Proceedings

ATZ live

Peter Pfeffer *Editor*

13th International Munich Chassis Symposium 2022

Volume 1: chassis.tech plus

Springer Vieweg

Proceedings

Ein stetig steigender Fundus an Informationen ist heute notwendig, um die immer komplexer werdende Technik heutiger Kraftfahrzeuge zu verstehen. Funktionen, Arbeitsweise, Komponenten und Systeme entwickeln sich rasant. In immer schnelleren Zyklen verbreitet sich aktuelles Wissen gerade aus Konferenzen, Tagungen und Symposien in die Fachwelt. Den raschen Zugriff auf diese Informationen bietet diese Reihe Proceedings, die sich zur Aufgabe gestellt hat, das zum Verständnis topaktueller Technik rund um das Automobil erforderliche spezielle Wissen in der Systematik aus Konferenzen und Tagungen zusammen zu stellen und als Buch in Springer.com wie auch elektronisch in Springer Link und Springer Professional bereit zu stellen. Die Reihe wendet sich an Fahrzeug- und Motoreningenieure sowie Studierende, die aktuelles Fachwissen im Zusammenhang mit Fragestellungen ihres Arbeitsfeldes suchen. Professoren und Dozenten an Universitäten und Hochschulen mit Schwerpunkt Kraftfahrzeug- und Motorentechnik finden hier die Zusammenstellung von Veranstaltungen, die sie selber nicht besuchen konnten. Gutachtern, Forschern und Entwicklungsingenieuren in der Automobil- und Zulieferindustrie sowie Dienstleistern können die Proceedings wertvolle Antworten auf topaktuelle Fragen geben.

Today, a steadily growing store of information is called for in order to understand the increasingly complex technologies used in modern automobiles. Functions, modes of operation, components and systems are rapidly evolving, while at the same time the latest expertise is disseminated directly from conferences, congresses and symposia to the professional world in ever-faster cycles. This series of proceedings offers rapid access to this information, gathering the specific knowledge needed to keep up with cutting-edge advances in automotive technologies, employing the same systematic approach used at conferences and congresses and presenting it in print (available at Springer.com) and electronic (at Springer Link and Springer Professional) formats. The series addresses the needs of automotive engineers, motor design engineers and students looking for the latest expertise in connection with key questions in their field, while professors and instructors working in the areas of automotive and motor design engineering will also find summaries of industry events they weren't able to attend. The proceedings also offer valuable answers to the topical questions that concern assessors, researchers and developmental engineers in the automotive and supplier industry, as well as service providers.

Peter Pfeffer
Editor

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Editor
Peter Pfeffer
Munich University of Applied Sciences
Munich, Bayern, Germany

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Vorwort

Herzlich willkommen
Im Dreiklang aus Fahrer, Fahrzeug und Fahrwerk ist letzteres die entscheidende Note, um Bestwerte bei Fahrsicherheit, Sportlichkeit und Komfort zu komponieren. Trends wie das automatisierte Fahren und die Antriebselektrifizierung lösen weitere Rückwirkungen auf die Chassisarchitekturen aus. Nur interdisziplinäre Ingenieurteams, die am Gesamtkunstwerk Chassis arbeiten, können diese Herkulesaufgabe meistern. Agile Entwicklungsmethoden und Computer-simulationen sowie Fahrsimulatoren und realer Fahrversuch helfen dabei – für heutige und zukünftige Systeme.

Das 13. Internationale Münchner Fahrwerk-Symposium chassis.tech plus möchte erneut bis zu 500 Fachleute zum Erfahrungsaustausch zusammenbringen. Hier können Expertinnen und Experten für Radaufhängung, Lenkung, Bremse und Reifen/Räder sowie ADAS gemeinsam neueste Informationen erhalten und aktuelle Entwicklungen ausführlich diskutieren.

Seien Sie gespannt auf Keynotes von Dr. Hans-Jörg Feigel (Continental), Helge Westerfeld (Bosch), Patricio Barbale (S&P Global Mobility) und Andreas Rigling (ADAC) am ersten Tag des Symposiums, aber auch auf die Kurzinterviews mit wichtigen Experten. Am zweiten Tag werden Prof. Dr. Frank Gauterin (Karlsruher Institut für Technologie) und Leonardo Bagnoli (Ducati) ihre wertvollen Einschätzungen präsentieren.

Wir freuen uns, Sie im Bayerischen Hof im Herzen von München oder virtuell im Live-Stream begrüßen zu dürfen, und wünschen Ihnen eine anregende Veranstaltung.

Prof. Dr. Peter Pfeffer
Hochschule für angewandte
Wissenschaften München,
Wissenschaftliche Leitung des
Symposiums, Munich, Germany

Preface

Welcome
In the triad of driver, vehicle and chassis, the latter is the decisive factor in composing the best values in terms of driving safety, sportiness and comfort. Trends such as automated driving and drive electrification have further repercussions on chassis architectures. Only interdisciplinary teams of engineers working on the overall work of art that is the chassis can master this Herculean task. Agile development methods and computer simulations, as well as driving simulators and real driving tests, will help – for current and future systems.

The 13th International Munich Chassis Symposium chassis.tech plus once again aims to bring together up to 500 experts to exchange experiences. Here, experts for wheel suspension, steering, brakes and tires/wheels as well as ADAS can jointly obtain the latest information and discuss current developments in detail.

You can look forward to keynote speeches by Dr. Hans-Jörg Feigel (Continental), Helge Westerfeld (Bosch), Patricio Barbale (S&P Global Mobility) and Andreas Rigling (ADAC) on the first day of the symposium, as well as short interviews with key experts. On the second day, Prof. Dr. Frank Gauterin (Karlsruhe Institute of Technology) and Leonardo Bagnoli (Ducati) will present their valuable assessments.

We look forward to welcoming you to the Bayerischer Hof in the heart of Munich or virtually via live stream and wish you a stimulating event.

Prof. Dr. Peter Pfeffer
Hochschule München University
of Applied Sciences, Scientifc Director
of the Symposium, Munich, Germany

Conference Report

13th Munich Chassis Symposium – chassis.tech plus 2022

There was a mood of excitement when, after a two-year break because of the pandemic, the 13th chassis.tech plus was at last held again as an in-person event. More than 300 participants traveled to Munich and were obviously pleased to be able to meet face-to-face once more. Together with the 100 people who took part via live stream, they held in-depth discussions on the latest trends in chassis development, which ranged from the influence of software to the importance of sustainability.

The chassis symposium was organized by ATZlive in cooperation with TÜV Süd. Over 400 attendees took part on July 05 and 06, 2022, (in person and via live stream). The symposium focused on two key trends: software and sustainability. The Scientific Director, Professor Peter E. Pfeffer from Munich University of Applied Sciences, aptly summed up the first of these themes at the end of the event when he said: "It's all about software, software and software." He highlighted in particular the ongoing development of the processes and the increasingly professional methods, together with the influence of the software-defined vehicle, which is also having an impact on chassis design. As far as development tools are concerned, driving simulators of different kinds will become increasingly important for the creation of good products and will fill the gap between computer simulation and real road trials. All of this is not merely an end in itself, but is done with the aim of cutting costs and shortening development times.

Reducing the Carbon Footprint of Entire Supply Chains

The second theme – "the sustainability of the chassis" – attracted considerable attention. Hans-Jörg Feigel from Continental came up with the motto "The sustainability quota is the new horsepower" in his keynote speech on the first day. More and more vehicle manufacturers are requiring their suppliers to take substantial measures to reduce the carbon footprint of their products and their companies along the entire supply chain. In future chassis systems, modularization offers significant potential for improving sustainability. The smaller number of control units will reduce the use of resources and the amount of cabling needed. In addition, modules can be reused. The option of updates ensures that the car will have a longer service life. Brake-by-wire systems are more environmentally friendly because of their lower losses and lack of operating fluids.

In purely mechanical and electrical systems, Feigel expects changes of a more evolutionary nature to take place. By contrast, the revolutionary transformation will occur in the area of self-driving vehicles and cars used as second homes. The solution for both of these developments lies in a new software architecture that is modular and scalable and can be adapted to each application, as well as allowing for over-the-air updates. The keyword in this respect is "software as a product" which will result in "major changes to our current business models." Just as the integral body with the safe passenger compartment became a standard feature of cars and was mastered by the engineers of the time, so steer-by-wire and brake-by-wire systems now open up new possibilities for packages, modularization and different applications.

New Dimensions in Vehicle Dynamics Control and Braking Systems

In his keynote speech, Helge Westerfeld from Bosch emphasized the fact that the work on vehicle dynamics control was by no means at an end. Its origins lie in the development of the Electronic Stability Program (ESP) system by the automotive supplier Bosch and the car manufacturer Daimler way back in 1995. However, the cooperation between carmakers and suppliers will have to change significantly with the introduction of new assistance systems for automated driving. The coexistence of systems from level 0 to level 4 remains an issue. A distinction needs to be made between vehicle motion control and the vehicle motion management system developed by Bosch which represents a more integrated approach to vehicle dynamics control. This opens up new dimensions in model-based control systems and multi-actuator integrations that will increase road safety, ride comfort and driving pleasure.

Patricio Barbale from IHS Markit, which is now a subsidiary of S&P, focused in his plenary presentation on the market penetration of assistance systems for automated driving. The figures he quoted reflected a certain disillusionment with the trend for automation, because the other key trend of electrification is taking off at a much faster rate. In 2019, the prediction was that electric cars would make up only 14 % of global sales by 2031. However, the current estimate (in 2022) is the impressive figure of 41 % for 2031. By contrast, the proportion of vehicles with level 3 functions is expected to rise from 2 to only 4 % in Europe, from 3 to 4 % in China and from 4 to 7 % in North America between 2026 and 2033. Barbale believes that the market penetration of Electro-hydraulic Brake (EHB) systems in particular will be good and expects the market share to reach 60 % by 2033. The next step will be toward electro-mechanical brake systems, which are likely to have a market share of between 5 and 10 % by 2033.

Next Event Held in June 2023

The date for the next chassis.tech plus was announced during this year's symposium in the Hotel Bayerischer Hof. The chassis community will come together once again on June 20 and 21, 2023, to hear many interesting presentations about the latest innovations in chassis systems. Hopefully there will be the same mood of excitement next year.

Michael Reichenbach

Tagungsbericht

13. Münchner Fahrwerk-Symposium – chassis.tech plus 2022
Leuchtende Augen: Nach zwei Jahren Coronapause konnte die 13. chassis.tech plus endlich wieder vor Ort stattfinden. Über 300 Teilnehmende genossen es sichtlich in München, dass Gespräche wieder in persona möglich waren. Zusammen mit den 100 virtuell Zuhörenden wurde intensiv über die Trends der Fahrwerksentwicklung diskutiert, vom Softwareeinfluss bis zur Nachhaltigkeit.

Das Fahrwerk-Symposium wurde von ATZlive in Kooperation mit dem TÜV Süd veranstaltet. Insgesamt waren über 400 Teilnehmerinnen und Teilnehmer am 5. und 6. Juli 2022 dabei (vor Ort und virtuell). Zwei Trends ließen sich auf dem Symposium ausmachen, und zwar Software und Nachhaltigkeit. Zum Ersten: „Es geht um Software, Software und Software“, wie es der Wissenschaftliche Leiter am Ende der Veranstaltung treffend zusammenfasste. Prof. Peter E. Pfeffer von der Hochschule München hob vor allem die Weiterentwicklung der Prozesse und die Professionalisierung der Methoden sowie den Einfluss des softwaredefinierten Fahrzeugs hervor, der auch vor dem Chassis nicht haltmache. In der Kette von Entwicklungswerkzeugen werde zudem der Fahrsimulator unterschiedlicher Ausprägung immer wichtiger für eine gute Produktentwicklung, um die Lücke zwischen der computergestützten Simulation und dem realen Fahrversuch zu schließen. Dies alles geschehe nicht aus Selbstzweck, sondern um Kosten zu sparen und Entwicklungszeiten zu verkürzen.

Co_2-Fussabdruck entlang der Lieferketten reduzieren
Zum Zweiten erhält das Thema „Nachhaltigkeit des Fahrwerks“ immer mehr Aufmerksamkeit. Dazu rief Hans-Jörg Feigel, Continental, am ersten Tag in seiner Keynote das neue Motto „Die Nachhaltigkeitsquote ist die neue Pferdestärke“ aus. Immer mehr OEMs forderten von den Zulieferern substanzielle Aktivitäten, um den CO2-Fußabdruck in ihren Produkten und Unternehmen entlang der Lieferketten zu reduzieren. Für zukünftige Chassissysteme biete die Modularisierung ein großes Potenzial für die Nachhaltigkeit: Die reduzierte Anzahl an Steuergeräten spare Ressourcen ein und verringere den Verkabelungsaufwand. Module könnten wiederverwendet werden. Die Möglichkeit zu Updates garantiere eine längere Lebensdauer des Produkts Automobil. Brake-by-Wire-Systeme seien umweltfreundlicher dank weniger Verluste und da sie ohne Betriebsstoffe auskämen.

Bei der reinen Mechanik und Elektrik erwarte er eher evolutionäre Änderungen, während sich die Revolution durch selbstfahrende Mobile und den Pkw als zweites Zuhause abzeichne. Die Lösung für beides liege in einer neuen Softwarearchitektur, die modular und skalierbar an die jeweilige Anwendung angepasst werden kann, ohne auf Updates per Funk zu verzichten. Hier sei „Software as a Product“ das Schlagwort schlechthin, was „unsere heutigen Geschäftsmodelle stark verändern wird“. So wie damals die Revolution der selbsttragenden Karosserie mit der sicheren Fahrgastzelle beim Pkw Einzug hielt und von den Ingenieuren beherrscht wurde, so offeriere nun das Steer-by-Wire und Brake-by-Wire viele neue Freiheiten bei Packaging, Modularisierung und Anwendungsfall.

Neue Dimensionen bei Fahrdynamikregelung und Bremssystemen
Helge Westerfeld, Bosch, zeigte in seiner Keynote auf, dass die Arbeiten zum Thema Fahrdynamikregelung nicht ruhen werden. Ihre Anfänge liegen mit der Entwicklung des Systems ESP durch den Zulieferer Bosch und den Automobilhersteller Daimler im Jahr 1995 zwar weit zurück. Aber aktuell wird sich in der Zusammenarbeit zwischen OEMs und Zulieferern mit der Einführung neuer Assistenzsysteme für das automatisierte Fahren viel ändern müssen. Denn das Thema Koexistenz der Systeme von Level 0 bis 4 bleibt bestehen. Es sei zu unterscheiden zwischen Vehicle Motion Control und dem vom eigenen Haus propagierten Vehicle Motion Management, dass die Fahrdynamikregelung ganzheitlicher abbilde. Bosch öffne somit neue Dimensionen modellbasierter Regelungen und Multi-Aktuator-Integrationen, um ein Mehr an Straßensicherheit, Fahrkomfort und Fahrspaß zu generieren.

Die Marktdurchdringung von Assistenzsystemen für das automatisierte Fahren stellte Patricio Barbale von IHS Markit, mittlerweile eine Tochterfirma von S&P, in den Mittelpunkt seines Plenarvortrags. Dabei spiegelten seine Zahlen etwas Ernüchterung beim Automatisierungstrend wider, weil das andere Trendthema Elektromobilität sehr viel besser hochlaufe: Ging man 2019 noch von einem globalen Absatzanteil an Elektrofahrzeugen von nur 14 % für das Jahr 2031 aus, rechnet man aktuell (2022) mit beachtlichen 41 % Anteil für 2031. Demgegenüber steige der Anteil von Fahrzeugen mit Level-3-Funktion von 2026 auf 2033 bloß von 2 auf 4 % (Europa), von 3 auf 4 % (China) und von 4 auf 7 % (Nordamerika). Speziell für elektrohydraulische Bremssysteme (EHB) sieht Barbale eine bereits gute Marktdurchdringung, 2033 erwartet er einen EHB-Anteil von 60 %. Der nächste Schritt gehe in Richtung elektromechanischer Bremssysteme, für die mit 5 bis 10 % Marktanteil 2033 gerechnet werden könne.

Erneutes Treffen im Juni 2023
Der Termin für die nächste chassis.tech plus wurde im Bayerischen Hof schon bekanntgegeben. Die Fahrwerk-Community wird sich am 20. und 21. Juni 2023 wieder für zahlreiche interessante Vorträge über die Innovationen des Fahrwerksystems treffen – dann hoffentlich auch wieder mit strahlenden Gesichtern.

Michael Reichenbach

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Integrated Vehicle Dynamics Control - Opening up New Dimensions

Helge Westerfeld(✉)

Robert Bosch GmbH, Chassis Systems, Deutschland
helge.westerfeld@de.bosch.com

Abstract. The ongoing and strong transition to electrified powertrain systems and by-wire technology gives rise to new potentials for the control of vehicle dynamics and at the same time imposes new requirements to the control system. Thus, modern vehicle dynamics control systems need to be capable of managing cross-domain actuator control, keeping system complexity low, creating synergies, and unlocking the full potential of each single actuator in any driving situation. Further, the ongoing trend to more centralized and zone-oriented vehicle E/E architectures is another major technological challenge in developing a future-proof vehicle dynamics control system.

Keywords: Vehicle dynamics control · E/E architecture · Software-defined vehicles

1. The ongoing and strong transition to electrified powertrain systems and by-wire technology gives rise to new potentials for the control of vehicle dynamics and at the same time imposes new requirements to the control system. Thus, modern vehicle dynamics control systems need to be capable of managing cross-domain actuator control, keeping system complexity low, creating synergies, and unlocking the full potential of each single actuator in any driving situation. Further, the ongoing trend to more centralized and zone-oriented vehicle E/E architectures is another major technological challenge in developing a future-proof vehicle dynamics control system.
2. Bosch responds to the current and future demands and shows a completely re-designed vehicle dynamics control system – Vehicle Dynamics Control 2.0. It is based on a model-based feed-forward control approach which allows to anticipate the vehicle behavior and to easily integrate, control, and utilize various actuators. Further, it follows the design principles of software-defined vehicles. First it is abstracted from a specific actuator system to allow portability and a flexible in-vehicle deployment. Second, the modular architecture allows an easy adaption to various vehicle platforms, from sports cars to light trucks. Finally, there is low dependency on other vehicle control functions. This enables a long-term evolution, flexibility in customization and deployment as well as updates without excessive complexity and cost.
3. Vehicle Dynamics Control is no longer a domain-specific function, and new dimensions open up with plenty of potentials and challenges – in terms of control theory, E/E architecture and cooperation models.

P. Pfeffer (Ed.): IMCS 2022, Proceedings, p. 1, 2024.
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Future Chassis Systems: Evolution or Revolution?

Hans-Jörg Feigel(✉)

Continental Automotive Technologies GmbH, Frankfurt a. M., Deutschland
hans-joerg.feigel@continental.com

Abstract. The Electrification of the powertrain, digitalization of the vehicle and automated driving are the major drivers of the transformation in the automotive industry. The implementation of the resulting requirements is taking place at the level of the E/E and the vehicle architecture in parallel.

Requirements such as easy scalability, fast upgradeability and learning ability as well as reduced complexity call for fundamental changes in the E/E architecture. The key concepts are centralization and zonalization as well as a standardized abstraction layer between the hardware and the vehicle functions/software. Legacy control units - especially for safety-critical functions such as braking, steering - are maintained at this stage of evolution. This creates the foundations for the long-term goal of creating a standardized central server architecture.

At the same time, there is a similar development in the vehicle architecture. More and more companies are showing studies and, in some cases, production-ready implementations of so-called rolling chassis and corner modules.

In this lecture, important aspects will be highlighted that are not only relevant for the rolling chassis. The electrification of the brake is shown with the associated development. Another topic is the central control of all vehicle motion actuators - brakes, steering, propulsion and chassis. This is also the case with the introduction of the rolling chassis, which requires a clearly defined, electrical and mechanical interface to easily separate the cabin and chassis.

Keywords: Rolling Chassis · E/E Architecture · Future Chassis Systems

1 Introduction

Climate protection and the associated reduction of CO_2, supported by legal regulation, have significantly accelerated the electrification of vehicles. With the increasing importance of sustainability, the reduction of driving resistance, lightweight construction and recuperation efficiency remain important to us in chassis development. However, topics such as re-use and circular economy will also be added in the future. In addition to environmental relevance, related cost savings are also important, for example by avoiding fines and achieving the same range more cost-effectively through optimization (Fig. 1).

Costs are also to be reduced with the improved processes in the smart factories. Consistent modular designs and the elimination of complex processes, such as the fill and bleed of brake lines, help here. Modularization can be realized much more easily in electric vehicles and is supported by new E/E architectures, which also have a standardization potential, which will certainly take some time to develop. (see 2) (Fig. 2).

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https://doi.org/10.1007/978-3-662-68160-2_2

Fig. 1. Future Chassis Systems: Evolution or Revolution?

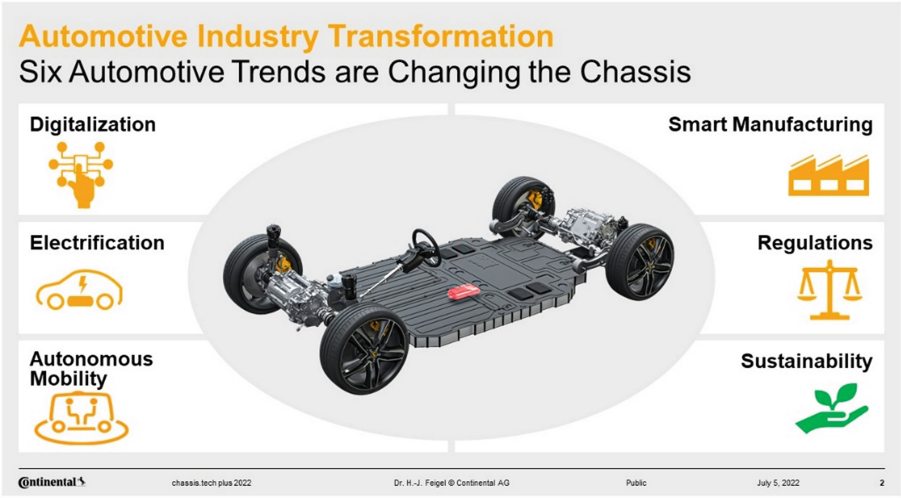

Fig. 2. Six Automotive Trends are Changing the Chassis

2 E/E Architecture

The expected and already visible further development of the E/E architectures is shown in the middle of this chart. Today, we mainly have a distributed single-domain ECU architecture with many ECUs connected to each other via complex wire harness. To reduce cost and Hardware complexity, the high number of ECUs is replaced by a server zone E/E architecture with high-performance computers and fewer master controller ECUs. This not only increases performance, but also high-speed connectivity to the

cloud and infrastructure for over-the-air updating. In later phases, we can expect even more standardized server architectures. The introduction of fully self-driving vehicles can be seen as a revolutionary change in mobility, even if we will only see a slow increase in more and more self-driving capabilities. Autonomous mobility will also have an impact on the passenger compartment. As the car will now become our second home and ultimate smart device with enhanced entertainment options, electronic demands are also increasing and being brought together in a common server arrangement. (see Fig. 3).

These changes in E/E Hardware architectures require a distributable modular software architecture, which could be challenging for today's single-domain system supplier. Regarding the Software, the development is as follows:

With a few exceptions, the individual domain ECUs host the corresponding software, such as brake or steering control. In the case of server zone E/E architectures, these and other functions are hosted in a common ECU. First the functions at vehicle level, while the hardware-related Software remains with the intelligent actuator or sensor.

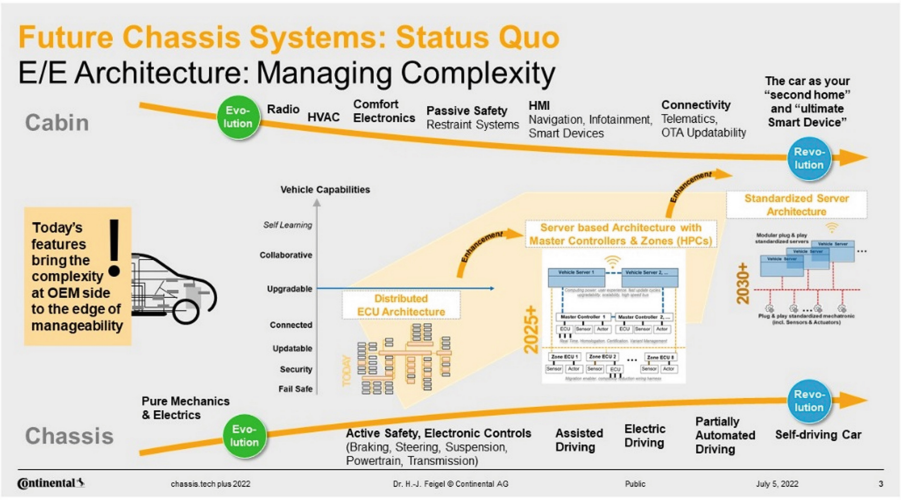

Fig. 3. Future Chassis Systems: Status Quo

The merging of chassis and electric powertrain control could be a useful intermediate step before all software functions are centralized in a standardized server architecture.

The key message is that a distributed, modular, scalable, and updatable software is needed! (see Fig. 4).

Each box represents a software module. Between the input signals from different sensors and other input devices and the different actuators such as brakes, steering, chassis, and electric drive, we see a modular software stack. This means that all control functions for vehicle dynamics will be optimally combined here. (see Fig. 5).

Thus, a considerable amount of today's single domain control functions is removed from the actuator ECUs. This means that the software will no longer be sold together with the electromechanical systems, which will remarkably change today's business models.

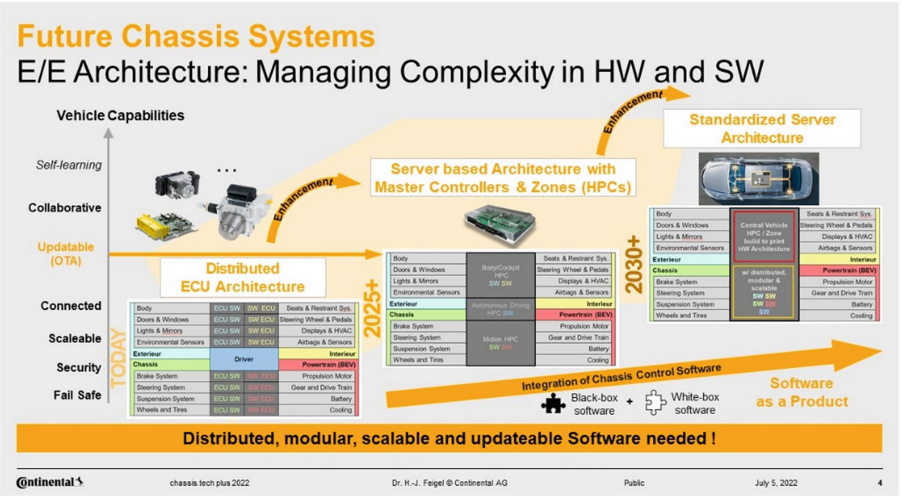

Fig. 4. E/E Architecture: Managing Complexity in HW and SW

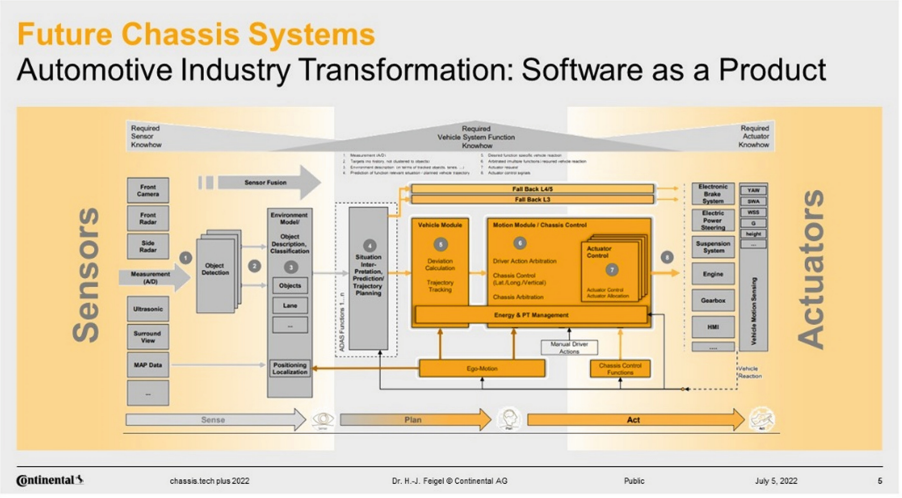

Fig. 5. Automotive Industry Transformation: Software as a Product

Instead, the extracted software functions could be sold separately as a new product. In this case, however, the software must be modular and distributable in order to be able to run not only on the original hardware, but also independently on other ECUs. The sale of software as a product requires further business processes, like maintenance over the entire service life, which is not common today. (see Fig. 6).

The described technical changes in E/E architectures will have a significant impact on today's business structures, which poses new challenges for the supplier industry. The software license models are important here in order to maintain profitability. A further

impact of the separate awarding of hardware and software will be that the competitive situation will intensify by further involvement of additional suppliers specializing in build-to-print for the ECUs.

For today's system suppliers, an unattractive sandwich position is developing. Previous Tier 2 for complex processor hardware or complex software functions are developing into Tier 1 and the customer OEM can become a competitor by taking over more and more in-house developments and in-house productions.

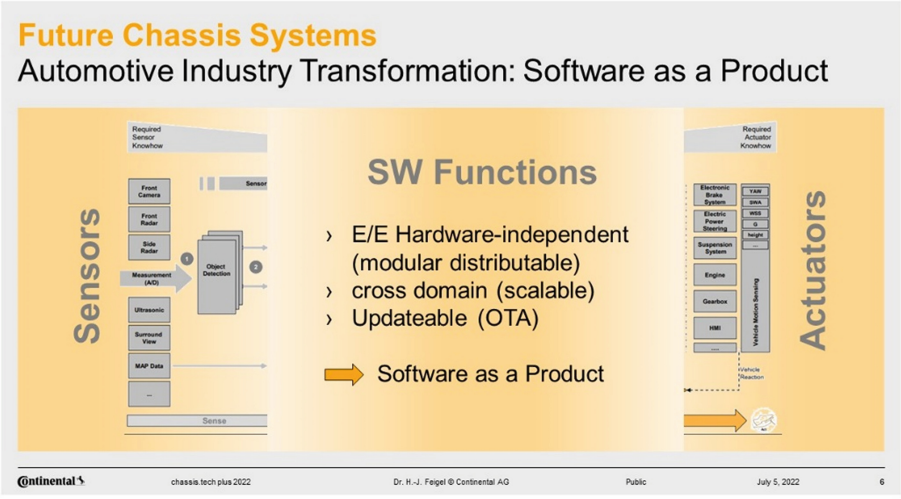

Fig. 6. Automotive Industry Transformation: Software as a Product

Alternatively, an opportunity develops for the existing system supplier to develop into a cross-domain system supplier. This disruptive change in business structures comes with the introduction of the new E/E architectures and can be classified as revolutionary. (see Fig. 7).

3 Vehicle Architecture

In the long past, there was a revolutionary change in mechanical vehicle structures from the self-supporting chassis to the self-supporting body.

The introduction of electric drives opens new possibilities for a modular vehicle design that can even lead back to self-supporting chassis. The arrangement of the more compact electric motors can be done with larger freedom - up to wheel-integrated drives. The battery, which is usually located in the underbody, is accommodated by a frame construction that can be easily extended to the axle suspensions, which means that the step to a self-propelled, so-called rolling chassis, is not far away.

Beside of a rolling chassis / hat architecture, also other possibilities are known to modularize the holistic body structure for easier creation of vehicle variants based on front end- and passenger cell modules. (see Fig. 8).

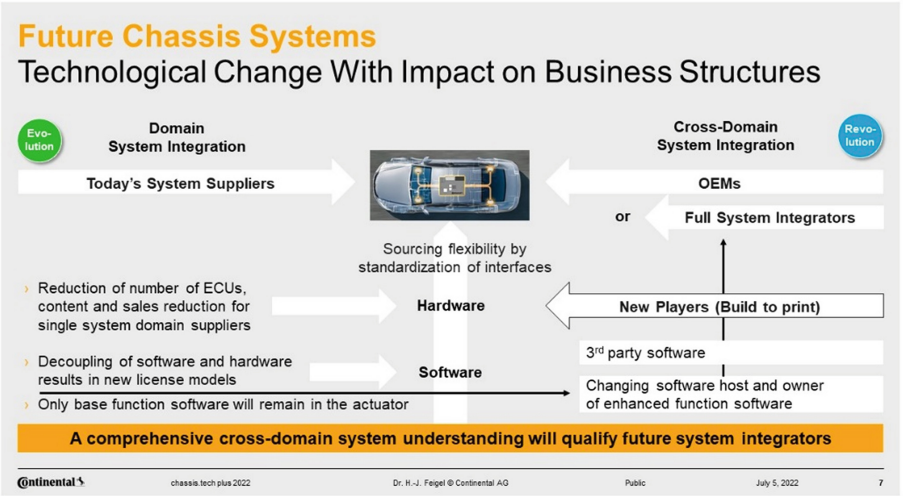

Fig. 7. Technological Change with Impact on Business Structures

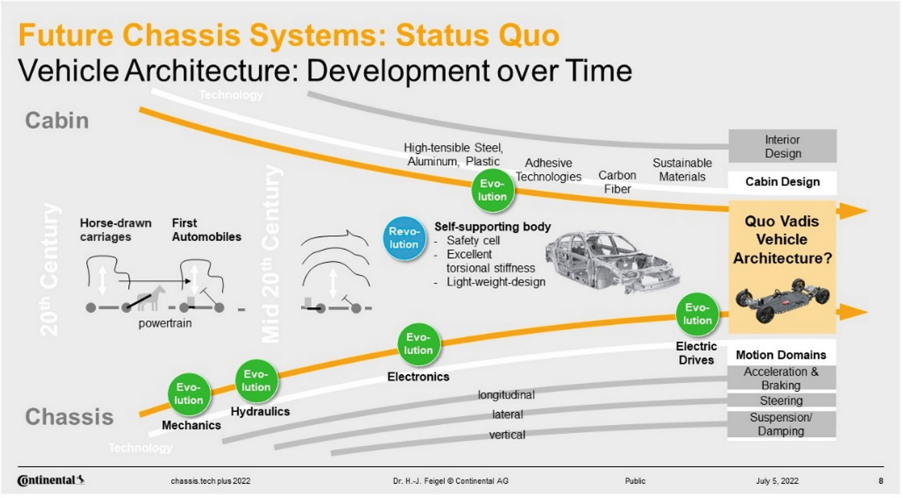

Fig. 8. Quo Vadis Vehicle Architecture?

4 Modularization

Of course, this can be achieved more easily if our chassis systems brake and steering have less rigid mechanical interfaces. With a steer-by-wire system and a brake-by-wire system with a dry electronic brake pedal, this can be easily displayed due to the plug and play technology.

On the left you can see the conventional design with rigid steering column and rigid pedal connection. (see Fig. 9). For both systems, the firewall must be broken through

and for the high forces on the brake pedal suspension, the firewall must be designed to be correspondingly stiff. With the introduction of steer-by-wire and brake-by-wire, shown in the middle picture, the various body modules can be freely designed independently of the mechanical constraints of the steering and braking systems that otherwise must be considered.

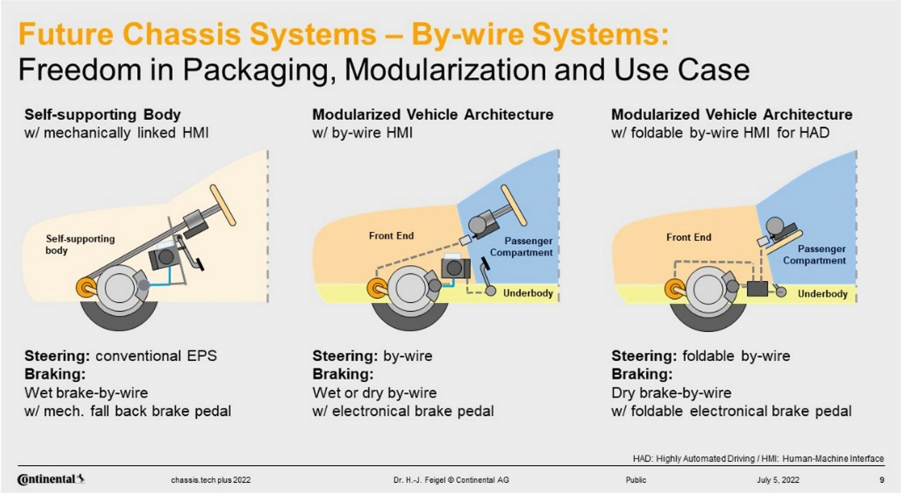

Fig. 9. Freedom in Packaging, Modularization and Use Case

This is a very big motivator for the introduction of by-wire systems. For the E/E architectures and the chassis systems, this means that they are redundant. This also facilitates the introduction of brake systems without brake fluid and the functions of automated driving. An additional requirement that often comes with automated driving is that the steering wheel and pedals can be stowed away for the duration of automated driving. This is also much easier to perform with steering wheels and pedals that have no mechanical connections.

Another modularization trend towards larger modules in particular concerns vehicle axles. Looking at today's axles with pre-assembled brake, steering and suspension components, the next step is to mount the actuators directly on the axle and thus replace the mechanical interfaces with electrical plug and play interfaces. Regarding the driven axles, the compact electric drive motors can also be integrated. (see Fig. 10). This results in axles that can also grow together across chassis systems regarding their electrical control. If the electrical energy storage system is also added, drivable self-sufficient axles or rolling chassis are created. With the rolling chassis concepts, you can alternatively also find the use of four corner modules, the applications of which will probably first be found in purpose-build vehicles in the future. These are also preferred by new entrants with more revolutionary approaches, such as the application of in-wheel motors. In any case, the trend towards larger modules offers optimization potential that can be used by system integration suppliers and thus open a field for increasing sales.

However, this does not explicitly mean the pre-assembly service of OEM-specified components, but an optimized module development and production that is based on requirements at module level.

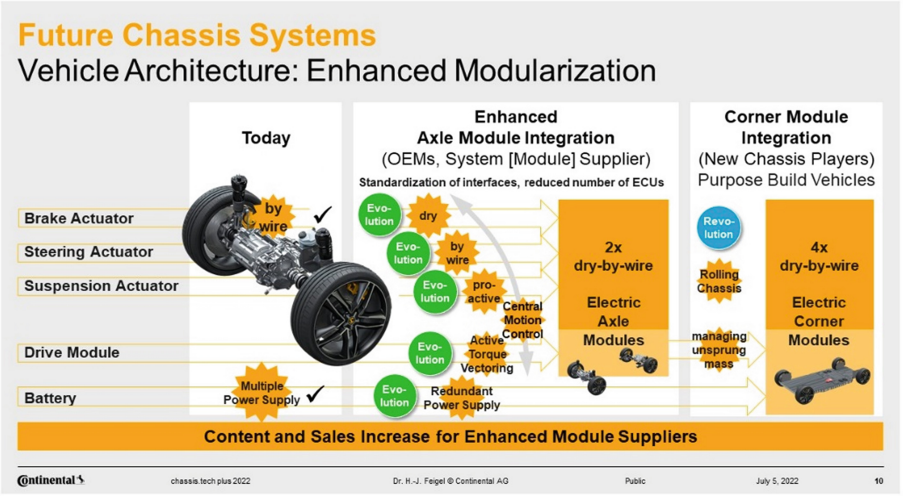

Fig. 10. Vehicle Architecture: Enhanced Modularization

In addition to the aforementioned modular design of the rolling chassis, this concept also has a far-reaching, revolutionary potential in production optimization.

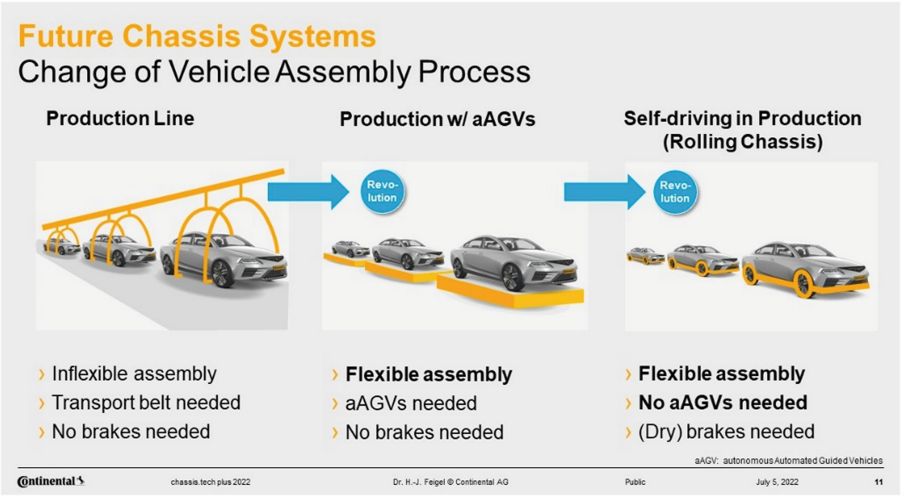

Fig. 11. Change of Vehicle Assembly Process

In today's vehicle factories, rigid production lines are still predominantly used in the assembly area. In the so-called Smart Factories, the assembly process is made flexible through the use of transport robots.

By using rolling chassis, the use of these aAGVs (autonomous Automated Guided Vehicles) can also be discontinued, as the self-propelled chassis drive by themselves to the respective assembly stations and get a wide variety of hats and equipment there. It also means that the rolling chassis can already brake independently. Since the fill and bleed process is usually done as one of the last production steps, the use of dry brakes and their early installation is central to such a modern manufacturing concept. (see Fig. 11).

In summary, here are the advantages of modularization: More vehicle variants can be featured on the basis of fewer platforms, which reduces the development and creation investments per variant. This is particularly an argument for the rolling chassis concepts. Plug & play assembly lines. For example: Dry brake-by-wire actuators reduce assembly time by eliminating the need for fill and bleed processes. Easily replaceable axis modules, support service concepts such as "predictive maintenance".

These are particularly advantageous for 24/7 operations in order to keep the availability of the fleet high, as they will certainly be important in some applications of autonomous driving. (see Fig. 12).

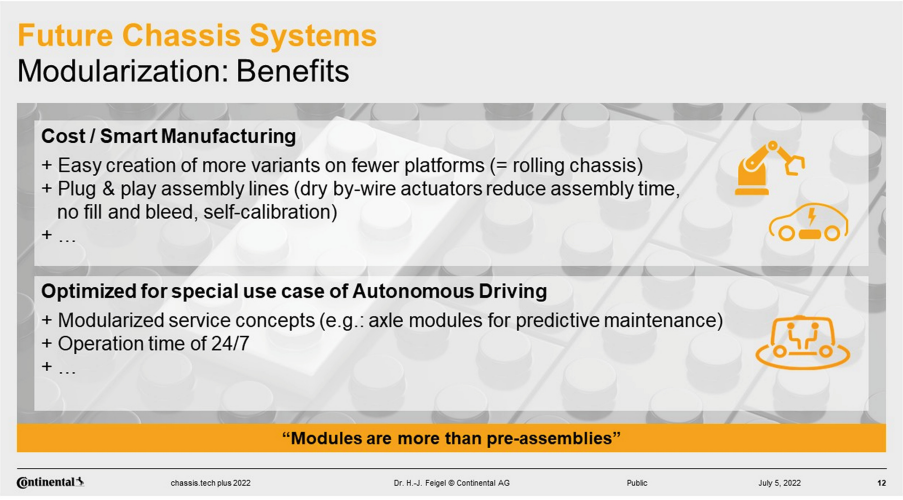

Fig. 12. Modularization: Benefits

However, modularization and the new E/E architectures already presented to have positive effects on the increasingly important requirements of sustainability. Thus, the reductions in the number of ECUs and wiring lead to a lower resource consumption and CO_2 footprint. One of the most effective ways to conserve resources is the reusability of vehicle components and modules. This allows the life cycle of the single module to be decoupled from the life cycle of the entire vehicle.

An important measure is that the modules and systems can be adapted to new functions and design lines over the period of use. This applies in particular to software functions, where attention must also be paid to downgrade capability. Compared to vehicles with combustion engines, electric vehicles already have good conditions for high sustainability in the powertrain sector. The electric motor and the very simple gearbox can easily achieve a longer service life. Good progress has also been made in preventing corrosion and the reduction of emissions in electric vehicles. That brings the focus of sustainability in electric vehicles mainly on the topics of tire and brake particle abrasion. (see Fig. 13).

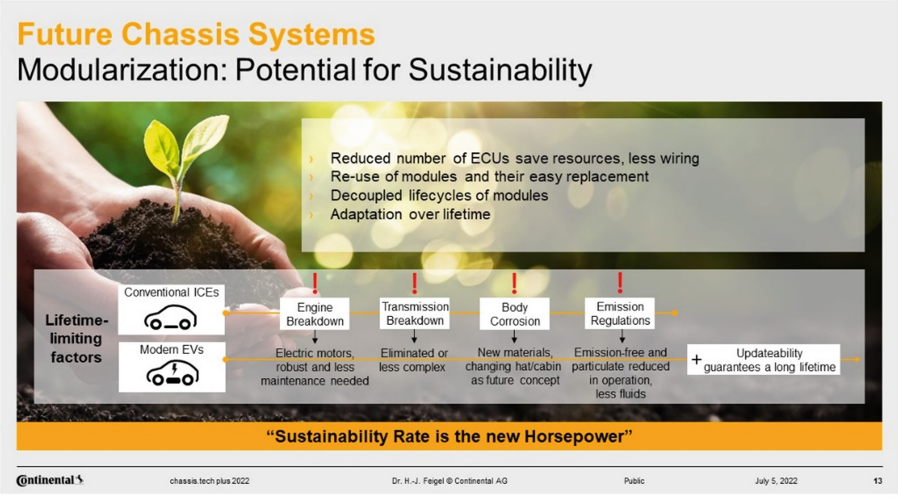

Fig. 13. Modularization: Potential for Sustainability

5 By-Wire Systems

In this context, too, let's come back to the brakes and their easily recognizable development trend. A first step to support the CO_2 reduction on the part of the braking systems was made with the introduction of the vacuum-less integrated simulator braking systems with hydraulic fallback level. With these systems, brake recuperation can already be displayed with high efficiency even with higher decelerations. These hydraulic, wet systems can also be used for highly automated driving with extensions.

With two further intermediate steps, this roadmap shows the way to a fully dry braking system.

The next development step is described with the introduction of an electronic simulator brake pedal. This supports the advantageous modularized design of the vehicle architecture already described above. The wet wheel brakes are still operated by a hydraulic central brake pressure actuator and modulator. In any case, this system requires that a redundant power supply must be available in the vehicle. This approach already

supports the plug & play connection between the electronic brake pedal and the freely placeable hydraulic modulator. This system thus paves the way for the introduction of a dry brake-by-wire system.

In the next step, electro-mechanical brake calipers or drum brakes are introduced on the rear axle with the semi dry by-wire brake system. This allows the advantages of free brake force distribution, reduced installation effort and the availability of hydraulic fallback for vehicles without redundant power supply to be exploited. With this system, field experience with the first electro-mechanical brake actuators can also be gained before the use of hydraulic fluids can be completely dispensed with in the full dry by-wire brake systems. (see Fig. 14).

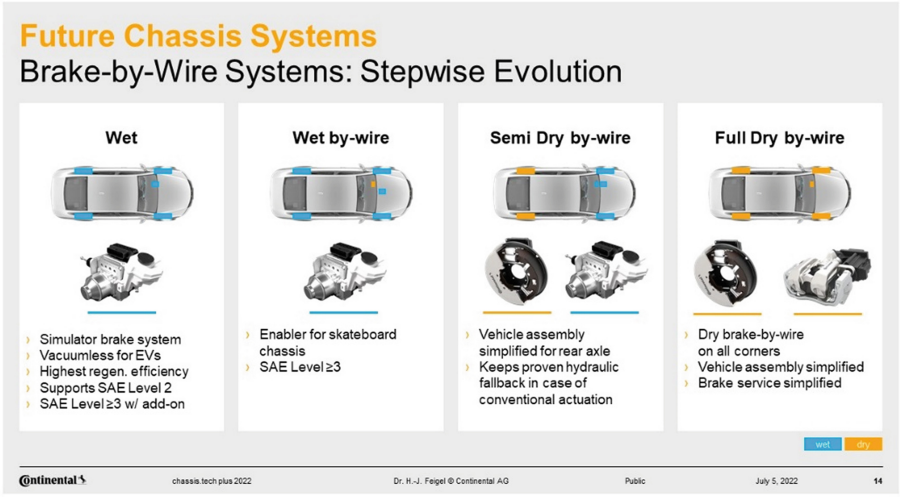

Fig. 14. Brake-by-Wire Systems: Stepwise Evolution

The technology of dry brake-by-wire systems has been known for many years, but only the previously described change in the automotive industry makes it possible to introduce it in the foreseeable future. Since the full dry brake-by-wire system requires a redundant power supply, this was one of the biggest cost hurdles to the introduction of EMB until the introduction of electric vehicles and the preparation for automated driving in the past. In addition, the relatively high costs for an electro-mechanical wheel brake are another challenge compared to a current hydraulic brake system. Electrification is accompanied by redundancy of the power source and automated driving functions are the ultimate need for reliable redundant circuits. These two enablers lower the implementation hurdles for a semi/full dry by-wire brake system. (see Fig. 15). The remaining challenge, the cost reduction of the electro-mechanical wheel brake, is now also being addressed, as we see an increasing interest in the introduction of dry brake-by-wire systems on the part of OEMs.

OEMs are becoming more and more aware of the advantages of dry production, especially as this will support the “smart factory” approach. Plug & play brake actuators

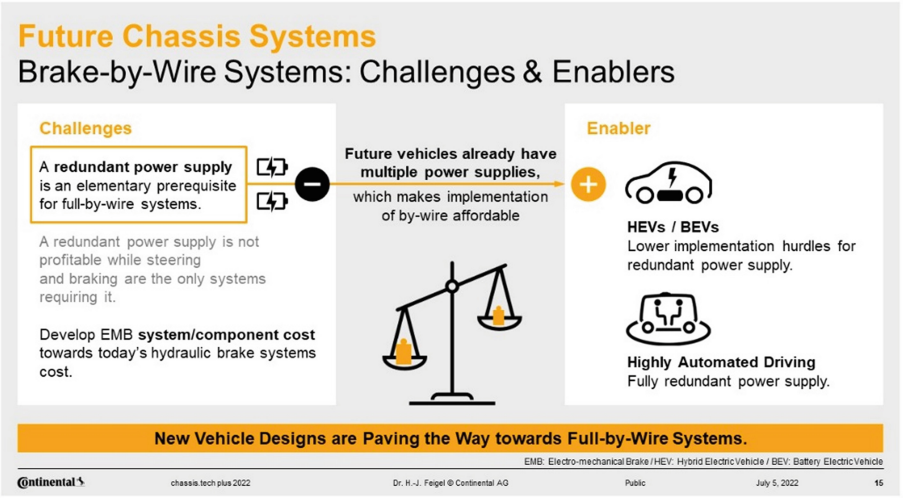

Fig. 15. Brake-by-Wire Systems: Challenges & Enablers

reduce assembly time compared to hydraulic systems, which require complex handling of brake lines and a complicated fill and bleed process. The associated investments can be saved and probably also the test bench for brake calibration at the end of the line.

If vehicles are produced on the basis of a rolling chassis, they can drive and brake independently from one assembly station to the next through the plant as already described. Since there is no longer a brake pressure modulator in the engine compartment, the dry brake system also offers new packaging and design freedom and supports the trend towards larger vehicle modules.

With regard to environmental aspects, the ability to actively control the air gap between the pad and the brake disc also reduces the residual drag to zero, thus supporting the further reduction of CO_2.

Another strong argument for a dry brake system is, of course, the elimination of the hazardous brake fluid.

For end customers, maintenance costs are reduced as brake fluid changes are no longer required. In addition to the silent ABS control and the silent torque vectoring, we also see the possibility to improve roll and pitch comfort, as the brake force distribution can be freely adapted to the driving situation. Higher redundancy, better self-diagnosis and more favorable crash behavior through the use of electronic brake pedals increase safety. So, it becomes clear that a dry brake-by-wire system offers advantages for all stakeholders – and therefore it is worthwhile to go this way. (see Fig. 16).

Two examples of electro-mechanical brake actuators are shown here (see Fig. 17).

An electro-mechanical caliper and an electro-mechanical drum brake.

It is interesting to note that the well-known disadvantage of brake coefficient dispersion in the duo servo drum brake can be eliminated by using a brake torque sensor. Thus, the main advantages of the high self-reinforcement and the encapsulated brake design of the drum brake can also be used for very heavy vehicles. It is also robust against corrosion and keeps the brake dust particles inside the drum.

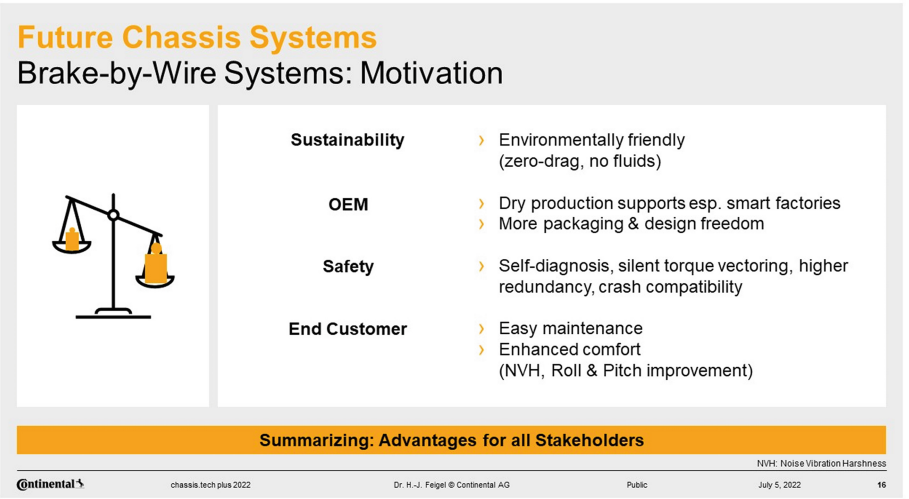

Fig. 16. Brake-by-Wire Systems: Motivation

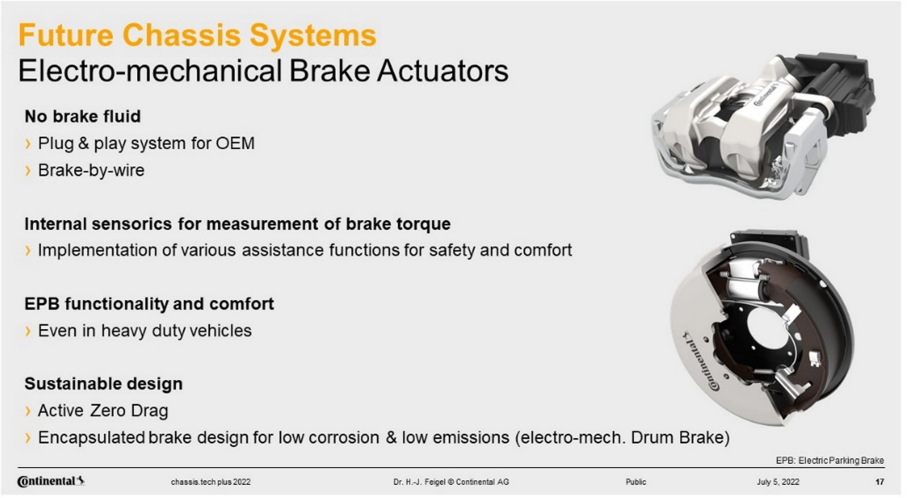

Fig. 17. Electro-mechanical Brake Actuators

Even with the dry fist caliper brake, the requirements for zero-drag can be met very well, as the large air gaps required for this can be overcome particularly quickly by the actuator. This capability will be taken into account with a correspondingly high bonus due to the CO_2 reduction potential.

At the last winter test, we at Continental presented both actuator types in two different vehicles. The very positive feedback we have received from our customers encourages us to continue our work in the development of dry brake systems.

Our vision is: The new standard for brakes is dry. Let us implement the evolutions in a revolutionary and confident way!