

Development of Active Damper System using Magnetorheological Dampers for 2007 Model Year Acura MDX

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ABSTRACT

This paper describes the development of magnetorheological (MR) dampers and their application to the 2007 model year MDX. MR dampers have been used in the market on various vehicles since 2001. They use a special oil-based fluid (Magnetorheological fluid, MRF) that contains small iron particles (1–10 μm in size) and a controllable electromagnetic piston to allow a wide range of damping forces. The system provides the customer a benefit over conventional dampers by using its wide range of available damping force to enhance body control while simultaneously providing outstanding ride comfort. This technology was implemented on the 2007 model year MDX under the name Active Damper System (ADS). The ADS system uses Honda-exclusive control logic that precisely controls damping force via skyhook, roll, pitch, and several other algorithms. The result is a vehicle with a higher level of both ride and handling performance that leaves all of our customers more satisfied.

要 旨

本文は磁性流体ダンパ(MR ダンパ)の開発およびその2007 年モデル MDX への適用について述べる。

2001 年以降, MR ダンパはさまざまな機種に採用されているが, 鉄の微粒子(1–10 μm 大)を含む特種なオイル(磁性流体, MRF)と, 電流コントロールが可能な電磁ピストンを組み合わせることにより, 幅広い減衰力レンジを可能にした減衰力可変ダンパである。

本システムは, その幅広い減衰力変化レンジを生かし, 従来タイプのダンパに対してボディコントロール性を向上させると同時に卓越した乗り心地を実現したものである。

本技術は, Active Damper System(ADS)の名称で, スカイフックロジックを基本としたHonda独自のロール, ピッチ, その他数種の高精度減衰力コントロールアルゴリズムと共に 2007 年モデル MDX に適用し, 結果多くのお客様に満足いただけるより優れた乗り心地とハンドリング性能を兼ね備えることができた。

1. Introduction

Magnetorheological (MR) dampers have been in the automotive market since 2001. The key component to MR dampers is a special Magnetorheological fluid (MRF) that consists of damper oil with approximately 20% pure iron particles that are 1–10 μm in size. Some of the early shortcomings of MRF that included sedimentation and long-term viscosity variation have been completely resolved by special additives being incorporated in the fluid⁽¹⁾. Honda investigated ADS technology and enhanced its overall vehicle performance and durability through electrical, mechanical, and control design.

The base structure of the MR damper is similar to a monotube damper except that the piston valve is replaced with an electromagnetic piston core that is then connected to the Electronic Control Unit (ECU) via an external electrical connector. This connection structure has been the detriment of MR dampers in the past and

has been enhanced during the development. Changes were made to the damper's internal structure to increase maximum damping force and to its external structure to increase robustness to electrical connectivity and oil sealability.

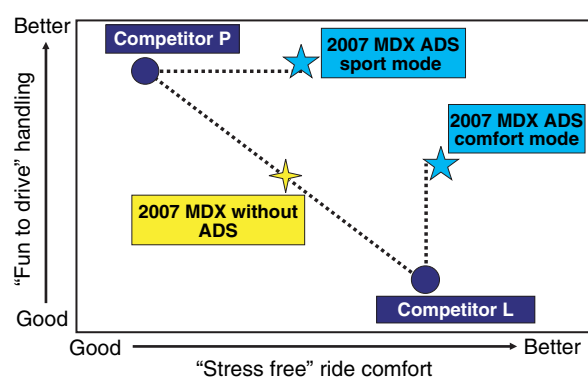


Fig. 1 Active Damper System targets

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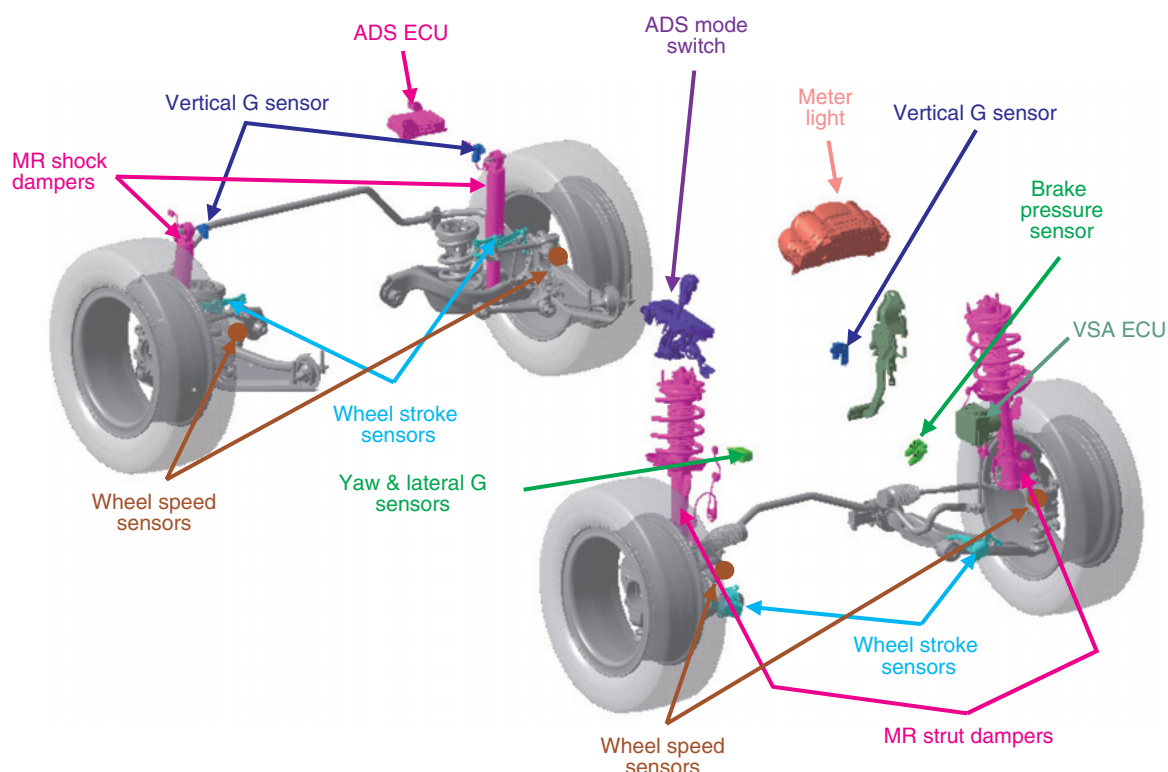


Fig. 2 Active Damper System components

The target of ADS was to enhance ride, handling, and overall sprung mass motions without compromise. In the end, two distinct settings of ADS were developed to accentuate the uniqueness of the system. Sport mode was developed to maintain the ride levels of the base 2007 model year MDX with conventional dampers and enhance handling to best-in-class levels. Comfort mode targeted base 2007 model year MDX levels of handling and class-leading levels of ride comfort. Figure 1 describes this concept.

2. System Overview

ADS consists of four wheel stroke sensors, three vertical acceleration sensors (G sensors), a combined yaw and lateral acceleration sensor, four MR dampers, and an ECU as visualized in Fig. 2. In addition, ADS communicates with the VSA system to determine vehicle speed and brake pressure. The output of each sensor is used by the control logic in the ECU to precisely determine the appropriate damping force required at each MR damper in order to achieve the desired level of lift, roll, pitch, and road input isolation for the vehicle.

3. MR Damper Construction

The 2007 model year MDX suspension is set up with front strut-type suspension and rear multi-link trailing arm-type suspension. In order to package the monotube structure of the MR damper in a strut, an inverted monotube strut is used. The rear MR damper uses a

monotube shock. Figure 3 shows the details of the MR damper internal structure.

Unlike a conventional oil-based damper, the MR damper piston does not utilize a valve structure of deflecting disks and springs. Instead, the MR damper has a simple structure consisting of a piston outer ring, an electromagnetic piston core and two piston plates which

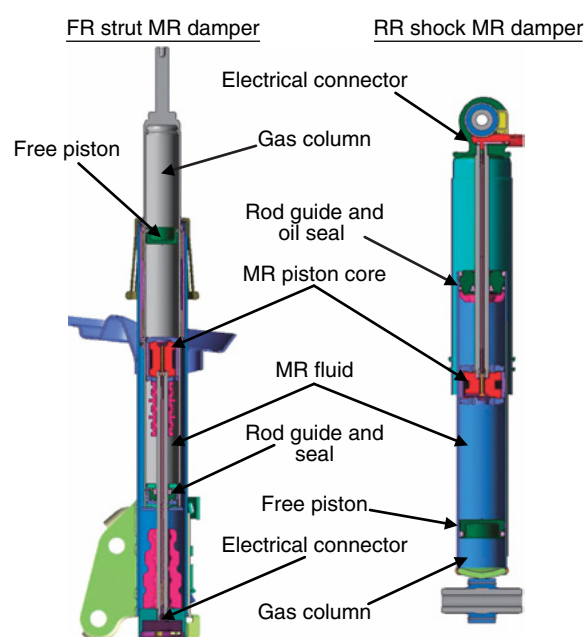


Fig. 3 MR damper construction

set the piston core concentric with the piston ring making a constant annular gap. It is this annular (radial) gap that defines the damping force characteristics of the MR damper. These structures are shown in Fig. 4.

Reference⁽³⁾ detail how an MR damper can vary the damping force versus velocity characteristics by applying a range of 0 to 5 Amps of electrical current to the electromagnetic piston core of the damper. When the damper is in its off state (no current applied), MRF flows

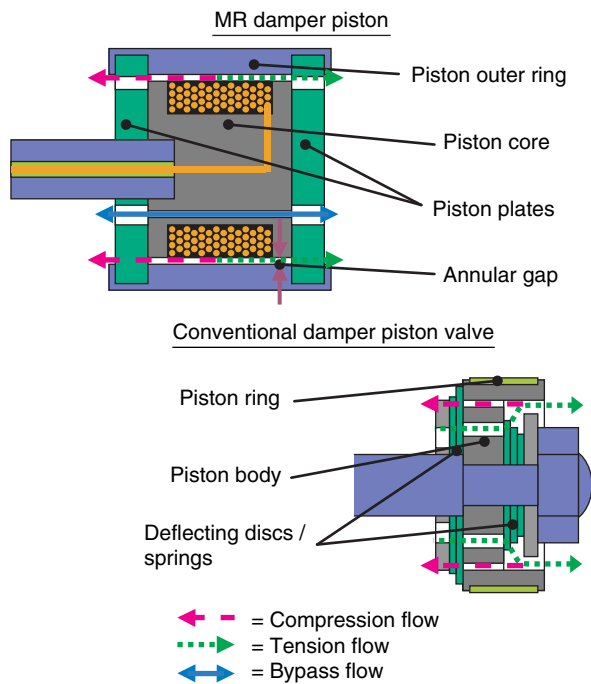


Fig. 4 Conventional damper piston valve versus MR damper piston

through the annular gap in a laminar state. When current is applied (on-state), the electromagnet builds up a magnetic field and creates magnetic bonds with the iron particles aligning within the annular gap. This effectively increases the viscosity of the fluid moving through the orifice, increasing the amount of damping force the damper produces. Higher levels of current will further increase the strength of the bonds, raising the fluid shear force and subsequent damping force. The shearing occurs in the walls of the annular gap where the stress caused by the motion of the damper is greater than the yield stress created by the magnetic bonds. The area between the shear walls flows as a plug of magnetically bonded iron particles. This is called the MR effect and can be seen in Fig. 5. The MR effect only occurs at the ends of the piston where the magnetic flux vector is perpendicular to the annular gap. Varying the current applied to the electromagnetic piston core varies the flux.

The ability to change damping characteristics on command is what separates the MR damper from a conventional damper. An MR damper responds more quickly than other semi-active and active damper systems with a response time of less than 5 milliseconds as compared to 10 milliseconds or more for other controlled systems and conventional dampers. The wide range of damping force available coupled with quick response time allows the vehicle to achieve simultaneous good ride and handling without the compromise that must be made when tuning the single damping force characteristic curve of a conventional damper. Figure 6 shows a comparison of a conventional damping force curve to that of an MR damper.

Within this characteristic curve, an MR damper can be tuned by two methods. The annular gap previously

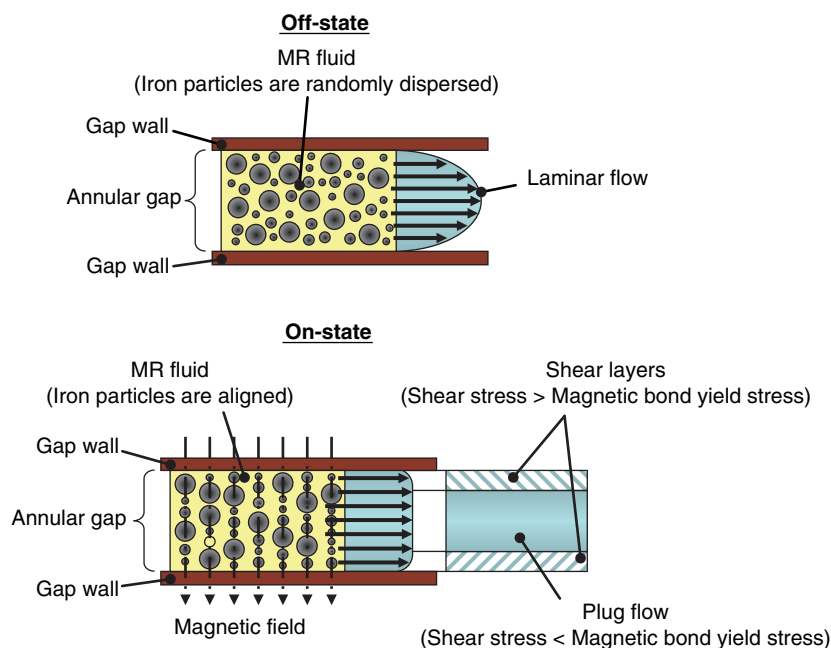


Fig. 5 MR fluid off- and on-state flow

described can be varied. A smaller gap will increase the peak damping force available; conversely, a larger gap will decrease the peak damping force. Within the piston there is also flow through an orifice inside the piston that does not see the magnetic field. This flow is called bypass flow. Varying the size of this orifice modifies the slope at which the damping force curve reaches peak damping force and off-state damping force characteristics.

Increased damping force was required for the 2007 model year MDX program over the current available capability of MR strut-type dampers in order to impart the SUV Platform with the desired level of roll control. Having already reduced the bypass lower than any other MR damper in production or test, the internal piston core bypass holes were removed, effectively filling them with the base steel of the core. This allowed more magnetic flux through the core and thus higher levels of damping.

The electrical connectors were also a focus for enhancement. On-vehicle connector vibrations were measured and modifications were made to the connector structure in order to enhance sealability in these conditions. The strut connector added three bolts and molded-in sleeves in order to maintain seal compression

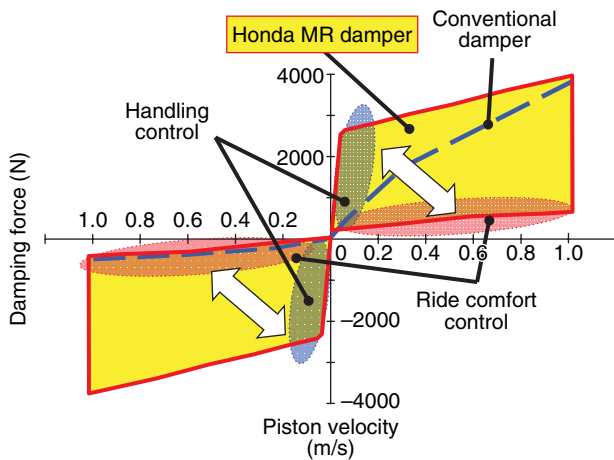


Fig. 6 Typical MR damper force versus velocity curve

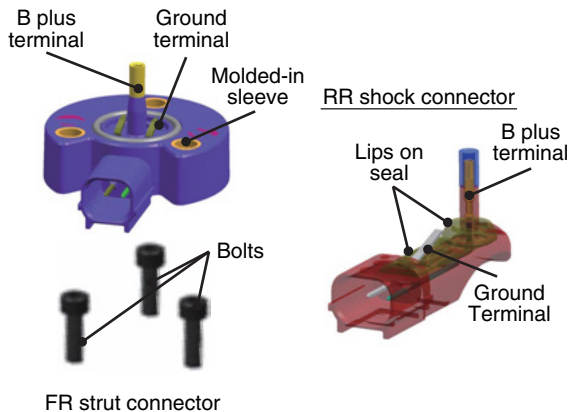


Fig. 7 Honda strut and shock MR damper connectors

over life. The rear connector seal structure was enhanced by adding lips and separating the ground and positive terminal seal structures. These changes are highlighted in Fig. 7.

4. ADS Control Logic

The basic theory for flat ride control of ADS control logic is skyhook suspension control. Skyhook control theory is visually depicted in Fig. 8. This well-known suspension concept applies damping force in a model that treats the sky as a fixed body with the damper C_1 between the sky and the sprung mass of the vehicle. The excitation force comes from the road surface through the tire with stiffness K_1 , the unsprung mass, and the vehicle suspension of stiffness K_2 and damping C_2 . Thus, the sprung mass motion can be controlled by the damping force provided by the damper connecting it and the fixed sky. In ADS, this control logic is taken to further understanding where the damping force can be controlled C_s in order to reduce sprung mass movements and thus flatten the ride of the vehicle for the customer.

In addition to skyhook control, ADS implements roll control logic, pitch control logic, and unsprung mass control logic. Reference⁽²⁾ describes.

the unique feature of the roll control logic in that it takes into account ride isolation while reacting to vehicle yaw and lateral acceleration response to firm-up the dampers and counteract roll. ADS implements this concept as a method that targets a roll control proportional to the lateral acceleration differential value of the vehicle. Figure 9 shows the block diagram of ADS control logic.

The vehicle inputs are converted to damper current values by ADS control logic in the following procedure:

- (1) Vehicle sensor inputs are interpreted by the body control logic (skyhook, pitch, and roll) after the derivative and integral processes have been completed on the sensor outputs

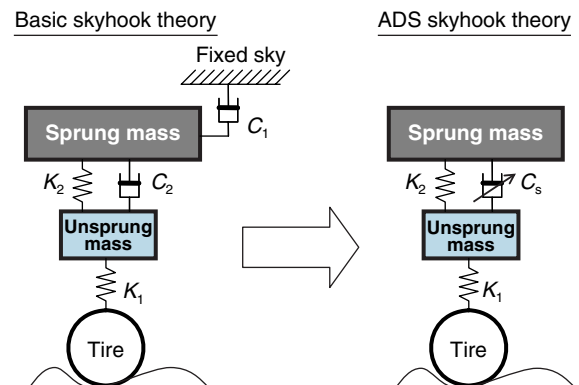


Fig. 8 Skyhook suspension control theory

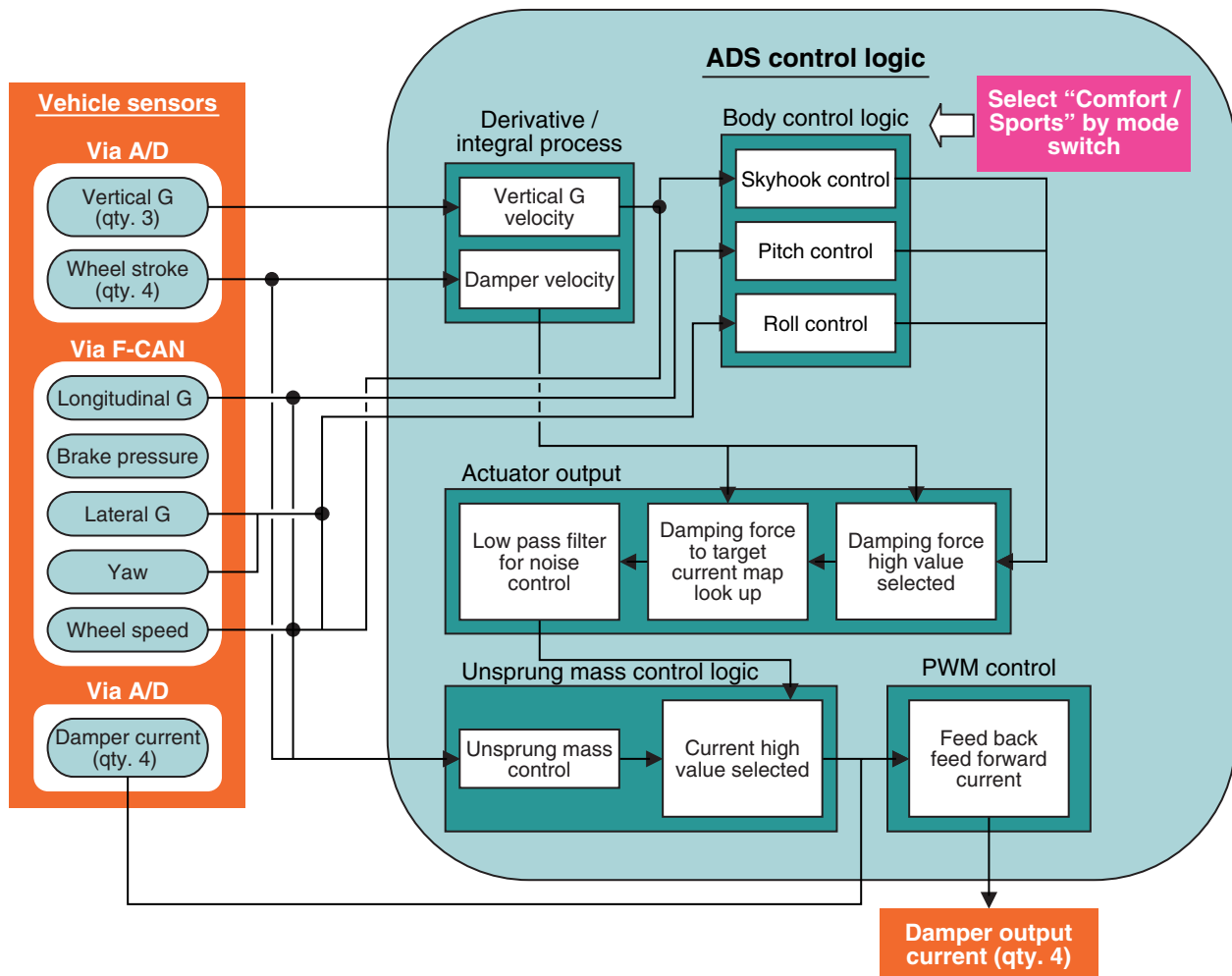


Fig. 9 Control logic block diagram

- (2) The highest damping force is selected from one of the three body control algorithms
- (3) Damper target current is looked up in the damping force map to match the high-selected damping force from the body control logic
- (4) The target current is then run through a low pass filter for noise control
- (5) If required, unsprung mass control logic adds current to the target current in order to modulate aftershake and other unsprung mass incidents
- (6) The target current is then compared to actual damper current and an adjusted output current is given to each damper

5. Vehicle Performance

The large range of damping force allowed by the MR dampers combined with the derivative control-based algorithm allow for a very wide range of ride and handling tunability. In order to appeal to the broadest possible range in consumer tastes, two driver-selectable damper modes were developed: "Sport and Comfort." The goal of the selectable mode is to allow the driver to tailor the ride comfort and handling of the vehicle to their mood or driving condition and broaden the overall

appeal of the 2007 model year MDX by reducing the ride-handling tradeoff that occurs with conventional damper tuning. Changing between the modes is accomplished using a two-position switch mounted on the console. The ADS operating mode is relayed to the driver via an indicator on the mode switch as well as through a message that is displayed on the combi-meter MID display for a short time, each time the ADS mode is changed.

Comfort mode and Sport mode operate using the same sensor inputs, algorithm, and damping force look-up tables. The ride and handling differentiation comes from higher Sport mode gain settings for the roll, pitch, and skyhook portions of the algorithm. These higher gain levels result in a higher commanded current for a given maneuver in Sport mode versus Comfort mode. The higher commanded current gives higher damping forces, yielding highly controlled roll, pitch, and heave motions. The highly controlled body motions in Sport mode have the added benefit of enhancing load transfer during transient maneuvers. Faster load transfer results in less delay in tire force build up, helping the vehicle to respond more quickly to driver steering and brake inputs. The net result is that the vehicle has a more

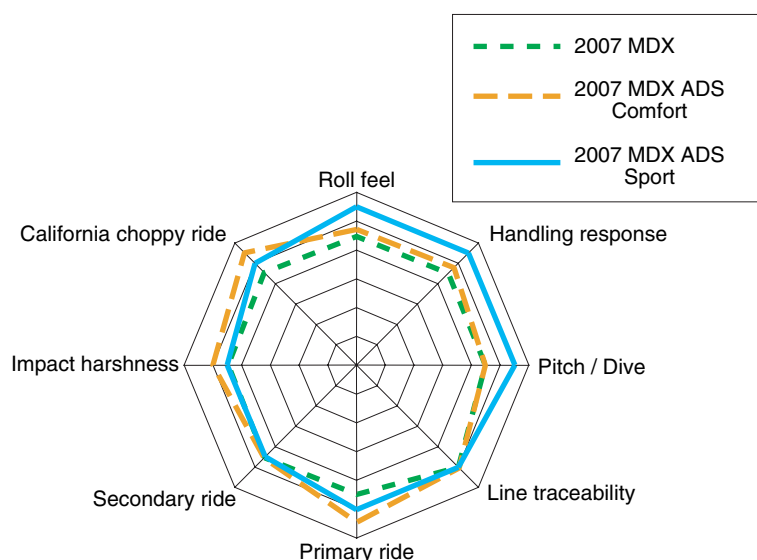


Fig. 10 ADS vehicle performance achievement

nimble, agile feel in Sport mode versus Comfort mode. The higher damping forces also result in a small decrease in bump isolation, though ride levels are still significantly better than that of a conventional non-MR damper sport suspension. Decreased isolation actually has some positive benefit in that it differentiates the Comfort and Sport modes and provides the driver with an increased, but not annoying, level of tactile feel. Overall achievement levels of both the Sport and Comfort modes can be seen in Fig. 10 as referenced to the base conventional damper.

The Comfort mode uses the same algorithm as the Sport mode but lowers the gains and resulting damping force to allow the sprung mass to have a more relaxed, isolated road feel. Roll, pitch, and vehicle heave motions are tuned to be closer to that of the conventional suspension vehicle and the result is a level of ride isolation that exceeds the capability of a conventional mechanical damper. To take full advantage of the damper capability and maximize Comfort mode ride isolation, the spring rates on the MR equipped vehicle were decreased by about 18% versus the conventional damper springs.

6. Conclusion

Having focused on the limits of MR damper capability, extensive investigation, testing, and tuning have provided the following results:

- (1) A unique MR damper with enhanced damping force capability and durability through changes to the piston core, electrical connectors, and sealing systems.
- (2) Combined with the enhanced MR damper and a two-gain mode algorithm, a vehicle that can exhibit traits of both a ride comfort-tuned and a sport handling-tuned suspension without typical tradeoffs.

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