42nd Annual Business Meeting and Conference on Tire Science and Technology

Theme: The Intelligent Tire

Program and Abstracts

September 12th – 13th, 2023

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VIRGINIA TECH

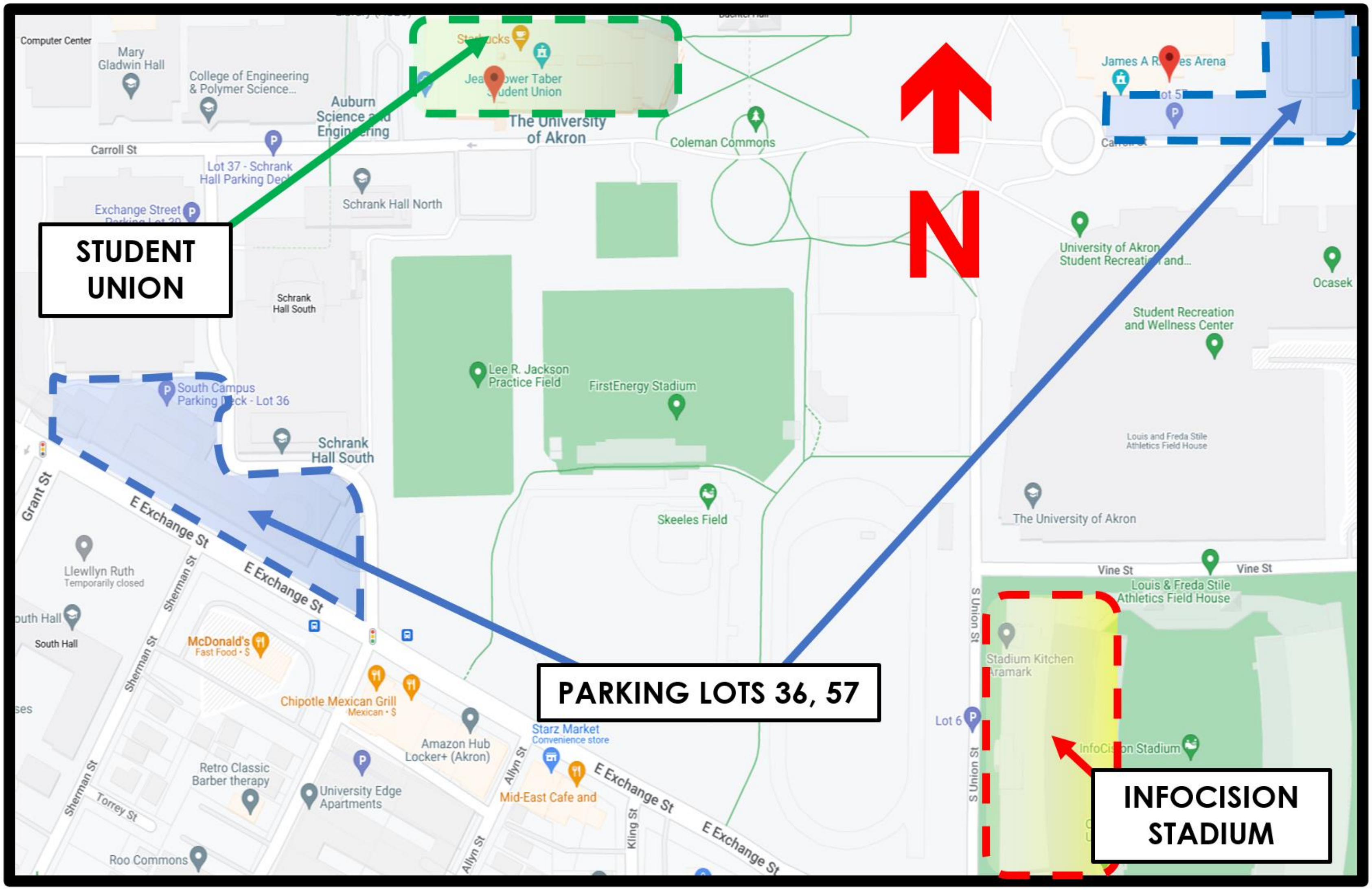
Day 1 – Tuesday, September 12th, 2023

8:00 AM		**Conference Opening**	**Jim McIntyre** *Tire Society President*
8:05 AM		**Welcome**	**Dr. Ajay Mahajan** *Associate Dean for Research & Industrial Engagement, University of Akron*
8:15 AM		**Keynote Address** The Intersection of Tire Intelligence and Sustainability - Sumitomo Rubber's Vision	**David Johansen** *Vice President, Technical* *Sumitomo Rubber USA*
9:15 AM		**Announcements**	**Cedric Mousseau** *2023 Conference Program Chair*
9:20 AM		**Break**	
9:40 AM		**Session 1: Tire Wear**	**Qian Li** *The Goodyear Tire & Rubber Company*
9:45 AM	1.1	Recent Approaches in Market Relevant Evaluation of Tire Wear	**Joerg Buschmeier** *Continental Tires*
10:10 AM	1.2	Investigation of the Interplay Between Road Surface Roughness and Tire Wear	**Alexander Boettinger** *Continental Tires*
10:35 AM	1.3	A Novel Solution for Tire Road Interaction Direct Measurements and its Applications on Tire Simulation and Analysis Methodologies	**Carlos Nerini** *CSN Vehicle Dynamics Consulting*
11:00 AM	1.4	Three Abrasion Studies: 1) Frictional Energy and Abradability, 2) The Role of Powder, and 3) Wear Particle Analysis	**Edward Terrill** *Akron Rubber Development Laboratory, Inc*
11:25 AM		**Session 2: Sensors**	**Pooya Behroozinia** *Maxxis Technology Center*
11:30 AM	2.1	Development of Intelligent Tire Technology for Tire Status Estimation in Real-world Applications	**Hojong Lee** *Hankook Tire and Technology*
11:55 AM	2.2	Structural Antenna Engineering	**John Lewis** *Dassault Systemes Simulia Corp*
12:20 PM		**Lunch (Provided)**	**Interactive Poster Presentations**
1:30 PM		**Session 3: Force and Moment**	**Adam Stackpole** *Stackpole Engineering Services*
1:35 PM	3.1	Tire Force & Moment Characteristic Optimization Driven by Vehicle ISO Metrics	**Ariel Avi** *OptimumG*
2:00 PM	3.2	Comparison of Tire Cornering Stiffness Estimation Methods on Real-World Driving Data Versus Sine Steer Tests	**Thijs Devos** *Department of Mechanical Engineering* *KU Leuven*
2:25 PM	3.3	A New Approach to Thermo-Mechanical Tire Modelling for Tire and Vehicle Development	**Henning Olsson** *Calspan Corporation*
2:50 PM	3.4	Investigation into Tire Tread Block - Slush Traction in Lab	**M. Hindemith** *Institute of Dynamics and Vibration Research Leibniz University Hannover*
3:15 PM		**Break**	
3:35 PM		**Session 4: Tire Design**	**Eric Zhang** *Bridgestone Americas*
3:40 PM	4.1	Mesh-free isogeometric simulation: developing a next-generation workflow for tread pattern optimization	**Michael Scott** *Coreform*
4:05 PM	4.2	Using Machine Learning to Improve Efficiency within Virtual Tire Cavity Development	**Brandon Kelly** *The Goodyear Tire & Rubber Company*
4:30 PM	4.3	Advanced Meta-Model Assisted FEM Tire Design Optimization	**Christoph Burkhart** *Fraunhofer-Institut für Techno- und Wirtschaftsmathematik*
5:15 PM		**Reception: InfoCision Stadium 5th Floor**	
6:15 PM		**Banquet Welcome Address**	**Cedric Mousseau**
6:25 PM		**Introduction to CenTiRe**	**Greg Bunting**
6:35 PM		**Awards Presentation**	**Yusheng Chen**
7:15 PM		**Dinner Speech** Automotive Trends and the 'Art of the Possible' with Simulation	**Judy Curran** *Sr. Chief Technologist Automotive, Ansys*
9:00 PM		**CLOSE OF DAY 1**	

Day 2 – Wednesday, September 13th, 2023

8:00 AM		**Opening Remarks**	**Cedric Mousseau** *2023 Conference Program Chair*
8:05 AM		**Plenary Address** Chances and Limitations of Intelligent Tires to Support Vehicle Performance	**Burkhard Wies** *Continental Tires Germany* *Vice President, R&D Tires*
9:05 AM		**Annual Meeting** Business Update & State of the Society	**Jim McIntyre** *Tire Society President*
9:55 AM		**Break**	
10:15 AM		**Session 5: Student Session**	**Matthias Wangenheim** *Leibniz Universität Hannover*
10:20 AM	5.1	An Intelligent Tire for Dynamic Tire-Pavement Friction Sensing with Embedded Sensors and Physics Models	**Baiyu Jiang** *Rutgers University*
10:45 AM	5.2	Multi-Length Scale Modeling and Testing of Wet Traction	**Sivaraman Ilanji Sethuramalingam** *Center for Tire Research (CenTiRe), Mechanical Engineering, Virginia Tech*
11:10 AM	5.3	Customizable Pressure-Sensitive Sensors for Tire Health Monitoring	**Ahadur Rahim** *The University of Akron*
11:35 AM	5.4	Structure-Borne Vehicle Interior Noise Estimation Using Accelerometer Based Intelligent Tires in Passenger Vehicles	**Yashasvi Achanta** *Center for Tire Research (CenTiRe), Mechanical Engineering, Virginia Tech*
12:00 PM		**Lunch (Provided)**	
1:00 PM		**Session 6: Noise**	**Xianwei Meng** *The Goodyear Tire & Rubber Company*
1:05 PM	6.1	An Approach to Reduce Pipe Resonance Noise with Zigzag Groove Wall	**Yo Lin Ruan** *Maxxis Tire Company*
1:30 PM	6.2	A Study on the Fidelity of FE Based Virtual Tire Assembly Models Used for Vehicle NVH SBN Performance Considering Vibrational Modal and Steady State Dynamic Simulations	**Yunpei Yang** *Hankook Tire & Technology*
1:55 PM		**Session 7: Materials**	**Annette Lechtenboehmer** *Retired*
2:00 PM	7.1	Computing Tire Durability from Multibody Dynamics Simulation of Nurburgring Circuit Events	**William Mars** *Endurica LLC*
2:25 PM	7.2	Comparative Chemical Composition of US and European Tyres VOC profile, Potential Environmental Impact, Including 6PPD	**Nick Molden** *Emissions Analytics*
2:50 PM	7.3	Rubber Tires for Mars Rovers: Effect of BR crystallinity on properties of BR/VMQ blends	**Rafal Anyszka** *Lodz University of Technology*
3:15 PM		**Break**	
3:35 PM		**Session 8: Friction**	**Nihar Raje** *Bridgestone Americas*
3:40 PM	8.1	Study on the Relationship between Wear of Tire Tread Rubber and Frictional Work Using FPS Abrader	**Tomoaki Iwai** *Kanazawa University*
4:05 PM	8.2	The Transition from Sliding to Rolling Frictional Abrasion of Rubber	**Michael Kaliske** *Technische Universität Dresden*
4:30 PM	8.3	Prediction of the Frictional Power Distribution in the Tire Contact Patch Based on an Empirical Tire Model and an Artificial Neural Network	**Lars Muth** *Paderborn University*
4:55 PM	8.4	Tire Burnish and Stopping Distance for Virtual Calibration	**Anudeep Bhoopalam** *General Motors*
5:20 PM		**Closing Remarks**	**Cedric Mousseau** *2023 Conference Program Chair*
5:25 PM		**2024 Conference Announcement**	**Matthew Van Gennip** *2024 Conference Program Chair*
5:30 PM		**END OF CONFERENCE**	

UNIVERSITY OF AKRON CAMPUS MAP



Keynote Address

David Johansen
Vice-President – Technical
Sumitomo Rubber USA

Title of Talk: ***The Intersection of Tire Intelligence and Sustainability - Sumitomo Rubber's Vision***

Mr. Johansen has over 25 years of experience in the tire industry, with expertise in tire design, vehicle testing and simulation, and manufacturing process control. He joined Sumitomo Rubber Industries, Ltd. in 2015. SRI is a leading manufacturer of automotive tires with over 40,000 employees and operates 12 manufacturing facilities located in 8 different countries. SRI is headquartered in Kobe, Japan where Mr. Johansen worked as a manager of tire design from 2017-2019. Since 2019, he is responsible for the SRI North American Technical Center in Buffalo, NY and Huntsville, AL. Mr. Johansen holds a Master of Science degree in Mechanical Engineering from Michigan Technological University. He has been a USTMA member since 2019.

Plenary Lecture

Burkhard Wies
Vice President Innovation & Applied Research Tires
Continental AG

Title of Talk: ***Challenges & Opportunities of Intelligent Tires to Support Vehicle Performance & Services***

Burkhart Wies has held a number of management positions in Tire Development and Industrialization for Replacement and Original Equipment, since he joined Continental in 1999. Prior to that he was a Tire Development Engineer and Section Head at Uniroyal Englebert GmbH in Aachen, Germany. He is a Program Committee member of VDI (German Association of Engineers) and, for 18 years, was Program Manager for Tire-Suspension- Road VDI-Congress. Dr. Wies is a member of the Tire Society Executive Committee Board. He holds a PhD in Mechanical Engineering at Technical University RWTH Aachen and lectures at Leibniz University, Hannover, Germany.

Banquet Speaker

Judy Curran
Senior Chief Technologist Automotive
ANSYS, Inc.

Title of Talk: ***Automotive Trends and the 'Art of the Possible' with Simulation***

Judy Curran is an accomplished senior automotive and software executive with over 30 years of experience in automotive/mobility engineering, and technology leadership. She currently is the Sr. Chief Technologist (CTO) Automotive at Ansys; partnering with OEMs and suppliers in their digital transformation. She is also an independent corporate board director at FORVIA, and MicroVision, providing guidance on the automotive industry, and key technologies. Incrementally, Judy is an independent director of the SAE International, and was elected to the Top 100 Women in the Automotive Industry by Automotive News. She holds a Master of Science degree in Electrical Engineering from the University of Michigan.

About The Tire Society

The Tire Society was established to disseminate knowledge and to stimulate development in the science and technology of tires. This is pursued through technical meetings and publication of the journal, Tire Science and Technology. The Society is a not-for-profit Ohio corporation managed by a duly elected Executive Board of tire industry professionals who serve on a volunteer basis.

2022-2023 EXECUTIVE COMMITTEE:

President:	Jim McIntyre	*Bridgestone Americas*	Akron, OH
Vice-President:	Jim Cuttino	*Yokohama Tire Corporation*	Cornelius, NC
Treasurer:	Xianwei Meng	*The Goodyear Tire & Rubber Company*	Akron, OH
Secretary:	Annette Lechtenböhmer	*Retired*	Luxembourg
Journal Editor:	Michael Kaliske	*Technische Universität Dresden*	Dresden, Germany
Past-President:	Will Mars	*Endurica LLC*	Findlay, OH

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	Bob Pelle	*The Goodyear Tire & Rubber Company*	Akron, OH
	Jerry Potts	*GRP Consulting*	Akron, OH
	Matthew Schroeder	*MathWorks*	Ottawa, OH
	Yaswanth Siramdasu	*Hankook Tire & Technology*	Akron, OH
	Burkhard Wies	*Continental AG*	Hanover, Germany

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Yaswanth Siramdasu	*Hankook Tire & Technology*

Many members volunteered their time to put together the 42nd Annual Meeting and Conference.

CONFERENCE COMMITTEE:

Committee Chair:	Matthew Schroeder	*MathWorks*
2023 Program Chair:	Ric Mousseau	*General Motors*
2024 Program Chair:	Matthew Van Gennip	*Link Engineering*
2025 Program Chair:	Qian Li	*The Goodyear Tire & Rubber Company*

Session Chairs:

Mohammad Behroozi	*General Motors*
Jae-Won Choi	*University of Akron*
Yusheng Chen	*Dupont*
Jim Peters	*Maxxis Technology Center*
Adam Stackpole	*Stackpole Engineering Services*
Xianwei Meng	*The Goodyear Tire & Rubber Company*
Matthias Wangenheim	*Leibniz Universität Hannover*
Eric Zhang	*Bridgestone Americas*
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* C – Conference Judge, S – Student Paper Judge

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The Tire Society also thanks KnowledgeWorks Global Ltd. for their many contributions! In particular, we wish to thank Chris Lapine and Terry Leatherman for their tireless commitment to assisting the Society in its goal of disseminating knowledge about the science and technology of tires.

In addition to the Journal Editor, the associate editors volunteer time to contribute to the peer review process associated with publishing manuscripts in the Tire Science & Technology Journal:

JOURNAL ASSOCIATE EDITORS:

TIRE SOCIETY BUSINESS OFFICE:

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Save the Date!

The 43rd Annual Meeting and Conference
September 10th & 11th, 2024

Conference Theme: **Beyond the Surface**

Program Chair:	Matthew Van Gennip	*Link Engineering*
Co-Chair:	Qian Li	*The Goodyear Tire & Rubber Company*

The Conference Committee would appreciate your assistance and suggestions. If you are interested in serving on the Conference Committee, please contact Committee Chair Matthew Schroeder.

A call for papers will be issued to attendees of the conference and will be available online.
Visit www.tiresociety.org for updates.

Paper 1.1

Recent Approaches in Market Relevant Evaluation of Tire Wear

Joerg Buschmeier[C,1]
Ana Filipa Portugal[1]
Wolfgang Milchers[1]
Benjamin Oelze[1]
Burkhard Wies[1]

Due to a rising focus on sustainability the importance of wear performance of tires is drastically increasing. Every on-vehicle wear test either for OEM or replacement tire performance evaluation has to take into account real market conditions and applications. Besides the absolute mileage in km, the abrasion rate or mass loss in mg/km/ton does reflect the amount of rubber emitted into the environment.

In order to define meaningful thresholds for the upcoming EU Wear rate regulation, it is of utmost importance to define the best market-relevant controlled outdoor tire road wear test. Real market data derived from hundreds of retailer shops within Germany for estimated mileage in km lead to the known Mileage distribution. Mileage data for different tire lines in the field are compared with predictions that are based on simulation and testing. Finally, a prediction of mileage and mass loss for a large range of passenger car tires as trend over years is shown.

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[C] Corresponding Author: joerg.buschmeier@conti.de

Paper 1.2

Investigation of the Interplay Between Road Surface Roughness and Tire Wear

Alexander Boettinger[C,1]
Pavel A. Ignatyev[1]
Joerg Buschmeier[1]
Benjamin Oelze[1]
Burkhard Wies[1]

Needs for emission reduction and sustainable technologies put topics related to tire wear in the focus of the automotive and tire industries. Running investigations and developments can have different goals, for example: wear reduction, development of robust test methods, investigation of the art and structure of wear particles. This variety of topics is due to the complexity of the tire wear process. Indeed, the rate of wear can vary depending on the driving style, curvature and topography of the road, the roughness of the road surface, the choice of vehicle, tire design and climatic conditions.

In this work, the scientific background behind the impact of road roughness on tire wear is explained. This point is illustrated by a case study dealing with wear rates of tires on roads with comparable and different roughness. It is demonstrated that comparable road roughness leads to comparable wear results. On the contrary, very different road roughness can change a rating or even a ranking of wear performance of tire.

[1] Continental Tires Germany, Hannover, Germany
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Paper 1.3

A Novel Solution for Tire Road Interaction Direct Measurements and its Applications on Tire Simulation and Analysis Methodologies

Carlos Nerini[C,1]
Flavio Farroni[2]
Aleksandr Sakhnevych[2]
Damiano Capra[3]
Nicolas Carabetta[4]

Direct measurements of tire behavior under real conditions of use are rarely performed due to many practical difficulties. The most important ones are installing transducers on rotating wheels, dealing with real world imperfections and knowing at every moment the position and orientation of a moving interaction surface (the road). This paper presents a novel technical solution to the previous problems that enables the analysis and characterization of tire performance in real condition, empowering virtual tires methodologies.

This work publishes, for the first time, the exploration of the use of that solution to feedback state of the art simulation models. Combining simulation techniques with experimental data, case studies are shown correlating the influence of tire temperature, speed, pressure and normal load on tire mechanics through the dynamic rolling radius. The analysis also evidences the importance of knowing the wheel orientation with respect to ground in the characterization of tire behavior. Also discussed is the relevance of knowing the real wheel-road camber on each circuit for performing evolved racecar simulations.

Finally, this investigation stimulates the debate on tire testing and simulation by considering real condition direct measurements as a complementary research path with the potential to take vehicle dynamics simulation to a next level of realism.

[1] CSN Vehicle Dynamics Consulting, Turin, Italy
[2] Università Federico II di Napoli, Naples, Italy
[3] MegaRide s.r.l., Naples, Italy
[4] Vehicle Interaction Measurement Research Project (VIM-RP), Turin - Buenos Aires
[C] Corresponding Author: cnerini@fi.uba.ar

Paper 1.4

Three Abrasion Studies: 1) Frictional Energy and Abradability, 2) The Role of Powder, and 3) Wear Particle Analysis

Edward R Terrill[C,1]
Jonathan E Martens[1]

A preliminary investigation into three areas of tread compound abrasion: The first was to calculate the frictional energy and abradability of a tire tread compound using the angle abrader. This information could be used for FEA models for predicting tire treadwear.

The second study looked at the effect of powder on abrasion rate. The variables included slip angle and powder dosage rate. The powder was found to perform as a third body with a significant effect. The dosage rate also had a significant effect. Powder eliminated sticky wear and increased the abrasion rate.

The third study was a preliminary investigation into abrasion (wear) by-products. The particle size and size distribution were studied along with the formation of other abrasion by-products including low molecular weight chemicals and gases. The extent of by-product formation correlated inversely with the oxidation resistance of the compound.

[1] Akron Rubber Development Laboratory, Inc., Barberton, Ohio
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Paper 2.1

Development of Intelligent Tire Technology for Tire Status Estimation in Real-World Applications

Sungwoo Lee[1]
Hojong Lee[C,1]

The intelligent tire concept was introduced in early 2000. Much research has been conducted presenting the possibilities of evolving tires into active sensors estimating self-status, road, and operational conditions with help of advanced sensor and estimation technologies. However, from the point of commercialization for field applications, the sensor system for intelligent tires and logic for features need to be improved more; they need to secure longer lifetimes by optimizing edge processing and transmission frequencies, and estimation algorithms at the proof-of-concept level should be adjusted in step with.

In this research, estimation methodologies were developed for axle loads and tread depths using tire-mounted sensors that have been developed for commercial applications in the real world. Validations were conducted over eight vehicles driving in real-operation conditions and validation results showed accurate estimations with more than 90% accuracy for axle loads and less than 1mm error for tread depths.

This research is expected to provide an effective way to realize the intelligent tire concept in a real-world scenario.

[1] Hankook Tire and Technology, Daejeon, Korea
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Paper 2.2

Structural Antenna Engineering

Jason Barr[1]
John Lewis[C,1]
Chris Jones[1]

For a certain category of customer tire manufactures are moving away from just selling a new set of tires every year, many large-scale fleet providers are starting to embrace tires as a service. This is a significant shift in a very old industry that has historically just had a single point of contact with their customers.

Tire as a Service: Rather than just selling hardware, tire OEMs are now selling mobility uptime. In order to make this efficient and worthwhile, tires are not just replaced on a fixed schedule, e.g., every 12 months, but rather when the wear and tear actually calls for it.

This new business model requires constant monitoring of the health of every individual tire. Tire-telemetry forms the bedrock on which decisions are made. A variety of sensors can be placed in and around the tire to measure things like irregular wear, run time, pressure and transient load. In order to read this data a wireless communication is a must as it is not practical or feasible to run wires to and from the tire. An antenna strategically placed on the inside of the tire can allow for fast and non-invasive collection of the data. Every time a vehicle passes by either, person with a hand-held reading device or a fixed reading station placed, for example, at highly frequented gas stations data is transmitted from the tire to the cloud for ongoing analysis.

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Paper 3.1

Tire Force & Moment Characteristic Optimization Driven by Vehicle ISO Metrics

Pedro Stella[1]
Girish R. Radhakrishnan[C,1]
Ariel Avi[P,1]
Claude J. Rouelle[1]

A recurring challenge faced by tire OEMs is minimizing the number of iterative prototypes needed to meet vehicle performance criteria set by their customers, the automotive manufacturers. To tackle this issue, tire OEMs frequently opt for virtual prototyping through computational simulations.

Various models, such as the brush model, magic formula, simple linear tire models, F tire, and CD tire, are available to aid in the virtual prototyping phase of tires. Magic Formula tire models are widely employed in vehicle simulations due to their real-time capabilities. A key application of these models is to identify an "ideal" virtual reference tire that satisfies a set of vehicle-level metrics or KPIs (Key Performance Indicators) derived from vehicle ISO simulations, which tire OEMs could use as a target. This typically involves a recursive method of simulation and model coefficient adjustment.

In this paper, we introduce a novel multi-objective, weighted optimization technique that uses vehicle-level handling KPIs to establish the ideal Magic Formula coefficients.

Standard handling & stability ISO simulations such as steady-state cornering, double lane change, J-turn and corresponding metrics facilitate the evaluation of tire models created by the optimization. By incorporating these KPIs as weighted objectives into our optimization process, we strive to determine the most suitable Magic Formula coefficients for the "ideal" tire, that meets the vehicle-performance criteria.

A sophisticated genetic algorithm is implemented and applied to an array of ISO tests conducted virtually using a high-fidelity sedan vehicle model. The base tire model is subsequently optimized to conform to the vehicle-level target metrics and KPIs, showcasing the potential of this novel approach for refining tire model parameters.

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Paper 3.2

Comparison of Tire Cornering Stiffness Estimation Methods on Real-World Driving Data Versus Sine Steer Tests

Thijs Devos[C,1,2]
Kanwar Bharat Singh[3]
Helder Costa[3]
Frank Naets[1,2]

Tire cornering stiffness is a vital parameter in vehicle dynamics and is essential for various driver assistance systems. Over the years, numerous estimation methods have been developed to estimate cornering stiffness along with vehicle sideslip angle. However, most of these methods have been validated on test track data with relatively high excitation levels.

This paper presents a comparative analysis of an extended Kalman filter (EKF) based joint sideslip/cornering stiffness estimator applied to an extensive open road dataset and a test track sine steer dataset. The comparison highlights the challenges faced when using these methods on open road datasets due to the relatively low excitation level of vehicle dynamics, which can cause observability issues. Nevertheless, long-term reliable estimates can be obtained through adequate covariance stabilization methodologies in combination with appropriate estimator tuning.

In the low excitation open road scenario, it is observed that commonly measured vehicle responses, such as lateral acceleration and yaw rate, are highly sensitive to the tire cornering stiffness distribution between front and rear axles but remain relatively insensitive to the absolute magnitude of the cornering stiffness. The observation was made that stable estimates can be achieved overall, although absolute stiffness values can only be accurately obtained for peak test scenarios containing high levels of excitation.

Based on measured force-sideslip angle characteristics and forward simulations using the identified parameters, sine steer tests appear to provide a good indication of the absolute magnitude, which is challenging to attain under regular driving conditions. This study offers valuable insights into the performance and limitations of cornering stiffness estimation methods in real-world driving scenarios compared to controlled test track environments.

[1] E2E Lab, Flanders Make @ KU Leuven
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[3] Tire Intelligence Department, The Goodyear Tire & Rubber Company
[C] Corresponding Author: thijs.devos@kuleuven.be

Paper 3.3

A New Approach to Thermo-Mechanical Tire Modelling for Tire and Vehicle Development

Henning Olsson[C,1]
Marco Furlan[1]
Mateo Gladstone[1]
Matthew Strang[1]

A new thermo-mechanical tire model has been developed to better address current and future needs of the automotive industry. The real-time capable physical tire model simulates tire behaviors using four main modules; friction, contact patch, structure and thermal. The mathematical formulations of the modules were developed with the availability of repeatable and accurate test methods in mind, resulting in a robust and repeatable model parameterization process.

The model takes advantage of a highly accurate contact patch model (which is parameterized from Dynamic Contact Patch Pressure data, either measured on a flat-belt tire test machine or derived from finite element analysis), to improve the overall fidelity for force generation, temperature distribution and tread wear calculations. It also provides the foundation for advanced friction models which include road roughness dependency.

[1] Calspan Corporation, Buffalo, New York
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Paper 3.4

Investigation into Tire Tread Block - Slush Traction in Lab

M. Hindemith[C,1]
H. Irmler[1]
M. Wangenheim[1]

Usually, winter tire tests on ice and snow are performed separately from those on dry/wet pavement. In reality, there is a smooth transition from winterly surface conditions to summer conditions. In the intermediate state of slush, i.e., melting snow or ice, particularly low traction conditions can occur.

In this study we present a reproducible method to create defined slush tracks in lab. We show an optical method of characterizing slush properties in, focusing on the water content in the slush and its density. While selectively varying the slush conditions, we analyze the traction of tire tread blocks for high and low slip conditions in braking and acceleration.

The coefficient of friction decreases significantly with increasing slip ratio. Furthermore, we show results on the evolution of slush traction level with the number of passes on the same surface area. The coefficient of friction on slush quickly approaches friction levels as low as tire tread block friction on smooth ice covered with water layers (CoF<0.02).

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Paper 4.1

Mesh-Free Isogeometric Simulation: Developing a Next-Generation Workflow for Tread Pattern Optimization

Michael Scott[P,1]
Mitch Hortin[1]
David Kamensky[1]
Kyle Richardson[1]
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The Coreform IGA solver is coupled with the Endurica CL self-heating workflow to study the effects of tread pattern design on steady state tire temperature and rolling resistance. Coreform IGA is based upon isogeometric analysis (IGA), which is a numerical technique that uses the native computer-aided design (CAD) representation to discretize geometry and simulate its nonlinear structural and thermal behavior. IGA avoids complicated meshing or over-simplification of geometry that is common in traditional tire modeling workflows, while retaining accuracy through the use of high-order smooth basis functions. In this implementation, the tire's local dissipative behavior is specified via Endurica's Kraus model, and its steady state temperature field and total rolling resistance are computed. IGA is applied to accurately represent intricate tread pattern features with the same level of detail as the original CAD model.

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Paper 4.2

Using Machine Learning to Improve Efficiency Within Virtual Tire Cavity Development

Brandon Kelly[C,1]
Allie Stern[1]
Ryan Zimmerman[1]
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Paresh Solanki[1]
Deep Samanta[1]

A framework and process of using machine learning to guide the design of tire cavity crown shapes given desired footprint targets is presented. This process relies on the interaction of tire engineers with machine learning and optimization algorithms. Our approach begins with the definition of the footprint targets, tire construction, dimensions, and design constraints. An optimization algorithm is used to search over a machine learning model that predicts footprint parameters and their variability. These probabilistic outputs are then used to make recommendations on the crown shape. Finite element models are constructed based on the recommended crown to confirm the footprint targets. In this talk we will discuss the implementation of our process, its performance, and its role in virtual tire design.

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Paper 4.3

Advanced Meta-Model Assisted FEM Tire Design Optimization

Christoph Burkhart[C,1]
Francesco Calabrese[1]
Tobias Ruhwedel[1]
Axel Gallrein[1]
Manfred Bäcker[1]
Günter Leister[2]

Currently, the automotive and tire industry is undergoing rapid changes by pushing for more and more virtual prototypes, virtual development and virtual validation. The aim is to supplement the classical development approach and consequently reduce physical testing and utilization of real prototypes.

The modern tire/vehicle virtual development approach consists of various phases: The tire industry condenses all their know-how about their tires like geometry, construction and material properties into advanced finite element (FE) tire prototype candidates for their vehicle customers.

Using virtual measurements, the FE results are then translated into tire models suitable for vehicle simulations. By means of vehicle simulation campaigns - including subjective assessment with driving simulators - vehicle engineers request changes, for example in tire characteristics. These requests must then be mirrored back to the FE model. This loop continues until the virtual submission and assessment process is successful. Only then can the production of real prototypes start.

Typically, the requested changes conflict in terms of achievable performance. As detailed FE tire models are still computationally too expensive to be used in numerical optimization schemes, this study is aiming for an approach that utilizes CDTire/3D as an intermediate model for the FE topology and material optimization. As the CDTire/3D model is derived from a bead-to-bead multi layered shell formulation, it can be used by an optimization scheme as Ersatz (surrogate) model and significantly reduce the overall optimization time.

In this paper, the methodology will be explained and qualified using an example of both a standard and a run-flat tire.

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Paper 5.1

An Intelligent Tire for Dynamic Tire-Pavement Friction Sensing with Embedded Sensors and Physics Models

Baiyu Jiang[C,1]
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Hao Wang[1]
Jingang Yi[2]

This study proposed an intelligent tire solution to predict tire-pavement friction from tire sensors and analytical models. Pressure-based sensors are embedded in tire tread rubber to measure multi-directional local friction forces on the tire contact patch. A laboratory platform was built to conduct dynamic tire tests and measure friction forces considering different velocities, slip ratios, and surface roughness. A physics-based model is built to interpret friction generation mechanisms and predict the global friction force from local sensor measurements.

The tire-pavement interaction model consists of a brush model for tire-pavement contact, energy dissipation theory for dynamic friction, and a flexible ring model for tire deformation. The flexible ring model parameters are first calibrated with tire load-deflection curves. The feasible dynamic friction coefficients and the deformed tire profile are then solved using an interactive process between three models based on sensor measurements. Finally, the predicted friction forces were compared with the reference measurements from load cells to evaluate the prediction accuracy.

The results show the ability of smart tire sensing for estimating tire-pavement friction coefficients at various tire loads, velocities, and slip ratios on unknown surface. This study demonstrates the potential of using intelligent tires for friction-informed vehicle control and safe driving.

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Paper 5.2

Multi-Length Scale Modeling and Testing of Wet Traction

Sivaraman Ilanji[1]
Sethuramalingam[C,1]
Saied Taheri[1]

The grip that a tire can offer when sliding on a wet road is governed by complex physical phenomena influenced by a multitude of factors including sliding velocity, surface roughness, normal load, etc. The aim of this work is to quantify the friction that a tire tread block faces when it slides on a wet road using an analytical model incorporating multi length scale roughness, viscoelastic material properties and different lubrication regimes, water depth levels, etc. For this purpose, a model based on various existing theories has been developed and validated considering different levels of "wetness" through boundary, mixed-hydrodynamic and fully hydrodynamic lubrication regimes. The experimental validation was done using data collected using a round sample sliding on the surface of a Linear Friction Tester designed and built in-house at the Center for Tire Research (CenTiRe).

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Paper 5.3

Customizable Pressure-Sensitive Sensors for Tire Health Monitoring

Ahadur Rahim[C,1]
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Measuring tire footprint pressure is essential for tire performance. The process that is used currently has number of limitations. The proposed work can mitigate some limitations for measuring tire performance in different condition.

In this work a soft stretchable pressure sensor was used to measure force in different locations of the tire. The sensor is comprised of several layers of material including an ionic liquid (IL) based pressure sensitive polymer layer sandwiched between two carbon nanotube (CNT)-based layers as electrodes. These materials are encapsulated by insulating layers whose properties can be tunable.

The sensor was embedded on the inner liner of a 3D-printed miniature tire with treads. The sensor was fabricated via two different manufacturing processes:

i) A molding and screen-printing process, and

ii) A 3D printing process.

Both screen-printed and 3D-printed sensors show promising results on detection of tire deformation due to the contact with a road.

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Paper 5.4

Structure-Borne Vehicle Interior Noise Estimation Using Accelerometer Based Intelligent Tires in Passenger Vehicles

Yashasvi Achanta[C,1]
Saied Taheri[1]

With advancements in technology, electric vehicles are dominating the world making internal combustion engines less relevant and hence vehicles are becoming quieter than ever. But noise levels remain a significant concern for passengers as it can affect the overall driving experience and safety due to vibrations levels and resonance generated in the cabin. Two main sources of vehicle interior noise are air-borne and structure-borne noise. Tire/road interaction noise, which is being considered in this study, is the more dominant of the two and is the primary cause of the structure-borne generated vehicle interior noise.

Previously several statistical, deterministic and hybrid models were developed to estimate the vehicle interior noise which are generally used in the design stages to mitigate any unwanted noise. However, these models don't estimate the noise in real-time and cannot further actively control them.

Intelligent tire technology is on the rise among several tire and automotive manufacturers which is used to control several safety and dynamic aspects like hydroplaning, tire/road friction, wheel slip etc., The intelligent tire technology uses a sensor in the tire to measure the vehicle's state at any given position and sends signals to the control systems to actively alter the operation of the vehicle in order to achieve the desired outcome.

The current study aims to use intelligent tire technology to estimate the structure borne component of the vehicle interior noise in real-time. Since the intelligent tire technology research being applied to noise detection is new, designing the experimental setup and processing the signals in spectral domain was a novel contribution of this work. Understanding and concentrating on the dominant frequency content in these signals helped achieve the desired results with higher accuracy.

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Paper 6.1

An Approach to Reduce Pipe Resonance Noise with Zigzag Groove Wall

Yo Lin Ruan[C,1]
Deng Kai Cheng[1]

Noise is an important factor in vehicle certification, particularly in electric vehicles where tire noise is the main source. Tire noise is generated by the tire pattern, which is essential for proper drainage of water, mud, and snow. However, achieving a balance between these performance requirements and noise reduction is a significant challenge for tire engineering development. A usual way to reduce pipe resonance noise is by reducing groove volume. While reducing groove volume can help to decrease pipe resonance noise level, but in this way, water might not be easy to leave tire which can cause hydroplaning.

This research involves a fundamental study of pipe resonance noise using near-field noise measurement, as well as an investigation of noise reduction methods that do not compromise groove volume. The noise reduction device successfully reduces pipe resonance noise, and a series of experiments is conducted to validate the results.

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Paper 6.2

A Study on the Fidelity of FE Based Virtual Tire Assembly Models Used for Vehicle NVH SBN Performance Considering Vibrational Modal and Steady State Dynamic Simulations

Yunpei Yang[C,1]
James Valerio[1]
Mirza Biag[1]
Shuchen Fan[1]
Bob Wheeler[1]

To be a digital twin, virtual tire models must have predictive accuracy and fidelity sufficient to identify performance changes that match those experienced with physical tire design changes during a tire and Original Equipment (OE) vehicle development cycle. The capability to include tire assembly component feature information while maintaining computational efficiency is necessary for design tuning and is of high interest for faster development cycle and reduced cost.

For Noise, Vibration & Harshness (NVH), structure borne noise (SBN) performance there is a long history of virtual tire models that have feature capability and computational efficiency by applying finite element (FE) techniques with vibrational modal and steady state dynamic simulations. The capabilities of the models have expanded over this history considering the nonlinear base state geometry and material properties, the expansion of frequency range, inclusion of wheel and enclosed air dynamics, and rolling operation.

The recent growth of the electric vehicle market has created added demand on NVH SBN performance and associated virtual tire capabilities. This study investigates the sensitivity of the FE prediction to the model representation fidelity for the tire-wheel-air assembly. The predictions are compared based on sequence and locations of modes, key features in predicted frequency response, and computation efficiency.

This investigation contributes towards better informed decisions in choosing the FE representations for NVH SBN performance predictions that best suits the project time frame and required level of detail. Simulation results are correlated with measurement data to help understand what the FE representation captures and its limitations.

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Paper 7.1

Computing Tire Durability from Multibody Dynamics Simulation of Nurburgring Circuit Events

William Mars[C,1]
Jason Barr[2]
Tom Ebbott[1]
John Lewis[2]
Jesse Suter[1]

A future intelligent tire application may require the tracking of damage accrual based upon the actual lived experiences of a tire. This work demonstrates such an application using commercial, off-the-shelf tools: the Simpack multibody dynamics code, the Abaqus finite element solver, and the Endurica EIE and DT fatigue solvers.

Nurburgring circuit vehicle events for laps on 4 P225/35R20 tires were simulated via multibody dynamics. For each of the 4 tires, 3 corner channels (slip angle, slip ratio, vertical tire load) were computed and recorded for 13 miles over 8 minutes at a data acquisition rate of ~250 Hz. Damage in the tire was accrued on a finite element mesh via Endurica DT, using strain history that was interpolated via Endurica EIE for each time step of event history. The interpolation grid, or map, was pre-computed in Abaqus using steady-state rolling simulation results over the range of -15° to +15° in slip angle, -25% to 25% in longitudinal slip ratio and 0.5x to 1.5x TRA in tire load.

The simulation shows how differences in actual lived tire experience vary from one vehicle corner to another, and within the tire cross section, and demonstrates the feasibility and requirements for live tracking of damage accrual.

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Paper 7.2

Comparative Chemical Composition of US And European Tyres VOC Profile, Potential Environmental Impact, Including 6PPD

Nick Molden[C,1]

Tires are complex products, with sophisticated physical design and chemical composition. They must deliver a range of often conflicting performances including slow wear (for maximum life), low rolling resistance (to reduce carbon dioxide emissions and fuel consumption), wet grip and low noise. There exist regulatory and labelling requirements around these. Where information is currently lacking is in the wear rates and chemical composition of the tires. This is relevant to the amount material released into the environment, where it goes and what damage it does to human and animal health, and the environment more widely.

This presentation will focus on the chemical composition of hundreds of different models of tires sold, drawn from both the US and European markets. Commonalities and differences will be analyzed. A hypothesis will be considered that US tires contain different chemical components as the market focuses more on durability, compared to the European market that tends to value lower rolling resistance more highly. It will draw on Emissions Analytics' tire material database, which typically identifies over 400 organic compounds in each tire, using its optimized process of thermal desorption and pyrolysis, coupled with two-dimensional gas chromatography and time-of-flight mass spectrometry.

Organic species that will be specifically analyzed are 6PPD and their substitutes. These are preservatives that are added to tires to prevent ageing and cracking, especially under sunlight. Recently, 6PPD has been linked to the death of a significant proportion of coho salmon and trout on the West Coast of the US. The concentration of 6PPD will be shown to vary significantly between different models of tire. The method will be shown to be the potential basis for enhanced product labelling.

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Paper 7.3

Rubber Tires for Mars Rovers: Effect of BR crystallinity on properties of BR/VMQ blends

Norbert Nizel[1]
Mateusz Imiela[1]
Magdalena Maciejewska[1]
Dariusz Bielinski[1]
Rafal Anyszka[C,1]

Designing a tire for a Mars rover is a challenging task. The weather conditions on Mars are much harsher than on Earth. For example, the temperature on Mars ranges from -120°C to 30°C with a daily amplitude often exceeding 70°C. The lack of an ozone layer results in much stronger UV radiation, while the lack of a magnetosphere allows Solar and Galactic particulate radiation to reach the surface of Mars. The pressure of Mars' atmosphere is over 200 times lower than on Earth and its surface is covered with dusty and sharp regolith particles. All these features need to be taken into account in the attempt to design rubber tires for Mars rovers.

To overcome all these issues and achieve satisfactory performance on Mars, it was proposed to use a blend of butadiene (BR) and vinyl-silicone rubbers (VMQ). In this blend BR constitutes a continuous phase assuring good mechanical and wear resistance, while VMQ as a dispersed phase improves low-temperature elasticity and UV resistance. However, depending on grade, BR exhibits the ability to crystallize (high -cis grades) or to remain amorphous (mixed, -cis, -trans, and low vinyl grades).

Crystallization of BR can significantly affect the mechanical and dynamic properties of BR/VMQ blends, influencing the overall performance of a Mars rover tire. Therefore, this work aims to investigate the effect of BR crystallinity on the related properties of BR/VMQ blends like tensile strength and mechanical moduli in extension, hardness, hysteresis, tear strength, and abrasion resistance.

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Paper 8.1

Study on the Relationship between Wear of Tire Tread Rubber and Frictional Work Using FPS Abrader

Tomoaki Iwai[C,1]
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Junichi Eba[3]
Hiroshi Enomoto[3]
Akira Horiki[3]

This research aims to study the relationship between the wear of tire tread rubber and frictional work by using an FPS abrader testing machine (Ueshima Seisakusho Co., Ltd., Japan). The FPS abrader testing machine is a modified Lambourn wear tester developed to provide more precise wear tests. Since there are many parameters which affect the wear of tire tread rubber, this study mainly focuses on frictional work input, where the first hypothesis is that the same frictional energy input will result in the same wear rate.

However, the experimental results showed a different outcome. By using the FPS abrader, slip ratio, sliding speed, and temperature may be varied. Experimental results showed that the frictional work input heavily affected the wear rate of the tire tread rubber. Tests with the same frictional energy input did not result in the same wear rate.

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Paper 8.2

The Transition from Sliding to Rolling Frictional Abrasion of Rubber

Felix Hartung[C,1]
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Wear, as a consequence of frictional abrasion, arises from physical separation due to micro-fracture, chemical dissolution or melting at the contact medium. It is classified as several types of wear, for instance: adhesive, abrasive, corrosive and fatigue wear. In laboratory, mainly short-term wear phenomena (adhesive or abrasive wear) are investigated using e.g., linear friction tester (LFT) or laboratory abrasion tester (LAT100) to analyze rubber wear. In the tire industry, however, knowledge of long-term (fatigue) wear is of even greater interest. In contrast to an LFT, where pure sliding between the rubber block and its abrasive substrate are observed, results of LAT100 originate from different mechanisms such as form slip and short-time sliding, since on LAT100, the rubber wheel, which is driven by a rough spinning disc, is almost in free rolling. Hence, the longitudinal slip is almost zero and the side slip rises as the slip angle increases.

To develop applicable friction and wear models on tire scale reliable test data is required. Consequently, LFT results are requested, because the distribution of contact pressure as well as slip velocity are nearly homogenous at the contact surface of the pulled rubber block. However, it is not possible to transfer the output of LFT to rolling rubber wheels since the wear mechanism as well as energy intensity levels of LFT and LAT100 differ significantly.

In this contribution, a wear model for rubber material is introduced to consider both form slip and sliding. The model input for sliding friction and resulting wear rate is derived from LFT experiments using rubber blocks at different loading. While linear friction tests with blocked rubber wheels at low-energy-intensity are performed to take wear during form slip into account. For the latter, the pressure, slip velocity as well as temperature ranges originate from LAT100 results that are applied for model validation.

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Paper 8.3

Prediction of the Frictional Power Distribution in the Tire Contact Patch Based on an Empirical Tire Model and an Artificial Neural Network”

Lars Muth[C,1]
Raphael Zharia[1]
Walter Sextro[1]

The estimation of not only the total amount of tire wear, but also of the wear distribution over the tire width, in order to predict and prevent uneven tire wear, requires knowledge of the frictional power distribution in the tire contact patch. Usually, only 3D structural tire models can generate such distributed contact results. However, they involve high computational costs and cannot be used for comprehensive optimization of a vehicle’s suspension system with respect to tire wear characteristics. Hence, this contribution presents a methodology on how to accelerate the prediction of the frictional power distribution using two components: The structural tire model is replaced by an empirical tire model, and an artificial neural network generates the desired contact results from the forces and kinematic quantities calculated by the empirical tire model.

In the initial training phase, both components are fitted to data generated by the original complex tire model. After training, the empirical tire model can replace the structural tire model in vehicle simulations, resulting in significantly shorter calculation times. The simulation results are fed into the artificial neural network, which accurately predicts the frictional power distributions over the tire width with negligible additional effort. Overall, the methodology – including training and post-processing – is much faster than using structural tire models, enabling optimization with numerous function evaluations.

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Paper 8.4

Tire Burnish and Stopping Distance for Virtual Calibration

Anudeep K. Bhoopalam[C,1]
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David Howland[1]
Bryan Miller[1]
Cedric Mousseau[P,1]
Heather Bobbitt[1]

Minimal stopping distance is a topmost safety requirement for any vehicle. It is also essential to note stopping distance is a system requirement with many contributing subsystems, with tires and the ABS system being amongst the most vital. GM's 100% virtual vision mandates predicting performance virtually - without any hardware. This also means that GM needs to be able to predict 3rd party media evaluation performance for its vehicles. This includes simulating the pre-conditioning performed prior to testing (See J2909) as well as how our software and calibrations interact with changing component attributes due to this pre-conditioning. To this end, tire models need to capture the burnish behavior to perform virtual calibrations for chassis controls with higher fidelity.

Tire level tests have been conducted on the Flat-Trac that mimic ABS braking situations and have been compared to vehicle level stopping distances including the rate of burnish of the tires. Stopping distance tests were also performed on the HiL bench with burnish compensated tire data and compared to vehicle level tests. If the burnish characteristics can be properly captured on the HIL bench, then this means the interaction of a specific ABS calibration with the burnish rate of a tire, as it pertains to a media evaluation condition, can be evaluated. This also means that calibration activity on the HIL bench can also take place with an understanding of the impact to the media evaluation performance at the pre-conditioned state. The objective of this study is to better model the burnish phenomena to allow for this HIL-based calibration work.

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Day 1 – Tuesday, September 12th, 2023

8:00 AM	**Conference Opening**
8:15 AM	**Keynote Address** David Johansen - Sumitomo Rubber USA
9:15 AM	**Announcements**
9:40 AM	**Session 1** Tire Wear
11:25 AM	**Session 2** Sensors
12:20 PM	**Lunch (Provided)**
1:30 PM	**Session 3** Force and Moment
3:35 PM	**Session 4** Tire Design
5:15 PM	**Reception and Banquet** InfoCision Stadium 5th Floor
9:00 PM	**Close of Day 1**

Day 2 – Wednesday, September 13th, 2023

8:00 AM	**Opening Remarks**
8:05 AM	**Plenary Address** Burkhard Wies - Continental
9:05 AM	**Annual Meeting**
10:15 AM	**Session 5** Student Session
12:00 PM	**Lunch (Provided)**
1:00 PM	**Session 6** Noise
1:55 PM	**Session 7** Materials
3:35 PM	**Session 8** Friction
5:20 PM	**Closing Remarks**
5:30 PM	**End of Conference**