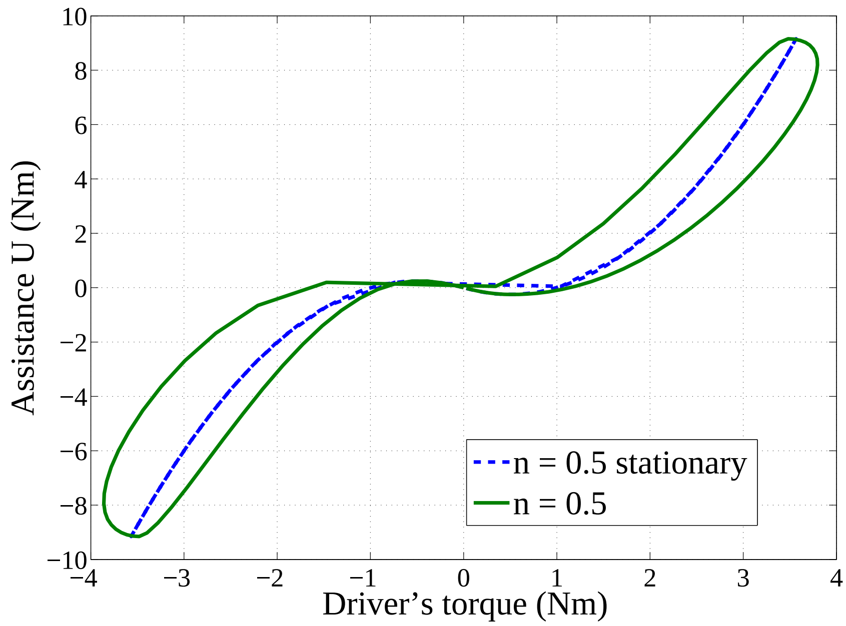

Figure 3: Amplification torque obtained to compensate the friction torque with rate of the sensation stimulus $n = 0.5$ in steady-state case (dotted) and dynamical one (full line)

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