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Benchmarking of Market Competitor Vehicles for Vehicle Dynamics Target Setting

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ABSTRACT

In this study, the importance of benchmarking competitor cars in the process of developing a new vehicle is explained in Vehicle Dynamics point of view. In order to evaluate the performance characteristics of the competitor vehicles, subjective evaluation and objective testing methods are used. Based on these evaluations, targets are set for certain sub-attributes for the design. Some of the most important objective testing procedures, namely Constant Radius Cornering, Ramp Steer Cornering, Frequency Response and Ride Comfort tests, used for obtaining various vehicle dynamics metrics are explained in detail.

Keywords: vehicle dynamics, benchmarking, constant radius cornering, ramp steer cornering, frequency response, ride comfort

ÖZET

Bu çalışmada, yeni bir araç projesinin taşıt dinamiği açısından geliştirme çalışmalarında rakip araçların karşılaştırmalı değerlendirilmesinin önemine değinilmiştir. Rakip araçların çeşitli açılardan performanslarının değerlendirilmesi amacıyla subjektif ve objektif değerlendirme yöntemleri kullanılmıştır. Bu değerlendirmelerden yola çıkarak da belli başlı performans kriterlerine hedefler konulmuştur. Başlıca objektif test prosedürlerinden olan Sabit Yarıçapta Dönüş, Artan Direksiyon Açısıyla Dönüş, Frekans Cevabı ve Sürüş Konforu testlerinin taşıt dinamiği ölçütlerini elde etmekte nasıl kullanıldığı ayrıntısıyla anlatılmıştır.

Anahtar kelimeler: taşıt dinamiği, sıra işaretleme, sabit yarıçapta dönüş, artan direksiyon açısıyla dönüş, frekans cevabı, sürüş konforu

1. INTRODUCTION

Benchmarking is a vital process for any industrial application. Both for marketing and engineering purposes, it is important to have a solid background concerning the state of the market competitors. Vehicle dynamics is not an exception in this respect.

Through benchmarking, a company can set its targets using the current state of the market as a reference. Benchmarking not only helps to determine the lower limits of certain aspects of a new design, but it also prevents the company from setting unrealistic targets. Thus excess effort and resources can be saved that would have been spent for an overdesign [1, 2].

1.1. Criteria for Selecting Competitors

The first step of benchmarking is the selection of competitor set. In order to properly determine these vehicles, one must take the following criteria into account.

- Weight distribution
- Chassis layout
- Dimensions (wheelbase, track width, height)

Also, primary competitors in the same market segment can be added to the set without taking the above properties into account.

A competitor set should be composed of vehicles with unique features in the aspect of dynamics. By choosing the vehicles which succeeded on different aspects, the benchmark process can generate more realistic vision for assessing the state of current design.

1.2. Target Setting

Target setting process is a statistical approach. As with all statistical procedures having as many samples as possible is favorable, however, if the set of competitors are selected properly as mentioned before, then the number of vehicles in the set can be reduced to a feasible count.

The preliminary step of target setting is to determine the intended level of major aspects of the product. These major aspects can be classified as "Ride", "Handling", "Steering" and "Braking" for Vehicle Dynamics purposes. These initial decisions are based on the surveys conducted by the marketing department of a company.

One cannot directly measure or manipulate a major aspect of the vehicle, rather these major aspects are divided into sub-attributes that can be evaluated subjectively and measured objectively.

These sub-attributes are used in the process of comparison of benchmark competitors and setting the engineering targets. While setting an individual sub-attribute, the decisions of marketing department are taken into account. As a result, these sub-attributes combine to form the overall major aspect of the product [2].

2. VEHICLE DYNAMICS TESTING OF BENCHMARK COMPETITORS

Evaluating a vehicle's dynamical behavior involves testing it subjectively and objectively. Subjective evaluation is primarily conducted to grade the quality of vehicle response to either inputs of the driver or the inputs from the road. However, subjective evaluation is a customer oriented procedure, and can only asses the quality roughly. These assessments are not adequate as an input to engineering development. Therefore, they need to be supported by measurements acquired from objective tests which are more repeatable and thus, reliable.

In the literature, there are a number of standardized, generally accepted objective vehicle dynamics testing procedures. Each of these procedures, has been developed with the purpose of revealing certain metrics that indicate the characteristics of the vehicle.

Constant Radius Cornering (CRC), Ramp Steer Cornering (RSC), Frequency Response (FR) and Ride Comfort tests can be counted among the most important objective Vehicle Dynamics tests [3 - 5].

2.1. Constant Radius Cornering

As the name implies, this test is a steady-state circular turning maneuver with increasing speed and thus increasing lateral acceleration. The most important relation obtained from this test is the required steering wheel angle as a function of lateral acceleration. In **Figure 1**, the curves represent this relation for three different vehicles. The increasing trend of the curves indicate that these cars are understeering, i.e. as the vehicle's lateral acceleration increases the amount of corrections required at the steering wheel also increases. The slope of these curves, known as "understeer gradient", can be directly used in the comparison of different vehicles' steady-state cornering performance.

Racelogic's VBOX data acquisition equipment is used for this measurement. Two channels including the signal from the steering wheel angle sensor and the IMU device measuring the lateral acceleration form this curve. Due to the steady state nature of this test, the signals are passed through a low-pass filter with a cut-off frequency as low as 1 Hz.

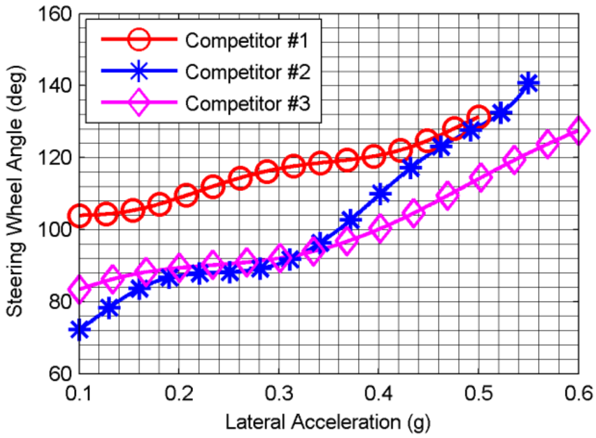

Figure 1 Steering Wheel Angle vs. Lateral Acceleration Plot in CRC Tests.

2.2. Ramp Steer Cornering

As previously mentioned, in Constant Radius Cornering tests the radius of cornering is held constant and the lateral acceleration on the vehicle is controlled through varying its speed. However, in Ramp Steer Cornering tests, the speed of the vehicle is not changed and using a gradually increasing steering input, a lateral acceleration build up is generated. Although, this test is quite similar to the CRC test in terms of the metrics obtained, it has several advantages. One is the possibility of measuring the steering wheel torque more accurately, due to the fact that during the maneuver the steering wheel is rotated in one direction unlike the CRC test, in which small steering wheel corrections are required in both directions. Thus hysteretic scatters in the steering wheel torque measurements occur.

Another advantage of RSC test compared to the CRC is that electronic stabilizing systems, such as air suspension leveling system, do not affect the actual vehicle behavior.

The Steering Wheel Angle vs. Lateral Acceleration curves obtained from the RSC tests are given in **Figure 2**, this is the same relation obtained from the CRC tests as shown in **Figure 1**. Note that, in RSC tests it was possible to cover the entire lateral acceleration range of the vehicle while in CRC tests the behavior of the vehicle does not show a repeatable trend at low lateral acceleration values. Moreover, repetitive corrections needed in CRC tests disturb the smoothness of the curve.

In our benchmarking processes both CRC and RSC tests are conducted and metrics obtained from this test are used to evaluate and compare steady-state handling capabilities of the competitor cars.

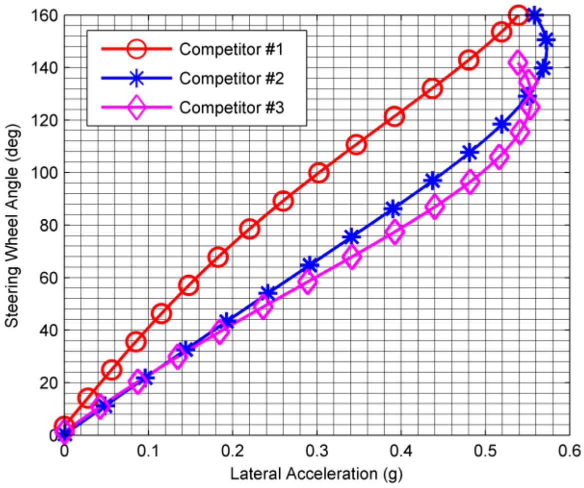

Figure 2 Steering Wheel Angle vs. Lateral Acceleration Plot in RSC Tests.

2.3. Frequency Response

A vehicle's response to driver inputs vary with speed of application of the input. In other words, its behavior is frequency dependent. As every suspended system, the steering response of a vehicle has several natural frequencies. Every flexible member of a suspension and steering system together with the inertial properties of the car determine these natural frequencies [4, 6].

The body motions that can be excited with the steering input are primarily the body's roll and yaw motions. Thus, these two natural modes directly affect the steady-state and transient cornering performances of the vehicle.

In order to accurately reveal the frequency dependent response characteristics of the vehicle, a test called Frequency Response is conducted. A sinusoidal steering input with a swept frequency is applied while the velocity is kept constant.

From the results of this test, one can compute the frequency responses of the yaw and roll gains as every single DOF damped system, each of these gains gradually increase towards the resonant frequency and then tends to decrease gradually until vehicle does not respond to steering wheel inputs.

The designer generally faces a number of trade-offs regarding to these frequency response characteristics, such as responsiveness, comfort, sportiness and handling. For relatively heavier vehicles the natural frequency values are generally lower. Therefore, it is important to objectively discover these characteristics of the competitor cars through several standardized metrics, such as peak yaw and roll gain frequencies and magnitudes, peak to steady-state yaw and roll gain ratios.

These metrics are measured using an IMU sensor coupled with a steering wheel angle sensor.

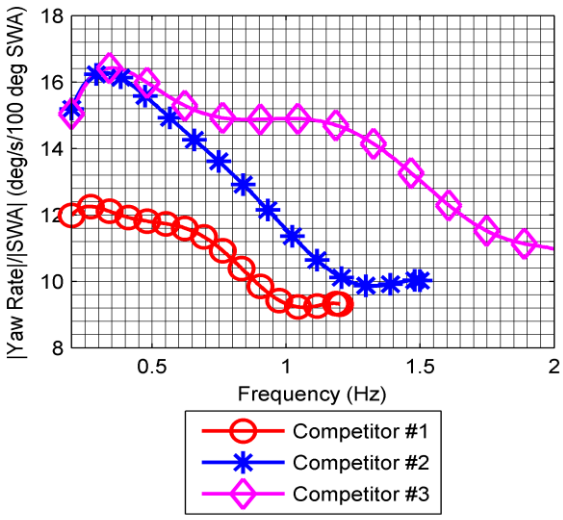

Figure 3 Yaw Gain Response Plot Obtained from Frequency Response Tests

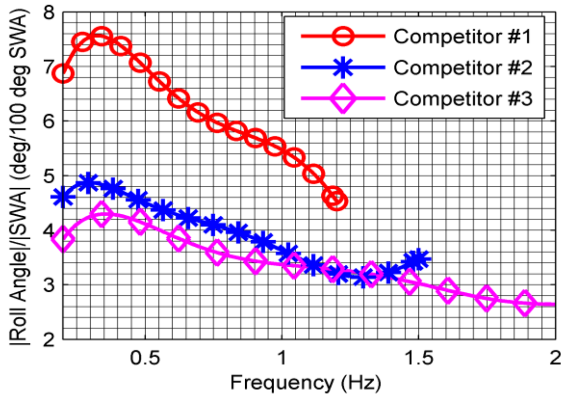

Figure 4 Roll Gain Response Plot Obtained from Frequency Response Tests

In terms of conducting and post-processing this test, there is a major issue. During the test, in order to excite the vehicle, the driver has to vary the steering input frequency with a fairly good resolution. In practice, this may not be the fact, hence, if a basic Digital Fourier Transform (DFT) is applied to the results, the resulting response spectrum becomes as if the vehicle does not responds at the frequencies where actually the excitation is not applied. This problem prevent proper interpretation of the results. In order to overcome this problem, a different methodology for extracting the frequency dependent behavior of the vehicles is developed. In this new method, the period of each steering wheel input cycle is calculated one-by-one by automatically detecting the zero-crossings of the signals. After identifying individual input cycles, the ratios between amplitude of the corresponding output signal and the amplitude input signal are calculated as the gain of the system at the frequencies of each particular input cycle. Therefore, as set of system gain vs. frequency data points are obtained. Then, using a proper curve-fit tool this problem caused by missing excitation frequencies are eliminated. This enables the determination of the frequency response of the system accurately as shown in **Figure 3** and **Figure 4**.

2.4. Ride Comfort Test

Undoubtedly, the ride comfort of a vehicle is among the most important characteristics. Therefore, with the purpose of having a comparison between competitor cars, a series of objective ride comfort tests are undertaken. In these tests, realizing driving conditions similar to daily customer usage is crucial.

In the objective comfort tests, the most important data is the vertical acceleration obtained at the rails of certain seat rows or on the seat cushions. The overall acceleration level at these locations indicate the amount of vibration exposure to the occupants in the vehicle. Obviously, the less the level of vibration transmitted to the occupants, the better the ride comfort is achieved. Although the magnitude of accelerations is a good indicator of the comfort, in its plain form it is not the best metric of comparing the occupant comfort. To convert the raw acceleration data into a more meaningful comfort metric a frequency-domain post-processing method is proposed in ISO 2631 standard [7].

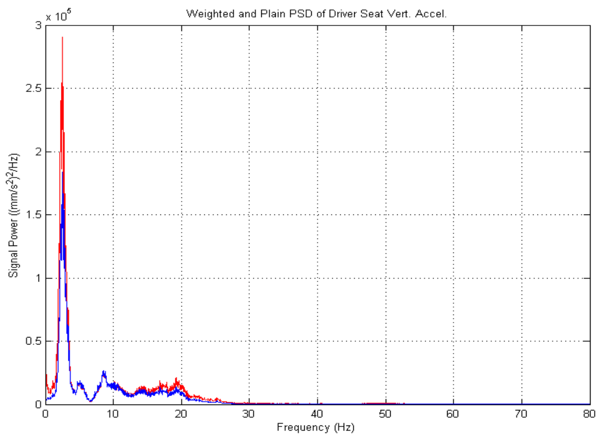

Figure 5 Weighted and Raw Driver Seat Vertical Acceleration PSD Curves Obtained from Ride Comfort Tests

In this standard, the effect of different frequency ranges on the human perception of comfort is discussed based on physiological studies and a frequency-dependent weighting function is given. When the Power-Spectral-Density curve of the raw seat-track acceleration data is scaled according to this weighting function and the area under this new curve is calculated, a single metric indicating the ride comfort of the vehicle is obtained. In **Figure 5** the PSD curve obtained from the driver seat vertical acceleration data obtained from the Ride Comfort test of one of the benchmark vehicles and its weighted form are plotted.

3. CONCLUSION

In the design phase of a new vehicle, the results obtained from the benchmark tests are the main references for a vehicle dynamics development. Without having a proper benchmarking result, targets set by the designer may either be too conservative or unachievable.

Subjective evaluation has the benefit of providing the developer the amount of progress needed to achieve the defined targets. These targets can be met by many ways while the engineering department seeks the most efficient solution. In order to meet these targets, the designer utilizes the results obtained from the objective measurements. In this study, some of the major objective vehicle dynamics test procedures and how they are used for the purpose of comparing the benchmark vehicles and setting targets are explained.

In advance to benchmarking, the design steps involve preparing the virtual model of the design, iteratively correlating the model through testing of actual prototypes and eventually improving the design to satisfy the corporate targets.

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