

Correlation of Subjective and Objective on Centre Steering Feel

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ABSTRACT

要 旨

Previous studies have described a new analysis technique for objective measurements of passenger car steering systems carried out using the ISO standards. This analysis technique is based on deriving linearised stiffness and damping, which are objective metrics, from the non-linear results typically obtained for vehicles.

In this paper, the previous work is extended by carrying out a more comprehensive study of the correlation between these objective metrics and driver subjective assessments using a wide range of vehicles.

It is concluded that subjective assessments of on centre steering effort level, response level, friction and delay correlate well in many cases with the proposed objective metrics.

これまでの研究では、ISO 国際標準規格に基づいて実施した乗用車の走行試験における、ステアリングシステムの特性に関しての新たな解析手法について述べた。この解析手法は、車両が示す非線形特性を等価な剛性及び減衰に置き換え、客観的評価指標として用いている。

本論文では、さまざまなカテゴリーの車両を用いて、これらの客観的評価指標とドライバーによる主観的評価との間の相関性についての、より広範囲での研究を実行することにより、これまでの研究の有効性を検証した。

オンセンター操舵力レベル、応答レベル、フリクション、及び遅れに関しての主観的評価結果は、多くの場合、提案した客観的評価指標と関連していることが認められた。

1. Introduction

Due to the common use of multi-lane, relatively straight, high speed roads (Autobahns, Motorways, etc.) the response of passenger cars to small angular inputs made by the driver is important. These small angular inputs (up to ± 20 deg at the hand wheel) are known as on centre steering feel.

In the past, on centre steering feel has been judged subjectively using expert drivers and some attempts have been made to objectively quantify the vehicle's response for a given condition of steering input speed and amplitude^{(3), (4)}. However in real situations these conditions vary considerably along with the dynamic response of the vehicle, especially steering torque which is strongly non-linear with changing steering input speed (frequency) and amplitude.

Recently a measurement technique was developed^{(1), (2)} which quantified on centre steering feel objectively and in a concise manner, as steering input frequency and amplitude is varied. These papers^{(1), (2)} detail the use of simple comparison studies with subjective evaluations to show that the objective measurement technique gave a good representation of driver subjective judgement.

This paper details a continuation of the research, where a more comprehensive study of the validity of the technique was undertaken using a wide range of passenger cars. To achieve this, a number of different vehicles were assessed subjectively by an expert driver on public roads and have been measured using the objective technique on a test track. Finally a detailed correlation between the objective and subjective results to ascertain the accuracy of the objective measurement technique in characterising the on centre steering feel of passenger cars is given.

2. Application of the Objective Technique

The objective measurement technique needed to be implemented in an efficient and portable manner to enable rapid testing of multiple vehicles. This involved the development of suitable instrumentation and software algorithms to not only acquire the data, but also to post process and display the results. All the testing and data processing was done to ISO136704-1:2003(E)⁽⁴⁾ standard to help achieve good repeatability of results.

The vehicle was equipped with: an instrumented clamp-on steering wheel to measure angle and torque; a

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gyro to measure yaw velocity at the centre of gravity and a GPS speed sensor to give an accurate indication of forward velocity. Data acquisition equipment was used in conjunction with a laptop to convert the analogue signals into digital data which was scaled, filtered, displayed and saved to the hard disc as ASCII files. Whilst trying to replicate each sine wave at each required frequency and amplitude, the driver was given audio and visual cues from the data acquisition software to produce accurate steering input.

The post processing stage was split into two halves, the creation of the steering hysteresis loops and then the parameter derivation. To attain the hysteresis loops, the continuous time history data was manually searched for the set of waveforms which matched the required waveform the closest. To allow an average to be made from the results, at least three continuous waveforms were found and then used to give the steering hysteresis loops, see Fig. 1.

The second stage involves using software algorithms which apply the “analytical method of equivalent linear system using the restoring force model of power function type”^{(1), (2)} to derive a set of parameters from these steering hysteresis loops. The exact generation of the parameters is given in detail in⁽²⁾, but can be briefly explained as calculating the equivalent spring stiffness K and damping coefficients C for an equivalent non-linear system. The derived K and C objective metrics are linearised metrics obtained from the non-linear steering hysteresis loop data and hence, they are functions of steering amplitude and steering speed.

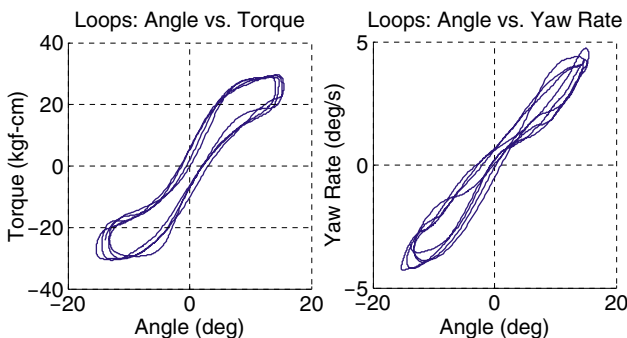


Fig. 1 Data processing stage 1: Steering hysteresis loops

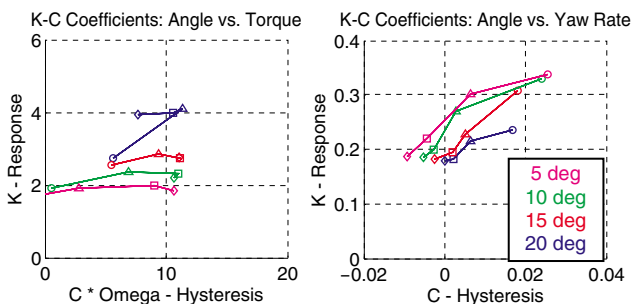


Fig. 2 Data processing stage 2: Steering characteristic parameters at various steering frequencies and amplitudes for a single vehicle

This is done for each waveform in the time history, which are then averaged together to generate four parameters for each steering frequency and amplitude (K_t , C_t – from steer torque versus angle data and K_y , C_y – from yaw rate versus angle data). Figure 2 shows how, for a single vehicle, these parameters vary with steering frequency and amplitude. Each coloured line is at constant steering amplitude and indicates a speed change from 0.25 to 1 Hz.

3. Subjective Evaluation

The vehicles were evaluated for steering feel at motorway speeds whilst driving on public roads, using small steering displacements. This evaluation was also complemented by further assessment on the test track at the test speed (140km/h) to confirm any changes of behaviour with increasing speed. All the assessment was undertaken by an expert driver with six years experience and his results were also checked against the opinion of other industry experts.

The vehicles tested were split into four categories:

- Compact passenger (7 vehicles).
- Larger passenger (6 vehicles).
- SUV (3 vehicles).
- Sports (1 vehicle).

Although different perceived performances were expected from each of the categories of vehicle, an attempt was made to judge all the vehicles on the same scale.

The main subjective assessment criteria were:

Effort Level: Amount of steering effort required for a given steering input. Vehicles with higher steering efforts were given a higher score.

Response Level: Amount the vehicle reacts to a given steering input. Vehicles with a larger response to a given input were awarded a higher score.

Friction Feel: This was evaluated by the difference in torque between applying and removing lock, and the linearity of torque build-up for small inputs.

Delay: The time lag between steering input and torque build-up, and time lag between input and vehicle response.

4. Objective Tests

Objective testing was performed for all vehicles according to the test method proposed by Tokunaga et al.⁽¹⁾, which describes a series of sinusoidal steer tests at 140km/h, with steer amplitudes ranging from $\pm 5^\circ$ to $\pm 20^\circ$ and steer frequencies from 0.25 Hz to 1 Hz.

Analysis of the relationships between steering angle and steering torque, and between steering angle and yaw velocity is performed using the method described above⁽²⁾. For all steering tests K_t , C_t (from steer torque versus angle data) and K_y , C_y (from yaw rate versus angle data) was found. For the Torque versus Angle curves, the damping coefficient C_t is multiplied by the effective rotational velocity ω (referred to as omega), in order to evaluate the actual damping force.

4.1. Correlation between Objective Data and Subjective Assessment

For each of the subjective assessment criteria, an objective metric was selected from the range of tests performed on all the vehicles.

Many of the metrics were selected from the 0.25 Hz tests, as this frequency is the most typical of normal driver inputs⁽³⁾. The $\pm 20^\circ$ tests were chosen for all the metrics because of their lower sensitivity to road input and other outside disturbances.

Correlation studies could be shown between all test frequencies and amplitudes, but these single values are used here not only for the reasons given above but for conciseness.

Figures 3 to 8 show scatter plots between the relationships of the subjective data and objective metrics. In each case a linear least squares fit was made and the residual values calculated $R^{2(5)}$. The R^2 value gives an indication of the accuracy of the linear least squares fit and thus the linearity of the results and therefore correlation between the subjective and objective data. The R^2 value should be above 0.8 (80%) to show a good linear correlation.

4.2. Effort Level

This was correlated with the gain of the Torque vs. Angle K_t relationship at 0.25 Hz. – chosen because the torque gradient can change significantly due to delay characteristics at the higher frequencies.

Figure 3 shows a high level of correlation between the subjective assessment and the objective criteria.

4.3. Response Level

This was correlated with the gain of the Yaw velocity vs. Angle K_y relationship at 0.25 Hz. Again, this frequency was chosen because the response gradient changes due to delay characteristics at the higher frequencies.

Figure 4 shows there is a relationship between the data, although there is one vehicle that falls far from the linear fit (car A). This vehicle was the sole ‘Sports’

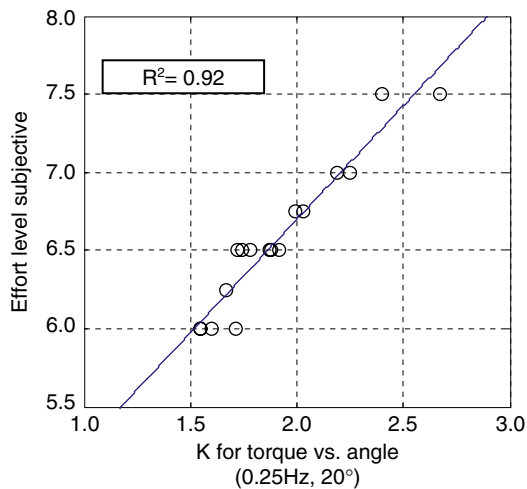


Fig. 3 Effort Level correlation

vehicle with subjectively a low yaw gain compared to its transient lateral acceleration build-up. This may have affected the subjective evaluation of yaw response. Otherwise, a good correlation is seen for non ‘Sports’ vehicles.

4.4. Friction Feel

This was correlated by the $C_t \cdot \omega$ value of the Torque versus Angle relationship at 0.25 Hz. The damping coefficient changes significantly with frequency due to steering delay and steering system damping effects.

In Fig. 5 there is a clear relationship between the subjective and measured data, although there is more scatter when the car is rated highly. It is expected that other effects (damping, delay) become more significant when friction levels are lower.

4.5. Delay

Delay was correlated with two metrics. Firstly, the delay in vehicle response, which is measured by the C_y value of the Yaw Velocity versus Angle relationship at

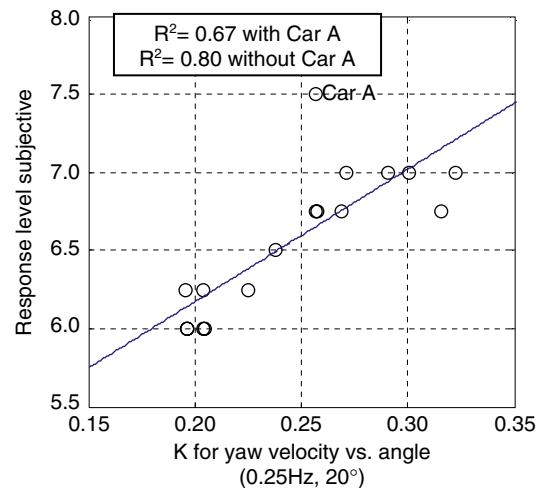


Fig. 4 Response Level correlation

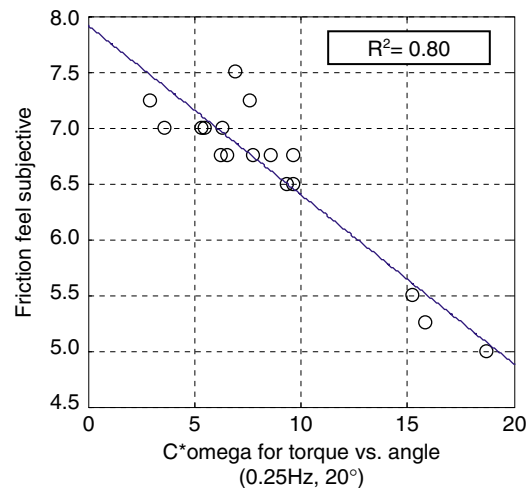


Fig. 5 Friction Feel correlation

1Hz⁽³⁾. This frequency is shown to give the highest value of delay for most vehicles.

Figure 6 shows no strong correlation between the data, although it does show a relationship between the subjective results and the measured data. Further study

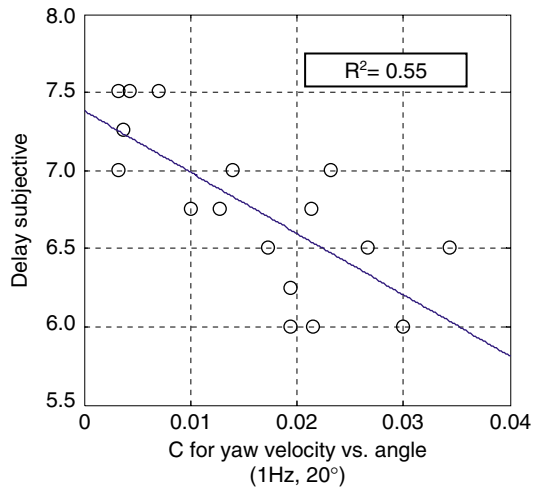


Fig. 6 Response Delay correlation

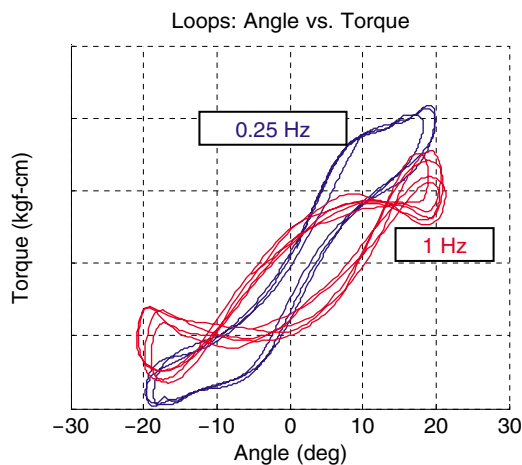


Fig. 7 Effect of increasing frequency on steering torque hysteresis

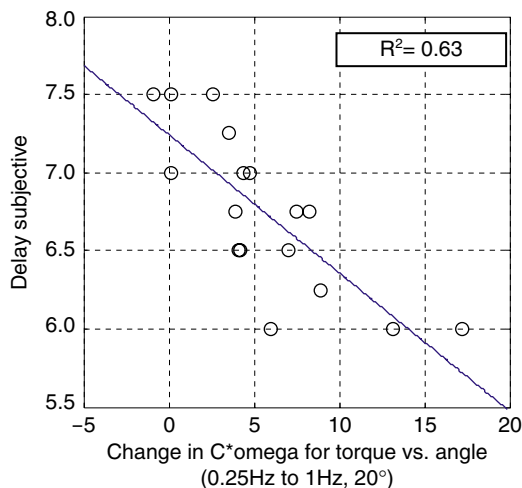


Fig. 8 Torque Delay correlation

did not produce a better correlation.

The second metric for delay was steering torque build-up delay, which is measured by the reduction in $C_y \cdot \omega$ values between 0.25 Hz and 1 Hz. A large reduction in damping values corresponds to a narrowing (or even a reversal) of the hysteresis band around the zero steering angle region due to increasing delay in steering torque build-up, see Fig. 7.

Finally, Fig. 8 shows no strong correlation between the data, although it does show a relationship between the subjective results and the measured data.

5. Conclusion

The paper has given details of an extensive subjective and objective study of vehicle steering feel.

These results have then been used to show that the objective metrics proposed by Tokunaga et al.⁽¹⁾ give significant correlation in several important areas of steering feel, namely Steering Effort and Response Level, Friction Feel and Delay, for a wide range of passenger vehicles.

References

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