

Tuning Dampers for Ride and Handling of Production Vehicles

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ABSTRACT

The goal of this paper is to discuss the critical aspects of damper tuning for production vehicles. These aspects include ride and handling performance attributes, damper basics, conflicts in achieving desirable results, tuning philosophies, and the influence of the damper design.

The marketplace has become increasingly competitive. Customer preference, cost, mass and regulatory pressures often conflict. Yet each year more vehicles are required to do all these things well. Damper tuning can play a significant role in resolving these conflicts.

Although many papers have been written on the theory behind damper design and capabilities, there has been very little written about the techniques of tuning dampers for production vehicles.

This paper attempts to discuss the critical aspects of damper tuning for production vehicles in four sections. The first section discusses the performance attributes of ride and handling. The second section provides a basic understanding of dampers. The third section discusses some of the conflicts in achieving performance results that will please a broad band of customers. Finally the fourth section discusses the design and tuning enablers to overcome these inherent conflicts.

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INTRODUCTION

The technical emphasis of this paper is on the effects of damper tuning on vehicle dynamics (ride and handling). Most of the information presented in this paper is original work and has been learned through experiences gathered over decades of production vehicle chassis tuning. Vehicle dynamics is one of many attributes that drive customer purchase decisions. The ride and handling performance of a vehicle can significantly enhance or diminish the customer experience.

Damper tuning is a very powerful tool for the vehicle chassis development engineer to affect ride and handling performance. Damper tuning alone can transform a vehicle from mediocre to acceptable to better. A vehicle with an excellent suspension design can still behave poorly for ride and handling performance with poor damper tuning. Conversely a vehicle with a weak suspension design can have surprisingly good performance with well-tuned dampers.

Traditionally, dampers are viewed as a means to provide control of body motions in pitch, heave, and roll, as well as wheel control. Increased body control does not necessarily ensure good handling nor does minimal control ensure good ride. So what defines good handling and good ride and how can dampers be tuned to optimize both?

SECTION 1. PERFORMANCE ATTRIBUTES

There are many differing opinions on what attributes make a good ride and handling vehicle with regard to tuning dampers. Customer preference as well as driving style can affect the priority of the attributes. Many customers desire a relaxed, comfortable vehicle that provides isolation from road roughness. Others are much more sport-minded and desire a very crisp and connected driving experience. In both cases, confidence in the vehicle is always a requisite. However, what provides that confidence may vary from attention to yaw, lateral and roll motions to a focus on heave and pitch motions.

Handling Attributes Impacted by Dampers

The experience/opinion of the authors is that the handling performance attributes affected by damper tuning that are most appreciated by customers during routine driving are agility, stability, dynamic roll control, fluid body motion control and normal force tire loading. These attributes are discussed in greater detail by Badiru and Neal in Reference 1.

Routine handling is meant to identify the operating regime where most customers spend their time driving. GM defines routine handling as events below 80 mph and less than 0.3 g lateral acceleration, see Figure 1.

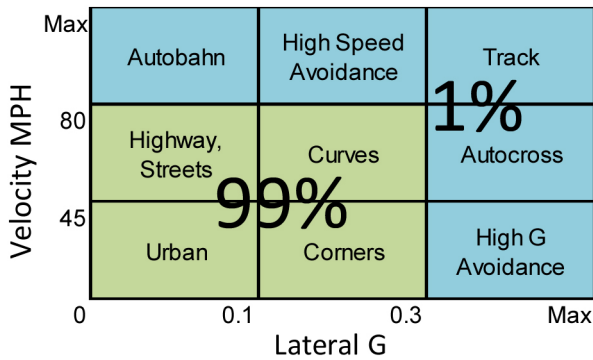


Figure 1. Customer exposure to vehicle velocity and lateral acceleration.

Agility (Response Delay)

Agility is defined as minimum sideslip overshoot (the difference between the heading angle and the road wheel angle) at the front axle during transient steer inputs. This is not a reference to steering sensitivity, but instead an assessment of the directness of the vehicle response to a quick steering input. The magnitude and speed of the input can vary from very small to quite large. Biasing the damper roll control to the rear axle will trade stability for agility.

Stability

Stability is defined as minimum sideslip overshoot (the difference between the heading angle and the vehicle center line) at the rear axle during transient steer inputs. Again the emphasis is not limit performance but routine handling. Feeling lateral compliance at the rear axle with a quick transient steer input, particularly at highway speeds, describes a lack of routine stability. Biasing the damper roll control to the front axle will trade agility for stability. Although there are tuning parameters that will improve both agility and stability, damper tuning typically causes one to be traded for the other.

Dynamic Roll Control

Dynamic roll control quantifies transient roll angle response characteristics and can be gaged by the magnitude and phasing of roll velocity relative to chassis yaw and lateral response. Dynamic roll control is important during transient maneuvers but not just for the confidence that it brings. Damper forces controlling the body are reacted at the tires and can have a significant impact on agility and stability by affecting the tire normal loading.

Fluid Body Motion Control

Fluid body motion control with regard to damper tuning is vehicle body motion that heaves, rolls and pitches smoothly during reversals without abruptness. Abrupt motions, although well controlled, do not inspire driver confidence. And since the vertical loads are reacted through the tires, abrupt body motions negatively affect handling due to the effect on tire contact patch load variation.

Normal Force Tire Loading

Controlling normal load variation at the contact patch over rough surfaces is another primary goal of damper tuning. Variation in tire normal loads reduces the tire's capability to provide tractive and lateral force. This lost capability will impact vehicle agility and stability behavior, ultimately degrading driver confidence.

Ride Attributes Impacted by Dampers

At the customer level, ride performance can be broken down into the following attributes: body motion smoothness, body motion control, coarse road isolation, impact hardness, shake, and end-of-travel performance. All are strongly influenced by damper tuning. Badiru and Cwycyshyn described these attributes in detail in Reference 2. The experience/opinion of the authors is that the motion attributes take precedence; the main purpose of the dampers is to provide control of primary motions (heave, roll, and pitch) and secondary motions (hop and tramp suspension modes). Damper tuning has a strong influence on the other attributes, but the balance between body motion smoothness and control is usually not compromised to improve performance of these.

Body Motion Smoothness

This performance aspect is the same as fluid body motion control introduced in the last section, with the emphasis shifted to ride comfort. Smoothness is a desirable characteristic of body heave motion, assessed primarily at the front and rear ride frequencies of the suspension (typically 1.1-1.6 Hz) [4]. Undesirable body motion can also occur in the 3-5 Hz range, the causes of which can be understood with a simplified two degree-of-freedom suspension model, see Figure 2. There are two springs in series, with the damper across only the suspension spring. If the damping forces are relatively low, there are two natural frequencies, body heave (approx. 1.3 Hz) and suspension hop (approx. 12 Hz) [4]. If the damping levels are set too high through aggressive tuning, the suspension spring becomes grounded out to a degree, producing a new mode of both masses moving in-phase, bouncing on the tire spring at approx. 3-5 Hz. Many terms are used to describe this uncomfortable motion, including "stiff-legged" and "choppy". Lack of smoothness is associated with body motions in this stiff-legged frequency range; smooth motions will have minimal content here.

Additional elements of motion smoothness include vehicle pitch, roll ("head-toss"), and rebound-to-compression balance issues (quick suspension reversals and abruptness). Although pitch is strongly influenced by front-to-rear ride frequency balance and by jounce bumper selection, it is also affected by damper tuning. Most objectionable head-toss can be minimized through careful balancing of suspension forces (rebound to compression), discussed in Sec. 4.

Motion smoothness is primarily used in reference to normal non-severe events where the majority of customer miles are accumulated, from parking lots and urban streets to well-maintained secondary roads and freeways. In summary, smooth relaxed motions have the following characteristics: occur at ride frequency with minimal content at 3-5 Hz; free of excessive pitch and roll motions; and free of quick abrupt suspension reversals, see Figure 3.

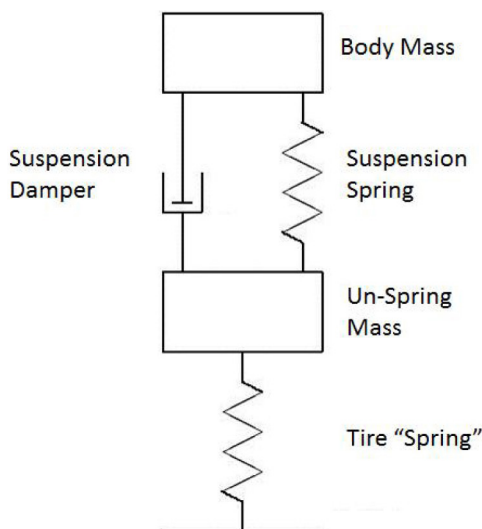


Figure 2. Suspension spring mass schematic

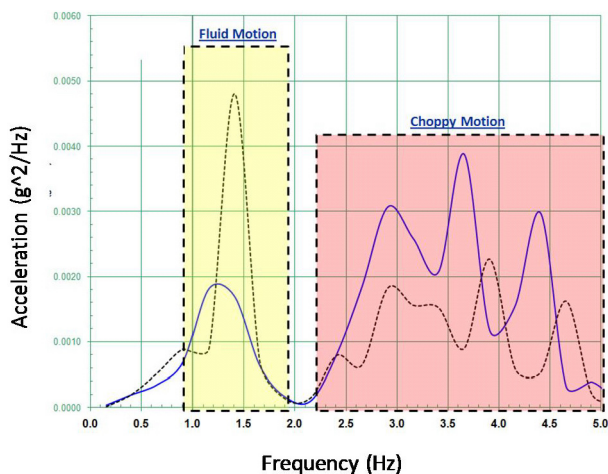


Figure 3. PSD of 2 damping tunings

Body Motion Control

Motion control is assessed on more severely undulating surfaces taken at higher vehicle speeds (poorly maintained secondary roads, railroad crossings, etc.). Good control occurs when these events can be traversed with minimal body acceleration and no oscillation at ride frequency. Good control is usually not achieved by having too-high damping levels. If the damping forces are set too high, the vehicle follows the road excessively, and the absolute body motion is large even though the motion relative to ground is small.

For body motion character (whether smoothness or control), the consequences of over-control have been pointed out (choppy motions and road-follow). Under-control for either attribute also produces consequences (float, oscillation, crash-through, and top-out). There is an optimum range of suspension damping that produces motion that is fluid and hydraulic, damped but not over-damped. This hydraulic quality is produced by different levels of damping force for different events. The amount of damper control necessary to produce hydraulic feel on a poorly maintained secondary road at 80 mph would be too high for hydraulic feel when driving on a city street at 25 mph.

An implication is that motion smoothness and motion control are inversely related, see Figure 4. There is a correct balance of these attributes for each application (vehicle type and/or market segment).

With sportier tunes, smoothness is acceptably degraded to achieve increased control; it is viewed as evidence that the vehicle feels capable. Motion smoothness and control are optimized primarily by adjusting the low- and mid-speed circuits within the dampers.

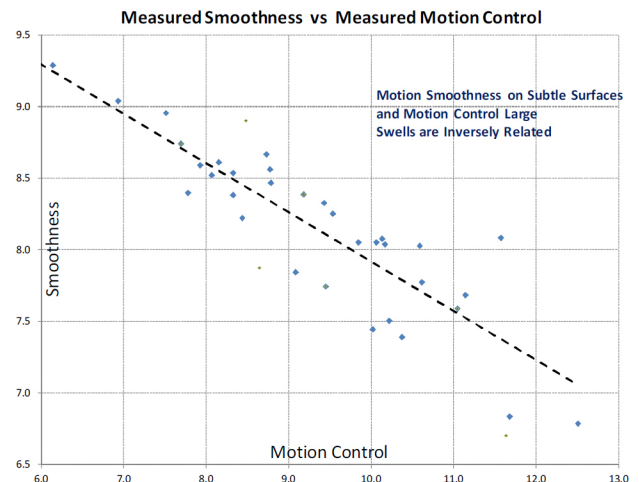


Figure 4. A variety of production vehicles plotted for Smoothness and Control

End of Travel

End of travel performance for suspensions is determined equally by damper tuning (especially the high-speed circuits) and jounce bumper tuning (and auxiliary rebound springs if so equipped). As the end of travel is encountered during severe events, it is desirable to avoid a sharp or abrupt quality (for structural stress containment and customer acceptance). Over-reliance on the dampers for end of travel performance can have negative consequences for harshness and isolation, which are associated with these circuits.

Coarse Road Isolation and Impact Hardness

Coarse road disturbance is associated with continuous small amplitude high frequency road content, usually in the 25-50 Hz, where most of the body structure flexure modes reside. It is influenced by damper tuning (especially the low- and high-speed circuits) and by damper friction levels.

Impact hardness is body response to discrete pavement disturbances such as frost heaves. The mid- speed damper circuits affect this while also being the primary component tuned for control of large body motions. At a given level of motion control, impact hardness can be minimized through careful rebound to compression balancing, discussed further below.

Shake

Shake (mostly 12-14 Hz) is divided into two broad categories, "loose" and "forced". Loose shake is usually associated with rigid-body modes of the suspension and powertrain, or flexure modes of the body. With regard to damper tuning, loose shake is caused by