

Assessment of the Capability of EPS to Reduce Steering Wheel Pull and Vehicle Misalignment

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ABSTRACT

Vehicle steering wheel pull is a condition experienced by customers where a constant torque at the steering wheel is required to maintain a straight path. Steering wheel pull may be accompanied by the secondary effects of steering wheel angle misalignment and vehicle thrust angle “dog-tracking.”

EPS pull compensation is a feature that can automatically compensate vehicle steering wheel pull. This paper examines customer benefits, operating principles, effectiveness, and robustness of EPS pull compensation in vehicles. Vehicle road test data indicate EPS can correct a severe vehicle steering wheel pull. Using fundamental physics equations, an analysis tool is derived to support further investigation of steering wheel angle misalignment and vehicle thrust angle. The final section presents a designed experiment revealing parameters most influencing vehicle robustness to chassis and road characteristics. The experiment results demonstrate tire plyrat, steer ratio, and rear tire cornering compliance are key vehicle design factors for steering angle misalignment and thrust angle.

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INTRODUCTION

Over the last several years, a significant percentage of OEM's (Original Equipment Manufacturer) have replaced Hydraulic Power Steering system with Electronic Power Steering (EPS) for their passenger vehicles. EPS provides many benefits including fuel economy, modularity, and development flexibility. A prime benefit is the ability to implement customer Value Added Features (VAF) into the EPS software. Customer VAF's can enhance driver safety, reduce vibration disturbances, and reduce driver workload.

EPS pull compensation is a VAF decreasing any steady state driver torque required to maintain a straight path. In four sections, this paper assesses the capability of EPS pull compensation to improve vehicle robustness to road slope, suspension alignment, and tire properties. The first section discusses the customer satisfaction impact of vehicle steering wheel pull. The second section provides a generic overview of how pull compensation algorithms work along with performance requirements. The third section derives the basic physics equations governing steering wheel angle misalignment and vehicle thrust angle. The consequent equations provide the basis for an analysis tool used for further investigative study. The final section illustrates a designed experiment to explore the performance robustness of a vehicle with pull compensation to road conditions and vehicle design parameters.

KEY DEFINITIONS

The following sections define fundamental terminology and concepts relevant to steering pull and misalignment behavior.

Vehicle Steering Wheel Pull

Vehicle steering wheel pull is a condition experienced by customers where a constant torque at the steering wheel is required to maintain a straight path. Uneven steering rack loads between left and right suspension produce vehicle steering pull torque. Specific causes include [1]:

- Suspension alignment asymmetry
- Mass asymmetry
- Tire Plyrat and Conicity
- Drivetrain output characteristics
- Road Slope

Steering Angle Misalignment

Steering wheel angle misalignment (SAM) is a non-zero steering wheel angle required to follow a straight path. Three factors can create misalignment: (1) The combination of vehicle steering wheel pull torque loading and torsional compliance in the steering system; (2) Asymmetry in suspension toe or camber settings; (3) Tire plysteer and conicity differences between vehicle corners [1].

Vehicle Thrust Angle

Vehicle thrust angle (VTA) is the angular orientation of the vehicle geometric centerline relative to a straight ahead heading angle, [Figure 1](#). VTA is colloquially referred to as “dog-tracking” [2]. A non-zero rear axle slip angle, β_r results in vehicle thrust angle. Rear axle slip angle when traveling on a straight path may be caused by tire force offsets, road slope, or axle misalignment.

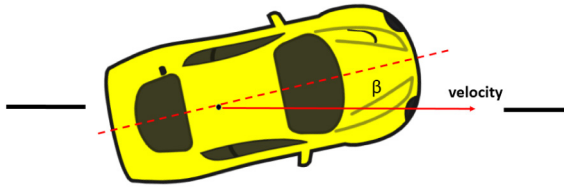


Figure 1. Vehicle thrust angle

Vehicle Pull and Misalignment

The combined three effects of steering wheel pull, steering wheel angle misalignment, and vehicle thrust angle are collectively referred to as vehicle pull and misalignment.

Tire Plysteer

Tire plysteer is a component of lateral force produced by a tire at zero slip angle. Plysteer force is a result of belt geometry and tread design asymmetry [2, 3].

Tire Plysteer Residual Aligning Torque “Plyrat”

The direct result of plysteer force, tire plyrat is a component of the aligning torque produced when lateral force output is zero. This aligning moment produces a torque at the steering wheel. Typically, OEM's designate a target value for tire plyrat intended to counteract the prevailing effects of road slope in the region of sale. Tire manufacturers can tightly control plyrat for a production run of tires [2].

IMPACT OF VEHICLE PULL ON THE CUSTOMER

Vehicle pull and misalignment directly impacts the customer. Engineering performance can be related to customer satisfaction using the Kano model for customer value, [Figure 2](#). The Kano model classifies product attributes into three categories based on their capacity to satisfy or dissatisfy a customer:

1. **Basic Needs** - the qualities all customers expect from a product. If these requirements are not satisfied, the customer will be very dissatisfied or will not even consider a product purchase. Exceeding customer expectations for these qualities offers minimal impact on customer satisfaction.
2. **Performance** - these qualities provide a proportional increase in customer satisfaction as product function improves.
3. **Exciters** - the qualities the customer may not expect or even imagine as possible. Increasing exciting quality provides an exponential increase in customer satisfaction.

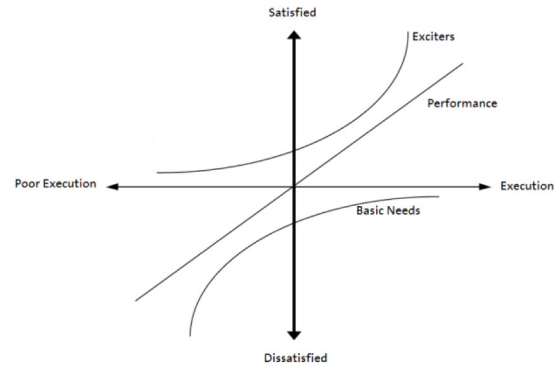


Figure 2. Kano Model of Customer Satisfaction

Vehicle pull and misalignment falls into the category of Basic Needs. Customers expect a vehicle will track straight and be free of pull on a straight road. Excessive vehicle steering wheel pull can be tiring during long drives and typically people associate SAM and VTA with a vehicle defect needing repair. A previous OEM sponsored customer clinic study helps quantify the loss function between vehicle steering wheel pull torque and customer dissatisfaction. [Figure 3](#) shows a clinic response distribution of novice drivers to varying levels of steering wheel pull torque.

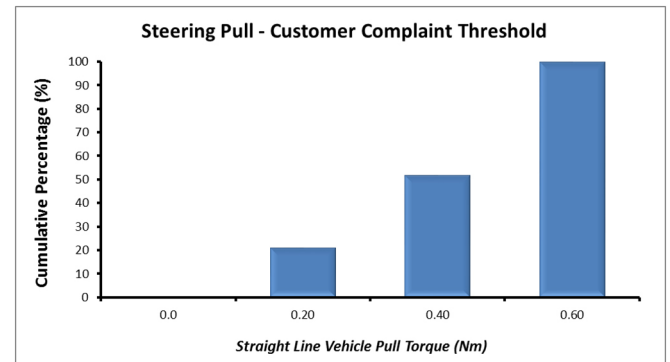


Figure 3. Customer Clinic: Vehicle pull torque vs. customer complaint level

This data clearly shows a relationship between increased steering wheel pull values and customer complaint likelihood. In Reference [1] Padilla explored in detail the relationship between vehicle pull tendency and OEM warranty performance.

EPS PULL COMPENSATION

Advantages of Pull Compensation

As discussed previously, many factors can induce vehicle pull and steering wheel misalignment. Road slope or steady state crosswinds are potential external factors beyond control. Internal factors such as variation in tire plyrat and conicity can be controlled in production, but enterprise costs increase correspondingly with tolerancing requirements on components and assemblies. Extremely tight alignment (caster, camber, toe, etc.) specifications increase vehicle assembly cycle time and reduce manufacturing throughput. The design principles improving vehicle robustness to vehicle pull sometimes conflict with steering feel goals or design constraints.