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「競争力の源泉」としてのダイナミック・パフォーマンス

常務執行役員 長岡 宏

近年、自動車産業を取り巻く環境は、ますます厳しいものになっているように思われる。従来のコンパクトカーでの激しいシェア争いや、市場の拡大による更なる新興国市場、多様化への対応の一方で、電動化や自動運転をめぐる新規参入ブレイクを含めた技術競争などもあり、我々は世界中で常に激しい競争を強いられている。この競争に勝ち抜くために、結局“お客様に満足頂ける競争力のある車を投入しつづけること”を置いて他に道はない。さらに、競争力がその会社や車の“らしさ”に結びついていることが理想である。

そういう視点で、これまで日産自動車が世に送り出してきた車たちの中でも、特に競争力が高かったものを振り返ると、競争力にはいくつかの要因があるものの、基本性能、中でも走りの性能で、非常に高い競争力を持っていたことが、共通して言えるのではないかと考える。古くはP10型ブリオーラやR32型スカイライン、そしてキャッシュカシオンフィニティG35、GT-Rなどは、走りの性能がその“車らしさ”を特徴づけていたことも事実である。

さらに、昨今自動運転技術の車への搭載がますます加速しているが、自動運転技術を追求し、良い自動運転技術車を造ろうとすればするほど、搭載する車の持ち動く基本性能、特に走りの性能の高さが重要であるということが分かってきている。それは、自動運転であろうと、基本的な車の動きを、乗っている“人”が敏感に感じるからであり、そういう意味では、この走りの性能は、何時までも必要不可欠の技術領域であり続けるといえるであろう。

我々はこれまで、この走りの性能で、お客様に価値ある商品を提供すべく、様々な活動を実施してきた。1980年代には「90年までに世界一の運動性能を目指す」というプロジェクト901活動を実施し、先に述べたP10型ブリオーラをはじめR32型スカイラインなど数多くの名車を生み出した。1990年代には、901活動を通じて構築してきた考え方を「走りの理念」としてまとめ、「期待どおりにクルマが動く」、「期待に反した余計な動きがない」、「クルマから人へのインフォメーションがある」という一貫した価値を、多くの車種に展開してきた。2000年代に入ってからは、日産の技術が提供する4つのコアバリューのひとつとして、これまでの動性能にNVH性能を加えた車両性能全体を扱う“ダイナミック・パフォーマンス”を定義し、走りと快適性を高い次元で両立した、つまり運転していて楽しく、それでいてリラックスできる車造りに取り組んできた。

本号では、日産のダイナミック・パフォーマンスを特集し、その最新技術のいくつかを紹介する。競争の激化やお客様要求に対応した長年の技術の積み上げによって、非常に高いレベルの性能が提供できるようになってきていることを感じ取って頂きたいと思う。

「走りの理念」構築以来、一貫して変わらないこととして、その性能の中心はいつも“人”であるということである。それは、今後ますます普及していく電動化や自動運転時代においても変わることはない。“人”によって理想的な車造りを常に探求することによって、その基本性能であるダイナミック・パフォーマンスを発展させ、ひとりでも多くのお客様に日産ファンになって頂ける車造りができるよう、日々努力を継続していくことが重要である。
The environment surrounding the automotive industry seems to have become increasingly more severe in recent years. Share competition has been intensifying in traditional core markets, and efforts have been required to deal with emerging market and diversification due to the global market expansion. At the same time, technological competition has also increased, including the entry of new players in connection with electrification and autonomous driving. We are constantly forced to engage in fierce competition throughout the world. Ultimately, there is only one way to win this competition and that is “to continue to introduce competitive vehicles that satisfy customers.” Ideally, competitiveness should be linked to the distinct identity of a company’s vehicles.

From that perspective, let us look back on the vehicles that Nissan has put on the market to date, especially ones that have been highly competitive. While competitiveness involves a number of factors, I think we can probably say that a common element of those vehicles is that they have possessed exceptionally strong competitiveness in terms of fundamental performance and in particular driving performance. In fact, driving performance is what has distinguished the unique identity of such vehicles as the P10-series Primera and the R32-series Skyline in the past, as well as the Qashqai, INFINITI G35 and the GT-R, among others.

The adoption of autonomous driving technologies on vehicles has also been accelerating in recent years. It is known that the more autonomous driving technologies are pursued and efforts are made to build excellent autonomous vehicles, the more important it is for such vehicles to have high levels of fundamental performance, especially driving performance. The reason is that, whether a vehicle is self-driving or not, its basic motions are sensitively perceived by human occupants. In that sense, driving performance can be regarded as an absolutely essential technological domain that will never fade in importance.

We have pursued a wide variety of activities to date for the purpose of supplying customers with products embodying driving performance as an intrinsic value. In the 1980s, we undertook Project 901, a program of activities aimed at achieving the world’s best vehicle dynamics by 1990. This project spawned many famous models, including the P10-series Primera and the R32-series Skyline mentioned above. In the 1990s, the ideas formulated though the 901 activities were incorporated in our “philosophy of driving performance.” One idea is that the vehicle should move as expected. Another is that there should not be any unnecessary vehicle motion contrary to what is expected. And still another is that the vehicle conveys information to the driver. These values have been consistently incorporated in many Nissan vehicles since then. After entering the 2000s, we defined dynamic performance as one of the four core values provided by Nissan’s technologies and as a value that encompasses vehicle performance in its entirety. This resulted from adding noise, vibration and harshness (NVH) performance to the dynamic performance provided previously. We have endeavored to design and engineer Nissan vehicles that offer both driving performance and comfort at the highest possible levels. In other words, they are enjoyable to drive and also provide relaxing comfort.

The special feature of this issue focuses on the dynamic performance of Nissan vehicles and describes a number of our latest technologies for delivering this value. I hope that readers will feel the exceptionally high levels of dynamic performance of Nissan vehicles, which result from the accumulation of advanced technologies over many years in order to cope with intensifying competition and respond to the demands of our customers.

Since the formulation of our philosophy of driving performance, one thing that has consistently remained unchanged is that people are always the focus of that performance. This will not change even as electrification increasingly spreads in the coming years or in an age of autonomous driving. The continuous pursuit of automotive engineering that is ideal for people will work to extend the dynamic performance that constitutes one of the fundamental values of Nissan vehicles. It is essential that we continue our day-to-day efforts to build vehicles that get as many customers as possible to become Nissan fans.
日産が目指すダイナミック・パフォーマンス

Nissan’s Targeted Dynamic Performance

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1. はじめに

ここ10年の世界の自動車史を振り返ると、グローバル市場の拡大や韓国勢の躍進に加え、昨今では中国ブランドが進出しており、多様化が激化している（表1参照）。今後も自動運転技術や電気自動車の普及に伴いこの傾向は、更に加速すると考えられる。

この多様化する市場の中で、日産自動車が継続的に成長を続けていくためには、ユーザの需要に応えつつも自動車メーカとして分かりやすい性能を指し示すことが必要と考えている。本特集では、ダイナミック・パフォーマンス領域*に着目し、日産として目指すべき方向、及び共通性能を紹介する。（*：ハンドリング性能、乗り心地、快適性、加速性能、騒音、ブレーキ性能などのお客様の運転操作にかかわる性能を対象領域とする。）

また、本活動ではブランド力を表す指標としてOaO（Overall Opinion）を参考とした。OaOとはブランドに対するお客様の好意度を測る指標であり、OaOを高めることは、シェア拡大や企業を継続的に成長させることにつながる。

表-1 販売台数の推移と増加率（Global合計）
Table 1 Global sales volume and growth ratio

<table>
<thead>
<tr>
<th></th>
<th>2007</th>
<th>2017</th>
<th>% increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global unit sales</td>
<td>65,501</td>
<td>92,667</td>
<td>41%</td>
</tr>
<tr>
<td>Hyndai / Kia</td>
<td>3,339</td>
<td>6,872</td>
<td>106%</td>
</tr>
<tr>
<td>Great Wall（長城汽）</td>
<td>118</td>
<td>1,070</td>
<td>807%</td>
</tr>
<tr>
<td>Geely（吉利）</td>
<td>219</td>
<td>1,402</td>
<td>540%</td>
</tr>
<tr>
<td>Toyota</td>
<td>8,298</td>
<td>9,842</td>
<td>19%</td>
</tr>
<tr>
<td>Honda</td>
<td>3,684</td>
<td>5,266</td>
<td>43%</td>
</tr>
<tr>
<td>VW Group</td>
<td>5,940</td>
<td>10,250</td>
<td>73%</td>
</tr>
<tr>
<td>Renault / Nissan</td>
<td>5,304</td>
<td>8,781</td>
<td>66%</td>
</tr>
</tbody>
</table>

1. Introduction

A review of global automobile history during the last ten years shows greatly intensified diversification typified by the recent advances of Chinese brands, in addition to expansion of the global vehicle market and the rapid progress made by South Korean automakers (Table 1). It is presumed that diversification will accelerate further in the coming years accompanying the spread of electric vehicles and autonomous driving technologies.

Amid this ongoing market diversification, at Nissan, we think it necessary as an automaker to present easy-to-understand performance while responding to users’ demands in order to ensure the company’s continuous growth. This special feature focuses on the domain of dynamic performance and describes our targeted direction as well as common performance attributes. This domain includes performance attributes such as handling, ride quality, comfort, acceleration performance, noise, braking performance and other aspects related to users’ driving operations.

In our activities here we refer to Overall Opinion (OaO) as an index expressing brand strength. OaO is an indicator for gauging customers’ favorability rating of a brand. Enhancing OaO leads to increased market share and continuous corporate growth.

表-2 OaOに寄与する動性能関連上位5項目
Table 2 Top 5 dynamic performance-related items contributing to OaO

<table>
<thead>
<tr>
<th></th>
<th>EUR G5</th>
<th>USA</th>
<th>JPN</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Make good quality, responsible cars</td>
<td>Dependable</td>
<td>Provide secure feel</td>
<td></td>
</tr>
<tr>
<td>2 Provide an enjoyable ride for all passengers</td>
<td>Comfortable for the driver</td>
<td>Reliable</td>
<td></td>
</tr>
<tr>
<td>3 Make sure cars are responsive</td>
<td>Responsive handling</td>
<td>Make vehicles that provide driving pleasure</td>
<td></td>
</tr>
<tr>
<td>4 Make vehicles with good engine performance</td>
<td>Safe</td>
<td>Make highly safe vehicles</td>
<td></td>
</tr>
<tr>
<td>5 Make cars that are a pleasure to drive</td>
<td>Fun to drive</td>
<td>Make vehicles that excite people</td>
<td></td>
</tr>
</tbody>
</table>
2. Performance Development Premised on Secure Feel and Comfort

An axis expressing the targeted goal is necessary in order to determine the direction Nissan should aim for as well as common performance attributes. Table 2 shows the top five dynamic performance-related items contributing to OaO in Europe (G5), the U.S. and Japan, representing principal markets for sales of Nissan products. We can see that, regardless of the region, items concerning secure feel and comfort rank at the top as indicated by the yellow cells. In other words, secure feel and comfort are key common elements that are indispensable in global markets. Therefore, for a high-volume manufacturer like Nissan, it is essential to concentrate efforts on secure feel and comfort.

On the other hand, there is also the opinion that wants to add sporty elements like agile handling, depending on the vehicle model. In this case, there are elements that conflict with comfort, so there is much discussion about what kind of common performance attributes should be pursued. As mentioned above, because secure feel and comfort are key attributes desired by customers, sportiness should be added after these essential performance items have been secured.

Nissan develops various types of models, ranging from minivehicles, minivans and pickup trucks to sports cars, but we position secure feel and comfort as top priority elements.

3. Evaluation of Items Emphasized

Secure feel and comfort are general terms the meaning of which is ambiguous. It is necessary to have more
きがない”を参考に重要項目二つを選定した（図2）。 快適に関しては、音や振動現象が主になると考え、これらが最も求められる1項目を選定した。 一貫した製品を作り出すために、これらを目指としての共通性能“３プライオリティアイテム”とし、ここに注力した技術開発や製品開発を進めることとした。

4. ３プライオリティアイテム

本章では前述した三つのプライオリティアイテムを紹介する。

(1) 車線幅が狭い郊外路でも正確にハンドル操作できるので安心
　欧州の道路が狭い郊外路（図3）で対向車とすれ違うシーン（対向車との相対速度200km/h）において、主にハンドル操作の正確性が求められる。安心して走行できる車は無駄な操作が少ない。
　(2) 路面がうねった道でも車の動きが安定しているので乗員も安心

---

4. Three Priority Items

This section describes the three priority items that were mentioned in the previous section.

(1) Driver can easily follow the intended path

Precise steering action is especially required when passing an oncoming vehicle at a relative velocity with it of 200 km/h on narrow European country roads (Fig. 3). A vehicle that can be driven with secure feel is one that requires minimal steering correction.

(2) The occupants feel relaxed by vehicle motion and seats support

Vehicle motions must be comfortable and stable when traveling on irregular country road surfaces in Europe...
(3) 音や振動によって乗員が不快にならない
   • ひび割れた道路（図5）を通過した時、音や振動が車体に響かない“しっかり”とした車の造り（しっかり感）。
   • 高速道路での合流シーン（図6）などで加速しても、エンジンの音で乗員を不快にさせない。

5. まとめ

多様化する時代に置いて、お客様のニーズに合った性能の差別化が必要であり、今回日産が目指す方向、共通性能、及びプライオリティアイテムを定義した。本活動で開発した技術を新型車から順次採用している。本共通性能を醸成実現することで、より多くのお客様に喜んでいただけると考える。

(Fig. 4). Such vehicle behavior gives both the driver and passengers secure feel without any sensation of discomfort.
(3) The occupants are not disturbed by noise and vibration
   • Vehicles must be solidly built with a "solid structure feel" so that the body does not vibrate or produce noise when traveling over a cracked road surface (Fig. 5).
   • Engine sounds must not cause occupants any discomfort when accelerating to merge with expressway traffic (Fig. 6).

5. Conclusion

In this age of diversification, performance must be differentiated so as to meet customer needs. This article has defined the direction, common attributes and priority items targeted for the dynamic performance of Nissan vehicles. The technologies developed through these activities are being adopted on new vehicle models in turn. It is envisioned that incorporating these common performance attributes in our new products will give enhanced driving pleasure to larger numbers of customers.

著者／Author(s)

| Tomoyuki Ousei | Hiroshi Mimura |

日産技報 No. 83 (2018–10) 6
1. Introduction

This article focuses on one of the three priority items described in the keynote article entitled “Nissan’s Targeted Dynamic Performance.” This item concerns “Driver can easily follow the intended path.” The details of several specific technologies that have been developed to facilitate this performance are described here.

The targeted vehicle performance is intended to enable drivers to operate their vehicles as they wish with a secure feel even in exceptionally severe situations encountered in everyday driving. An example of such a situation is meeting an oncoming vehicle on a narrow country road in Europe without slowing down. In order to obtain this high performance, the vehicle must accurately trace the driver’s intended driving path without deviating from it. As a result, the driver does not have to perform any unnecessary steering corrections to the steering inputs applied to follow the targeted driving path.

In the process of developing vehicle handling and stability heretofore, vehicle characteristics such as the suitableness of the vehicle response gain relative to steering inputs, minimal response delay and smallness of vehicle roll have been measured in so-called open-loop tests. The results have then been compared with data measured for various vehicles and necessary improvements have been made. Because this has been the main approach to
the development of vehicle handling and stability, it has been difficult to tell whether the necessary and sufficient performance has actually been obtained in the targeted driving situations.

Accordingly, in addition to the open-loop criteria evaluated previously for improving handling and stability, the actual steering angle was measured while the driver drove through a curve so as to evaluate the amount of steering corrections made. In other words, closed-loop testing was included in the process of developing handling and stability with the aim of obtaining performance that would respond more faithfully to drivers’ expectations in the targeted driving situations defined in this work.

The following sections explain the closed-loop evaluation method, the quantitative definition of the steering correction amount, the mechanism inducing steering corrections, and the validation results for the handling and stability improvement obtained with a prototype vehicle. In addition, a method is also explained for reducing steering corrections based on improvement of aerodynamic characteristics in an expanded driving situation that envisioned high-speed driving such as on the Autobahn.

2. Method of Evaluating Steering Corrections and Definition of Evaluation Indices

First, we will explain the method used to evaluate steering corrections in closed-loop testing. As shown in Fig. 1, evaluations were conducted by driving a test vehicle through curves at a steady speed of 100 km/h on a test course that simulated a European country road with two curves of 200 m and 400 m in radius. Measurement of the steering angle provided an evaluation of whether the driver was able to trace the target driving path without making any corrections to the steering inputs. The ease of tracing the path was also evaluated on the basis of subjective evaluations by the test drivers.

Next, we will explain how the steering correction amount was defined. Figure 2 shows an example of the steering angle measured for a certain vehicle in relation to time on the horizontal axis. At around 12 s on the time axis the vehicle exited the 200-m-radius curve and similarly
高い関係があることが確認されている。

3. 修正操舵が発生するメカニズムの紹介

修正操舵を低減するためのメカニズムについては、これまでいくつかの研究がなされている。本章では、それらの中でも取り上げられ、実際に車両開発でも大きな効果が確認されている、操舵に対する車両ヨーレイトの応答遅れの改善による修正操舵の低減について紹介する。

最初に、ドライバーと車両のクルーズドライブの中で修正操舵が生じるプロセスについて簡単に説明する。ドライバーは、狙った走行ラインへの操舵入力に対して、車両の応答が足りないと感じると、それを補うために追加の操舵を行う。ステアリングギヤ比が低い、あるいは車両のアンダーステアが大きいなど、車両の応答が低いことがその要因である場合には、この追加の操舵は目標とした走行ラインをトレースするために必要な操舵であり、これが新たな問題を生むことはない。この追加の操舵を発生させないように、応答ゲインを適切に設定することが必要となる。

一方、ドライバーに対する車両応答が足りないと感じる要因が、車両の応答遅れにある場合、ドライバーの追加の操舵に対して車両は遅れて大きく反応してしまうため、ドライバーはそれを修正するための切り戻しの操舵を行う必要が出るのである。この切り戻しの操舵に対しても同様に、ドライバーは切り戻しの操舵を発生させないように、応答ゲインを適切に設定することが必要となる。

3. Explanation of the Mechanism Inducing Steering Corrections

Mechanisms for reducing steering corrections have been researched in several studies conducted to date. This section describes the reduction of steering corrections by improving the yaw rate response delay of the vehicle to steering inputs. This approach has been examined in previous studies and confirmed to have a large beneficial effect in actual vehicle development work.

First, we will briefly explain the process in which steering corrections occur in a closed loop comprising the driver and the vehicle. When the driver feels that the vehicle response to a steering input for tracing the target driving path is insufficient, the person performs additional steering to compensate for the insufficiency. The vehicle’s response gain may be small because the steering gear ratio is low or the vehicle’s understeer is large. When these factors are the cause, the additional steering action is necessary for tracing the target driving path. This does not pose any new problems. The response gain must be suitably set so that such additional steering does not occur.

In contrast, if a vehicle response delay causes the driver to feel that the vehicle response is insufficient, the vehicle will exhibit a large belated reaction to the driver’s additional steering action. Therefore, to correct that vehicle behavior, the driver must turn the steering wheel back in the opposite direction. In turning the steering wheel back, the driver similarly steers more than what is necessary. This increasingly amplifies the steering correction amount, as shown schematically in Fig. 5. Therefore, reducing the vehicle’s response delay is a key factor for minimizing steering corrections.

Next, we will explain the factors causing a response delay in the vehicle yaw rate. There are two types of response delay, for which the causal mechanism differs greatly depending on differences in the frequency band of the steering input.

One type is a phenomenon that is most commonly treated in the development of vehicle handling and stability. This concerns a phase delay in the vehicle yaw at approximately 15 s it entered the 400-m-radius curve. Jagged disturbances are observed in the steering angle waveform at those moments. These disturbances captured the driver’s steering corrections. The steering angle disturbances were defined as shown in Fig. 3. The steering angle was converted to the steering angle velocity by performing a first-order differentiation on the data with respect to time. The mean steering angle velocity in the evaluation interval was defined as the steering correction amount.

In Fig. 4, the results of a subjective evaluation of line traceability conducted with the evaluation scale shown in Table 1 are plotted on the vertical axis in relation to the steering correction amount on the horizontal axis for a number of typical vehicles. It is seen that there is a relatively high correlation between the two sets of data.

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<tr>
<td>9</td>
<td>Very good</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>8</td>
<td>Good</td>
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<td></td>
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<tr>
<td>7</td>
<td>Slightly better</td>
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<tr>
<td>6</td>
<td>Average</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>5</td>
<td>Slightly worse</td>
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<tr>
<td>4</td>
<td>Poor</td>
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<tr>
<td>3</td>
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<td></td>
<td></td>
<td>Very poor</td>
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Table 1 Subjective evaluation scale
rate in relation to the frequency of the steering input and
toward the vehicle’s yaw resonance frequency that is
generally around 1-2 Hz. The mechanism of this delay is
shown in Fig. 6 (a) using a simple half car model, which
facilitates an intuitive understanding of the frequency
response characteristics of the steering action shown in
Fig. 6 (b) as well as a quantitative analysis. Raising the yaw
resonance frequency of the vehicle is effective in reducing
this phase delay. That can be accomplished in several ways
such as by reducing the vehicle’s yaw inertia, increasing
the cornering power (CP) of the tires or by increasing the
equivalent CP by designing a suspension-induced steering
effect like the steering that occurs during cornering.
Here, we will refer to this delay as being caused by a “yaw
resonance mechanism” and use the phase delay [deg.] at
1 Hz as a typical value of this delay.

The other type is a yaw rate response delay the
mechanism of which is shown schematically in Fig. 7. It is
caused by a force transfer delay due to deformation of
various parts in the process from the driver’s steering
input until the vehicle begins to turn.3）

Similar to the aforementioned yaw resonance
mechanism, an analysis of this response delay on the
frequency axis shows that a phase delay of only around
several degrees finally begins to occur in the region above
5 Hz. That represents an extremely tiny delay which is
very hard to measure in open-loop testing. However, as
described above, there is a process in closed-loop testing
in which the driver amplifies this tiny delay. Accordingly,
it is known about this delay mechanism that steering
correction differences can be evaluated quantitatively by
measuring the amount of steering correction applied. One
example is shown in Fig. 8 concerning measurement of the
steering correction with and without a strut tower bar as a
member for increasing body stiffness. Subjective evaluation
results showed a steering correction difference between
these two conditions, but that difference was difficult
to measure in open-loop testing. The steering correction
amount was measured with/without the strut tower bar for
increasing body stiffness, and the steering correction
difference was identified. That is referred to here as a
delay caused by the “vehicle stiffness mechanism.” As a
typical value of that delay, we decided to use the yaw rate
phase delay at 5 Hz in relation to the steering input.

Finally, we will explain the quantitative
relationships between the steering correction amount

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**Fig. 6** Yaw resonance mechanism delay
(a) Half car model (b) Steering response

**Fig. 5** Concept of increasing steering correction

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**Fig. 7** Component deformation
(a) Steering system (b) Tire (c) Suspension (d) Body
and the phase delay at 1 Hz caused by the yaw resonance mechanism and the phase delay at 5 Hz due to the vehicle stiffness mechanism. In order to analyze these quantitative relationships, a driver model was prepared that accurately captures the driver’s steering characteristics and it was combined with a previously established vehicle model. It was necessary to be able to simulate the driver’s steering angle accurately in closed-loop testing. Extensive research has also been done on driver models, but a driver model has yet to be constructed that can accurately predict steering angle characteristics up to the frequency band where they are affected by vehicle stiffness. Therefore, a driving simulator was used to conduct experiments with participation by specialist evaluators. The experimental results revealed the quantitative influence of the phase delays at 1 Hz and 5 Hz on the steering correction amount without knowing the driver’s steering mechanism. In Fig. 9, the steering correction amount measured experimentally is shown on the vertical axis for seven specifications in which the phase delays at 1 Hz and 5 Hz were varied as shown in Table 2 and the phase delays are shown along the horizontal axis. Averaging the results indicates that the steering correction amount was effectively reduced by 0.1 deg/s for every 1 deg. reduction in the phase delay at 1 Hz due to the yaw resonance mechanism. The steering correction amount was reduced by 0.3 deg/s for every 1 deg. reduction in the phase delay at 5 Hz. The results thus revealed the respective sensitivity of steering corrections to each phase delay. The details of this experiment were examined and approved by the company’s internal Ethics Committee for Experiments. It was conducted after obtaining the informed consent of the participants.

![Fig. 9 Delay vs. steering correction](image)

**Table 2** Evaluation specs

<table>
<thead>
<tr>
<th>Delay @ 1Hz [deg]</th>
<th>Delay @ 5Hz [deg]</th>
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<td>80</td>
<td>80</td>
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<tr>
<td>85</td>
<td>85</td>
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<tr>
<td>90</td>
<td>90</td>
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</table>

**Fig. 8 Steering correction difference by body stiffness**

**Fig. 9 Delay vs. steering correction**
Using these sensitivity lines makes it possible to design steering correction amounts for new vehicles under development based on test vehicle data showing the relationship between phase delays at 1 Hz and 5 Hz and steering corrections. The following section presents an example of the reduction of steering corrections for a previously developed vehicle.

4. Validation Results for an Advanced Developed Vehicle

This section describes the validation details of the steering correction reduction obtained for a prototype vehicle based on an actual C-segment production vehicle. This was done by applying the mechanism for reducing steering corrections and the related quantitative relationships explained in the preceding section.

First, we will explain the measures adopted to reduce the amount of steering correction due to the delay caused by the yaw resonance mechanism. For modifying a production vehicle, it would not be easy to substantially reduce its yaw inertia. Therefore, the measures taken here to reduce the vehicle response delay were mainly to increase the tire CP and the equivalent CP attributed to suspension-induced steering. As shown in Fig. 10, tire CP was increased by approximately 20% to the upper limit of the general prevailing value among ordinary passenger vehicle tires having the same size and tread width as the tires of the production vehicle. Suspension-induced steering was improved by raising it to the top level of the prevailing values in all categories. Figure 11 plots the front suspension steering angle on the horizontal axis and the rear suspension steering angle on the vertical axis along with the improvement made this time with respect to the toe angle changes of the suspension during cornering which correspond to induced steering. It is seen that the changes increased the front equivalent CP by 16% and the rear equivalent CP by 42%, which reduced the yaw rate phase delay at 1 Hz by 7.5 deg. as shown in Fig. 12.

The steering correction amount was estimated from the sensitivity line to be reduced by approximately 0.8 deg/s.

Next, we will explain the measures taken to reduce the steering correction amount due to the phase delay caused by the vehicle stiffness mechanism. The details of the places improved are omitted here, but body stiffness was increased by approximately 34% mainly by increasing stiffness around the areas where the upper struts are attached and around the stays for attaching the bumper, in addition to adding a tower bar. Suspension stiffness was increased by approximately 42% by attaching the subframe rigidly to the body and by increasing axle stiffness, among other measures. Tire lateral stiffness was increased by approximately 38% mainly by reinforcing the sidewalls. Steering system stiffness was increased by approximately 95% primarily by improving the torsional stiffness of the column. These stiffness improvements reduced the phase delay at 5 Hz by 5.3 deg., which would have an estimated effect of reducing the steering correction amount by...
Minimal Steering Correction Technologies

Approximately 1.6 deg/s (Fig. 13).

All of these modifications were incorporated in a prototype vehicle and an experiment was conducted to verify the effect on reducing steering corrections. Based on the reduction mechanism, a steering correction reduction of 0.8 deg/s was attributed to the yaw resonance mechanism and a reduction of 1.6 deg/s to the vehicle stiffness mechanism for a total reduction of 2.4 deg/s. The experimental results showed that the actual reduction was 2.6 deg/s (down from 6.2 deg/s to 3.6 deg/s), which confirmed that the steering correction amount was reduced for the most part as planned (Fig. 14).

The steering correction amount of 3.6 deg/s achieved in this work represents a small value equal to or smaller than that of European cars which are highly rated for this performance attribute, as indicated by the subjective evaluation results shown in Fig. 15.

5. Steering Correction Reduction in High-speed Driving by Improving Aerodynamic Characteristics

The relationship between handling and stability and aerodynamic force is often discussed in terms of lift, which is directly related to the vertical load at the wheel and yaw moment that describes the leeward turning round movement that occurs when a crosswind strikes a vehicle. However, here we will describe an example for improving the steering correction amount during high-speed driving principally by changing rear wheel lift under a condition without a crosswind.

Because lift acting on a vehicle is proportional...
5. 空力特性改善による高速走行時の修正操舵低減

操縦安定性と空気力との関連は、タイヤ接地面荷重に直接関連する揚力と、横風が作用した際に生じる風下への回頭運動に関連する抗力モーメントについて論じられることが多いが、今回は横風がない条件において、主に後輪の揚力を変化させることで高速走行中の修正操舵量を改善した事例について紹介する。

車両に働く揚力は流速の2乗に比例しているため、低速時には車重によるタイヤ接地面荷重が卓越し揚力の影響がほとんど表われないが、高速時には揚力による接地面荷重変化を無視できない。例えば、前輪に働く揚力係数（以下 CLf）を正の符号（上向き）にして記述、高速になるにつれ前輪接地面荷重が減少することから、高速走行時の前後輪負荷の相違（＝安定方向）を作ることができる。また、後輪に働く揚力係数（以下 CLr）は、前輪に相対的に負の符号を持つことが望ましい。これにより、高速になるにつけ後輪接地面荷重大し、アンダーステア傾向を強めることができるためである。

以上より、高速走行時の安定性向上という観点から空力性能として解くべき問題は、定性的にはCLf<CLrの方向の前後揚力バランスを作ること、特に操縦安定性からの要求の高い1Hz付近の位相遅れを改善させるためにはそれぞれの数値をどう決定すればよいかを見つけることである。

この問題を解くために、（1）前後輪揚力と高速走行時ヨー／角位相の関係把握（風洞実験による揚力変更仕様の作成、ブルーピンググラウンドにおける高速走行時ヨー／角位相の実測）、及び（2）空気抵抗係数（以下 CD）悪化を伴わず所望の揚力特性を達成するための空力的方策の検討、の二つの実験を実施した。

to the square of the flow velocity, there is hardly any influence of lift at low vehicle speeds because the vertical load at the wheel due to the vehicle weight is predominant. At high vehicle speeds, however, the change in the vertical load at the wheel due to lift cannot be ignored. For example, if the lift coefficient acting on the front wheels (CLf) is given a positive sign (upward), as the vehicle speed becomes higher, the vertical load at the front wheel will decrease, so an understeer tendency for promoting vehicle stability can be created at high vehicle speeds. In addition, it is desirable for the lift coefficient acting on the rear wheels (CLr) to have a negative sign opposite that of the front wheels. That is because the understeer tendency can be strengthened owing to the larger vertical load at the rear wheel at higher vehicle speeds.

Based on the foregoing discussion, one aerodynamic performance issue that must be resolved from the standpoint of improving stability at high vehicle speeds is to create a front-rear lift balance such that CLf > CLr qualitatively. It is especially important to find a suitable solution for determining the respective lift value so as to improve the phase delay in the vicinity of 1 Hz where there is a high requirement with respect to handling and stability.

In order to resolve this issue, the following two types of experiments were conducted: (1) clarification of the relationship between front-rear wheel lift and yaw rate/steering angle phase, which was done by creating different lift specifications in wind tunnel tests and by measuring the yaw rate/steering angle phase during high-speed driving in proving ground tests; (2) investigation of aerodynamic measures for attaining the desired lift characteristics without degrading the drag coefficient (CD).

In experiment (1), aerodynamic devices were made focusing simply on CLf and CLr without imposing any limit on the increase in CD. The CLf value was varied in a range of -0.06-0.05 and the CLr value in a range of -0.03-0.07 in wind tunnel tests before conducting proving ground tests. The yaw rate/steering angle phase was measured on a proving ground test course for each set of specifications, and the characteristic curves shown in Fig. 16 were obtained.

The results in Fig. 16 clearly show that the change in yaw rate/steering angle phase involves the opposite signs in relation to the changes in CLf and CLr and that varying CLr had the largest effect. These results substantiate the aforementioned explanation that giving CLf and CLr different signs contributes to greater vehicle stability. In addition, because the contribution of CLf was relatively small, the subsequent examination of absolute valves focused only on CLr.

As a summary of the experimental results from the proving ground tests, we can obtain the relationship between CLf and the steering correction amount as well as the relationship between the steering correction amount and the yaw rate/steering angle phase differences. The relationship between the yaw rate/steering angle phase differences and rear tire CP can be derived from an
実験1ではCₐ增大に対する制限は加えず、純粋にCₐとC₂のみに着眼して空力デバイスを作成し、Cₐは-0.06〜0.05の範囲で、C₂は-0.03〜0.07の範囲で変更してブローニンググラウンドでの実験に臨んだ。ブローニンググラウンドでは各仕様におけるヨー/角度相を測定し、図16の結果を得た。

この図より明らかのように、CₐとC₂の変化に対するヨー/角度相変化は符号が逆であり、影響が大きいのはC₂であることが分る。これは、先に述べた車両安定方向に対して寄与するC₂とCₐの符号が逆であることを裏付けるものである。また、相対的にCₐの寄与が小さいことから、以降の絶対値の検討はC₂に絞って行うこととした。

ブローニンググラウンドで行った実験結果を整理することで、C₂と修正操舵量の関係、及び修正操舵量とヨー/角度相の関係を得ることができ、車両ヨー方向の運動方程式よりヨー/角度相とリヤタイプCPとの関係が導ける。これにリヤタイプCPとリヤ接地荷重の関係を考慮することにより、当該車両のリヤタイプCPとC₂の関係をつなぐ4象限グラフを描くことができる。この4象限グラフにより、車両として達成させたい指標の絶対値から、目標とすべきC₂を定量的に設定することが可能となる（図17）。

次に実験2では、C₂悪化を伴わず望ましいC₂をどう実現するかを検討した。C₂低減策として通常用いられるリヤスポイラは、（a）車両上面の主流を直接受け、その結果として発生する正圧により負の揚力を得る、または

equation of motion for the vehicle yaw direction. By taking into account the relationship between rear tire CP and the vertical load at the rear wheel, a four-quadrant graph can be created that leads to the relationship between rear tire CP and C₂ of the vehicle concerned. Based on this four-quadrant graph, we can quantitatively define the target C₂ from the absolute values of the indices that we want the vehicle to attain (Fig. 17).

Next, in experiment (2), we examined ways of achieving the desired C₂ without degrading Cₐ. There are two types of rear spoilers that are generally applied as measures for reducing C₂. One type is struck directly by the main airflow coming over the vehicle roof, resulting in the generation of positive pressure with which negative lift is obtained. The second type obtains negative lift with an airfoil having a convex cross section at the bottom. However, both types cause an increase in drag. Therefore, without applying a rear spoiler, an attempt was made to obtain negative lift by improving the underfloor airflow so as to produce lower pressure under the floor than the surrounding pressure. Such low pressure can be produced by creating a flow velocity under the floor that is higher than the surrounding flow. Accordingly, the floor panel was made flat with the aim of enabling airflow, having its velocity increased at the front apron, to pass smoothly all the way to the vehicle rear. As a result, the flow velocity under the floor was increased compared with that before the flattening and lower surface pressure was obtained at the vehicle rear compared with the previous pressure level.
6. ま と め

日産が目指すダイナミック・パフォーマンスの一つ、「車線幅等が狭い郊外においても、正確にハンドル操作できるので安心」に対して、その評価方法と定量評価指標、性能向上のメカニズムをいくつかの具体的な向上策について紹介した。

従来のオープンループでの評価指標による性能向上に加え、実際に車線に沿って走行している、クローズドループでのドライバーの操舵角を計測し、その修正操舵量のメカニズム分析から必要な方策を検討することによって、より効果的に性能向上を実現することを示した。

また、所望の修正操舵量を空力的に実現する手段として、当該車両のサスペシション特性を基に揚力の目標値を設定する手法と、それを空気抵抗を悪化させずに実現する方策を開発し、その有効性を実車検証した。

これらの手法や技術は、既に多くの日産車に適用しており、今後はさらにシーンや、更に、意のままに操舵され安心できる車づくりを目指して、技術開発を実施していく。

7. 参考文献

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2) 久岡雅二ほか：ドライバーにとって望ましい車両応答と操舵トルクに関する研究、自動車技術会論文集、Vol. 28, No. 4, pp. 61-66 (1997).
1. Introduction

This article focuses on one of the three priority items discussed in the keynote article entitled “Nissan’s Targeted Dynamic Performance.” This item concerns “the occupants feel relaxed by vehicle motion and seats support.” It describes in detail several technical measures that have been developed to deliver this performance.

Nissan has continued to develop methods for evaluating ride comfort in relation to low-frequency road surface inputs\(^1\) as well as methods for improving ride quality. These methods have defined evaluation indices for single-direction or two-direction vibration inputs and have dealt with general vibration characteristics that express relative superiority or inferiority based on an evaluation of only the magnitude of acceleration.

On the other hand, in order to attain high levels of a secure feel and comfort that Nissan aims for, it is necessary to evaluate comprehensively body motions and vehicle movements under a condition of complex road surface inputs, which also includes cornering, such as what actually occurs on country roads in Europe. Vehicle movements should be stable so that occupants can feel secure and relaxed without experiencing any unpleasant vehicle body motions. In this project, a quantitative index of body motion was newly developed. This index defines a physical quantity corresponding to the velocity of gaze movement, which several previous studies have shown has a significant influence on motion perception.\(^2\)\(^3\)

Body motions typically refer to vehicle behavior in relation to the driver’s operational inputs to the vehicle such as steering wheel, brake pedal and accelerator pedal.

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*Special Feature*

**Development of Body Motion Control Technology**

**Key words**: Vehicle Dynamics, ride comfort, ride quality, handling, body motion, vehicle motion

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石毛 昭*  小西 健司*  桐田 英二**  玉木 良典**

抄 録  近年プレミアム、ノンプレミアムブランドに関わらず、安心・快適な動性能を実現することを日産自動車では目指してきた。その中で重要な要素を占めている、うねった道でも安心・快適と感じるボディモーションの評価技術と性能向上技術を開発してきている。今回、性能の評価方法と性能向上方策の一例について紹介する。

Summary  One of the most important attributes of Nissan’s targeted dynamic performance is that “the occupants feel secure because the vehicle moves stably even on an undulating road surface.” This article describes the methodology for evaluating body motions, a mechanism for improvement, and examples of specific technical measures applied.

Key words : Vehicle Dynamics, ride comfort, ride quality, handling, body motion, vehicle motion
Development of Body Motion Control Technology

2. Body Motion Evaluation Method and Definition of Evaluation Index

First, we will explain the conditions for evaluating body motions. The targeted driving situation in which Nissan wants customers to feel the excellent body motion characteristics of Nissan vehicles involves driving at a speed of around 100 km/h on an undulating country road surface in Europe. Another condition is that it includes driving through curves of around 100 to 200 m in radius.

Figure 1 presents time series data for vehicle behavior measured when driving at a steady speed of 100 km/h on a test course simulating a European country road. It is seen that the yaw rate and lateral acceleration also fluctuated in addition to sprung resonance phenomena such as vehicle bounce, pitch and roll. The results indicate that complex vehicle behavior occurred.

Skilled drivers who received prior training on several vehicle models under these evaluation conditions took part in subjective evaluations of vehicle motions using the evaluation scale shown in Table 1. The results revealed that vehicles displaying few behavior disturbances and little movement of the driver’s gaze on curves received good subjective evaluation scores with respect to the evaluation criteria of a secure feel and comfort.

Studies have shown that visual field information is a physical quantity that makes a large contribution to human perception of motion, as mentioned in section 1. We investigated the velocity of gaze movement at a point ahead which the own vehicle will reach in 2 s, representing

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a typical forward gaze point.

Figure 2 shows a model of gaze moment velocity that we examined as a quantitative evaluation index for body motions. Gaze movement velocity while cornering was calculated from five vehicle motion components: body roll, pitch, yaw, and vertical and lateral translational motions. The vertical components consist of roll, pitch and vertical translational motion and the lateral components are yaw and lateral translational motion.

Figure 3 shows the conceptual relationships between gaze movement velocity and these five vehicle behavior components. The vertical components indicated by the blue arrows and the lateral components indicated by the green arrows were first calculated from the vehicle behavior. They were then synthesized and the equation in Fig. 2 was used to calculate gaze movement velocity representing the integrated motion of the vehicle indicated by the red arrow. Effective values were then calculated in the evaluation interval time as representative values. Figure 4 shows a time series waveform of gaze movement velocity calculated based on driving data measured for the five vehicle motion components.

This evaluation index was defined on the basis of sprung vehicle behavior and no direct measurements were made of the driver’s gaze. The results of a previous study indicate that drivers use their body, neck and eyeball muscles to compensate their gaze when trying to concentrate on the forward view under a condition of large sprung motion, with the result that they no longer feel secure or comfortable.4)

In this study, a body motion index was created for vehicle motions in order to eliminate variation in the evaluation results due to drivers’ physical characteristics. As a result, a high correlation was largely obtained with the subjective evaluation results. The relationship between gaze movement velocity and the subjective evaluation results is shown in Fig. 5.

3. Causal Mechanism of Gaze Movement Velocity and Example of a Reduction Measure

As described in the foregoing section, gaze movement velocity is composed of the five components of vehicle roll, pitch, yaw and vertical and lateral translational
Development of Body Motion Control Technology

The respective contribution of these five components to gaze movement velocity is shown in Fig. 6 for a certain mass-produced C-segment sedan.

The results indicate that vehicle pitch is the component making the largest contribution to gaze movement velocity. The reason for that can be understood as follows. Under a condition of a curve with a radius of around 200 m, vehicle pitch behavior is multiplied by the long distance to the forward gaze point 2 s ahead of the vehicle as shown in Figs. 2 and 3. In addition, the vehicle pitch rate is larger than the yaw and roll rates. The same tendencies were also confirmed for other vehicles. Accordingly, this section describes a measure for reducing the vehicle pitch rate that makes such a large contribution, with the aim of reducing gaze movement velocity.

It is known from previous studies that the pitch component due to a time difference in road surface inputs to the front and rear tires when traveling on an undulating road is related to the vehicle speed and the vehicle’s wheelbase length. Under the driving condition considered here, the lowest order vibration is around 5 Hz, which is sufficiently higher than the vehicle pitch resonance frequency of less than 2 Hz. Therefore, in the following discussion we will consider the bounce input as the principal input component of the sprung resonance frequency.

Figure 7 is a schematic representation of the front/rear wheel suspension spring stiffness and the front/rear wheel sprung mass when a vehicle is viewed from the side. Under a condition where same-phase bounce inputs are applied to the front/rear wheels, vehicle pitch behavior occurs when the position of the pitch rotation center, determined by the spring stiffness and the front/rear wheel sprung mass, and the position of the vehicle’s center of gravity do not coincide. On the other hand, as shown in Fig. 8, by making the position of the vehicle’s pitch rotation center and that of the longitudinal center of gravity coincide, the front and rear wheels move equally and pitch behavior does not occur when a bounce input is applied.

The road surface input under the evaluation condition used in this study induces large sprung resonance, causing not only the suspension springs but also the bumper bounds to deflect greatly and stroke from the outset. In order to prevent the vehicle from pitching even under this condition, the characteristics of the suspension springs and bumper bounds must be carefully examined so as to make the position of the vehicle pitch rotation center and that of the longitudinal center of gravity coincide even under a large vehicle stroke condition.

Figure 9 shows the difference between the pitch rotation center and the vehicle’s center of gravity on the vertical axis in relation to the suspension stroke on the horizontal axis. The green line shows the effective value of the mass-produced C-segment sedan. In the region near zero suspension stroke, it is seen that there is virtually no difference between the pitch rotation center and the vehicle’s center of gravity. However, in the region of a large
ピッチ成分は、車速と車両のホイールベース長さに関係することが過去の研究からわかっている。今回は走行条件では最も低次のもので約5Hz前後となり、2Hz以下の車両ピッチ共振周波数に対して十分高いため、ばね上共振周波数の入力成分としては、パウフォン力を主体として考えていく。

図7に車両を横から見たときの、前後輪サスペンションスプリング剛性と前後輪ばね上質量の図を示す。前後輪同相のパウフォン力が入ったときに、スプリング剛性と前後輪ばね上質量から決まる車両ピッチ回転中心位置が重心位置とは一致していないと、車両ピッチ現象が発生してしまう。一方、図8に示すように、車両ピッチ回転中心位置と前後方向重心点位置を一致させることで、前後輪が等しく動きパウフォン力時にピッチ現象は発生しない。

本評価条件の路面入力は、ばね上共振が大きく励起され、サスペンションスプリングのみならず、パッサバーも初期から大きくわたんでストローキリハーサル条件である。こういった条件でも車両をピッチさせないためには、車両ストローキが大きさ条件で含めて車両重心位置と車両ピッチ回転中心位置が一致するように、サスペンションスプリングとパッサバー特性を検討する必要がある。

図9に横軸にサスペンションストローク、縦軸にピッチ回転中心と重心位置の関係を示す。縦線は、Cセグメントの乗用車での実力値を求めている。ストロケがゼロ付近の領域では、ピッチ回転中心と前後重心位置の差はほぼ生じていないが、大きくストロークする領域ではフランクサスペンションのパッサバーが強く当たって、リヤサスペンションに対して相対的に大きな反力が発生していたため、ピッチ回転中心が前寄りとなっている。

一方、青線はこの考え方からもとに、前後サスペンションの剛性バランスをパッサバー含めて特性検討したものであり、ストロークが大きさ領域でも差異がないことがわかる。

また、サスペンションスプリング剛性バランスだけでなく、サスペンションストローク、前後輪サスペンション前後の差異も考慮して検討する必要がある。
Development of Body Motion Control Technology

く、ショックアブソーバ前後減衰力バランスと減衰力自体
の確保も視線移動速度の低減に対して当然有効である。

4. 先行車両での検証結果の紹介

前述のピッチ回転中心と前後重心位置の差異をスト
ロークが大きい領域まで大幅に低減し、さらに高応答
ショックアブソーバなども適用した試作車両の改善結果
と、ベース車両の比較結果を図10、図11に示す。

視線移動速度値を約10%低減させた結果、官能評価で
も2点向上して大きく改善した。本性能の評価が高い欧州車
両と同等以上の評価となり、世界トップレベルの高い性能
であることが確認できた。

5. まとめ

本稿では、欧州郊外路で安心かつ快適な総合的ボディ
モーション官能評価を、実走車両データから算出した視線
移動速度で計測をすることを示し、その発生メカニズム
と、具体的な向上策についての一例を紹介した。

また、これらをもとに先行試作車で視線移動速度の
低減と世界トップレベルの官能評価結果であることを確認
した。

これらの評価手法や性能向上技術は、すでに多くの日
産車に適用しており、その詳細については、本稿以降の新
型車種のパートの中で紹介する。

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the difference in the positions of the pitch rotation center
and the vehicle's longitudinal center of gravity even in the
region of a large suspension stroke and also adopted
highly responsive shock absorbers, among other
improvements. The results obtained for the improved
prototype are compared with those for the base vehicle in
Figs. 10 and 11.

The prototype reduced gaze movement velocity
by approximately 10% (Fig. 10), resulting in a large
improvement of its subjective evaluation score of more
than two points (Fig. 11). Its evaluated performance was
equal to or better than most of the tested European cars,
which are evaluated highly for this performance attribute.
The results confirmed that the performance of the
improved prototype ranks among the best in the world.

5. Conclusion

This article has shown that subjective evaluations
of comprehensive body motions providing a secure and
comfortable ride on European country roads can largely
be expressed by gaze movement velocity calculated from
data measured in vehicle driving tests. The causal
mechanism involved and an example of a specific measure
for reducing gaze movement velocity were described.

The findings were incorporated in a prototype
vehicle, which was confirmed to reduce gaze movement
velocity and was ranked among the best in the world in a
subjective evaluation of this performance attribute.

This evaluation method and performance
improvement technology have already been applied to
many Nissan vehicles. The details are described in
subsequent articles that focus on newly developed models.

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1. Introduction

The annual global auto sales volume has continued to increase in recent years and competition is intensifying in every market. Customer demands for vehicle performance are also becoming more rigorous every year. In order to win the competition under these circumstances, it is necessary to continue to provide more attractive products with even higher levels of performance.

As explained in the preceding articles, Nissan is placing emphasis on a secure feel and comfort. In this regard, one aspect on which R&D efforts should be focused is a “solidly built feeling.” The feeling of being solidly built is mainly perceived from the noise and vibration transmitted to occupants from the vehicle when traveling on uneven road surfaces with bumps or cracks. By improving the solidly built feeling of Nissan vehicles, we aim to provide customers with emotional value in terms of the feelings of satisfaction and superiority engendered by owning a luxury and authentic vehicle. This article describes the solidly built feeling we incorporate in Nissan vehicles.

2. Solidly Built Feeling and Low-frequency Noise

2.1 Selection of sample vehicle types

Attention was paid to phenomena that occur when traveling over a bump as a typical driving situation representative of a solidly built feeling. Subjective evaluations were conducted of multiple models when driving on a proving ground course with bumps and other level differences. Two of the vehicles evaluated were

Key words: Noise, Vibration, solidly built feeling, ride comfort, ride quality
B車のしっかり感の評点を示す。このグラフは縦軸に官能評点を示しており、専門スキルを持った評価者により、表1のように評価した結果を示している。A車は25点、B車は40点であった。

2.2 しっかり感と低周波音の関係

昨今、低周波音が振動知覚に与える影響について述べられている。中川ら的研究（2011）を基に、低周波音の音の増減が、振動強度の知覚に影響を及ぼすことが分かっている。振動から人間が予測する音の大きさと実際の音圧の差により、認識上の混乱が生じるため、不快感が増加すると報告されている。

しっかり感を評価したコメントの中に、「比較的静かで、ポルブ音だけが響き、しっかり感を損ねる」ということが報告されている。筆者らは、こういったポルブ音を示す音音を着目し、振動から予測されるものよりも明かに大きく、大きさを同様に、認識上の混乱が生じることから、低周波音がしっかり感にも影響を与えているのではないか、と仮説を置いた。

今回、低周波音及び「響く」を観察するため、前述の突起段差を乗り越えた時の、2車の運転席フロア上下振動と運転席耳位置音圧について、低周波領域において時間的分解能に有効なウェーブレット解析を実施した。後軸乗り越し時の運転席耳位置音圧、フロア振動の解析結果を図2に示す。横軸が時間、縦軸が周波数である。変動の大きさをカラーで示しており、赤が強いほどその変動が大きいことを表している。

選択されたサンプルは、車Aがその劣下のしっかり感を示し、車Bがその良好なしっかり感を示す。図1は、2車の運転席耳位置音圧の評価を示す。音圧の変動が示されている。音圧は垂直軸に示されており、評価は5段階に分かれている。A車は2.5点、B車は4.0点である。

2.2 Relationship between solidly built feeling and low-frequency noise

The influence of low-frequency noise on the perception of vibration has been discussed in recent years. It is known from a study by Nakagawa et al. (2011) that changes in noise levels in the low-frequency region influence the perception of vibration intensity. Differences between the noise level that people expect from vibration and the actual pressure level experienced are reported to increase feelings of discomfort because they cause perceptual confusion.

Among the evaluation comments concerning a solidly built feeling, it was reported that a bong noise was transmitted amid the relative quietness, which detracted from the feeling of being solidly built. The authors focused attention on this transmitted bong noise. It lasted longer than what was expected from the vibration and caused perceptual confusion. Accordingly, it was hypothesized that low-frequency noise also apparently influences a solidly built feeling.

In order to visualize low-frequency noise and its transmission in this study, the vertical vibration of the floor panel under the driver’s seat and the noise level at the driver’s ear position of the two vehicles when traveling over a proving ground bump were subjected to a wavelet transform.

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ここで、音の変動時間について着目した。フロア振動の変動と運転席位置音圧の増加の起点を、図2の点で示している。これを2車両で比較した場合、B車の音は振動と変動開始タイミングが一致しているのに対し、A車の音は振動の変動開始から約0.1秒遅れて発生していることが確認できる。また、その終了時間も遅れていることことが確認でき、遅れて発生し、遅れて終了している。

車室内に低周波音圧が遅れて発生するということは、車両の何れかの発音部位が約0.1秒後に振動しているということである。すなわち、その低周波音がフロア振動開始タイミングと一致しないことから、何れかの部位がフロア振動と時間差を持って振動が励起され、発音を開始していると推察される。

2.3 低周波音発生部位の確認

そこで、低周波で、大きくて長く振動している部位を多点で詳細に確認するために、台車2軸3方向加振器を用いて突起段差加振乗車を実施し計測を行った。

例として図3に、部位ごとの振動の収束完了時間を示す。縦軸に部位、横軸に時間を取りている。フロア振動の開始点からピークレベルの1/10になった点を振動終了点として、その時間を読み取った。

最大の値がフロア振動収束完了であり、振動開始よりおよそ0.1秒後に振動が終了したことを表しており、他部位をみると、フロア振動よりも長く振動し"analysis"が有効である。図2はこれらの2つの基準を満たす場合を示す。B車の音は振動の変動開始から約0.1秒遅れて発生していることが確認できる。また、その終了時間も遅れていることことが確認でき、遅れて発生し、遅れて終了している。

車室内に低周波音圧が遅れて発生するということは、車両の何れかの発音部位が約0.1秒後に振動しているということである。すなわち、その低周波音がフロア振動開始タイミングと一致しないことから、何れかの部位がフロア振動と時間差を持って振動が励起され、発音を開始していると推察される。

2.3 確認のための低周波音発生部位

図3は、フロア振動収束完了時間を示す。縦軸に部位、横軸に時間を取りている。フロア振動の開始点からピークレベルの1/10になった点を振動終了点として、その時間を読み取った。

最大の値がフロア振動収束完了であり、振動開始よりおよそ0.1秒後に振動が終了したことを表しており、他部位をみると、フロア振動よりも長く振動しています。
いることが確認できる。
以上より、これらの部位がフロア振動と異なる振動を起こすことで低周波音を発生させており、更には、低周波音が認識上の混乱を起こし、しっかりと感を損ねているのではないかと考えた。
そこで、これらの部位を補強することで低周波音が収まること、更に低周波音が収まることでしっかりと感が向上するのか、を検証することとした。

2.4 低周波音発音部位の改修
一番振動時間が長いルーフ後部に着目し、いくつかの補強を実施した。一例として図4に示すように、補強を施工し剛性を1.36倍向上させた。他の部位についても、類似の内容を実施している。
改修した結果の振動収れん完了時間を図5に示す。ルーフ後部で見ると、83%収れん完了時間が短縮していることが確認できる。

2.5 低周波音圧変動の確認
前述2.2節と同様に、突起振動を乗り越えた時の、A車改修後の運転席フロア上下振動及び運転席耳位置音圧のウェーブレット解析を実施した。後輪乗り越し時の結果を図6に示す。
図5左図が改修前、右図が改修後である。運転席耳位置音圧を見比べると、改修前は30～50Hz域の音が0.1～0.2秒にかけて遅れて大きく発生していたが、改修後の同領域にて変動がなくなり、フロア振動と時間的に変動開始が一致することを確認した。

2.4 Improvement of parts producing low-frequency noise
Attention was focused on the roof rear that vibrated the longest and several reinforcing measures were implemented. One example is shown in Fig. 4, where reinforcement was applied to increase the stiffness by 1.36 times. Similar reinforcement was also applied to the other parts.

The vibration convergence time of the improved parts is shown in Fig. 5. It is seen that the convergence time of the roof rear vibration was shortened by 83%.

2.5 Confirmation of change in low-frequency noise
Similar to the analysis described in section 2.2, a wavelet analysis was performed on the vertical vibration of the floor panel under the driver’s seat and the noise level at the driver’s ear position for improved car A when the rear wheels traveled over a bump. The results are shown in Fig. 6.
The left-hand graphs in Fig. 6 are for car A before the improvements and the right-hand graphs are for the car after the improvements. A comparison of the noise level at the driver’s ear position reveals that loud noise occurred with a 0.1-0.2 s delay in the 30-50 Hz region before the improvements, but that delay in this frequency range disappeared after the improvements. As a result, the time for the onset of the change in the noise level coincided with that for the floor panel vibration.

2.6 Improvement of solidly built feeling
Figure 7 presents the subjective evaluation score for improved car A together with the scores shown in Fig. 1. In line with the hypothesis mentioned earlier, the score
2.6 しっかり感の向上

図1にA車改修後の結果を加え、図7に示す。前述した仮説の通り、低周波音の変動発生タイミングのずれを無くすことで、しっかり感を向上させることができた。改修を施したA車は、B車に近いしっかり感を実現することがで

きている。

3. まとめ

本稿では、しっかり感が低周波音の変動タイミングを改善することで向上すること、低周波音発生部位を補強することで変動発生時間を短縮することができること、を明らかにした。今後、更に低周波音などが振動知覚に及ぼす影響やメカニズムを明確にして、お客様が“安心・快適”を感じる技術開発を進めていく。

また、この新たに開発した“しっかり感”を向上させるような車体特性改善アイテムを、新型車種へ投入している。この詳細については、本稿以降の新型車種のパートの中で紹介する。

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for the solidly built feeling was improved because the difference in the duration for the change in low-frequency noise was eliminated. The results indicate that improved car A achieved a solidly built feeling which approached that of car B.

3. Conclusion

This article has made clear the enhancement achieved for a solidly built feeling by improving the duration of the change in low-frequency noise. It also made clear that reinforcing parts radiating low-frequency noise shortens the time for the occurrence of such change. In future work, it is planned to make clear the mechanism by which low-frequency noise and other phenomena influence the perception of vibration in order to develop technologies for enabling customers to better perceive a secure feel and comfort.

The newly developed measures described here for improving vehicle body characteristics for the purpose of enhancing a solidly built feeling are being incorporated into new vehicle models. Some applications are described in subsequent articles about newly developed models.

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1. Introduction

Vehicle quietness has been dramatically improved in recent decades and many may feel that further improvement is unnecessary. There is a tendency seen especially among Japanese living in Japan not to place so much significance on quietness because interior noise levels are not that high. The reasons for that include the fact that vehicles travel at low speeds in Japan’s traffic environment, road surfaces are generally good with few potholes and bumps, and there are few situations where the engine is running at high speed. However, among the ways in which vehicles are driven in other countries, noise and vibration conditions in the passenger compartment are not necessarily ideal. Accordingly, automotive engineers are still continuously making necessary efforts to improve noise and vibration levels for the sake of customers living in other lands.

On the other hand, simply lowering the noise level is not the only issue. Low-frequency noise, tiny rattles and other sounds that occur on not-so-rough road surfaces are also strongly related to the “solidly built feeling” that is one constituent element of dynamic performance. In addition, there is a tendency to think that electric motor-driven vehicles like those fitted with Nissan’s e-POWER electric powertrain are naturally quieter than internal combustion engines.

Summary

There may not be many people perceive that noise and vibration performance constitutes one element of dynamic performance. Noise and vibration (NV) phenomena often have trade-offs with major dynamic performance attributes such as handling, stability, acceleration, and fuel economy. Dynamic performance is perceived on the basis of multisensory integration. This article explains three important NV technologies as part of dynamic performance: body stiffness for a solidly built feeling, technology for obtaining an EV-like feel with e-POWER, and active control techniques supporting acceleration performance and CO₂ reduction.

Key words : NVH, body stiffness, e-POWER, ANC, active control mount
（ANC）技術がその対策とし、さらに車の燃費を助け
る技術として採用が着実に進んでいる。

2. 車体骨格の高剛性化による静穏性向上

車体剛性は年々向上しているが、DPや静穏性にとって、
向上することの意義は失われていない。特に車体全体の
変形を抑制する骨格の剛性は、様々な低周波の音振現象
を改善させる上で、キーとなる特性である。

低周波の音振現象は、エンジンからのこもり音や、路面
からのドレミング、突起乗り越し音などがあり、従来、車
両の不具合現象として評価され、お客様の不満を抹拭さ
せる意味合いが強かった。しかし近年、低周波の音のレ
ベルをより一層低減させることで、走行時のすっきりとし
た車室内空間を実現させ、魅力性能の向上や高品質に
つなげている。

路面からの入力は約-6dB/octの周波数特性を有しており、
高周波ほど入力が小さい。そのため、伝達特性のピー
ク周波数が高ければ高いほど、結果として掛け合わされた
音のレベルが小さくなり有利となる（図1）。

その伝達特性のピーク周波数を決めるのは、タイヤ、サ
スペンション、車体などの共振系であるが、特にキャビン
内の空間の体積変化に直接関係する車体骨格の固有値が
重要である（図2）。

車体骨格の固有値は、全体の剛性を高めることで上昇
し、結果、車室内音のレベルを低減させることができる。
一例として車体骨格固有値を高めた車両のホイートボディ
（BIW）固有値（図3）と、低周波ロードノイズ（図4）の
検証結果を示す。

图1 低周波ノイズ低減のメカニズム
Fig. 1 Mechanism for reducing low-frequency road noise

图2 キャビンの変形を伴う車体変形モード
Fig. 2 Body bending modes causing cabin deformation

图3 補剛前後の車体固有値
Fig. 3 Body eigenvalues before and after stiffening the body
車体骨格の剛性を高めることは古くから求められており、さまざまな設計手法や方策が考えられてきたが、断面の確保と変曲点をつくることや結合剛性を確保するなどの素直な設計がいまだ重要な理由である。国内では車両のサイズや重量、車室内空の確保などの要件から、それらを軽じる論議はしばしばなされるが、世界的には骨格共振は依然向上し続けており、骨格剛性を重視している傾向が見られる（図5）。

今後、日産車の静粛性を高め、魅力性能や高品質感を継続的に向上させていくために、車体骨格の剛性を高めるといった基礎となる技術を、引き続き磨いていく。

3. e-POWERのEV的な走り味を実現するための技術

e-POWERの利点は、エンジンを停止したまま、バッテリの電力を使ってモータのみで走行できることである。エンジン騒音がなくなることで、電気自動車（EV）らしい高い静粛性を実現することができる。

一方で、エンジンの動作している間は、燃費性能や動力性能、空調性能など、さまざまな要件から、回転数やトルクなどのエンジン動作点が決定され、駆動性能に不利な条件になり得る。この条件でもEV的な走り味を損なわないために、従来のICE車のように車体感受や音響を向上するinputs in the higher frequency ranges. Consequently, the higher the peak frequency of the transfer characteristics is, the lower the level of the multiplied sound becomes as a result, which is advantageous for a quieter interior (Fig. 1).

The peak frequency of the transfer characteristics is determined by the resonance systems of the tires, suspension, vehicle body and so on. The eigenvalues of the body frame, which are directly related to changes in the volume of the cabin interior space, are particularly important in this regard (Fig. 2).

The eigenvalues of the body frame can be increased by raising the overall body stiffness, making it possible to reduce interior noise levels as a result. As one example, Fig. 3 shows the change in the eigenvalues of the body-in-white (BIW) by increasing the eigenvalues of the body frame, and Fig. 4 shows the results of an investigation of the resultant effect on low-frequency road noise.

Increasing the stiffness of the body frame has been required for a long time, and various design methods and measures have been considered for that purpose. Straightforward designs that secure the desired cross sections, avoid creating inflection points and ensure joint stiffness, among other requirements, are still important even now. In Japan, discussions that make light of such things are often heard because of requirements regarding the vehicle size and weight and the necessity of securing interior space. However, one can still see global trends toward improving the resonance of and emphasizing the stiffness of the body frame (Fig. 5).

Continued efforts will be made in the coming years to refine further the technologies for increasing body frame stiffness as the basis for enhancing the quietness of Nissan vehicles and continuously improving attractive performance attributes and high perceived quality.

3. Technologies for Attaining EV-like Driving Feel with e-POWER

One advantage of the e-POWER electric powertrain is that the car can be driven by the traction motor alone using electric power from the battery with the engine turned off. Because there is no engine noise, remarkable quietness is obtained resembling that of an electric vehicle...
する技術などを採用するだけでなく、エンジン動作点にも振動・騒音の要件を織り込むことが重要である。

しかし多くの性能がトレードオフの関係にあるため、それぞれの性能で効果を既に選りvoirを確認しながら、動作点を決定していかなくてはならない。そのため、試作車のない開発初期段階でのシミュレーションのポテンシャル制約や、制御定数を変更した際の短時間での確認・判断に課題があった。

また、パッテリ残量や外気温など、エンジン動作点に影響を与える因子が多いため、従来のICE車とは比較にならないほど多くの条件で、これらのトレードオフを解かなければならない（図6）。

この課題を解決するため、既存のパワートレインのシミュレーションモデルや実験データベースに、エンジンマウントの特性や車体、避音などの振動・騒音モデルを組み合わせることで、他性能と同じ条件、短時間で、大容量の振動・騒音解析を可能とする1D CAEを開発した（図7）。

（複数の物理現象をひとつのモデル上で再現するシミュレーション技術。）

これによって、他性能と振動・騒音性能を同時に評価することができる。そのため、性能間のトレードオフの解決と制御ロジックの最適化が、開発初期段階から可能となる。また、短時間で多くの条件の評価も可能となった。

4. DPに寄与するアクティブ制御技術

この章では、振動や騒音を能動的に制御するアクティブ制御技術について説明する。

高出力、低燃費は静粛性とトレードオフである場合が多い。これを高レベルで両立するために、日産はANCやACM（アクティブコントロールエンジンマウント）などのアクティブ制御技術を用い静粛性を向上させている。

また近年は静粛性向上のみならず、商品の魅力向上やブランドイメージ向上にもアクティブ制御技術を活用している（EV）。

On the other hand, when the engine is running, its operating points, including speed, torque output and so on, are determined by various requirements such as for fuel economy, power performance and air-conditioning performance. Those conditions can also be disadvantageous for quietness. So as not to detract from the EV-like driving feel even under such conditions, it is essential to factor noise and vibration requirements into the engine operating points, in addition to applying technologies for improving noise isolation and reducing the body's influence on noise levels as has been done for conventional ICE vehicles.

However, because there are trade-offs among many performance attributes, the effect on each attribute and possible repercussions must be confirmed in the process of determining the operating points. That has posed issues for judging the potential of each vehicle system at the initial development stage before physical prototypes are built and for verifying and judging the effects of control constant changes in a short period of time.

In addition, there are numerous factors that influence engine operating points such as the remaining battery capacity and external temperature, among others. Consequently, performance trade-offs must be resolved under so many conditions that it is nearly impossible to make a comparison with conventional ICE vehicles (Fig. 6).

In order to resolve this issue, a 1D CAE simulation program was developed for reproducing multiple physical phenomena with one model, making it possible to conduct a large-capacity noise and vibration simulation in a short period of time under the same conditions as for other performance attributes. This program combines a noise and vibration model, including engine mount properties, vehicle body, noise isolation measures and other factors, with an existing powertrain simulation model and an experimental results database (Fig. 7).

This makes it possible to evaluate noise and vibration simultaneously with other performance attributes. As a result, trade-offs between performance attributes can now be resolved and the control logic can be optimized from the initial stage of development. Moreover, many conditions can now be evaluated in a short period of time.

Driving conditions

Powertrain model

Noise and vibration level

Fuel economy etc.

Fig. 7 1D CAE 出力イメージ

Fig. 8 U13 Nissan Bluebird
4.1 低燃費ANCの普及
日産は4気筒エンジン特有のこもり音を消音するために、1991年にU13型プルーバード（図8）で世界初のANCを採用した。近年は省燃費を目的にANCを使用することが多い。省燃費のためには、エンジン出力の伝達ロスを少なくすべく、変速機のロックアップ領域拡大が有効である。一方ロックアップ領域拡大を実現する際には、エンジンこもり音が課題となる。日産は2009年のY51型フーガより、それまでのなかったエンジン低回転域および高負荷域へ広げたロックアップ領域とこもり音性能の両立を、ANCの適用により実現した。以降、ANC採用台数は図9に示すように年々拡大しており、今後も拡大が見込まれている。

4.2 ACMの進化
省燃費エンジン（ディーゼルエンジンやダウンサイズエンジンなど）で悪化するエンジン振動を低減する技術としてアクティブコントロールマウント（ACM）がある。日産は1998年U30型プレサージュの直噴ディーゼルエンジンモデルでACMを採用した。ACMはエンジンマウント内部に搭載したアクチュエータにより、エンジン振動とは逆位相の振動を発生させることで、車体へ伝達する振動を低減する。
新型INFINITI QX50ではアクティブトルクロッド（ATR）を採用した（詳細は後稿「QX50で実現したダイナミック・パフォーマンス技術」参照）。ATRは初代ACMから3世代目のアクティブエンジンマウントと呼ばれるもので（図10）、VCターボエンジンの高周波の振動を低減する。

4.3 アクティブ・サウンド・コントロール（ASC）
従来、車両の加速サウンドは、吸気系もしくは排気系での音づくりをすることが一般的な手法であったが、音環境の悪化を避けるべく今後強化されている車外騒音規制を鑑みると、これらによる対応には限界がある。これらの

4. Active Control Technologies Contributing to Dynamic Performance
This section explains active control technologies for controlling noise and vibration actively. There are many times when high power output and high fuel economy involve trade-offs with quietness. At Nissan, we improve vehicle quietness by applying active control technologies such as ANC and active control engine mounts (ACMs). In recent years, active control technologies have also been used to enhance product attractiveness and the brand image, in addition to enhancing quietness.

4.1 Spread of ANC for high fuel economy
Nissan adopted the world’s first automotive ANC system on the U13-series Nissan Bluebird (Fig. 8) in 1991 to cancel the booming noise characteristic of 4-cylinder engines.

In recent years, ANC has often been applied for the purpose of improving fuel economy. Expanding the lockup region of the transmission is an effective way of reducing losses incurred in transferring engine power, which works to enhance fuel economy. On the negative side, engine booming noise becomes an issue when the lockup region is expanded. Beginning with the Y51-series Fuga in 2009, Nissan expanded the lockup region to both the low speed range and the high load region, which had never been done before. Booming noise performance was reconciled with that expansion by applying ANC. Since then, the volume of Nissan vehicles equipped with ANC has increased every year as shown in Fig. 9 and is expected to expand further in the years ahead.

4.2 ACM evolution
ACM technology is one approach to reducing engine vibration that worsens for high fuel economy engines such as diesel engines, downsized engines and others. In 1998, Nissan adopted ACM on the U30-series Presage equipped with a direct-injection diesel engine. ACM reduces the transmission of vibration to the body by generating vibration in the opposite phase to that of engine vibration using an actuator incorporated inside the engine mount.

The new Infiniti QX50 adopts an engine mount vibration damping system called Active Torque Rod (ATR). (For further details see a later article entitled “Dynamic Performance Technologies on the New INFINITI QX50.”) ATR is Nissan’s third-generation active engine mount system since the initial ACM technology (Fig. 10). It effectively reduces the high-frequency vibration generated by the VC-Turbo engine.

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**図9 ANC累計採用実績（日産車）**

**図10 ACMの進化**
トレードオフを解消する技術として、オーディオスピーカから電気的に加速時の音を付加するASCシステムを、2011年に発表したV37型スカイラインより採用した。以降これまでに新型INFINITI QX50を含め7車種に同技術を採用しており、商品魅力向上の一助となっている。

5. ま と め

今後、車の電動化は確実に進む。車の中で最大の騒音源である内燃機関がなくなることで、路面起因の騒音や風音の寄与が高くなることから、そのための振動・騒音技術は今後も重要である。また、軽量化などの制約条件もますます多くなっており、機械的な対策だけでは対応できない領域でアクティブ技術を適用する範囲は確実に広がるものと思われる。

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4.3 Active Sound Control (ASC)

In the past, the acceleration sound of a vehicle was generally generated by methods applied either to the intake system or the exhaust system. However, there are limits to these methods in view of the tightening of pass-by noise regulations in recent years to avoid degradation of the sound environment. One technology for resolving this trade-off is an ASC system that adds sound electrically through the audio speakers during vehicle acceleration. Nissan adopted an ASC system on the V37-series Skyline announced in 2011. Since then, this same technology has so far been applied to seven models, including the new INFINITI QX50, to help improve product appeal.

5. Conclusion

There is no doubt that vehicle electrification will advance steadily in the coming years. The elimination of the ICE that is the biggest source of noise in conventional vehicles will make the contributions of noise from the road surface and wind noise more predominant. Consequently, technologies for suppressing noise and vibration will continue to be important in the future. There will also be increasingly more constraints, including further weight-reduction demands. It can be expected that the range of application for active control technologies will definitely expand in areas where mechanical measures alone are not sufficient.

6. References

1. Introduction

The new Nissan LEAF was launched in the electric vehicle (EV) market, which has been expanding in recent years, as a vehicle symbolizing Nissan Intelligent Mobility. It was developed to provide improved driving safety, to contribute to the creation of a clean environment, and to give customers greater driving pleasure with a feeling of being more closely connected to society.

This article describes the development aims set for the handling, stability and ride comfort of the new Nissan LEAF (Fig. 1) and the technologies applied to attain high levels of these performance attributes.

2. Dynamic Performance Targeted for the New Nissan LEAF

The driving range of the new Nissan LEAF has been greatly improved by expanding the energy storage capacity of the battery to 40 kWh, among other improvements, in anticipation of an increase in long-distance, long-duration driving. Accordingly, the vehicle was developed with emphasis on the following points so as to reduce the driver's workload for a more enjoyable driving experience.

(1) Driver can easily follow the intended path
(2) The occupants feel relaxed by vehicle motion and seats support
(3) The occupants are not disturbed by noise and vibration
Dynamic Performance Technologies on the New Nissan LEAF

3. Reduction of Steering Corrections

An EV delivers smoother, more powerful acceleration characteristic of an electric drive motor compared with that obtained with accelerator pedal control. One aspect that can be cited for taking advantage of this smoothness to enable customers to drive as they wish with a secure feel and enjoy comfortable driving without getting tired even after long hours on the road is minimal steering corrections (Fig. 2). The following discussion describes the technologies adopted on the new Nissan LEAF to reduce the amount of steering corrections made.

As described in an earlier article entitled “Minimal Steering Correction Technologies,” one mechanism inducing steering corrections is a vehicle response delay. It is known that it is important to reduce the response delay that occurs in the vehicle’s force transfer path from the steering wheel to the tires (Fig. 3). Therefore, the stiffness of the steering system, which contributes significantly to this response delay, was improved with the aim of ensuring ample stiffness in each component of the transfer system.

The stiffness of the torsion bar in the steering system of the new Nissan LEAF was increased by approximately 13% (Fig. 4), which improved the torsional stiffness of the steering system by approximately 10% over that of the previous model when a steering input is applied (Fig. 5). This improvement reduces the vehicle’s response...
新型日産リーフで実現したダイナミック・パフォーマンス技術

で、ドライバのハンドル操作に対し、よりリアリティなヨーレートや旋回加速度を発生させることができるようになり、ドライバの思った通りのラインでの走行を実現している。

また新型日産リーフには電動パワーステアリングの制御において、舵角センサと連動した日本向け日産車初採用となる新しいハンドル反り制御を採用している。これは操舵角および操舵速度を用いて、姿勢性を最適化し、スタビライジング機能を中立位置に戻す力を発生させるものである（図6）。この機能により、直進からのターンインやコーナリング中の切り出し、中立を跨（また）いでの切り返し時に手応えをドライバーにしっかりと伝え、より自然でしっかりと操舵感を実現したことでは、安心感をもってコーナリングすることができる。また、操舵しながら回転に必要な操舵角をイメージしやすくなることで、修正操舵量の低減に貢献している。

さらに新型日産リーフにはインテリジェントドライビングコントロールおよびインテリジェントトレースコントロールを採用している。これらはドライバのハンドル操作、ブレーキ操作、アクセル操作からドライバの運転状態を推定し、コーナリングに適した駆動トルクを四輪それぞれの制動力を制御し、コーナでのライントレース性を向上させる制御システムである（図7、図8）。運転を手先と手足ドライバは、コーナ手前からスムーズにハンドル操作を行うことができると、一般ドライバのハンドル操作は、切り始めが遅れ気味になったり、必要以上にハンドル操作が速くなったり、

delay even in the region of tiny steering inputs, enabling the generation of a more linear and natural yaw rate and cornering acceleration in response to the driver’s steering actions. As a result, the vehicle can better trace the driver’s intended driving path.

In addition, the control program of the electric power steering system used on the new Nissan LEAF incorporates a new steering wheel return-to-center control that operates in conjunction with a steering angle sensor. This control has been adopted for the first time on a Nissan vehicle for the Japanese market. Based on the steering angle and steering angle velocity, this control function increases the self-aligning torque artificially, thereby generating a force for returning the steering wheel to its neutral position (Fig. 6). This function gives the driver solid feedback when turning in from a straight-ahead course, performing additional steering during cornering, and turning the wheel back across the neutral position, thus providing a more natural and definite steering feel that enables the driver to corner with a secure feel. It also contributes to reducing the steering correction amount because the driver can more easily imagine the steering angle needed for cornering while steering the vehicle.

The new Nissan LEAF also adopts Intelligent Ride Control and Intelligent Trace Control. These control technologies estimate the driver’s intention from the operation of the steering wheel, brake pedal and accelerator pedal and controls the drive torque and the braking force at each wheel to levels suitable for cornering. In this way, these control systems improve the ability to trace the intended path during cornering (Figs. 7 and 8). Experienced drivers who drive skillfully are able to steer smoothly just before entering a curve. However, ordinary drivers tend to begin steering too late, turn the steering wheel faster than is necessary, and overshoot the amount of steering needed, among other steering actions. Even for these differences in the driver’s steering operations, the use of the steering angle velocity makes it possible to suitably vary the timing for intervening in drive torque and braking force control in anticipation of an understeer tendency. This enables control that matches drivers’ varying levels of driving skill.

图6 ハンドル戻し制御ブロック図
Fig. 6 Block diagram of steering return control

图7 インテリジェントトレースコントロール制御ブロック図
Fig. 7 Block diagram of Intelligent Trace Control

图8 インテリジェントトレースコントロールおよびインテリジェントライドコントロールのイメージ
Fig. 8 Concept of Intelligent Trace Control and Intelligent Ride Control
Dynamic Performance Technologies on the New Nissan LEAF

操作量もオーバシュートするような傾向がある。このようなドライバの操作の違いにより、ストーリング角度を用いてアングステラ傾向を劣化させ、駆動トルクや制動力の制御を介する速度を適切に変化させることなどにより、さまざまなスキルのドライバに対応した制御が可能となっている。

またEVである日産リーフは駆動制御をモータで行うことから、エンジン搭載車のトルク制御に比べ応答が早く、より積極的な制御が可能であり、アングステラを軽減することで修正操舵低減に貢献している。

これらの技術により、あるコーナーを走行する際に必要とする修正操舵を前後比約10%の低減を実現した（図9）。

4. ボディモーションコントロール実現技術

安心して思い通りに車を運転できる安心感と不整路でも体が揺れない快適な乗り心地を実現する上で、ビッチ、ロールによる乗員の不快な身体の揺れが少ない、ゆっくりと安定した車の動きが重要である。新型日産リーフでは重量物であるバッテリを車両下部に、高密度に配置するとともに、全高をより低くすることでさらに低重心化を実現した。ロール、ピッチモーメントが小さいため、サスペンションの硬さを抑えることが可能となり、乗り心地を犠牲にすることなくロールやピッチモーションを低減させることができた（図10、図11）。

Moreover, because the new Nissan LEAF EV controls drive torque by means of a motor, response is faster and control is more finely tuned compared with the torque control of an engine-powered vehicle. Reduction of the understeer tendency also contributes to reducing steering corrections.

These technologies work to reduce steering corrections when driving through certain curves by approximately 10% compared with the previous model (Fig. 9).

4. Body Motion Control Technology

Stable and comfortable vehicle motion is important for providing a secure feel enabling drivers to be at ease in driving the vehicle as they wish and for obtaining pleasing ride comfort with little occupant body sway even on irregular road surfaces. The heavy battery pack on the new Nissan LEAF is positioned under the floor in a high density layout and the overall height was also reduced, thereby lowering the vehicle's center of gravity. Small roll and pitch moments made it possible to hold down the stiffness of the suspension. Roll and pitch motions were thus reduced without sacrificing ride comfort (Figs. 10 & 11).

5. Solidly Built Feeling

As described in an earlier article entitled "Improvement of Solidly Built Feeling through Noise and Vibration Control," the solidly built feeling of the new Nissan LEAF was improved to enable customers to enjoy secure, comfortable driving without becoming fatigued even after long hours on the road. That was done to further enhance the value of the new Nissan LEAF in terms of quietness exceeding its class. To enable occupants to truly sense the solidly built feeling of the new Nissan LEAF, low-frequency noise and vibration were reduced to avoid transmitting them through the vehicle. Differences in the time of occurrence of low-frequency noise and vibration were also reduced. It is known that these approaches are effective in reducing uncomfortable sensations imparted to the occupants. The following describes the technologies that were developed for the new Nissan LEAF focusing in particular on reducing low-frequency noise transmitted...
5. しっかり感

新型日産リーフでは実験しているクラスを超えた静粛性の価値をさらに一段高めるため、前出記事「音と振動のコントロールによるしっかり感の向上」で紹介したように、長時間走行でも疲れにくく、安心かつ快適と感じいただければしっかり感を向上させた。しっかりととした感じを実感していただくためには、低周波音や振動が車に響かないように少なくし、振動と低周波音の発生タイミングの差を小さくすることで、乗員への不快感を低減することが知られている。新型日産リーフでは、特に突起を乗り越した際に車室内に響く低周波音と変動タイミングの改善に着目し、開発した技術について述べる。

新型日産リーフのようなハッチバックの場合、低周波音と変動タイミングが生じるメカニズムの一つとして、後輪乗り越し時に車体が振動し、バックドアを撃つことによる車室の圧力変化がある（図12）。そのためしっかりと感の実現のために重要となる特性の一つとして、突起を乗り越した際の車体への突き上げ力を受ける車体剛性がある。新型日産リーフではリアハッチゲート周辺の構造や板厚変更などにより車体破壊曲げ剛性を約14%向上し（図13、図14）、しっかり感向上を実現した（図15）。

6. ま と め

新型日産リーフはシャシー制御の採用や、各部の剛性の向上などにより、狙いであった「思った通りスムーズに車を運転できる安心感」、「不整路でも体が揺れずに快適な乗り心地」、「音や振動が車に響かないしっかりととした

to the passenger compartment and variation in the time such noise occurs when traveling over a bump.

In the case of a hatchback like the Nissan LEAF, one mechanism causing low-frequency noise and variation in the time of occurrence is a change in pressure in the passenger compartment due to back door shaking caused by body vibration that occurs when the rear wheels travel over a bump (Fig. 12).

Accordingly, one of the key characteristics for achieving a solidly built feeling is the body frame stiffness for resisting the force acting to lift up the body when the vehicle goes over a bump. The body vertical bending stiffness of the new Nissan LEAF has been increased by approximately 14% by changing the structure around the rear hatch gate and the panel gauge, among other improvements (Figs. 13 & 14). These measures have achieved a solidly built feeling as indicated by the subjective evaluation results in Fig. 15.

6. Conclusion

The new Nissan LEAF adopts new chassis control technologies and various stiffness improvements, among other enhancements. As a result, it provides a secure feel enabling smooth driving according to the driver's wishes, pleasing ride comfort without any occupant body sway even on irregular road surfaces, and a solidly built feeling without noise and vibration being transmitted through the vehicle. The new Nissan LEAF is already being sold mainly in Japan, North America and Europe and is highly acclaimed for its smooth body motion that imparts a
Dynamic Performance Technologies on the New Nissan LEAF

secure feel in response to steering inputs. We intend to further improve its dynamic performance so as to obtain a higher level of customer satisfaction in the increasingly competitive EV market.

7. References

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新型アルティマで実現したダイナミック・パフォーマンス

Dynamic Performance Technologies on the New Altima

1. Introduction

The all-new Altima is a leading sedan model with annual sales of approximately 255,000 units in the U.S. market and approximately 115,000 units in the Chinese market. The latest model is the sixth generation of this series. As a D-segment sedan, the new Altima features expressive exterior and interior trim design highlighting the low-center-of-gravity body proportions, outstanding habitability and numerous advanced technologies such as ProPILOT Assist and the latest connectivity. In addition, it is equipped with a variable compression ratio engine, pursues advances in platform and chassis technologies, and delivers segment-leading dynamic performance.

This article describes the aims set for the handling, stability, ride comfort, and noise and vibration performance of the new Altima (Fig. 1) and the technologies adopted to obtain high levels of these performance attributes.

1. は じ め に

新型アルティマは、北米市場で年間約255万台、中国市场で約115万台を販売する主力セダンであり、今回6世代目となる。Dセグメントセダンとして、低重心プロポーションの内外装デザインと居住性の実現や、プロパイロットや最新のコネクティビティなどの先進装備に加え、可変圧縮比エンジン、プラットフォームやシャシーの進化を追及し、セグメントトップレベルの動性能を実現することができた。

本稿では新型アルティマ（図1）の操縦安定性、乗り心地、音振性能の狙い、それらを高いレベルで実現した技術について紹介する。

1. Targeted Handling, Stability, and Ride Comfort

As described in the keynote article entitled

Key words: Vehicle Dynamics, Chassis, ride comfort
Dynamic Performance Technologies on the New Altima

2. 操縦安定性・乗り心地の狙い

キーノート「日産が目指すダイナミック・パフォーマンス」で述べたように、新型アルティマにおいても以下の二つのプライオリティアイテム、①車線幅が狭い郊外路でも正確にハンドル操作できるので安心、②路面が凹凸だらけの道でも車の動きが安定しているので乗員も安心、③音や振動によって乗員が不快にならない、を中心にして“安心”“快適”な走行性能を実現することを目指した。

具体的には、フリーライドやワインディングロード、市街地や郊外で車線幅の狭い路面上において、①車線コントロールが容易な応答の良さを感じさせる操舵特性、②ドライバーの操舵による安心感と安定性を高めるべく抑えられたボディモーション、③長時間走行でも疲れない、しっかりとした感覚を実感する低振動、低騒音技術に重点をおいて開発を進めました。

3. 新型アルティマ性能向上技術

3.1 修正操舵の少ない走行性能

フリーライドやワインディングロード（Fig.2）を走行する際に対応の良さを感じさせる操舵特性、走行中の車線確保の容易さを追求するため、直接的に、この性能が担保されることで、修正操舵の少ないことが挙げられる。修正操舵を低減するために新型アルティマで適用した技術について以下に述べる。

修正操舵低減技術の紹介で述べられている修正操舵（Fig.3）が発生するメカニズムの一つとして、操舵入力～タイヤ接地点の車両伝達系において、応答遅れを抑えることが効果的であることが示されている（Fig.4）。そこで、新型アルティマでは十分な車両、サスペンション、スチアリング剛性を確保することを目指した。

まず、図5に示す通り、新設計のデュアルピシンオンタイプブラックEPS（Electric Power Steering）を採用し、ラッ

“Nissan’s Targeted Dynamic Performance,” the aim set for the new Altima was to achieve comfortable driving performance with a secure feel centered on the following three priority items. (1) Driver can easily follow the intended path. (2) The occupants feel relaxed by vehicle motion and seats support. (3) The occupants are not disturbed by noise and vibration.

Specifically, the new Altima was developed with emphasis on providing the following attributes when driving on freeways, winding roads, urban streets and rough country roads. (1) Steering characteristics that feel responsive and allow easy lane control. (2) Suppression of vehicle body motions to enhance the secure feel and comfort of the driver and passengers. (3) Low noise and vibration technologies for avoiding fatigue even on long drives and for imparting a solidly built feeling.

3. Technologies for Enhancing the Performance of the New Altima

3.1 Driving performance with minimal steering corrections

Steering characteristics should feel responsive and allow easy lane control when driving on freeways and winding roads (Fig. 2) as well as not causing fatigue even in high-speed driving over long periods of time. One such characteristic is minimal steering corrections when driving on a certain specified course. The technologies adopted on the new Altima for reducing the amount of steering corrections are described below.

One mechanism inducing steering corrections (Fig. 3) as described in the article entitled “Minimal Steering Correction Technologies” is a response delay in the force transfer path of the vehicle from the driver’s steering input to the tire contact patch. It is known that suppressing this delay is effective in reducing steering...
ク軸に直接モータでアシスト力を加えることで、ステアリングシステムの高剛性向上を図った。また、フロントストラットサスペンションは前型車に対しナッカルアーム半径を約8%増加させ、ステアリングラック軸入力を減らすことにより、高剛性なサスペンションとした。これらの変更により新型アルティマでは、ステアリング剛性が前型車比で120%増しし、競合車トップレベルに向上させている（図6）。その結果、ドライバ操舵に対して、微軽から遅れなくリアにヨーレイトが発生する車両特性に与えられた。

次に、安心して思い通りに乗車可能ですを実現するためには、車の応答性にリニアなステアリング操舵力特性を実現する必要があります。

新型アルティマでは、図7に示す通り、フロントサスペションのホイールアライメントは見直し、クラストップのキャスタ角と適正なキャストトレインに設定することで、直進時の微小操舵に対して、ヨーレイトと復元力を遅れなく十分に発生させることができる特性とした。また、リアサスペションにおいても、図8のようにサブフレームの補強により、各部が変形することによる力の伝達遅れを低減し、ドライバが容易に運転できる車両特性とした。

これらの技術を適用することで、新型アルティマでは修正操舵を競合車対比で約7%向上することができた（図9）。

3.2 Technologies for body motion control

新型アルティマで実現したダイナミック・パフォーマンス

エンジンに直接モータでアシスト力を加えることで、ステアリングシステムの高剛性化を図った。また、フロントストラットサスペションは前型車に対しナックルアーム半径を約8%増加させ、ステアリングラック軸入力を減らすことにより、高剛性なサスペンションとした。これらの変更により新型アルティマでは、ステアリング剛性が前型車比で120%増しし、競合車トップレベルに向上させている（図6）。その結果、ドライバ操舵に対して、微軽から遅れなくリアにヨーレイトが発生する車両特性に与えられた。

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3.2 Dynamic Performance Technologies on the New Altima

Vehicle pitch and roll motions must be suppressed when driving on a continuously uneven road surface (Fig. 10) in order to reduce uncomfortable body sway by the occupants and minimize vehicle movements that interfere with steering actions so that the driver can drive in a relaxed manner.

As described in an earlier article entitled “Development of Body Motion Control Technologies,” it is essential to optimize the balance of the front and rear suspension systems, including in the high load region, for driving on uneven, undulating roads. The position of the vehicle’s center of gravity and the position of the vehicle pitch rotation center must be designed to coincide, including for driving conditions with large vehicle stroking. Because not only the coil springs but also the bump stops (Fig. 11) deflected and stroked under such conditions in the early development stage, the characteristics of the suspension springs and bump stops were carefully examined.

Monotube shock absorbers (Fig. 12) were adopted for the rear suspension to achieve a comfortable ride with an enhanced secure feel by suitably suppressing vehicle body motions during cornering and on undulating roads.

In addition, the seat back and lumber support were shaped to match the curvature of the human torso while also lowering the position of the shoulder supports (Fig. 13). These measures were taken both to reduce body sway on rough roads and to improve the body-holding support of the seats against lateral acceleration (G).

3.3 Technologies for achieving a solidly built feeling

Reducing noise and vibration so that they are not transmitted to the vehicle, thus minimizing the discomfort they may cause occupants, is a key factor in avoiding fatigue even on long drives and in enabling occupants to truly feel the car is solidly built. In developing the new Altima, efforts were focused on controlling vibrations transmitted to the body and noise transmitted to the interior especially when traveling over bumps in the road. The technologies described here were developed and
3.3 シラリ感実現技術

長時間走行でも疲れず、しっかりとした感覚を実感していただくためには、音や振動が車に響かないように振動や騒音を少なくし、乗員への不快感を低減することが重要である。新型アルティマにおいては、特に突起を乗り越した際の車室内に響く音と車両を伝わる振動の取まり、またその音色に着目して開発を行った。その適用技術について以下に述べる。

図14のようなひび割れた路面やスピードバンプなどの突起を走行する際にしっかりとした感覚を感じるには、前出記事「音と振動のコントロールによるしっかり感の向上」で述べているように、低周波音の変動低減、及び音と振動の取まりを早くすることが重要となる。新型アルティマでは、主に車体後部の骨格変形、ローカル変形の変形に着目し、図15のようにトランク内のリヤエンドバー形状変更、リヤパーセルのエンボス形状変更、トランクリッドとadopted on the new Altima also paid attention to tonal quality.

As described in an earlier article entitled “Improvement of Solidly Built Feeling through Noise and Vibration Control,” early attenuation of noise and vibration and reduction of the fluctuation of low-frequency noise are essential for giving occupants a solidly built feeling. This is especially true when traveling on a cracked road surface and going over speed bumps and other projections (Fig. 14). In developing the new Altima, attention was primarily paid to deformation of the vehicle frame at the rear and deformation of local parts. As shown in Fig. 15, measures were taken to reduce rear end shape deformation inside the trunk and shape changes of the rear parcel shelf embossment as well as to increase the stiffness of the trunk lid and hinges. As a result, noise fluctuation in the 30-50 Hz range in the cabin was reduced (Fig. 16).

3.4 Technologies for reducing noise and vibration

Quietness is an essential element of D-segment vehicles. The measures explained here were taken to attain the target of segment-leading quietness.

The new Altima is equipped with Nissan’s variable compression ratio VC-Turbo engine. High-frequency
3.4 振動・騒音低減技術

Dセグメントで静粛性は重要な要素であり、新型アルティマは以下の対応により、目標のセグメントトップレベルの静粛性を達成している。

新型アルティマは可変圧縮比エンジンVCターボを搭載しており、燃費向上のための高圧縮化による燃焼速度上昇により、高周波の加振力が増大する。また、エンジントルクも増加しており、高周波の加振力の伝達をいかに低減するかがポイントである。

これまで日産では、パスファインダーHEVで電動アクティブコントロールロールマウント（E-ACM）を採用するなどしてきているが、高トルクのダウンサイジングエンジン（VCターボ）をベンデュラマウントへ搭載するために、新たにアクティブトルクロッド（ATR）を開発した。パッシブとアクティブを活用した新しいマウントシステムであり、エンジンのロール反力を大きく受けるアッパーテールクロッドに採用した。

ATRは従来システムに比べ省スペース、軽量、安価なシステムとなっている。システム概略図を図17に示す。ATRの原理概要は、トルククロッド共振を200Hz以下に設定し、トルククロッド共振の防振領域を拡大することで、高周波の加振力を低減する。これにより、加速騒音の低減とエンジン音質の向上が実現した。

excitation force is increased because of the faster combustion velocity due to the higher compression ratio for improving fuel economy. Engine torque is also higher, so a key point is how to reduce the transmission of high-frequency excitation force.

Previously, electronic active control engine mounts (E-ACMs) were adopted on the Pathfinder HEV and other Nissan models to address this issue. In order to apply pendulum mounting to the downsized high-torque VC-Turbo, a new Active Torque Rod (ATR) system was developed. Combining both active and passive control, this new mount system was applied to the upper torque rods that are subjected to the large roll reaction force of the engine.

ATR is a space-saving, lighter, low-cost system compared with the previous E-ACM system. The configurations of the two systems are shown schematically in Fig. 17. The operating principle of the ATR system is outlined here. Torque rod resonance is set below 200 Hz to expand its anti-vibration range. This reduces engine vibration inputs that are worsened by the increased combustion velocity due to the higher compression ratio. On the other hand, the booming noise region is worsened by torque rod resonance. The transmitted force of torque rod resonance is reduced by the control force applied to the intermediate mass of the torque rods (Fig. 18).

The configuration of the ATR system adopted on the new Altima is shown schematically in Fig. 19. An
圧縮化による燃焼速度の上昇によって悪化したエンジン振動の入力を低減する。一方でトルクロッド共振によるこもり音を防ぐためには、トルクロッドの周辺質量に加えた制御力により、トルクロッド共振の伝達力を低減する（図18）。

新型アルティマに採用したATR構成要因図を図19に示す。本システムでは、制御力の発生に慣性マスアクチュエータを使用し、トルクロッドの周辺質量にエンジンからの主入力である車両前後方向に制御力を入力できる構成とした。制御は、エンジン加振力の入力時に周辺質量の振動加速度検出し、検出した振動加速度に制御ゲインをかけた制御力を応答性の良い電磁式アクチュエータによって加振力にフィードバックを行う、速度フィードバック制御である。

次に、加速時騒音及びこもり音の対策状況を述べる。加速時騒音は、ATR採用による防振領域拡大により、従来のアッパーテールロッドに対し大幅に改善し（図20），結果、競合車同様のレベルを達成した。一方、こもり音は、ATRの制御により無理な大幅に低減し（図21）、バランス付直4エンジンを搭載した車両と同等のこもり音レベルを達成した。

これらの技術を適用することで、新型アルティマは競合車に対し、振動や音が車内に響かないしっかりとした感覚を実現する低振動・騒音キャビンを実現した。

4. ま と め

新型アルティマは、可変圧縮比エンジン、新型ステアリングシステム、サスペンションシステムの改良などによるプラットフォームやシャシーの進化で、セグメントトップレベルの動性能と、日産が考えているダイナミック・パフォーマンスの“安心・快適”な走行性能を実現した。昨今、SUVの販売が急激に伸び、セダンの販売比率が減少傾向にあるが、総販売台数は堅調に推移しているセグメントであり、ダイナミック・パフォーマンスの向上で北米市場、中国市场の販売に大いに貢献することを期待する。

5. 参 考 文 献

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inertial mass generator is used to generate the control force. The system is constructed such that the control force can be applied to the intermediate mass of the torque rods in the vehicle longitudinal direction, which is the same direction as the principal force input from the engine. Control is accomplished by a velocity feedback control principle. The vibration acceleration of the intermediate mass is detected at the moment the engine excitation force is input. An electromagnetic actuator with good responsiveness generates the control force, which applies a control gain equal to the detected vibration acceleration, and feeds it back to cancel the excitation force.

Next, we will explain the acceleration noise and booming noise levels obtained by the new Altima. Acceleration noise has been markedly reduced compared with conventional upper torque rods by expanding the anti-vibration range as a result of adopting the ATR system (Fig. 20). This results in an interior noise level that is equal to or better than that of rival models.

ATR control has also substantially reduced booming noise, as intended (Fig. 21). The booming noise level attained by the new Altima is equal to that of a 4-cylinder engine equipped with a balancer shaft system.

Thanks to the application of these technologies, the new Altima features a low-noise, low-vibration cabin because noise and vibration are not transmitted to the vehicle body compared with rival models, thus providing a solidly built feeling.

4. Conclusion

The new Altima achieves segment-leading dynamic performance as a result of adopting Nissan’s variable compression ratio engine and further advanced platform and chassis created with a new steering system and an improved suspension system, among other measures. It delivers driving performance that provides a secure feel and ride comfort, representing attributes Nissan considers vital to dynamic performance. In recent years, SUV sales have grown rapidly while the sedan sales ratio has tended downward. Yet the overall sales volume of the sedan segment has remained firm. It is expected that the improved dynamic performance of the new Altima will greatly contribute to sales in the U.S. and Chinese markets.

5. References

Dynamic Performance Technologies on the New Altima

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1. Introduction

The new INFINITI QX50 (Fig. 1) was developed as a compact SUV positioned in the premium segment, not only featuring distinctive exterior and interior design, roominess and an expanded range of advanced equipment such as ProPILOT Assist, but also pursuing comfortable, high-quality dynamic performance befitting a premium vehicle. Toward that end, it adopts Nissan’s newly developed VC-Turbo variable compression ratio engine along with a new platform and suspension, enabling the QX50 to provide top-level dynamic performance as a premium SUV while satisfying the latest fuel economy, emissions and safety requirements.

This article describes the aims set for the handling, stability, ride comfort and noise and vibration performance of the new QX50 as well as the technologies adopted to achieve high levels of these attributes.

Key words : Vehicle Dynamics, Chassis, ride comfort, ride quality, Noise, Vibration
2. INFINITIの目指すダイナミック・パフォーマンス

INFINITIブランドが目指すプレミアムセグメントの動性能の価値として、以下の二つのコンセプトを掲げて開発を行った。

- 長時間の高速走行でも疲れない
  例えばフライデイで流れに乗って巡環するシーンで、乗客が疲労を感じることなく快適に移動できることを目指す価値として。それを実現するためには、車速コントロールが容易な動性性能、車線コントロールが容易な操船特性を兼ね備えることで快適で安心したドライビングができるか、さらにキャビンの静音性とフロアの耐振性を高めることでキャビン内を快適な移動空間にすることを目指した。

- 上手く運転できるように感じる
  主にワインディングでドライバが積極的にハンドル操作を行うシーンで、期待以上の正確な走りができること、それによって感じる安心感を目指す価値とした。それを実現するためには、応答の良さを感じる運操、容機特性に加えてドライバを高揚させる加速サウンド、そして乗員の快適性、安心感を高めるべく適宜に抑えられたボディモーションの実現を目指した。

3. 静音性（NVH）

プレミアムセグメントでは静音性は重要な要素であり、新型QX50でセグメントトップの静音性を目指すに開発を行った。新型QX50は搭載エンジンが前型車のVQ37から世界初の可変圧縮比エンジンVCターボとなり、音振への影響は、①複リンク化によるエンジン振動の変化、②ダウンサイジングターボ化により1気筒あたりのトルク量増加による加振力の増大、③高圧縮化による燃焼速度上昇に伴う高圧度の加振力の増大、3点があったが、数々の技術によってセグメントトップレベルの静音性を達成している。以下に詳細について説明する。

まず①に関して、図2に従来エンジンとVCターボとの構造比較を示す。

VCターボはビストンと4極リンク機構で構成された複リンク機構であり、運動部品が増えたことによる慣性力変

with steering characteristics that facilitate easy lane control, thereby enabling comfortable driving with a secure feel. In addition, interior quietness and the anti-vibration performance of the floor were enhanced with the aim of creating a cabin space for traveling in comfort.

- A feeling of being able to drive skillfully

The targeted value is to give drivers a secure feel by being able to drive more accurately than expected in situations where they are steering aggressively mainly on winding roads. To achieve that, responsive power and steering characteristics are provided along with an uplifting acceleration sound for inspiring the driver. Another aim was to suppress vehicle body motions to a suitable level for enhancing the comfort and secure feel of the passengers.

3. Noise, Vibration and Harshness

Quietness is a key element of vehicles in the premium segment, and the new QX50 has been developed with the aim of providing segment-leading quietness. Powering the new QX50 is the VC-Turbo, the world’s first variable compression ratio engine that replaces the VQ37 engine of the previous model. There are three aspects of the VC-Turbo that affect noise and vibration: (1) increase in engine vibration due to the multi-link mechanism, (2) increase in excitation force due to the greater torque volume per cylinder resulting from the downsizing of the turbo engine, and (3) increase in high-frequency excitation force accompanying the faster combustion velocity due to the higher compression ratio. However, the application of numerous technologies enables the QX50 to attain segment-leading quietness. The details of these technologies are explained below.

First, with regard to aspect (1), Fig. 2 compares the structure of a conventional engine and the VC-Turbo. The structure of the VC-Turbo consists of the piston and a multi-link mechanism comprising four links. There was concern that the larger number of moving parts would increase the inertial force, but the inertial force generated by each link of the 4-link mechanism is cancelled by the individual link geometry. As a result, the inertial excitation force in both the vertical and lateral directions is reduced to the excitation force level of an engine fitted with a balancer shaft system (Figs. 3 and 4).

With regard to aspect (2), when a V6 engine is replaced with an inline 4-cylinder engine, the torque capacity per individual cylinder is increased in order to generate equivalent engine torque. Consequently, torque fluctuation causes second-order engine vibration to worsen. However, compared with a conventional engine, the inertial excitation force of the VC-Turbo increases because of the multi-link mechanism, so greater force is available for cancelling the combustion excitation force. For that reason, there is less torque fluctuation than for a conventional 4-cylinder engine, and the VC-Turbo has approximately the same level of torque fluctuation as a V6 engine (Fig. 5).
化が懸案であるが、4個リンク機構の各リンクに発生する慣性力を、各々で打ち消すリンクオメトリとした。その結果、上下方向、左右方向の慣性加振力はいずれもバランスシャフト付エンジン並の加振力に低減している（図3、図4）。

②に関して、V型6気筒エンジンを直列4気筒エンジンへ転換した場合、同等のエンジントルクを発生させるためには、単位気筒あたりのトルク量が増える。そのためトルク変化によるエンジン2次振動が悪化する。ただし、VCターボの従来のエンジンに対して、複リンク化したことで慣性加振力が増えるため、燃焼加振力に対するキャンセル力が増え、加振力が悪化することになる。そのため、従来の4気筒エンジンに比べてトルク変動が小さく、V型6気筒エンジンとほぼ同等のトルク変動となっている（図5）。

③に関して、燃費向上のための高圧縮化による燃焼速度の上昇によって、高周波の加振力が増しエンジン振動が悪化する。図6に気筒内圧力の変化を示す。

VCターボでトルクが増加しているが、高い静音性を実現させるには、このようなトルクを受けた状態で、高周波の加振力の伝達をいかに低減できるかがポイントである。

従来これらの両立のために、電動アクティブコントロールマウント（E-ACMs）をパスファインダーHEVなどで採用したが、QX50の場合は新型エンジンマウントシステムを採用した。これにより、VC-Turboのエンジンを小型化することで大型のエンジンに比べてトルクが増加するが、従来のE-ACMsよりも空間を節約し、軽量化、コストダウンが実現した（図7）。

An outline of the ATR operating principle is explained here. The increase in combustion velocity owing to the higher compression ratio increases high-frequency excitation force, which worsens engine vibration. Figure 6 shows the change in the cylinder pressure level in relation to the compression ratio.

While the VC-Turbo generates greater torque, it achieves a high level of quietness. The key point for accomplishing that is how the transmission of high-frequency excitation force is reduced under a condition where such large torque is produced.

Previously, the Pathfinder HEV and other models adopted electronic active control engine mounts (E-ACMs) in order to reconcile large torque with quietness. The new QX50 features a novel engine mount system called Active Torque Rod (ATR) that combines active and passive control. This system is applied to the upper torque rods that are subjected to the engine's large roll reaction force. This enables the downsized high-torque VC-Turbo engine to be mounted with a pendulum mounting system. Compared with the previous E-ACMs, the ATR system is space-saving, lighter and less expensive. Figure 7 shows the two systems schematically.

With regard to aspect (3), the faster combustion velocity due to the higher compression ratio for improving fuel economy increases high-frequency excitation force, which worsens engine vibration. Figure 6 shows the change in the cylinder pressure level in relation to the compression ratio.
用いてきているが、新型QX50ではバッシブとアクティブを活用した新しいマウントシステムであるアクティブトルクロッド（ATR）を、エンジンのロール反力を大きく受けるアッパーロールクロッドに採用することで、高トルクのダウンサイジングエンジンVCターボをベンデュラムマウントシステムで搭載することを実現した。ATRは従来の電動アクティブコントロールマウントに比べ省スペース、軽量、安価なシステムとなっている。システムの概略図を図7に示す。

ATRの原理概要は以下の通りである。高圧縮化による燃焼速度の上昇によって、高周波の加振力が増大することと加速時騒音領域（250〜800Hz）のエンジン振動入力が悪化する。この悪化のリカバリーメートとして、トルクロッド共振を200Hz以下に設定し、トルクロッド共振の防振領域を拡大することでエンジン振動入力を低減する。一方でトルクロッド共振によるこもり音領域の伝達力の悪化は、トルクロッドの中間質量に加え制御力によりトルクロッド共振の伝達力を低減する（図8）。

新型QX50に採用したATRの構成概要図を図9に示す。本システムでは、制御力の発生には慣性マスアクチュエータが用いられている。加速度出力アクチュエータ（E-ACM）を駆動部とするアクティブトルクロッドアーム（ATR）が、エンジンロールマウントに取り付けられ、車体の纵向に対して制御力が作用する。制御力は、アクチュエータの制御力に応じて変調され、制御力の出力をフィードバックされる。これにより、エンジンロールマウントの加振入力が減衰され、車両の乗り心地が向上する。
With the pendulum mounting system used on the new QX50, ATR technology was adopted for the upper torque rods that contribute greatly to acceleration noise as shown in Fig. 10.

Next, we will explain the acceleration noise and booming noise levels attained by the new QX50. Acceleration noise has been substantially reduced compared with conventional upper torque rods by expanding the anti-vibration region as a result of setting the ATR resonance below 200 Hz (Fig. 11). This results in an interior noise level that is equal to or better than that of rival companies’ vehicles (Fig. 12).

ATR control has also markedly reduced booming noise, as intended, in the torque rod resonance region (Fig. 13). As a result, the booming noise level attained is equal to that of a vehicle with an inline 4-cylinder engine fitted with a balancer shaft system (Fig. 14).

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**Fig. 10** Pendulum Mounting System

**Fig. 11** Effect of ATR on acceleration noise (250-800 Hz band-pass filter)

**Fig. 12** Comparison of interior noise levels

**Fig. 13** Effect of ATR control on engine 2nd-order vibration

**Fig. 14** Comparison of engine 2nd-order booming noise

**Fig. 15** Representative index for solidly built feeling
4. しっかり感

長時間の高速走行でも疲れず、またお客様にプレミアムセグメントに相応しい高級感を実感していただくために
は、乗員が感じる不快感を低減することが重要である。

新型QX50開発においては、特に内装を高めた際の車室内に響く音と車体を伝わる振動の収まり、またその音色を着目して開発し、高級感・しっかり感を演出した。音
と振動の収まりが早い、またその音色が豊かなほどそのクルマに高級感・しっかり感を感じることができる（図15）。

しっかり感向上のために重要となるのが車体剛性であり、剛性向上が求められる。しかし、一般的に車体剛性を
向上すると質量増加が背反となるため、燃費制約がある中、如何に両立させるかが課題となる。この課題に対して
新型QX50では車体各部位の構造を見直すことで、質量増
加を抑えつつ剛性向上を達成した。これに貢献している技術
が、車体周辺に取り込まれた環状構造とフロア面に施され
た複雑な構造のビードである。

新型QX50では、突起を乗り越えた際の車体への突き上
げ力等を効率よく受け止めるため、部分的な剛性ではな
く、骨格や平面上で剛性を確保する構造とした。車体に補強
材を施すと、質量増の問題の他に他部品とのレイアウト成
立が課題となる。例えば、フロントサスペンションメンバ
周辺にはエンジン、変速機などのパワートレイン部品が存
在し、補強構造の工夫によるレイアウト課題の解決も必要
となる。

この課題に対し、新型QX50では車体のフロントに2ヶ
所、リヤに2ヶ所の計4ヶ所にも環状の骨格構造を取り入
れ、レイアウトも考慮し、質量の増加を抑えながら剛性
確保に成功した（図16）。

新型QX50のフロアパネルには縦、横、斜め3方向に複
雑に構成されたビードが施されている。一般的にパネルの剛
性向上には板厚増加などの対策がとられるが、先に述
べたように質量増の観点からは望ましくない。そこで採
用されたのがこのビードである。ただし複雑なビード形状
は成形性の観点で制約があるため、剛性と成形性的シミュ
レーションを活用することで最適形状を決定した。これに
より質量増加なくパネル剛性の向上に成功した（図17）。

4. Solidly Built Feeling

Any discomfort that occupants might feel must be
reduced in order to prevent fatigue even during high-speed
driving over long periods of time and also to give customers
a feeling of superb quality befitting the premium segment.

In developing the new QX50, efforts were focused
on controlling vibration transmitted to the body and noise
heard in the interior especially when traveling over bumps
in the road. Careful attention was also paid to tonal quality
in order to develop and project an image of outstanding
quality and a solidly built feeling. The quicker noise and
vibration subsides and the more solid the tonal quality is,
the more customers can perceive the excellent quality and
solidly built feeling of the vehicle (Fig. 15).

Body stiffness is a key factor for improving the
solidly built feeling, making it imperative to improve
stiffness. However, improving body stiffness generally has
a trade-off with an increase in mass, so how to reconcile
both of them within the constraints imposed by fuel
economy is a challenge. This issue was resolved for the
new QX50 by reviewing the structure of each body part,
enabling stiffness to be improved without increasing the
body mass. The technologies contributing to this include
the ring-shaped structures incorporated throughout the
body and the intricately shaped beads applied to the floor
panel.

In order to efficiently absorb the strong upward
inputs to the body when traveling over a bump, the
new QX50 is built with frame and plane structures that
secure stiffness, rather than having partial stiffness
improvements. If members are applied to the body to
augment stiffness, there is a problem of increased mass
and also the possibility that the layout with other parts
may not be viable. For example, powertrain parts like
the engine and transmission are present near the front
suspension. Layout issues must be resolved through the
application of innovative stiffening structures.

To resolve this challenge, ring-shaped frame
structures were applied to the body of the new QX50 at
four locations, two in front and two at the rear. By also
taking into account the layout, this approach successfully
secured the desired stiffness while holding down the
increase in mass (Fig. 16).
Intricate bead shapes have been applied to the floor panel of the new QX50 in three directions: longitudinal, lateral and oblique. Body panel stiffness is generally improved by increasing the panel gauge, among other measures, but that approach was not desirable from standpoint of the mass increase. Therefore, it was decided to apply beads. However, intricately shaped beads have limitations with regard to formability, so the optimal shapes were determined by conducting stiffness and formability simulations. This successfully improved panel stiffness without any increase in body mass (Fig. 17).

The application of these innovative body structures was effective in efficiently improving the body stiffness of the new QX50, thereby achieving the best solidly built feeling in the premium segment (Figs. 18 and 19).

5. Vehicle Body Motions

For an SUV with a high vehicle height, stable vehicle body motions even on an undulating road surface are essential for giving occupants a comfortable, secure feel.

The front suspension of the new QX50 adopts shock absorbers with a built-in displacement sensor. The base valve and piston valve that act against tiny vertical inputs from the road surface are designed to produce relatively weak damping force. For large force inputs, a floating valve provides additional damping force (Fig. 20). This technology achieves high ride quality when traveling straight ahead in city driving, while suitably suppressing vehicle body motions during cornering and when traveling on undulating roads to give occupants a highly comfortable ride with a secure feel.

In addition, the shape of the seat back has been formed to match the curvature of the human back so as to provide a comfortable ride with little body sway even in high-speed driving over long periods of time. Figure 21 presents comparative data for body sway (i.e., lateral acceleration at an occupant's chest position) measured during freeway driving in the U.S. The results indicate that the frequency of sudden body sway is markedly smaller in the QX50 compared with other vehicles in the same segment.
QX50は同セグメント他車に対して、唐突に体が揺られる頻度が極めて少ないことが分かる。

6. Driving Performance with Minimal Steering Corrections

One feature of vehicle characteristics that do not cause fatigue even during high-speed driving over an extended period of time is minimal steering corrections when driving on a specified course (Fig. 22). This section describes the technologies adopted on the new QX50 to reduce the amount of steering corrections.

The driving characteristics of drivers were analyzed in closed-loop tests conducted on a driving simulator. The results revealed that suppressing the vehicle response delay up to a steering input frequency of around 5 Hz in the transfer system from a steering input to the tire contact point is effective in reducing the steering correction amount. Accordingly, the new QX50 has been engineered with sufficient body and suspension stiffness to reduce this phase delay.

As shown in Fig. 23, the newly designed front suspension of the QX50 increases the knuckle arm radius by over 30% compared with that of the previous model as a result of reviewing the vehicle layout. That improves the steering system stiffness of the QX50 to the top level among rival models. As a result, vehicle characteristics have been achieved that produce a linear yaw rate relative to the driver's steering inputs during straight ahead driving.

In addition, the wheel alignment was reviewed to achieve a class-leading caster angle setting that enables an ample yaw rate and recovery force (i.e., self-aligning torque) to be generated without delay in relation to the driver's tiny steering inputs during straight ahead driving.
て、ヨーレイトと復元力（セルフアイニングトルク）を遅れなく十分に発生させることができ、ドライバが楽に運転できる車両特性としている。

また新型QX50には電動パワーステアリングのほかに、Q50から採用されたINFINITIブランド独自のダイレクティブアダプティブ・ステアリングもオプション設定されている。ステアリングホイールとタイヤが機械的に連結されていないため、通常のステアリングではドライバに伝えてしまう路面のわだち、凹凸による外乱入力を遮断しつつ、反力モータで発生させた理想的な操舵反力をドライバに伝える。さらにドライバのハンドル操作を補正制御してタイヤに伝えすることで、急な切り返しなどの切り遅れがちなシーンでも正確にタイヤを動かし、走行することができる。

これら機能によってダイレクト・アダプティブ・ステアリング装着車では、より直観的で安心感の高い走りが可能となり、劇的に修正操舵量を低減することができた（図24）。

7. ま と め

新型INFINITI QX50は、採用した新型プラットフォーム、世界初の可変圧縮比エンジンVCターボ、アクティブトルクロッド、新型サスペンションなどに、長年培ってきた日産のダイナミック・パフォーマンスの先進技術を適用することで、目指す動性能の価値である“長時間の高速走行でも疲れない”、“手早く運転できるように感じる”を実現することができた。

既に米国では発売を開始しており、多数のメディアによってプレミアムコンパクトSUVの中でも卓越した動性能が賞賛されている。今後もより幅広い層でのINFINITIブランドのロイヤルスタマを獲得すべく、魅力的な動性能の磨きこみに取り組んでいく。

8. 参 考 文 献

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These vehicle characteristics enable exceptional driving ease.

Besides being equipped with electric power steering, INFINITI’s unique Direct Adaptive Steering, which was first adopted on the Q50, is also optionally available on the new QX50. Because there are no mechanical links between the steering wheel and the tires in this system, it feeds back to the driver only the ideal steering reaction force generated by the reaction force motor, while blocking external disturbances input from road surface ruts, dips and bumps that are usually fed back to the driver in a conventional steering system. Moreover, the driver’s steering actions are transmitted to the tires under compensation control, enabling driving in which the tires are steered precisely even in situations where the driver’s steering action tends to be delayed such as when making a quick turn.

For vehicles equipped with Direct Adaptive Steering, these functions dramatically reduce the steering correction amount to provide a more intuitive driving experience with an enhanced secure feel (Fig. 24).

7. Conclusion

The new INFINITI QX50 incorporates many advanced dynamic performance technologies accumulated by Nissan over many years, including an all-new platform, the VC-Turbo as the world’s first variable compression ratio engine, Active Torque Rod, and an all-new suspension, among others. These technologies enable the QX50 to provide the targeted dynamic performance values of no fatigue even after a long hours of high-speed driving and a feeling of being able to drive skillfully.

Sales of the QX50 have already been launched in the U.S. where its outstanding dynamic performance among premium compact SUVs has been highly acclaimed by many media. In the future, we intend to further refine its attractive dynamic performance so as to obtain more loyal INFINITI customers among a wider range of car buyers.

8. References

Dynamic Performance Technologies on the New INFINITI QX50

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1. Introduction

A driving simulator is widely known to be a valuable validation tool in vehicle development work because anyone can safely experience designed and simulated vehicle performance without building a physical prototype. It is expected that the use of a driving simulator especially in the development of autonomous driving technologies and vehicle dynamic performance will substantially improve design accuracy. A driving simulator mainly requires image technology for providing visual information and motion technology for imparting somatic sensations. In using a driving simulator in the development of autonomous driving technologies and vehicle dynamic performance, it is expected that the use of a driving simulator will substantially improve design accuracy. A driving simulator primarily requires image technology for providing visual information and motion technology for imparting somatic sensations. In using a driving simulator in the development of autonomous driving technologies and vehicle dynamic performance, it is expected that the use of a driving simulator will substantially improve design accuracy. A driving simulator primarily requires image technology for providing visual information and motion technology for imparting somatic sensations. In using a driving simulator in the development of autonomous driving technologies and vehicle dynamic performance, it is expected that the use of a driving simulator will substantially improve design accuracy. A driving simulator primarily requires image technology for providing visual information and motion technology for imparting somatic sensations. In using a driving simulator in the development of autonomous driving technologies and vehicle dynamic performance, it is expected that the use of a driving simulator will substantially improve design accuracy.

Key words: Performance, driving simulator, motion system, dynamic performance
of vehicle dynamic performance, it is necessary to recreate faithfully the motions of a vehicle so as to obtain sensations equal to those of an actual vehicle. For that purpose, motion technology is especially important. The appearance of our newly developed driving simulator is shown in Fig. 1.

This article mainly describes the details of the motion technology developed for this driving simulator with the aim of using it in evaluating vehicle dynamic performance.

2. Development Concept

A driving simulator imparts somatic sensations by moving the driver by means of actuators that constitute what is called the motion system. To accomplish that, new actuators were developed that can accurately and responsively generate high levels of acceleration. Notably, an XY-translation device, consisting of X-axis and Y-axis rails with a long stroke, adopts linear motor-based direct drive technology in its drive system to enable responsive movement of large, heavy objects and linear ball guides in its guideways. This has resulted in the development of a lightweight device with high stiffness.

3. System

3.1 Configuration

The newly developed driving simulator consists of motion systems that recreate vehicle acceleration, an image projection system for presenting visual information, and a cockpit system that presents sounds and the reaction forces of the operating systems and is equipped with a driver’s seat. A hexapod (six-axis swiveling device) is positioned on top of the XY-translation device comprising the X-axis and Y-axis rails that move longitudinally and laterally. A dome is located on top of the hexapod. The inner walls of the dome are mounted with screens that show 360-degree omnidirectional images from seven projectors. Inside the dome is a turntable that revolves.
A cockpit against the screens. The configuration of the overall driving simulator system is shown in Fig. 2, and Fig. 3 shows the control system configuration. Signals from the vehicle operating systems such as the steering wheel, brake pedal and accelerator pedal are input into a vehicle dynamics simulation model along with information on the road surface condition; the calculated steering reaction force and braking reaction force of these operating systems are presented to the driver.

The calculated acceleration that moves each of the motion systems via the motion control logic, which was developed independently in-house, is presented to the driver. Images of the road, surrounding environment and traffic flow are calculated in relation to the driver and projected on the screens via the projector system. These operations are processed on the basis of a real-time vehicle dynamics simulation in a step size of 1 ms, enabling the system to reduce any delay in the visual information and somatic sensations perceived by the driver.

3.2 Motion systems

In addition to the XY-translation device that generates acceleration in the XY-axes, other motion systems include the hexapod that reproduces yaw, roll, pitch and acceleration in the XYZ directions and the turntable that reproduces yaw motion. The XY-translation device allows an 11-m stroke on one side in the Y-axis direction, which assumes a lane change maneuver in ordinary expressway driving. The maximum acceleration was set at 12 m/s² for the purpose of reproducing vehicle acceleration in a double lane change maneuver for emergency avoidance. Response was defined so as to avoid any feeling of delay in vehicle movement based on advance confirmation by a skilled driver. The development aim was to achieve high output and high response, with a maximum dead time of 5 ms and a maximum time constant of 30 ms defined for a step response. The specifications of each motion system are given in Table 1.

There is an especially heavy weight of around 40 t in total on the Y-axis rail of the XY-translation device because it carries large, heavy objects such as the X-axis rail, hexapod, dome, turntable and the cockpit. When loaded with these heavy objects, the base, referred to here as the Y-axis saddle, of the long XY-translation device can move with high response at a maximum acceleration of 12 m/s² and a maximum velocity of 10 m/s. The development of the equipment to facilitate such performance was a key aspect of this driving simulator. Therefore, linear motor-based direct drive technology was adopted for the drive system to ensure high acceleration/deceleration performance over the long stroke. The structure of a linear motor unit is shown schematically in Fig. 4. In order to generate large thrust, a drive system was developed with multiple linear motors arranged in two rows at both ends of the saddle. The motors are controlled simultaneously to produce the maximum thrust required. A control program was

<table>
<thead>
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<td>XY-axis rails</td>
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</tr>
<tr>
<td>X</td>
<td>± 3</td>
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<tr>
<td>Y</td>
<td>± 11</td>
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<tr>
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<tr>
<td>X</td>
<td>± 0.3</td>
</tr>
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<td>Y</td>
<td>± 0.3</td>
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<tr>
<td>Z</td>
<td>± 0.25</td>
</tr>
<tr>
<td>Roll</td>
<td>± 15</td>
</tr>
<tr>
<td>Pitch</td>
<td>± 15</td>
</tr>
<tr>
<td>Yaw</td>
<td>± 15</td>
</tr>
<tr>
<td>Turntable</td>
<td></td>
</tr>
<tr>
<td>Yaw</td>
<td>± 160</td>
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Fig. 4 Linear motor unit
Development of a High-performance Driving Simulator

剛性が高く、直進時の上下、左右の変位が少ないことから工作機械などに用いられている精密なリアガードを採用した。また、通常の使い方に対し連転速度が2～3倍速いため、高速での使用に対する耐久性確保を目的として、市販品に対し部品材料の変更などを実施した特殊なリアガードを新規に開発した。さらに、ユニット単体での走行耐久評価を実施し、10m/sの速度運転での耐久性を保証した。

レールの組み付け誤差に関しては、独立した3列のベアース部分に複数の長尺自動調査のレールを必要と組み付け誤差内に設置するために、新たに開発した専用治具及び計測器を用いて組み付けを実施し、70μm以下の平行度の取り付け精度を実現した。

その他にも、応答性を果たすための重要な開発要素として、XY並進装置の剛性を確保することが求められる。一方、可動するサドル部分については、リアモータの出力要件から軽量である必要がある。そこで今回、高剛性かつ軽量なサドルを実現するために、鋼管構造を採用した。設計段階では、モーションシステムのサーボ系と機械系をモデル化した応答性シミュレーションを実施し、要求の応答性を達成するために必要な機械系の固有周波数を満足するように、設計値を42Hz以上とし、有限要素法（FEM）による構造解析を用いて設計を実施した（図5）。実機での検証結果は45Hzであった。

上記にて開発したXY並進装置単体で、ステップ応答試験を実施した。すなわち目標値5ミリ秒以下に対し2ミリ秒、時定数目標30ミリ秒以下に対し23ミリ秒という結果が得られ、目標を達成できた。

4. 検 証

DSの完成状態における検証として、実際のテストコースにて実車でレンチングをした結果と、実車とコリレーションをとった車両運動解析で実体と同一の操作入力をした場合の車両の横加速度の計算結果をDSのモーションシステムで発生させた結果を、時系列データで比較した。試験時の車速は65km/hとし、図6に示す操作角を入力している。図7に実車とDSのコックピット内での計測した横加速度を示す。実車波形に対し少ない違いで追従し、加速度ピークも再現できており、車両挙動を確認できた。また、スキルドライバーによる評価においても、車両特性の違いによる挙動の違いを実車同様に感じられるとのコメントを得られた。

従来の実車を使ったダイナミック・パフォーマンスの検証実験では、実際の部品やシステムを変更することで車両特性を変更できない。そのため、以下の様々な課題がある。

(1) 部品やシステムの特性変更に伴って複数の車両特性が同時に変わってしまうため、特定の車両特性のみを
developed that can change the motor output characteristics on both sides to ensure smooth movement in the event that an unbalanced load occurs due to a different position of the dome on the X-axis rail or an inclination of the hexapod.

Precision linear guides were adopted for the supporting guideways so as to achieve little sliding resistance during movement and not cause the driver any unintended vibration. Such guides are often used for machine tools and other equipment because they have high stiffness and show little vertical and lateral displacement in straight-ahead movement. Special-purpose linear guides were newly developed by changing the part materials compared with commercial products in order to ensure ample durability for high-speed use because the operating speed would be 2-3 times faster than that of ordinary applications. The durability of the guides by themselves was evaluated in driving tests and the results confirmed that sufficient durability could be guaranteed for high-speed operation at 10 m/s.

The rails were installed using newly developed dedicated jigs and measuring instruments in order to install the long rails with multiple direct-acting bearings in the base in three independent rows within the allowable installation error required. Installation accuracy in terms of maximum parallelism error of 70 μm was achieved.

Another important development element for achieving the desired responsiveness was to ensure the necessary stiffness of the XY-translation device. On the other hand, the movable saddle had to be light in weight because of the output performance of the linear motors. Therefore, a steel pipe structure was adopted to obtain a lightweight saddle with high stiffness. At the design stage, a response simulation was conducted using models of the servo system and mechanical system of the motion systems. A design value of 42 Hz was set so as to satisfy the natural frequency required of the mechanical system for achieving the desired responsiveness. The design was executed on the basis of a structural analysis conducted with the finite element method (FEM). As shown in Fig. 5, the result measured in a validation test of an actual saddle was 45 Hz.

A step response test was conducted on the XY-translation device that was developed as described above. The results showed a dead time of 2 ms in relation to the targeted time of 5 ms maximum and a time constant...
of 23 ms in relation to the target of 30 ms maximum. This confirmed that the development targets were achieved.

4. Validation

Validation of the completed driving simulator was done by making a comparison with the results recorded for a lane change maneuver executed by a test vehicle on an actual test course. The same operational inputs as those applied to the test vehicle were input into a vehicle dynamics simulation model having a proven correlation with the test vehicle. The calculated lateral acceleration of the vehicle and the lateral acceleration produced by the motion systems of the driving simulator were compared by examining their time series data. The vehicle speed in the experiment was set at 85 km/h and the steering angle input for the lane change is plotted in Fig. 6. Figure 7 compares the lateral acceleration measured for the test vehicle and that measured in the cockpit of the driving simulator. The waveform of the driving simulator traces that of the test vehicle with little delay and also reproduces the acceleration peak, thereby confirming that the test vehicle behavior was reproduced. In evaluations conducted with skilled drivers, they commented that differences in vehicle behavior due to different vehicle characteristics were perceived in the same way with the driving simulator as in the actual vehicles.

In validation testing of dynamic performance heretofore using actual vehicles, vehicle characteristics could only be varied by changing actual parts or systems, which gave rise to the following issues.

1) Multiple vehicle characteristics changed simultaneously as a result of changing parts or system characteristics. That made it difficult to change the details of only particular vehicle characteristics and to evaluate the difference. It was difficult to ensure the accuracy of the validation exercise.

2) It took time to produce prototypes of parts or systems and the number of prototypes that could be built was limited. That made it difficult to conduct validation exercises efficiently.

These issues can be resolved by combining the driving simulator described here with a vehicle dynamics simulation model that allows vehicle characteristics to be changed digitally at will. It is expected that this would enable validation of vehicle characteristics ideal to drivers and efficient validation of parts and system characteristics for achieving targeted vehicle characteristics.

5. Conclusion

Motion systems with high accuracy and responsiveness were developed and applied to develop a driving simulator intended for use in evaluating vehicle dynamic performance. In driving simulation tests for validating the completed driving simulator, it was confirmed that the lateral acceleration waveform measured with the simulator traced that of an actual vehicle with little delay and that differences in vehicle characteristics could be experienced.
Development of a High-performance Driving Simulator

with the simulator. The driving simulator will be used in developing new models in the future and is expected to contribute to improving the dynamic performance of Nissan vehicles so as to respond better to the strong demands of customers in this regard.

6. References

応用脳科学の視点からみたダイナミック・パフォーマンス

Dynamic Performance from Applied Neuroscience Perspective

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抄録
本稿では、ダイナミック・パフォーマンスの評価手法として脳波（EEG）計測を用いた先駆的な取り組みを紹介する。ドライバーの脳波データと実験結果が幾つかの条件下で獲得し、動的応答性を解析する実験を行った。さらに、各実験ではコクピティビティ解析も行った。操作のしやすさに関する計測評価値、二つの脳波解析手法の結果から導いた。高い計測評価値は、MRCPと高い相関を示し、前頭-頚部のアルファ波帯域と強い関係性が見られた。脳活動が低い状態（デフォルト）モードに近い状態にある間、この強い関係性が得られ、MRCPはカーブを曲げる前の手順操作の準備のしやすさに特徴を示すものと解釈できた。

Summary
In this article we present the results of a pioneering attempt to develop an evaluation methodology for vehicles dynamic performance based on electroencephalography (EEG) measurements. An experiment was performed with the subjects driving a car on a simulated road in a driving simulator while there were several condition in the dynamic response of the vehicle. The EEG activity was analyzed during periods just before steering by extracting Motion Related Cortical Potentials (MRCPs). Furthermore, connectivity analysis have been performed for the length of each trial. Subjective evaluations of the easiness of control have been strongly supported by the results of the two EEG analysis methods. Higher subjective scores correlated strongly with deeper MRCPs and with stronger connectivity in alpha band between frontal and parietal areas of the cortex. Deeper MRCPs can be interpreted as signatures of easiness of preparation for steering before each corner, while stronger connectivity shows an overall brain state closer to default mode interpreted as low workload mode.

Key words: Vehicle Dynamics, Performance, measurement, handling, driver behavior, knowledge engineering

1. はじめに

脳波（EEG）信号は、プレインコンピュータイン评测（BCI）を開発するために用れており、脳内の特定の働きや認知状態と相関した脳信号を解釈する手段となっている。本稿では、車のダイナミック・パフォーマンスを評価する計測手法にEEGを用いた新たな取り組みを紹介する。このような技術の開発が成功すれば、例えば、未熟なドライバーのように正確に可能的フィードバックを行うことが難しい場合でも、ダイナミック・パフォーマンスの感じ方について詳細な評価を得ることが可能となる。実際の運転とシミュレーションの双方において、EEGと眼電図（EOG）を基に、覚醒レベルの予測と注意レベルの検出が研究されている(38)。自動車業界は、環境を解釈し必要に応じて車両の制御とドライバへのフィードバックがでる

1. Introduction

Electroencephalography (EEG) signals have been used to develop brain-computer interfaces (BCI) that provide means of interaction by decoding brain signals correlated with specific tasks or cognitive states(31). In this study we present a novel attempt of using EEG measurements in order to develop an evaluation methodology for vehicles' dynamic performance. The successful development of such technology would enable in detail evaluation of dynamic performance perception even for drivers whom are less likely to provide accurate subjective feedback, like for example novice drivers. Arousal level prediction based on electroencephalography (EEG) and electrooculogram (EOG) has been vastly investigated(30), as well as attention level detection, both in real and simulated driving environments(5). At the same time the automobile industry has made big steps towards the implementation of smart cars that could interpret the environment, provide feedback to the driver.
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2. Methods

2.1 Experimental protocol

A simple but realistic driving simulator was used for this experiment (Fig. 1). The layout was close to a small size vehicle using a real automobile electrical seat in order to accommodate the subject in a comfortable driving position. The simulator was fitted with six degrees of freedom highly responsive motion system in order to emulate the dynamics of the vehicle response.

The driving scene simulated a one lane road with four main corners. Ten subjects with normal or corrected

and, if needed, control the vehicle\textsuperscript{[30]}. As cars become more intelligent the interaction with the user may increase (to provide more feedback, or suggest potential maneuvers). Efforts have been made to evaluate precisely the drivers’ workload in order to facilitate information delivery from the vehicle\textsuperscript{[30]}. Our philosophy is to survey the drivers’ brain activity related to driving, and to use these results in order to build and evaluator of the dynamic response of the vehicle with respect of the steering input. We focus on leveraging two different relatively new applied neuroscience breakthroughs. One is know how on neural correlates of movement. One of the first reports of neural correlates of movement was made by Kornhuber and Deecke back in 1965 showing a slow cortical potential (SCP) appearing 1.5 s before movement\textsuperscript{[31,32]}. Libet et al. made a deep analysis of these potentials proving the presence of preparatory brain activity beginning 1 s before the onset of movement\textsuperscript{[33,34]}. Several preliminary studies aimed at detecting movement intention showed encouraging results\textsuperscript{[35,36]}. On the other hand, few attempts have been made to predict drivers’ motion while driving. Haufe et al. build a system to predict the timing of braking when the car in front slows down\textsuperscript{[37]}. Gheorghe et al. were the first to present the possibility of extracting Motion Related Cortical Potentials (MRCPs) correlated with steering actions while driving a driving simulator\textsuperscript{[38]}. At the same time focusing on the differences of the characteristics of the MRCPs, Suzuki et al. showed clear correlations between the depth of MRCP and the performance of a sensorimotor task\textsuperscript{[39,40]}. We aim at building evaluators of the depth of MRCP relative to steering actions and observe the correlation with the dynamic performance of the vehicle response.

The second is the ability of performing connectivity analysis using EEG recordings and recent results on such connectivity interpretation. Zhang et al. have been the first reporting techniques to retrieve connectivity information from EEG signals while driving\textsuperscript{[30]}. On the other hand an in depth fMRI study performed by Palva et al. explained the meaning of alpha band synchronization between different areas of the cortex\textsuperscript{[39]}. On finding was that higher frontoparietal synchronization can be interpreted as easiness of allocation for resources in sensory motor task. In this study we aim to build fronto-parietal alpha band synchronization methodology based on EEG and observe the correlation with vehicle dynamic response during a steering task.
to normal vision were instructed to drive at constant speed (approx. 80 km/h) and to subjectively evaluate the dynamic response of the vehicle. Six different conditions were implemented by setting three independent parameters: the delay in phase of the yaw rate, the delay in phase of the lateral acceleration and the delay in phase of the roll angle with respect to the phase of the steering angle. The set up for each of the case are presented in Table 1. This experiment was conducted after details were reviewed and approved by Nissan Motor Ethics Committee, and informed consent was obtained from the participants.

Steering and pedal positions, vehicle dynamics and the position of the vehicle in space were recorded at a sampling rate of 256 Hz. Another computer recorded 64 EEG channels (Biosemi ActiveElectrodes) placed according to the 10/20 extended standard at 2048 Hz and down sampled at 256 Hz. The two recordings were synchronized by a hardware trigger. The recording was split in 12 sessions of 10 minutes recorded the same day. At the subject’s request shorter or larger breaks were taken between the sessions with the goal of keeping low fatigue and high concentration levels throughout all the sessions. In order to adapt to the driving simulator visual field and to the controls, a trial driving session was performed before the experiment by all subjects. At that time the driving simulator sickness tendencies were also evaluated with all the subjects and no subject showed sickness symptoms.

For each session a different dynamic response of the vehicle has been set up. The three parameters were changed between sessions.

### 2.2 Driving data processing

The simulated road emulates a part of an existing test course having in sight a follow up experiment in real vehicles. The shape of the road used is presented in Fig. 2 (a). The subjects were instructed to drive at a constant speed of 80km/h and one run was about 90 s. Four main corners were used for the evaluation of motor cortex preparatory activity. First the data sequence was segmented based on the 3D position of the vehicle extracting the portions preceding the curves. The red segments in Fig. 2 (a) present the respective portions corresponding to each of the four corners. Next the onset of the steering was extracted using the steering profiles during the extracted segments. The steering profile for one subject for one run is presented. The black dots in Fig. 2 (b) present the detected

<table>
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<td><strong>Lateral G.</strong></td>
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<tr>
<td><strong>Roll angle</strong></td>
<td>60</td>
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(a) 運転シミュレータにおける実験参加者用運転席
Driver seat for the subjects in the driving simulator

(b) 視界となるスクリーン例
Example of visual field showing in the simulator

図-1 実験プロトコル
Fig. 1 Experimental protocol
point which represent the initiation of the steering action necessary to drive through each corner. This timing was used for EEG data segmentation and grand average calculation in the MRCP evaluation.

On the other hand connectivity analysis was performed using the continuous data from the beginning of the first corner until the end of the last corner.

2.3 EEG signal processing MRCP

The EEG signals were filtered between 0.1Hz and 1Hz using a 4th order Butterworth filter. Next, in order to remove background brain activity the average of sensors T7 and T8 has been subtracted from all the channels. Finally, the mean value was subtracted from each channel as baseline alignment.

Each time the driver initiated the steering movement in one of the 4 corners, a new trial was defined. Each trial was defined as an interval of [-4 s to 4 s] with 0 s as the timing of the steering onset. Note that for this study, left and right steering actions were considered together. The subject drove 10 times the same condition, meaning that only 40 (4 corners x 10 runs) relevant actions could be retrieved for each subject. In order to perform nomenclature and averages shape comparison we decided to use the grand average between all the subjects for each of the conditions. From a pool of 400 trials, about 10% were rejected due to strong movement or muscle activity artifacts. The rejection was performed by setting a threshold for the signals from the sensors in the proximity of Cz sensor (located close to the motor cortex area) to ±50 μV after the preprocessing.

Figures 3 (a) and (b) show the grand averages for the epochs on Cz for one condition A and B. t=0 s is the onset of the steering action. A negative potential locked on the onset of movement builds up in the first half of the steering period and recovers afterward. The other 4 conditions showed similar topologies with some differences in trend strength. For the each trial a negative potential builds up more than 1 s before the onset of the movement, akin to the reported MRCP. The topographic display in Fig. 4 shows that the negative potential is spread over the motor cortex.

And automated algorithm was built in order to calculate the slope of the MRCP for each of the condition. The peak of the MRCP, just after the onset of the movement was detected and the segment of 2 s before the peak was extracted. The thick segment in Figs. 3 (a) and (b) show the selected data. For such segments the slope of the negativity was calculated as the slope of the linear approximation of the segment. As Suzuki et al. research presented this slope would be correlated with the performance of the task performed.

2.4 EEG signal processing connectivity analysis

In this study, the method used to compute brain connectivity is directed transfer function (DTF), which is based on the estimation of multivariate autoregressive model (MVAR), and is an extension of Granger causality. 

2.2 運転データ処理

シミュレータに映し出される道路は、実際の車両で既存のテストコースの一部を模擬化したものである。その道路の形状を図2(a)に示す。実験参加者は80km/hの一定速度で運転するよう指示され、1回の運転は約90秒である。運転時の運動計測を評価するために、四つのコーナを用意した。最初に、コーナに差しかかる前の車両の3D位置に基づいてハンドル操作データの配列を区分化した。図2(a)の赤色区分は、四つのコーナそれぞれを示している。次に、ハンドル操作開始点は、各区分間の軌跡を用いて抽出された。図2(b)の黒い点は、各コーナを通過するのに必要なハンドル操作の開始点を示している。このタイミングは、MRCP評価におけるEEGデータの区分分けとMRCPの評価に活用した。一方、コネクティビティ解析は、最初のコーナの進入時から最後のコーナの退出時までの連続データを使用した。

2.3 MRCPの信号処理

EEG信号は、4次元のパタワースフィルタを使い0.1～1.0Hz以下の周波数帯域を用いた。次に、バックグラウンド脳活動を除去するために、センサT7およびT8の平均をすべてのチャネルから差し引いた。最後に、平均値をパーソナルデータに適用し、データを10回繰り返した。
スラインの基準として各チャネルから差し引いた。実験参加者が四つのコーナそれぞれでハンドル操作を開始した時点を1試行の中心として定義した。各試行はハンドル操作開始の4秒前～4秒後を1セットとして定義した。この研究では、左右のハンドル操作を併せて検討したことに関注した。実験参加者は同じ条件下で10回の試行を行った。つまり、各参加者の40回（4コーナ×10回）の行動データを取り込んだことになる。命令による評価と平均形態の比較を行うために、各条件について全参加者の総平均を使用することとした。全体で400回に及ぶ試行データから、各運動条件または筋肉活動によるアーチファクトを含んだ約10％を除外した。この除外は運動野近くに設置されるCzセンサからの信号、前処理後の信号の値が閾（しきい値）値である±50μVを超えた場合に行われた。

図3(a)と(b)は、条件A、BにおけるCzセンサの細平均値である。t = 0 はハンドル操作の開始点である。ハンドル操作の前半では、動作の開始時にロックされた負の電位が蓄積し、その後、回復する。条件Aは、同様なトポロジーを表し、傾向の強度に著しい違いが見られた。各試験で、負の電位は運動開始の1秒以上前に形成され、報告されたMRCPと類似している。図4のトポグラフィ表示は、負の電位が運動野に広がっていることを示す。

そして、各条件についてMRCPの傾きを計算するために、自動アルゴリズムが構築される。運動の開始点をMRCPのピークが検出され、またピークの2秒前の領域を抽出された。図3(a)～(b)の太線の領域は、選択されたデータを示す。このような領域について、傾きの傾きを領域の直線近似の傾きとして計算した。鈴木らの研究によると、この傾きはタスクの成績と関係がある。

### 2.4 EEG信号処理のコネクティビティ解析

この研究では、脳のコネクティビティは、多変量自己回帰モデル（MVAR）から導かれたもので、グレンジャー因果説の拡張したものである。この方法の基本的な考え方は、ある変数の過去の状態が別の変数の現在の状態の予測に寄与しているかどうかを評価することである。寄与が重要である場合は、最初の変数から予測された変数への因果的な影響がある。

\[ X_t = [x_{1,t}, x_{2,t}, \ldots, x_k,t]^T \]

を、時点tにおけるk個のチャネル（上付きTは行列の転置を表す）を含むEEGサンプルのベクトルであると定義すると、MVARのマトリックス形態は式(1)のよう表すことができる。\( e_t \)はサイズ1×kのゼロ平均ホワイトノイズのベクトルであることを意味し、\( A_0 = -I \)（Iは単位行列）のk×k係数行列である。ここで、pは現在の状態を推定するために、以前のサンプルが幾つ使用されているかを示すモデルの次数である。

The basic idea of this method is to evaluate whether the past states of one variable contributes to the prediction of the current state of another variable. If the contribution is non-trivial, there is a causal influence from the first variable to the predicted variable. Defining \( X_t = [x_{1,t}, x_{2,t}, \ldots, x_k,t]^T \) to be a vectors of an EEG sample including k channels at time point t (superscript T denotes matrix transposition), the matrix form of MVAR model can be represented as in Equation 1. \( e_t \) is a vector of zero-mean white noise with size 1 x k, and \( A_0 = -I \) (I is the identity matrix). Here, \( p \) is the model order, indicating how many previous samples are used to estimate the current state.

\[
X_t = \sum_{i=1}^{p} A(i) X_{t-i} + E_t 
\]

... Equation 1

The estimation of the coefficient matrix \( A(i) \) in Equation 1 could be achieved using Yule-Walker method. We used the Matlab package arfit to compute the coefficient.

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Fig. 3 EEG grand averages of Cz for all subjects

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Fig. 4 Topoplot of electrical activity over the motor cortex related to steering action movement initiation

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matrices. The output of arfit is the estimated coefficient matrix $A(i)$, which is in time domain. In order to focus on activity in particular frequencies we analyze the connectivity in frequency domain. Using Fourier transform, we can analyze the system transfer function in frequency domain, as shown in Equation 2.

$$E^F = A^F X^F = X^F = H^F E^F \quad \cdots \text{式(2)}$$

$H^F = (A^F)^{-1}$ では、$A^F$ は係数行列 $A$ のフーリエ変換であり、$A(0)=\sum \alpha e^{j\omega}$ で、$j$ は虚数単位である。正規化されていないDTF $\theta_{ij}(f)$ は、システム伝達行列 $H^F$ によって定義される。式(3)は、$f$Hzでのチャネル$i$からチャネル$j$への情報転送（方向性のあるコネクティビティ）を表す。DTFの値は、チャネル間に位相差がある場合にのみ、顕著な値を示す。

$$\theta_{ij}^2(f) = |H^F_{ij}(f)|^2 \quad \cdots \text{式(3)}$$

図5に示すように、脳の前頭-頭頂部間のコネクティビティを解析するのに、チャネルPzとFzを使用する。MVARモデルは、50％（5秒）のオーバラップを伴う10秒のスライドウィンドウ内に構築される。ここで、係数は各ウィンドウで取得される。フーリエ変換し、時間ウィンドウを端から端まで平均化した後、主な関心領域であるアルファ波領域の9〜13Hzの平均をさらに算出する。

3. 結 果

図6に、6条件における官能評価を示す。高いスコアは

![図-5 コネクティビティ解析: 前頭-頭頂間のデータ転送に焦点をあてたポールを設定](image)

Fig. 5 Connectivity analysis: pole setting for connectivity focused on data transfer between frontal and parietal areas

![図-6 官能評価: より良い操舵応答性を示す車両が高いスコアとなる](image)

Fig. 6 Subjective score: higher scores mean better control feeling generated by the dynamic response of the vehicle

3. Results

Figure 6 presents the subjective evaluation scores for the 6 conditions, with higher scoring meaning better steering feeling. In this study, we consider this result as the ground truth and we compare the EEG measurements result with rapport to this results. In terms of subjective evaluation conditions A, E and F which introduces no delays or small and balanced delays received high scores while condition B, due to the high delays in all three parameters,
より良い操縦感覚を意味する。この研究では、この結果を検証データとして、EEG計測結果との相関を比較した。

官能評価の観点から、遅れがない条件A、微小の遅れかつ均等の取れた遅れ条件E、Fが高いスコアを得ている。
一方、三つのパラメータすべてのうち最大の遅れという条件Bは、最も低いスコアとなった。

23節で提示した方法論に基づいて、各条件下における総平均を出した後、MRCPの傾きを計算した。MRCPの傾きとタスクの精度には相関があると鈴木らが示したのと同じように、この研究でも、より良い車両制御がより深いMRCPの傾きと相関するという仮説の検証を行っている。6条件それぞれについて計算された傾きの絶対値を図7に示す。

図7より、主観評価値と一致して、条件A、E、Fの傾きは条件Bよりも高い。各条件についてただ一つの評価値しか得られないため、統計的分析として、MRCP傾きと官能評価との間の線形回帰を行い、回帰の決定係数$R^2$を計算した。10パーセント以上、二つの変数間の相関が高いことを示す。この場合$R^2=0.8807$であり、実際にMRCPの解析結果が官能評価と同様の傾向を示している。この研究の課題はランダム操作であると、より深いMRCPの傾きは、環境などの簡単な同期化（動的応答性が高いこと）によって各コーナーの前に準備を容易にすることができると考えられる。

さらに、コネクティビティ解析の結果を統合した。各実験参加者の正確性のコネクティビティ性評価（点）と各条件の平均値（棒）を図8に示す。条件ごとに10の測定点を設けて、分散分析（ANOVA）により条件間に有意差があるかどうかを検証した。実際p値0.003は、条件がコネクティビティ解析に強く影響することを示している。

MRCP傾きの場合と同様に、官能評価と脳コネクティビティ計測値の相関についても解析した。

ピアソン積率相関係数は、これら三つの変数間の線形的関係を示しているのと同じように、p値がゼロではない相関の有意性を意味している。この場合、相関係数は0.38である。

![Fig. 7 MRCP 傾き：より深い傾き（絶対値が高い）は行動準備プロセスの容易さの特徴として解釈できる](image7)

Based on the methodology presented in section 2.3, after extracting the grand average for each condition, the slope of the MRCP has been calculated. Suzuki et al. presented a high correlation between the slope of MRCP and the accuracy of a movement control task. In this research, we also try to assess the hypothesis that better vehicle control correlates with deeper MRCP slopes. The absolute values of the slopes calculated for each of the 6 conditions are presented in Fig. 7.

A first look the slopes for the condition A, E and F are indeed higher than for condition B, which is in line with the subjective evaluation. As statistical analysis, having retrieved only one evaluation value for each condition we performed a linear regression between the MRCP slope and the subjective evaluation and calculated the R-squared of the regression. A closer value to 1.0 shows higher correlation between the two variables. In this case$R^2=0.8807$which indeed shows the MRCP describes each condition in a very similar manner with the subjective scores. Given the task of this study is steering actions, deeper MRCP slopes can be interpreted as signatures of easiness of preparation before each corner by easier synchronization with the environment.

Furthermore, we integrated the connectivity analysis results. The calculated normalized connectivity scores for each subject (the dots) as well as the average (the bars) for all of the conditions are presented in Fig. 8. Having 10 measurement points for each condition we were able to perform analysis of variance (ANOVA) to verify whether or not there is significant difference between conditions. Indeed a p-value of 0.003 showed that the conditions strongly effect the connectivity analysis. Similar to the case of MRCP slope the correlation between the subjective score and the brain connectivity measures was also investigated. Pearson's correlation coefficient is used to show linear dependency between these two variables, as

![Fig. 8 コネクティビティ性の強さ：アルファ波領域が強いと前頭部と頭頂部の間のデータ輸送が容易になる](image8)
Dynamic Performance from Applied Neuroscience Perspective

4. Conclusions and Discussion

In this article we presented the results of a pioneering attempt to develop an evaluation methodology for vehicles dynamic performance based on electroencephalography (EEG) measurements. We proposed using the slope of MRCPs related to steering actions as an evaluator for the easiness of motion preparation processes. While acquiring a large number of trials is still necessary in order to perform such analysis, the extracted slopes for the six different dynamic response set ups showed a high correlation with the subjective score.

Furthermore we showed that the fronto-parietal alpha frequency connectivity is very sensitive to the dynamic response set ups and that it also shows a trend very similar with the subjective evaluation. Higher connectivity values can be interpreted as more efficient brain activity which could drive the increase in subjective evaluation.

A natural line for future works is to expand the pool of subjects and to also evaluate the effects of larger variability between the driving skills. One hypothesis to be confirmed is that lower skill levels could mean lower sensitivity in conscious evaluation of the driving experience which would in turn support using EEG based evaluation tools which focus on relevant brain activity rather than subjective scales.

Another line is obviously to perform follow up experiments in real vehicles. In such situation the authors plan to leverage in vehicle recording systems that have been already developed in previous studies that showed the possibility to extract both MRCP and connectivity signatures correlated with real vehicle control.

We strongly believe that leveraging knowhow and methodologies generated by studies like the current one, will have a strong contribution to Nissan’s strive forward for developing vehicles that can easily reflect driver’s will as well as highly trustworthy and comfortable autonomous driving.
6. 参考文献


5. Acknowledgment

We would like to thank all subjects that have participated in the experiments spending long time in a just as intended by a driver in manual mode driving, as well as highly comfortable autonomous simple repetitive task.

6. References


13) S. Palva et al.: Functional Roles of Alpha-Band Phase Synchronization in Local and Large-Scale Cortical Networks. Frontiers in Psychology, Vol. 2, No. 204
**1. Introduction**

The SUV segment has shown remarkable growth primarily in the U.S. market in recent years while the sedan segment has tended to contract, though rival manufacturers still continue to exert vigorous efforts in this fiercely competitive segment. Since its release in 1993, the Altima has been a hit model in the sedan segment, with successive generations recording cumulative sales of over five million units. The current model has been favored by customers in more than 65 countries as a classic sedan.

**2. Product Concept**

The new Altima is targeted at graceful women for dashing powerfully and enjoyably through their busy everyday lives for their own sake, not just for their children and families. The vehicle concept is that of a “life racer” that is always close to women in daily life and enriches their lives. It has been designed and engineered to serve as the representative “face” of Nissan brand cars. The new Altima will also continue to be sold in China as a midsize sedan. While sharing the same design, the dynamic performance and equipment features of the respective versions differ according to the different market needs in the U.S. and China. This approach has been taken to ensure product competitiveness in each market. The new Altima continues a tradition of over 25 years as an orthodox D-segment sedan. At the same time, the development aim was to provide an impressive design, greater driving pleasure, and safety performance embodying the company’s proclaimed Nissan Intelligent Mobility, thus creating a classic dynamic sedan that can be driven...
Product Overview of the New Altima

3. アピールポイント

3.1 デザイン

アルティマらしさをお客様に伝える要素として、デザインに特にエクステリアは重要である。これまでアルティマがお客様に提供してきたクールな走りをそれを体現するデザインの両立は、本モデルの絶対の条件として様々なアイデアが提出され、議論がなされた。

次世代日産ブランドのエクステリアデザインの象徴として発表された「Vmotion 2.0」コンセプトをベースとし、前モデルより全高を27mm下げ、全長を26mm、全幅を20mm延ばしワイド&ローとダイナミックなプロポーションを実現している。さらに、日産ブランドの重要なデザインアイコンを数多く採用している。例えば、ダイナミックに仕上げたVモーショングリル、ダイナミックランニングライトを搭載した印象的なLEDプロジェクターヘッドライク、LEDフォグライト、スリムピラーのフローティングルーフや、日産ブランド車の「顔」としてのアルティマをより引き立てる（図1）。

インテリアデザインには、これからも次世代の日産デザインのテーマである「グライディングウィング」デザインのインストルメントパネルを採用した。薄く水平に広がるセンタークソソールとインストルメントパネルにより、開放感のある空間を演出している。トリムに使用する素材にも気を配り、お客様が心地よく室内で過ごせるプレミアム感を提供している（図2）。

3.2 進化したインフォテイメント

先進安全装備などを拡充していく反面、お客様は時に複雑な操作を必要とする場面に直面している。運転中で自信を持てる走りを提供するトヨタのダイナミックセダンの実現を目指した。

3. Appealing Features

3.1 Design

The exterior design in particular is a key element for conveying the Altima’s unique character to customers. An absolute condition set for the new model was to achieve both the exciting driving performance that the Altima has heretofore promised customers and the design embodying such performance. Various ideas were proposed and discussed for how to accomplish that.

The exterior styling was inspired by the Vmotion 2.0 concept that was announced as the symbol of Nissan’s next-generation exterior design. Key themes of wide, low and dynamic were achieved by lowering the overall height 27 mm and increasing the overall length 26 mm and the overall width 20 mm compared with the previous model, resulting in extended proportions with a lower center of gravity. Moreover, the new Altima also adopts many signature Nissan brand design cues. Examples include the dynamically executed V-motion grille, impressive LED projector headlamps incorporating daytime running lights, LED fog lights and the floating roof with slim pillars. These design features accentuate the distinctive exterior of the Altima as the “face” of Nissan brand cars (Fig. 1).

The interior styling is distinguished by the “gliding wing” design of the instrument panel, another thematic element of Nissan’s next-generation design. The thin, horizontally expansive center console combines with the instrument panel to create an open, airy interior space. Careful attention was also given to the trim materials used so as to provide a premium interior in which customers can spend time comfortably (Fig. 2).

3.2 Further evolved infotainment

With the ongoing expansion of advanced safety equipment and other features, customers sometimes encounter situations where complicated operations are required. For confirming information and performing operations safely even while driving, the newly designed instrument cluster incorporates a 7-inch color display that mainly presents information concerning driving in an easy-to-understand format. The 4-way operable steering wheel...
switches enable quicker, simpler operations and switching, thereby minimizing gaze movement and distractions while driving.

The 8-inch center color display also adopts a new-generation infotainment system with smartphone-driven Android Auto™ and Apple CarPlay™ provided as standard features in the U.S. version owing to especially high customer sensitivity to these items. This aspect gives the new Altima a strong advantage over rival models. In addition, the on-board telematics system connects to a telematics center to provide one-level higher safety and security services, including tracking of a stolen vehicle and remote door lock/unlock, among others. The USB ports provided in both the front and rear seats are also compatible with the latest Type-C standard, enabling customers to charge their batteries without preparing a conversion adapter or other device in advance.

3.3 Enhanced driving performance thanks to new engines

The new Altima has been developed to meet customers’ expectations for confidence-inspiring driving performance. Meticulous care was taken especially to reduce body vibration, optimize steering performance and ensure reliable driving performance for complete peace of mind. As part of that effort, two completely new engines are provided for the U.S. market.

The first one is the world’s first production-ready variable compression ratio turbocharged (VC-Turbo) engine (KR20DDET). The compression ratio is seamlessly varied automatically between 8:1 (for high power) and 14:1 (for high efficiency) by a multi-link system and engine control logic responsive to the driving conditions. This achieves both substantially improved fuel economy and dynamic power output at the highest possible levels. Representing Nissan’s latest turbo engine, the VC-Turbo has been under research and development for over 20 years. It delivers performance that clearly distinguishes it from other companies’ downsized turbo engines (Fig. 3).

The second one is a new 2.5L inline 4-cylinder direct-injection engine (PR25DD) that also enhances fuel economy while improving power and torque. It is expected to serve as a clean engine friendly to the environment. This engine also contributed significantly to the attainment of the wide and low proportions mentioned in section 3.1 as a result of moving the mounts closer to the center while still effectively suppressing noise and vibration.

Moreover, the Altima is available for the first time with 19-inch wheels and tires, and a grade is offered with a suspension featuring sportier tuning for enhanced agility. These features are in response to customers’ demands for a more enjoyable driving experience.

3.4 Enhancement of safety through expansion and improvement of advanced technical features

While serving as the “face” of Nissan brand cars, the new Altima will also contribute substantially to the

![Fig. 3 KR20DDDET VC-Turbo engine](image-url)
ある。出力とトルクを改善させながら燃費も向上し、環境に優しいクリーンなエンジンとしての役割が期待されている。また、騒音・振動を抑制しつつもエンジンマウントをより中心に近づけることより、31節で広ぎしたウィド&ローナープロポーションの実現に大きく貢献している。

さらに、19インチのホイールとタイヤの初採用と、スポーツ的なチューニングを加味したサスペンションで敏らしさを高めたグレードを用意し、もっと走りを楽しみたいというお客様の要望に応えた。

3.4 先進技術装備の拡大・充実による安全性の向上

日産ブランド車の「顔」としての役割を持つモデルは、私たちが社会に約束する自動運転技術の拡大にも貢献する。新型セレナ、新型エクストレイル、新型日産リーフが続いて、高速道路同一車線内自動運転技術プロパイロットを通じて進化している。次世代モビリティへの第一歩となる本技術は、高速道路の単一車線での走行を自動で行うことを目的に、主に渋滞時と長時間の巡航走行時にドライバーのストレスを軽減することができる。ステアリング上にある自動運転専用スイッチで席レースやシステムを起動することが可能で、レバーを操作して席周辺の状況を検知し、安全性に細心の注意を払い、ステアリングを制御して人間が運転している感覚に近い自然な走行を実現する（図4）。

このプロパイロットを支える主要技術の応用として、後方の物体を検知して自動的にブレーキを作動させる「リヤオートマチックブレーキ（RR-AB）」、カーナビゲーション機能と連動して走行している道路の車速制限をメータ内のディスプレイに表示する「トラフィックサインレコグニション」を1台として初採用した。

また、日産の新車種セーフティ・シールドを実現する技術として「オートマチックエマージェンシーブレーキ（AEB）」、「インテリジェントFCW（前方衝突予防警告）」、「後方車両検知警報（BSW）」、「インテリジェントクルーズコントロール（ICC）」、「後退車両検知警報（RCTA）」、「歩行者検知機能付エマージェンシーブレーキ」、「車線逸脱警報（LDW）」、「ハイビームアシスト（HBA）」、「インテリジェントアラウンドビューモニター（I-LAVM）」などの先進安全装備を多数搭載している。（グレードにより、搭載技術は異なる。）

3.5 四輪駆動モデル追加による新たな市場の開拓

新型アルティマで新たに挑戦した重要技術のひとつが四輪駆動（AWD）システム「インテリジェント４×４」の新規投入である。同じ日系セダンの競合車と明確に差別化できる攻めのパワートレインであり、主に北米北西部のお客様の開拓を想定し、新型2.5L４気筒エンジン（PR25DD）と組み合わせた。タイヤ、エンジン、ステアリングなどのexpansion of autonomous driving technologies, which Nissan has promised to society. Following the new generations of the Serena, X-Trail and Nissan LEAF, the new Altima is equipped with ProPILOT Assist technology to enable single-lane autonomous driving on motorways. This technology represents a first step toward next-generation mobility. It can reduce driver stress primarily in congested traffic and during cruising for a long period of time. The system is seamlessly activated via a dedicated steering wheel switch for autonomous driving. It uses radar, cameras and other devices to detect the surrounding conditions, paying careful attention to safety. It provides a natural driving feel by controlling the steering action in a manner resembling the behavior of a human driver (Fig. 4).

The key technologies supporting ProPILOT Assist are utilized to facilitate Rear Automatic Braking (R-AB), which detects rearward objects when backing up and automatically applies the brakes if necessary. Another feature facilitated in this way is Traffic Sign Recognition that operates in conjunction with the navigation system to show in the instrument cluster display the detected speed limit of the road being traveled on. Both technologies have been adopted by Nissan for the first time ever.

Many advanced safety technologies have been adopted to achieve Nissan's safety strategy called Safety Shield, including Automatic Emergency Braking (AEB), Intelligent Forward Collision Warning (IF-CW), Blind Spot Warning (BSW), Intelligent Cruise Control (ICC), Rear Cross Traffic Alert (RCTA), Automatic Emergency Braking with Pedestrian Detection, Lane Departure Warning (LDW), High Beam Assist (HBA), and Intelligent Around View Monitor (I-AVM), among others. (The technologies provided vary depending on the grade.)

3.5 New market development with the addition of all-wheel-drive models

The Intelligent 4x4 all-wheel-drive (AWD) system has been adopted on the new Altima for the first time as a key technology in a new challenge for this model. This system creates an aggressive powertrain that clearly differentiates the Altima from other rival Japanese sedans. The AWD system is paired with the new 2.5L 4-cylinder PR25DD engine with the expectation of cultivating new customers mainly in northern U.S. market regions. It automatically distributes the optimum torque to the front...
The new Altima offers an overview of the new Altima, focusing mainly on its appealing product features. The design promises a refined driving experience and the new engines deliver a high-level balance of power and environmental friendliness faithful to the Altima design. Advanced technologies leading the way to next-generation mobility are provided along with an AWD system not found on rival models as a strong point of the Altima for cultivating new markets. We are confident that the provision of these features at reasonable prices will make the new Altima a key model for reenergizing the sedan market.

Finally, the author would like to thank everyone involved with the design, engineering, quality assurance, manufacturing, marketing, and sales of the new Altima for their concerted efforts exerted for this new model.
Introduction of Patents

特 許 紹 介
Introduction of Patents

当社の登録特許のうち、重要課題をブレーキスルーすることにより会社への大きな貢献をもたらした特許計4件を紹介する。

Among the patents registered to Nissan in recent years, these four patents have contributed significantly to the company by achieving breakthroughs in important issues.

1. 車両のトルクステア抑制構造（図1、図2）

出願：2004年11月18日 特願2004-335043号
登録：2010年12月10日 特許第4639769号
名称：車両のトルクステア抑制構造
発明者：Nissan 第一製品開発部 富樫 宽之
カスタマーパフォーマンス＆実験技術部 味村 宽
Nissan 第三製品開発部 太田 圭介
プログラム管理部 米持 嘉宏

1.1 発明の狙い

近年、エンジン性能の向上によりエンジンの出力トルクが増大している。エンジンの出力トルクが増大すると、車両正面向かって駆動輪の折れ角左右差が僅かであっても駆動トルクの左右差は大きくなり、トルクステアが顕著となってしまう。

本発明では、車両の加速度が大きくなるほど左右駆動輪の折れ角が小さくなるため、左右駆動輪それぞれに発生するキングピン中心軸周りの2次偶力が小さくなるようにした。このため、トルクステアの原因となる2次偶力の左右差を小さくすることができ、トルクステアを効果的に抑制することができる。

1.2 発明の構成

本発明のトルクステア抑制構造は、左右駆動輪の折れ角を、車両の加速度が大きくなるに従って小さくなるようにしたため、左右駆動輪それぞれに発生するキングピン中心軸周りの2次偶力が小さくなり、もってトルクステアの発生力を2次偶力の左右差を小さくすることができる。

1.3 活用実績

マキシマ、ムラーノなどのDプラットフォーム車、INFINITI QX60、日産リーフに採用されている。

1. Structure for Suppressing Vehicle Torque Steer (Figs. 1 & 2)

Patent application date: November 18, 2004
Japanese patent application No.: 2004-335043
Registration date: December 10, 2010
Japanese patent No. 4639769
Title: Structure for suppressing vehicle torque steer
Inventors:
Hiroyuki Togashi, Nissan Product Development Department No. 1
Hiroshi Mimura, Customer Performance and Test Engineering Department
Keisuke Oota, Nissan Product Development Department No. 3
Yoshihiro Yonemochi, Program Management Department

1.1 Aim of invention

Improvement of engine performance in recent years has increased engine output torque. When an engine produces greater output torque, torque steer becomes more noticeable because of a difference in drive torque between the right and left drive shafts, even if there is only a tiny difference in their bending angles as seen from the vehicle front.

This invention reduces the secondary coupling force generated around the king pin center axis of the right and left drive shafts by reducing the bending angles of the shafts as vehicle acceleration increases. Consequently, the right-to-left difference in the secondary coupling force that induces torque steer can be reduced, thereby effectively suppressing torque steer.

1.2 Composition of invention

The structure of this invention for suppressing torque steer is designed to reduce the bending angles of the right and left drive shafts as vehicle acceleration increases. Accordingly, the secondary coupling force generated around the king pin axis of the drive shafts decreases, making it possible to reduce the right-to-left difference in the secondary coupling force that produces torque steer.
1.4 Status of use

This invention has been applied to D-platform vehicles such as the Maxima and the Murano as well as to the INFINITI QX60 and the Nissan LEAF.

1.4 Inventor’s thoughts

At the time of this invention, Nissan was facing many issues regarding suppression of torque steer compared with the situation at other companies. Nissan was also endeavoring to provide customers with faster vehicles than other companies by raising engine torque higher and using a low final gear ratio.

However, with our previous platform for front-wheel-drive (FWD) vehicles, an engine torque cut-off had to be included in order to suppress torque steer. That made it difficult to take full advantage of the engine’s output. Therefore, in developing a new platform for FWD vehicles, we aimed to suppress torque steer to a level that would be comfortable for customers without applying any engine torque-cut-off.

Other companies attempted to suppress torque steer by adopting a sophisticated suspension such as a double wishbone system. In contrast, at Nissan we sought to develop a breakthrough technology for suppressing torque steer even with an ordinary strut suspension.

In the U.S. market where FWD platforms are the mainstream as Nissan brand models, there are many driving situations such as merging with high-speed traffic where even vehicles equipped with high-power 3.5L engines are accelerated under full throttle. Therefore, we undertook this development project with a strong sense of mission because suppression of torque steer would lead to improved customer satisfaction.

In order to suppress torque steer while holding down the cost, it was necessary to seek a breakthrough solution to this issue by reviewing the entire powertrain structure from the engine to the tires, rather than on the basis of the performance of individual suspension parts. In the process of mentally connecting the mechanisms of the drive train, engine mounts, chassis parts and other parts developed by other departments, we discovered that torque steer during acceleration could be suppressed by reducing the bending angles of the right and left driveshafts (θR and θL) as shown in Fig. 1. We arrived at a structure in which the exit position (inner joint) of the drive shafts from the powertrain is set lower than the outer joint.

We regard a patent as being proof that engineers have reached an original solution to an issue earlier than anyone else. We consider it our good fortune as engineers that we were able to submit this patent application.

It was necessary to position the exit of the drive shafts from the powertrain lower in order to achieve a different positional relationship of the parts than previously. We would like to thank the other inventors for making that possible as well as everyone who cooperated with this project until the developed technology was mounted on production vehicles.
2. Reciprocal Internal Combustion Engine (Figs. 3 & 4)
Patent application date: May 18, 2009
Japanese patent application No.: 2009-119376
(divided from patent application No. 2000-37380)
Registration date: December 22, 2011
Japanese patent No. 4888518
Title: Reciprocal internal combustion engine
Inventors:
Katsuya Moteki, Engine & Drivetrain Engineering
Department
Takayuki Arai, Retired employee
Hiroya Fujimoto, Mobility Services Laboratory

2.1 Aim of invention
Second-order vibration that originates from the second-order vibration component of crankshaft rotation tends to cause booming noise in the passenger compartment owing to the inclination of the connecting rod, which increases the piston speed near top dead center and reduces it near bottom dead center. As the connecting rod is lengthened, piston motion approaches simple harmonic oscillation, enabling the second-order component of piston acceleration to be reduced. However, because it increases the overall engine height, it tends to add more weight and to worsen vehicle mountability.

This invention is aimed at effectively reducing the second-order vibration component of crankshaft rotation without increasing the overall engine height by connecting the crankpin and the piston pin by means of multiple links.

2.2 Composition of invention
The multilink mechanism comprises a lower link, which is supported such that it can rotate around the crankpin of the crankshaft, an upper link that connects the piston and the lower link, and a third link one end of which is supported by the engine proper and the other end is connected to the lower link. The links are arranged such that as the piston descends from top dead center, when the inclination of the upper link relative to the cylinder axis increases, that of the third link relative to the cylinder axis decreases. As the piston descends toward bottom dead center, when the inclination of the upper link relative to the cylinder axis increases, that of the third link relative to the cylinder axis decreases. As a result, the effect of the inclination of the upper link on the piston speed and that of the inclination of the third link on the piston speed are mutually cancelled. Consequently, the piston speed near top dead center and that near bottom dead center become similar, resulting in piston motion resembling simple harmonic oscillation, which makes it possible to reduce the second-order vibration component.

2.3 Status of use
This invention has been adopted on the Altima and the INFINITI QX50.
2.4 感想

複数リンクを組み合わせたマルチリンクをエンジンのクラシック機構に適用して圧縮比を変えるという発想は昔からありましたが、どれも騒音、振動が大きいという本質的な問題を抱え、実用化できない状況でした。それでも「ダメなものがあるなら、良いものもあるのではないか」という楽観的な気持ちから検討を始めた記憶があります。

一方、その当時から直列4気筒エンジンは、その基本機能の高さと優れた搭載性から乗用車用エンジンの主力になっていたが、その悪い音振フィーリングの元因とも言うべき2次振動（クランクシャフト1回転に2回振れる振動）に悩まされており、これを打ち消すためにバランサという追加デバイスを装着するメーカが現れた時代でもありました。そこで、うるさいと言われていたマルチリンクでは、その2次振動を消せないか、と大胆にも思い立ったのです。

しかし、マルチリンクで2次振動を消す以前に、そもそも単純なのはの従来クラシック機構で、なぜ2次振動が発生するのか、という疑問が浮かびました。「如何に」作用するかを示す文献、資料は沢山見つかりますが、「なぜ」に答えてくれるのは見当たらず。悩んだ末に、コンロッドが振動して、傾いたり直したりすることにより2次振動が発生していることがわかりました（実はこのように言い切っている文献は見当たらない）。それなら、コンロッドに相当するものを上下に対向配置（上がUリンク、下がCリンク）し、動きを反転させるシーソー（Lリンク）で連
made possible all the fundamental characteristics of the VC-Turbo engine, from the first prototype built in the laboratory to the KR20DDT engine that went into mass production.

3. Steering Control Device (Fig. 5)

Patent application date: October 22, 2012
Japanese patent application No.: 2013-540647
Registration date: October 10, 2014
Japanese patent No.: 5626480
Title: Steering control device
Inventors:
Yuwun Chai, Infiniti Product Development Department
Takaaki Eguchi, Retired employee
Igarashi Kazuhiro, Chassis Engineering Department
Yukinobu Matsushita, Retired employee

3.1 Aim of invention

The Direct Adaptive Steering (DAS) system disengages the clutch between the steering wheel and the tires under normal driving conditions, thereby mechanically uncoupling them. In that state, the tires are turned by a steering angle actuator in response to the driver's steering inputs, and a steering force actuator generates steering reaction force that is fed back to the steering wheel. Consequently, inputs to the tires from an uneven road surface during straight-ahead driving are not reflected in this steering reaction force feedback. This prevents steering wheel vibration, making it possible to achieve overwhelming straight-ahead stability. However, if the road surface inputs to the tires are not reflected in the steering reaction force feedback, the driver cannot recognize changes in driving conditions such as the tire gripping state, through the changes in the steering reaction force that is fed back to the steering wheel.

This invention reflects essential information such as the tire gripping state in the steering reaction force feedback, while still enabling excellent straight-ahead stability. As a result, it facilitates DAS that both reduces the driver's steering workload when driving straight ahead and provides a directly connected feeling.

3.2 Composition of invention

This invention compares a feedforward axial force, representing the steering rack axial force calculated based on the driver's steering inputs such as the steering wheel angle, and a feedback axial force, representing the steering rack axial force calculated based on certain vehicle conditions such as the current of the steering angle actuator, vehicle's yaw angle, its lateral acceleration (G) and so on. When the difference between the two axial forces is small and the vehicle state is stable, the invention generates steering reaction force mainly on the basis of the feedforward axial force. On the other hand, when there is a large difference between the axial forces and the
3.2 発明の構成

本発明は、操舵角などのドライバ入力に基づいて算出したステアリングラック軸力であるフィードフォワード軸力と、転舵モータの電流、車両のヨー角、横Gなどの車両の状態に応じて算出したステアリングラック軸力であるフィードバック軸力とを比較し、両軸力の差が小数値で車両が安定状態にある場合は主にフィードフォワード軸力に基づく操舵反力発生させる一方、両軸力の差が大小の車両が小不安定状態にある場合は主にフィードバック軸力に基づく操舵反力を発生させるものである。

3.3 活用実績

スカイライン（クーペ含む）、INFINITI Q50、Q60、QX50に採用されている。

3.4 発明者の思い

先行研究段階では、DASならではの価値を色々検討した。一つは、従来車両では特に日常で一貫通の直進走行シーンにおいて、路面の細かい不整によってハンダを介して伝わってくる細かい操舵反力変動に対して、ドライバは常に無意識に細かくハンドル角度を修正していることに着目した。DASであれば、路面不整に対してタイヤ角が変化しないように制御する路面不整による操舵反力変動を排除する事ができ、車両の動きをより安定させると共にドライバの修正操舵量を大きく減らして、トータルでドライバの運転負荷低減を実現できると考えた。そこで、ドライバの意識的な操作入力（操舵角、車速など）によって発生するステアリングラック軸力（フィードフォワード軸力）に応じた疑似的な操舵反力であるフィードフォワード操舵反力を作り込む事にチャレンジした。この疑似反力は実際のタイヤや路面状況に影響されない反力なので、反力の特性を任意に設定する事ができ、常にすっきりした、滑らかな操舵特性を作り込むことができた。

しかしながら疑似反力だけでは、タイヤが限界に近づく時や、車両挙動が不安定になる時に、実際にタイヤや路面状況などの車両の状態に応じて発生するステアリングラック軸力（フィードバック軸力）の変化が操舵反力の変化として反映されない事になり、今までの運転感覚との違いによって、例えば熟練ドライバにとっては操舵フィーリングが低下する可能性がある。そこで、既存のシステムセンサ（転舵モータ電流、車両モーションなどのみを用い、新規センサの追加を行わないことによってコスト抑えつつ信頼性を確保しながら、車両の状態に応じた自然な操舵反力であるフィードバック操舵反力を作る事にチャレンジした。試行錯誤を繰り返して様々な路面に適合した結

3.3 Status of use

This invention has been adopted on the Skyline, including the Coupe, and the INFINITI Q50, Q60 and QX50.

3.4 Inventor’s thoughts

Various studies were conducted concerning the inherent value of DAS at the advance engineering stage. One study focused on the tiny steering wheel angle corrections that drivers unconsciously make all the time in relation to minute fluctuation in the steering reaction force fed back to the steering wheel due to small unevenness in the road surface. This behavior occurs with conventional vehicles especially in straight-ahead driving that people experience most often in everyday vehicle use. We reasoned that DAS control would avoid tire angle changes due to road surface unevenness and also eliminate fluctuation in the steering reaction force caused by such unevenness. That would result in more stable vehicle behavior and simultaneously greatly reduce the amount of steering corrections done by the driver, thereby decreasing the driver’s overall workload and fatigue.

Therefore, we endeavored to create a feedforward steering reaction force as a pseudo steering reaction force corresponding to the steering rack axial force (feedforward axial force) generated by the driver’s conscious operational inputs (steering wheel angle, vehicle speed, etc.). This pseudo reaction force is not influenced by the actual condition of the tires and road surface. That enables the reaction force characteristics to be set arbitrarily, making it possible to create distinct and smooth steering force characteristics at all times.

However, with this pseudo steering reaction force alone, changes in the steering rack axial force (feedback axial force) produced in relation to the vehicle state, such as the actual condition of the tires and road surface, would not be reflected as changes in the steering reaction force fed back to the steering wheel. That would occur, for example, when the tires approach their limit or when vehicle behavior becomes unstable. As a result, because of the difference from the usual driving feeling hereafter, experienced drivers, for example, might feel that the steering performance had declined. Therefore, we sought to create a natural feedback steering reaction force corresponding to the vehicle state, while ensuring reliability and holding down the cost by not adding any new sensors and using only the existing system sensors for the steering angle actuator current, vehicle motion and so on. As a result of a repeated process of trial and error involving the use of this invention on various road surfaces, we succeeded in reproducing a natural steering reaction force like that of conventional vehicles.

The final remaining issue was how to connect the feedforward steering reaction force (pseudo force suitable to ordinary driving) and the feedback steering reaction.
force (real force suitable to driving conditions such as a low-μ road surface or the tire limit). As a result of various arduous efforts, we succeeded in developing a simple and reliable steering reaction force transition logic. That was done by synthesizing the feedforward steering reaction force and the feedback steering reaction force according to the amount of divergence between the feedforward axial force and the feedback axial force, based on the fact that the amount of divergence between them is actually equivalent to the slip state between the tires and the road surface. After entering the production vehicle development phase, the logic parameters were thoroughly tuned in driving tests on evaluation course surfaces and the optimal constants, threshold values and other parameters were determined.

Based on this logic, further logic improvements were made repeatedly after the mass production launch to achieve smooth, seamless steering reaction force characteristics with a directly connected feeling that are easy for drivers to understand in various driving situations.

(Figs. 6 & 7)

Patent application date: August 26, 2010
Japanese patent application No.: 2010-189067
Registration date: November 28, 2014
Japanese patent No.: 5652054
Title: Device for estimating vehicle body vibration
Inventors:
Yuuki Shiozawa, Mobility Services Laboratory
Masaaki Nawano, Prototype and Test Department
Yosuke Kobayashi, AD/ADAS and Chassis Control System Engineering Department
Tamaki Nakamura, Customer Performance and Vehicle Test Engineering Department

4.1 Aim of invention
Vehicles encounter both large and small dips and bumps in the road surface that cause occupants to experience uncomfortable vehicle body motions as vehicles travel over these irregularities. Suitable control of the engine and brakes can suppress these uncomfortable vehicle body motions to provide a comfortable ride. However, accomplishing such suppression requires an accurate estimation of vehicle body vibration.

Therefore, this invention is aimed at increasing body vibration estimation accuracy.

4.2 Composition of invention
This invention is configured to calculate and estimate vehicle body vibration (i.e., vertical bounce velocity and pitching angle velocity) from information pertaining to the wheel speed, based on the expected correlations (suspension geometry characteristics) between the amount of longitudinal displacement and vertical displacement of the front and rear wheels relative to the body. This refers
4.3 活用実績
エクストレイルに採用されている。

4.4 発明者の想い
路面の凹凸を乗り越えるときに乗員が不快と感じる車体の揺れを抑制するには、電子制御サスペンションを利用することが一般的ですが、高価なデバイスを追加せずに駆動やブレーキの制御を用いて行う方法もあります。クルマは加速すると車体の前半部分が浮き上がり、減速すると沈み込みます。この特性を利用して、路面の凹凸に合わせて加減速を行えば、路面の凹凸により生じる車体の揺れを抑制することができます。

このような技術を開発する際に直面する共通課題の一つが、車体の揺れをいかに精度良く推定するかです。挙動を計測するためにサスペンションストロークセンサを付ける、あるいはたくさんのGセンサを追加する手法がありますが、センサのコストがかかります。

そこで、一般的に車載されているセンサを使って挙動作推定する方法を見出すことにしました。たくさんの走行データを解析し、車体の揺れに絡む要素を探す中で、車輪と車体の揺れとの関係があることがわかり、そのメカニズムの解明に取り組みました。最終的には、サスペンションの構造により、車体の上下方向の揺れに応じて車輪が前後方向に変化していることを突き止め、これが車輪速の変化として現れていたことがわかりました。既存の車輪速センサを用いて車体の揺れを推定できる本発明は、幅広い車種で採用できる技術となりました。

完成まで、膨大な実験を行ったり、関係する特許を調
We conducted an enormous number of experiments and searched through numerous related patents to see if we had overlooked any factors. It was an extremely long road to the completion of this invention, but it has left us with fine memories now.

Finally, we would like to thank everyone, beginning with the Intellectual Property Department, for their invaluable cooperation in connection with the patent application for this invention.
編集後記

昨今自動車業界は百年に一度の変革期と言われております。実際自動運転技術をはじめとした知能化や電気自動車（EV）といった電動化の技術の進歩はめざましいものがあります。そんな中で「ダイナミック・パフォーマンス」に求められるものは何であろうでしょうか。

知能化、電動化が進んだとしてもタイヤが存在する限り、タイヤが地面との間で発生する力をによって走る、曲がる、止まるという車の基本概念は変わらないので、ダイナミック・パフォーマンスの目指すべき方向はあまり変わらないとも言えます。一方で自動運転技術が進化し、ドライバーの負荷が減ってくると、「安心・快適な空間」へのお客様の期待値はより高まるでしょう。また電動化はパッケージングに革新的な進化をもたらし、従来の車では考えられなかった低重心、最適重量配分など、ソリューションの面で大きく進化することが可能となりました。

今号では「安心」「快適」を理論的に解明するアプローチと、その技術を実車に適用するアプローチを掲載しました。実車の中には電動化の象徴であるEV、新型日産リーフへの適用例も紹介しています。今回の特集記事が社内外のダイナミック・パフォーマンスに関わる研究開発者の皆様にとって、更なる技術進化に向けたチャレンジへの参考となれば幸いです。

― 日産技報編集委員・佐 藤 正 晴 ―

2018年度日産技報編集委員会

委員長

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Editorial Postscript

It is said that the automotive industry has lately been in a major transitional period that occurs once in 100 years. Indeed, profound technological advances are taking place including the application of intelligence as typified especially by autonomous driving technology as well as electrification in the form of electric vehicles (EVs). Amid this transition, what is required with respect to dynamic performance?

Even though the use of intelligence and electrification are advancing, so long as tires are present on vehicles, there will be no change in the fundamental concept that the forces produced between the tires and the contact surface cause a vehicle to go, turn and stop. So it would seem that the direction targeted for dynamic performance will not change appreciably. On the other hand, as autonomous driving technology evolves, the reduction of the driver’s workload will probably heighten customers’ expectations for a comfortable interior space with a secure feel. Moreover, electrification has brought about revolutionary advances in packaging, making possible significant evolution of solutions for a lower center of gravity, optimal weight distribution and other aspects that were inconceivable in vehicles previously.

This issue presents approaches for theoretically explaining attributes like a secure feel and comfort and the approaches employed for applying the related technologies to production vehicles. Among the actual vehicles mentioned here, examples are given of the application of such technologies to the new Nissan LEAF, an EV that symbolizes electrification. It is hoped that the special feature articles in this issue will serve as a useful reference for undertaking the challenge of achieving further technological evolution by everyone involved in research and development concerning vehicle dynamic performance both within and outside the company.

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The cover design of this issue expresses two key principles of Nissan’s philosophy of driving performance. One is that the vehicle should move as expected, and the other is that the vehicle conveys information to the driver. These ideas stem from our engineers’ emotion to design and develop vehicles that customers will feel comfortable driving and will want to drive forever. Several technologies for accomplishing that aim are arranged around the vehicle. They are related to the physical and dynamic characteristics of the vehicle, the operating characteristics of the driver and the driver’s perceptions. We are working hard every day to further refine our technologies for addressing many issues that remain to be resolved.

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