The Tire Society
32nd Annual Meeting and Conference on Tire Science and Technology

September 10 – 11, 2013
Hilton Akron/ Fairlawn
Akron, Ohio, USA

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32nd Annual Meeting and Conference on Tire Science and Technology
Day 1 – Tuesday, September 10, 2013

8:50	9:00		Welcome	Ric Mousseau, President
9:00	9:40		Keynote Address	Chuck Yurkovich
9:40	9:45		Conference Opening Remarks	Mohammed Sobhanie, Conference Chair
			Session 1: Wear Mechanisms	Chair: Marion Pottinger
9:45	10:10	1	Link Between Wear and Surface Topology for a Sliding Rubber Sample	Paul Wagner
10:10	10:35	2	Average Worn Profile of Tires in Europe	Frédéric Biesse
10:35	10:45		Break	
			Session 2: Properties of Tire Materials	Chair: Mahmoud Assaad
10:50	11:15	3	Ultrasonic Devulcanization of Tire Rubber and Copolymerization of Rubber Blends for Tire Manufacturing	Avraam I. Isayev
11:15	11:40	4	A Study On Rubber Viscoelasticity Using Molecular Dynamics Simulation	Hiroyuki Takahashi
11:40	12:05	5	The Use of Rubber Composition-Properties Relationships During Tire Numerical Simulation and Design Optimization	Alexey Mazin
12:05	12:30	6	Numerical Simulation of Tread Shaping and Material Flow During Tire Manufacturing Process	Minwu Yao
12:30	1:30		Lunch | Distinguished Technical Achievement Award - Dr. Hans Pacejka	
1:30	1:35		**Session 3: Heavy Truck Tires**	Chair: Jim McIntyre
1:35	2:00	7	Heavy Truck Driver Workload Investigation	Ryan Pawlowski
2:00	2:25	8	Commercial Truck Tires - Effect of Tire Inflation Pressure On Tire Footprints & Impact on Fuel Economy, Rolling Resistance, and Mileage	Al Cohn
2:25	2:50	9	Cost and Benefits Associated with the Use of NGWBS tires in North America	Joel Neff
2:50	3:00		Break (10 minutes)	
			Session 4: New Light on Tire Technology (Student Competition)	Chair: Michelle S. Hoo Fatt
3:05	3:30	10	Simulation of Tire Rolling Resistance Generated On Uneven Road	Chongfeng Wei
3:30	3:55	11	Development and Improvement of Active Vehicle Safety Systems by Means of Smart Tire Technology	Mustafa Ali Arat
3:55	4:20	12	Efficient in-Plane Tyre Mode Identification By Radial-Tangential Eigenvector Compounding	Vasilis Tsinias
4:20	4:30		Break	

32nd Annual Meeting and Conference on Tire Science and Technology

Day 1 – Tuesday, September 10, 2013

Time		NO.		
			Session 5: New Light on Tire Technology (Student Competition)	Chair: Kory Smith
4:35	5:00	13	Characterization of Road Profiles Based On Texture Parameters and Fractal Properties	Mohammad Motamedi
5:00	5:25	14	Simulation of Heat Build-Up in Aircraft Tires Under High Speed Free Rolling Using an Explicit Approach	Mohammed Behroozi
5:25	5:50	15	A Rigid Ring Tire Model in the Analysis and Development of Anti-Lock Brake Systems	Srikanth Sivaramakrishnan
			End of Day's Papers	
6:45			**Awards Banquet**	
7:30			Awards Presentation: 2012 Superior Paper	Gary Tubb
7:40			Dinner Speaker	Tim Joseph

Day 2 – Wednesday, September 11, 2013

7:30			Registration	
8:00	8:05		Conference Opening Remarks	Mohammed Sobhanie, Conference Chair
8:05	8:25		**State of the Society**	Ric Mousseau, President
8:25	8:30		**Session 6: Modeling and Simulation**	Chair: Ron Kennedy
8:30	8:55	1	FEA Of Tire Performance For Snow Traction	Jan Terziyski
8:55	9:20	2	Inertial Representation of Non-Axisymmetric Tire Structural Attachments to Perform Steady State and Dynamic Explicit Rolling Tire Analysis	Thulasiram Gobinath
9:20	9:45	3	Advances in Modeling Rolling Tires	Stephen Vossberg
9:45	10:10	4	Impact of Initial Thermal Strain and Viscoelasticity of Hybrid Merged Cords On Tire Performance	Xianwei Meng
10:10	10:20		Break	
10:20	11:15		**Plenary Lecture – Bill Langer, MTS Fellow, Ground Vehicles**	

32nd Annual Meeting and Conference on Tire Science and Technology
Day 2 – Wednesday, September 11, 2013

Time		NO.		
11:15			**Session 7: Durability**	Chair: Michael Kaliske
11:20	11:40	5	Design & Analysis Paradigm for Gauging Thermomechanochemical Aging of Tires	Joseph Padovan
11:45	12:05	6	Evaluation of the Sidewall Crack Life By Fatigue Test of Sidewall Compound and Finite Element Method	Min Sung Kang
12:10	12:30	7	Aging Mechanisms Involving Oxygen and Strain in Tire Beltcoat Compound	Ed Terrill
12:35	1:30		Lunch - On Your Own	
1:35			**Session 8: Intelligent Tire Technology**	Chair: Kanwar Bharat Singh
1:40	2:00	8	A New Methodology for Tire Wear Prediction Part I - Mathematical Derivation	Saied Taheri
2:05	2:25	9	Wireless Structural Health Monitoring of a Tire Under Steady-State Free-Rolling	Vijaykumar Krithivasan
2:30			Break	
2:40			**Session 9: Various Topics**	Chair: John Luchini
2:45	3:10	10	Effect Of Conicity and Ply Steer On Long Combination Vehicle Yaw Plane Motion	James Patterson
3:10	3:35	11	Tire Transient Lateral Force Generation: Characterization and Contribution to Vehicle Handling Performance	Terence Wei
3:35			**Conference Closing Remarks**	

About The Tire Society...

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

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The 2014 Conference Committee would appreciate your assistance and suggestions.
A call for papers will be issued soon. Visit **www.tiresociety.org** for updates.

Keynote Address

Chuck Yurkovich

Vice President of Global Research & Development,
Cooper Tire & Rubber Company

Leveraging Technology and Innovation in Today's Tire Industry

As the world around us becomes more and more complex, the tire industry faces a growing number of challenges related to raw materials supply and pricing, economic conditions, consumer expectations, demand for green products and technology, government legislation and compliance standards. The products we develop and the tools we use are becoming more and more complicated by the day. How can the tire industry survive, adapt, and even thrive when faced with these challenges? These and other questions will be addressed by Mr. Yurkovich as the industry works to develop new innovative solutions to all of these issues.

Distinguished Technical Achievement Award Winner

Dr. Hans Pacejka

Professor Emeritus, Delft University of Technology

Dr. Hans Pacejka is the recipient of the 2013 Tire Society Distinguished Technical Achievement Award. This honor is given biennially by the society to an individual who has made substantial contributions to the science and technology of tires.

Dr. Pacejka has been actively contributing to the understanding and modeling of tires for decades – beginning in the 1960s and continuing into the 2000s. He is best known as the creator of the so-called "Magic Formula" which he developed in 1987 in conjunction with Volvo to describe measured tire behavior for vehicle dynamics modeling.

Magic Formula-based models are still in use today and the Magic Formula has spurred the development of similar but more advanced models that include higher frequency response. These include MF-Tyre and MF-Swift, both of which are widely used in vehicle dynamics simulation and vehicle development. Magic Formula-based models are even used in race car gaming. They provide an accurate and efficient description of tire-road interaction forces required for most any vehicle handling simulation, including motorcycles, trucks, and cars.

Dr. Pacejka was the invited plenary lecturer at the 1991 and 1993 Tire Society Meetings. He wrote extensive chapters on the subject of tire dynamics for both the 1971 and 1981 editions of "Mechanics of Pneumatic Tires". He is a world-renowned expert in vehicle system dynamics, culminating in the publication of a text book, "Tire and Vehicle Dynamics" in 2002, with its third edition published in 2012.

Dr. Pacejka obtained his Ph.D., researching wheel shimmy phenomena, from Delft University of Technology and continued as a tire and vehicle researcher and teaching professor at the same facility from 1966-1996. From 1977-2000 he served with the International Association for Vehicle System Dynamics (IAVSD) – as Secretary General from 1977-1989 and as President from 1994-2000. He has been awarded an Honorary Doctorate from the Stockholm Royal Institute of Technology and been a Consultant to TNO-Automotive, the Netherlands from 1993-2006.

As a teacher, Dr. Pacejka has advised approximately 150 Master's degree and 15 Ph.D. students – with 70% of these going on to work in the automotive industry.

Banquet Speaker

Dr. Tim Joseph, P. Eng., FCIM
Director AEGIS
Dean and Associate Professor, School of Mining Engineering
Univeristy of Alberta

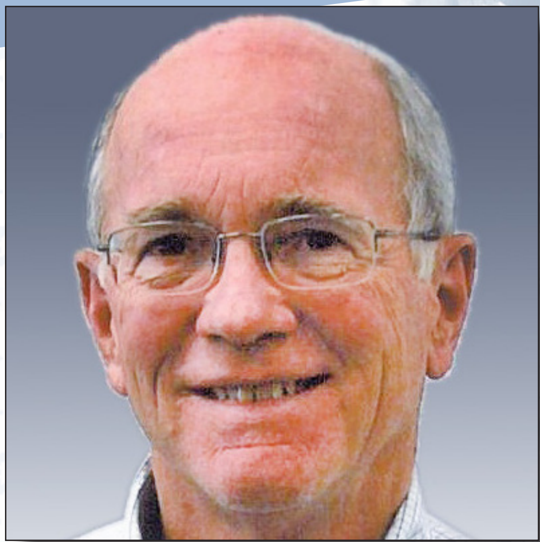
Meeting Tire Challenges in The Oil Sands Surface Mining Industry

The global surface mining industry and in particular the Athabasca oil sands deposits of Northern Alberta provide some of the most challenging issues for OTR tire performance. Major mining operators and OEMs have expressed that if haulage units can survive the adverse oil sand operating conditions, they will survive any adverse environment on the planet.

From deep rutting and ground undulations, high rolling resistance, poor fuel burn and high emissions, to inadequate suspension response and payload balance, tires acting as the sandwiched component between machine and running surface face a never-ending list of adverse impacts.

This very visual presentation will introduce an alternative view of evaluating tire performance under such adverse conditions. Dr. Joseph will provide insights into the benefit of load balance, reducing running surface deterioration, and improving suspension performance; which in turn will extend structural performance, reduce fuel emissions and extend tire life.

Plenary Lecture



Bill Langer
MTS Fellow, Ground Vehicles,
MTS Systems

History of Flat Belt Technology at MTS

Flat belt systems refer to machines using a steel band surrounding two drums and supported by a flat bearing. In the last 35 years, MTS has applied flat belt technology to tire testing, automotive chassis dynamometers, and to moving ground planes in aerodynamic wind tunnels. An overview of the application of the technology at MTS will be given with an emphasis on the technical problems and solutions.

Day 1, Paper 1

Link Between Wear and Surface Topology for a Sliding Rubber Sample

Paul Wagner
Frank Schmerwitz
Hagen Lind
Burkhard Wies

The wear mechanism of rubber is complex and the direct experimental observations of wear are limited. The understanding of the wear mechanism and the prevention of it are an important aim and field of investigation in the tire industry. The wear performance depends strongly on the chemical ingredients and the geometry of the tire. Besides good wear performance, parallel development goals have to be achieved, like tread durability, and good wet and dry grip of tires. These aims lead to conflicting chemical measures for achieving good performance. The simplest way to quantify wear is measurement of the mass loss after wear experiments. The mass loss of different rubber materials is used to classify the wear performance of the materials. The setting of relevant test conditions is the art of test engineering.

An additional way to obtain information about the wear behavior of different compounds and the mechanism is to take a look of the worn surface of the wheels. After wear experiments with real tires on the street or on small rubber wheels in laboratory micro-structures normal to the slip direction occur, the so called Schallamach waves. The analysis of these structures can lead to a deeper understanding of the wear mechanism. The question is: is there is a direct link between wear and the surface topology for tread compounds. The surfaces of four compounds with a different wear performance are investigated in this paper with the aim to distinguish them not just with the measured mass losses but also with an analysis of the surface and the extraction of a characteristic. The load parameters are set constant while identifying a characteristic surface property during test runs on a laboratory abrasion tester.

A method for the tracking of surface structures is presented. This method is used to visualize the observed displacement of surface structures at the rubber wheels. The observed displacement is quantified by the application of an established method from the field of fluid dynamics. It is possible to compute the lateral displacement of the surface structures with the “Particle Image Velocimetry (PIV)-method”. After each of the 15 test runs a 3D dataset of the worn surface is recorded by a structured-light 3D scanner. For obtaining a tall section of the wheel surface 21 single shots are stitched together. The 3D-surface data of the worn surfaces are transferred into images. This allows an analysis of two following images with the open source Matlab tool PIVlab. The lateral displacement between two test runs can be derived by averaging the resulting vector field calculated with the PIV analysis. The results show that the four tread compounds can be clearly distinguished by the lateral displacement, but do not correlate precisely to the measured mass losses. All results and observations are used to postulate an extended model of physical pattern movement.

Average Worn Profile of Tires in Europe

Frédéric Biesse
Jérôme Mahé
Nicolas Lévy

Tire tread wear is a key issue in the tire development process as well as for tire customers. In order to measure the wear performance, tire manufacturers usually proceed to wear tests and calculate the tire life from those tests. An important point in this tire life computation is the criteria chosen for defining the tire's end of life. In Europe, there is a legal minimum tread depth set to 1.6 mm applicable to 75% of the tread pattern width. However, outside those 75% (i.e. on the shoulder part), no clear and shared limit is defined. Also, the usual behavior of the customers to decide when their tires should be changed is not well known.

The goal of this 2012 study is to identify an average worn profile of tires in Europe, and the behavior of customers for replacing their tires. For that, 3,000 tires worn out by customers have been collected in scrapyard and measured, in 5 European countries. In this article, we will present the tire collecting method, the measurement process, the analysis method, some general results and statistics on this 3,000 tire database. Finally, the method to compute the average end of life profile and the resulting profile is given.

Ultrasonic Devulcanization of Tire Rubber and Copolymerization of Rubber Blends for Tire Manufacturing

Avraam I. Isayev

Recycling of tire rubber and copolymerization of rubber blends are carried out by the application of high power ultrasound in single- and twin-screw extruders. Ultrasonic waves of certain levels, in the presence of heat and temperature, can rapidly breakdown the three-dimensional network of crosslinked rubbers making them reprocessable and revulcanizable. Ultrasonic waves can also cause in-situ copolymerization of rubber blends leading to materials with improved properties.

The present paper provides an up-to-date account of ultrasonic decrosslinking of rubbers including the history of development of the technology, available reactors, extensive experience accumulated on devulcanization of various types of rubbers. Attempts to develop mechanisms of devulcanization and models to theoretically describe the process. A possibility for scale-up of the process is also discussed.

The paper gives a comparative analysis of process characteristics, rheological and mechanical properties, structural transformations and curing behavior of rubbers during their ultrasonic treatment. Properties of blends of devulcanized and virgin rubbers are also presented. Details of degradation mechanisms of the rubber network by ultrasonic waves are presented. Results accumulated on ultrasonic copolymerization of SBR/NR and SBR/BR blends are discussed with an emphasis on the improvement of their mechanical properties. Future challenges and perspectives of technology of ultrasonic decrosslinking and copolymerization are discussed.

A Study on Rubber Viscoelasticity Using Molecular Dynamics Simulation

Hiroyuki Takahashi
Osamu Hino
Yuji Kataoka

Molecular dynamics simulations are performed to study the viscoelastic properties of cross-linked polymers. The dynamic moduli of the cross-linked polymers are obtained by the Fourier transform of the relaxation moduli, which have been obtained by using the Green-Kubo formula. The time-dependent stress tensors, which we use in the Green-Kubo formula, are calculated from the equilibrium molecular dynamics trajectories. The relationship between the viscoelasticity of the cross-linked polymers and their crosslink density is investigated and discussed from the microscopic point of view.

The Use of Rubber Composition-Properties Relationships During Tire Numerical Simulation and Design Optimization

Alexey Mazin
Alexander Kapustin
Mikhail Soloviev
Alexander Karanets

Numerical simulation based on finite element analysis (FEA) is widely used now during design optimization of tires drastically reducing time of designing process and improving tire performance as it is obtained from the optimized solution. Rubber material models, which are used in numerical calculations of stress-strain distributions, are non-linear and may include several parameters. The relations of these parameters with rubber formulations are usually unknown, so the designer has no information whether the optimal set of parameters is reachable by the rubber technological possibilities or not. The aim of this work is to develop such type of relations.

The most common approach to derive the equation of state of rubber is based on the expansion of the strain energy in a series of invariants of the strain tensor. In this paper we show that this approach has several drawbacks, one of which is problems that arise when trying to build on its basis the quantitative relations between the rubber composition and its properties. An alternative is to use a series expansion in orthogonal functions, which ensures the linear independence of the coefficients of elasticity in its evaluation of the experimental data and the possibility of constructing continuous maps "the composition to the property". In the case of orthogonal Legendre polynomials the technique for constructing such maps is considered and a set of empirical functions is proposed to adequately describe the dependence of the parameters of nonlinear elastic properties of general-purpose rubbers on the content of the main ingredients. The calculated sets of parameters were used in numerical tire simulation including static loading, footprint analysis, braking/acceleration and cornering and also in design optimization procedures.

Numerical Simulation of Tread Shaping and Material Flow During Tire Manufacturing Process

Minwu Yao

In recent years, a great challenge to the tire industry is to develop and produce fuel efficient tires with low rolling resistance to meet market demands. Among all tire components, the tread is the most influential component for rolling resistance reduction. As a result, many new advanced tread designs with innovative concepts have been developed. The emergence of these new tread designs also posed a great challenge to tire manufacturing. In this area, simulation technology can play an important role in helping to reduce the tire manufacturing development cycle time.

During the tire building and shaping process, the tread experiences very large shaping deformation and distortion. "Material flow" occurs inside the tread when its initial uncured mass distribution differs from its designed shape. Among all the tire components, the tread is one of the most difficult components to model due to the large shaping deformation and excessive material flow.

Traditionally, the tread is modeled as a structural component with the solid mechanics approach. However, it is inherently difficult for the Lagrangian formulation to handle the excessive element distortion computationally. To properly model the large distortion, a good adaptive re-meshing technique is usually required. Unfortunately, the adaptive re-meshing techniques currently available in the commercial structural software are still not as robust as those available in the Computational Fluid Dynamics (CFD) codes.

In the present study, we consider the shape change of tread from its uncured to its cured configuration during the press-shaping process. A sub-modeling approach is used to isolate the tread component from the tire and the interaction between the tread and the rest of the tire is represented through properly defined boundary conditions. Both the solid mechanics approach and the CFD approach are explored with and without the adaptive re-meshing technique. Several modeling strategies are proposed and tested. The CFD solutions from sub-modeling approach are verified through quantitative comparisons with the full-model solution from the solid mechanics approach. As a validation, the predicted material flow is compared to the available experimental measurements. The applications of the tread shaping model will also be discussed.

Heavy Truck Driver Workload Investigation

Ryan Pawlowski

Driver workload is of growing interest in the automotive society as the number of in-vehicle technologies and vehicles on the road grows. Non-critical tasks and environmental factors impact the driver's ability to negotiate a chosen course and place heavy demands on the driver in terms of mental and physical capacity. A key component of the driver's operating environment is the vehicle itself.

In this research, the impact of various tire configurations for a Class 8 tractor trailer combination vehicle on driver workload performance is presented. Driver workload performance is assessed during four maneuvers: 60m radius steady state circle, 120m radius steady state circle, road course and North Atlantic Treaty Organization (NATO) emergency lane change maneuver. Surface electromyography (sEMG) electrodes were placed on the left and right wrist flexors (flexor carpi ulnaris) and right wrist extensors (extensor carpi ulnaris) in order to capture muscle activity during all maneuvers. Peak sEMG (pEMG) and integrated sEMG (iEMG) values are presented for each maneuver, normalized to maximum voluntary isometric contraction (MVIC) values taken prior to each trial.

Results of the study show distinct separation of muscle activity for each tire configuration. Objective vehicle data are also presented to obtain potential correlations to the physiological measurements. Differences in driving techniques were also identified based on the dominant hand of the driver and the orientation of the maneuver, i.e. clockwise or counter-clockwise.

Commercial Truck Tires – Effect of Tire Inflation Pressure on Tire Footprints & Impact On Fuel Economy, Rolling Resistance, and Mileage

Al Cohn

Maintaining proper tire inflation is the number one issue facing commercial fleets today. Common, slow leaking tread area punctures along with leaking valve stems and osmosis through the tire casing, lead to tire underinflation with a subsequent loss in fuel economy, reduction in retreadability, treadwear loss, irregular wear, and increases in tire-related roadside service calls.

Commercial truck tires are the number one maintenance cost for fleets. This paper will examine tire footprint, rolling resistance data and the effects on vehicle fuel economy and removal mileage from tires run at a variety of under-, over-, and recommended tire pressures. This analysis will also include the tire footprint impact by running tires on both fully loaded and unloaded vehicles. The footprint analysis addresses both standard dual tires (295/75R22.5) and the new widebase tires (445/50R22.5).

The results of our tire footprint analysis run under a variety of pressures and loads clearly reveal that tires running on unloaded commercial vehicles generate a significantly reduced overall tire footprint area that leads to fast and uneven wear but with an improvement in rolling resistance / fuel economy. Footprints taken on tires run 30% underinflated on both loaded and unloaded conditions (very common on trailer tires) show an elongated footprint with 18% more rubber on the road. This correlates directly to increased rolling resistance, reduced fuel economy, and early removal miles.

The impact of running widebase tires underinflated on unloaded trailers had an even more dramatic effect on the tire footprint versus standard dual tires.

Costs and Benefits Associated with the Use of NGWBS tires in North America

Joel Neff

More than a decade of market use and analysis has shown that New Generation Wide Base Single (NGWBS) tires and wheels deliver significant overall environmental, societal, and economic benefits versus comparable dual tire assemblies when used in a competitive transportation network. The adoption rate in North America has steadily increased as the direct benefits to the trucking industry have been recognized.

However, there are still some governmental restrictions in North America and internationally which impede adoption and thus limit full exploitation of key economic and environmental benefits. These restrictions are often based on the perceived costs of wide-base tires without regard to the overwhelming benefits. The perceived costs are often based on outdated or insufficient assumptions or models.

This paper addresses this issue by drawing together existing information and the latest data to provide a balanced view of the overall costs and benefits associated with the use of NGWBS tires.

Simulation of Tire Rolling Resistance Generated On Uneven Road

Chongfeng Wei
Oluremi Olatunbosun
Mohammad Behroozi

Because of the limitations of laboratory test rigs to reproduce some of the more extreme tire operating conditions, not all tire parameters and characteristics can be derived using tire dynamic tests. However, most tire dynamic responses and vibration properties can be virtually simulated using Finite Element analysis, which has long been recognized as a significant simulation tool for tire characteristics investigation. Rolling resistance generated by the longitudinal force against motion because of the road unevenness can be predicted using a commercial FE code ABAQUS, particularly for the tire traversing large obstacles or random uneven roads. In this study, a detailed tire model is developed with the geometry and material definition, and validated with static and dynamic tests on the rolling tire.

The objective of this study is to determine the energy loss generated in the tire and the equivalent longitudinal force during the tire rolling on an uneven road in terms of rolling resistance. The effects of different tire rolling speeds and different kinds of road unevenness on rolling resistance are also investigated in this study. Two different conditions are defined for the simulations – constant vertical load and vertical constraint of the wheel with a spring-damper combination and vehicle weight as in a quarter-car. Results of tire response in the two conditions in traversing uneven roads in both time domain and frequency domain will be presented to demonstrate the properties of tire dynamic characteristics.

Development and Improvement of Active Vehicle Safety Systems by Means of Smart Tire Technology

Mustafa Ali Arat
Saied Taheri

A vehicle's dynamic behavior is defined in large part through the given steering, braking and acceleration inputs by the driver. However these inputs do not directly control the vehicle motion, but essentially affect the tire forces that actually generate the forces and moments acting on the vehicle body. As a result, tire characteristics can dramatically change vehicle response, especially during maneuvers that cause the tires to reach to their limit adhesion levels. To assist the driver in such cases and to prevent other possible failure scenarios various vehicle control systems e.g. anti-lock brakes (ABS), stability controllers (ESP, ESC), or rollover mitigation schemes are introduced, which are also known as active vehicle safety systems. Based on the above facts one can easily come to the conclusion that a successful vehicle control system design requires matching its dynamics to the dynamics of the tires available on the vehicle.

This study proposes the use of a smart tire system that can provide information on momentary variation of tire features through sensor units attached directly on the tire and which develops control algorithms based on this information to assure a match-up between tire and controller dynamics. A prototype smart tire system is developed for field testing and for detailed analysis of the technology's potential. Based on the collected prototype data, novel observer and controller schemes are developed to obtain dynamic tire state information and to improve vehicle handling performance. The proposed algorithms are implemented using numerical analysis in a software environment (MATLAB/Simulink) for evaluation. The non-linear mathematical vehicle models are downloaded from the CarSim commercial simulation software for more realistic simulations.

Efficient in-Plane Tyre Mode Identification by Radial-Tangential Eigenvector Compounding

Vasilis Tsinias
George Mavros

Tyre modal testing is frequently used for validation of numerical tyre models and identification of structural tyre model parameters. Most studies deal with the case of a tyre fitted to a rigidly mounted rim and focus primarily on in-plane dynamic behaviour.

Here, an identification method of in-plane tire dynamics is developed for the case of a free tyre-rim combination. This particular case is important when the aim is to construct a full tyre model from modal testing, capable of predicting ride and NVH phenomena involving the whole vehicle.

Key attributes of the proposed approach include ease of implementation and efficient processing of measurements. For each type of excitation, (i.e. radial and tangential), both radial and tangential responses are recorded. Compounding of the corresponding radial / tangential eigenvectors results in smooth mode shapes, which are found to agree with those published in other analytical and experimental studies.

Characterization of Road Profiles Based on Texture Parameters and Fractal Properties

Mohammad Motamedi
Saied Taheri
Corina Sandu

Pavement texture is a feature of the road surface that determines most tire/road interactions, including wet friction, noise, splash and spray, rolling resistance and tire wear. In terms of the deviations of the pavement surface with characteristic dimensions of wavelength and amplitude, pavement textures can be grouped into micro-texture and macro-texture.

A major problem in road engineering is to understand the mechanisms of friction between rubber and the road. Adhesion (based on microtexture) and hysteresis (based on macrotexture) are two important components of friction. Since the effects of microtexture and macrotexture dominate the friction measurement at low and high slip speeds, they can provide sufficient resistance to skidding.

Several researches have demonstrated that most road profiles show fractal behavior on given ranges of scales. In the present work, a contact type profilometer is used to measure the macro and micro texture of several different road surfaces. The friction of the surfaces is also measured using a dynamic friction tester. The texture and fractal parameters of the measured profiles are estimated, and it is shown that all road profiles indeed display strong fractal behavior. In addition, in order to find out which parameters can discriminate profiles with different friction properties, the correlation between texture and fractal parameters and friction is also investigated.

Simulation of Heat Build-Up in Aircraft Tires Under High Speed Free Rolling Using An Explicit Approach

Mohammad Behroozi
Oluremi Olatunbosun

A high level of safety is demanded for the design and manufacture of aircraft systems and components and is strictly enforced by legislation. Hence the legislative requirements for the qualification of aircraft tyres are very onerous. The design of aircraft tyres is necessarily very complex, with many layers of reinforcement, in order to satisfy the extreme strength requirements of aircraft tyres.

In order to reduce the design costs while meeting the legislative requirements virtual tools such as Finite Element (FE) analysis are now being routinely used to assist tyre designers to achieve a reasonable estimation of the final design before costly prototypes are built. Simulation of heat build-up in the tyre and its distribution along its cross section profile is a vital issue that influences tyre mechanical performance in taxiing, take-off and landing. High temperature can considerably reduce material strength and can speed up potential failure modes. Therefore, the simulation of heat build-up in aircraft tyres is an important consideration in the evaluation of tyre performance prior to prototyping.

A coupled temperature analysis with deformation is proposed through an explicit approach in order to simulate the generated heat in the tyre. A nonlinear hysteretic material property for rubber is employed in predicting the dissipated energy by viscous effects. This dissipation will result an equivalent heat generation leading to consequent increase in rubber temperature. The environmental phenomena such as heat dissipation through radiation are neglected in this study, so that a proper simulation of heat build-up in the tyre can be carried out.

A Rigid Ring Tire Model in the Analysis and Development of Anti-Lock Brake Systems

Srikanth Sivaramakrishnan

Vehicle dynamic performance is predominantly controlled by tire dynamic characteristics through the forces and moments generated at the tire-road contact patch. The control of the tire vertical force can improve the vertical vibration characteristics and ride behavior. Previous studies have confirmed that the vibrations of the belt due to road irregularities and brake torque oscillations have a significant effect on the braking performance of the tire and cannot be neglected. To better study this effect, a number of artificial road profiles were generated by regarding the road surface as randomly irregular. This allowed us to represent it by a power spectral density (PSD) function. In addition to the surface model, the vehicle dynamics are modeled in an eight degree-of-freedom system integrated with an ABS algorithm developed based on a commercial system. In what follows, simulations have been carried out by first varying the frequency content of the surface irregularities and then by varying the road roughness.

The proposed rigid ring model was used as a tire model for running simulations and obtaining tire forces. In this model, the belt is modeled as a rigid ring connected to the wheel axle through sidewalls which are modeled as vertical, longitudinal and torsional springs and dampers. A relaxation length based contact model with tread element damping was used to incorporate the transients in longitudinal slip. The transient slip generated from this contact model was then used in a brush model to calculate the force generated by the tire at the contact patch. The model parameters were estimated by developing a script that is capable of setting-up and running a finite element analysis for a given tire structure. The script is designed to loop the analysis for the required simulation conditions along with the curve fitting algorithms to compute the desired rigid ring parameters. The model is further extended by an enveloping model that was included to calculate the effective road height and slope using the tandem elliptical cam approach. This would serve as an input to the single point of contact rigid ring model in addition to the axle movement. This model was particularly chosen because of its capability to model short wavelength road excitation at frequencies less than 100 Hz. Using this model, it is also possible to understand the influence of various aspects of the structural dynamics of the tire on its ability to generate braking force from dynamic torque variations.

Initial results showed that tire slip yields to considerable reduction in its vibrational response as compared to when it is in full grip. Additional simulations revealed the effects of tire enveloping phenomenon on vehicle's brake performance by means of obstacle testing (i.e. cleat testing). In conclusion, the proposed tire model presents an invaluable analysis tool for improving the effectiveness of modern ABSs.

FEA of Tire Performance for Snow Traction

Jan Terziyski

Snow traction is an important tire performance parameter for product applications in markets where snow is present for several months during the year. It is very difficult to perform multiple tests because proving grounds and consistent test conditions are available only for limited periods of time and due to prototyping and test expense. This paper deals with the simulation aspects of the ASTM F1805 snow traction test.

The first part of this paper describes the chosen test method and offers a review of the available simulation technology. A modeling methodology for realistic snow interaction is examined using small-scale simulations, in order to evaluate its applicability to snow traction simulations. Next, simulations of snow traction are developed for a tire rolling freely over snow, and for a tire spinning over a snow surface. The tire models employ fine-resolution tread patterns and snow domain. Physical phenomena such as snow shear, digging and friction are taken into account by an adaptive-explicit FEA. The proposed analytical procedure is validated through comparison with test data of a commercial tread pattern and several hand-carved modifications.

Inertial Representation of Non-Axismmetric Tire Structural Attachments to Perform Steady State and Dynamic Explicit Rolling Tire Analysis

Thulasiram Gobinath

Many new innovations in tire technology are a challenge for the simulation process, which is typically based on axisymmetric representations. Some examples are intelligent sensors & antennas attached to tires, air maintenance regulating devices, TPMS systems, RFID systems for inventory tracking, etc. In order to design these tires for production a reliable analysis methodology is required to evaluate non-axisymmetric tire structures under high speed operating conditions. In this paper an approach stemming from the basic principles of finite element analysis is presented. While the approach is generic and can be used in any nonlinear finite element code, all the analyses in this work were performed using the commercially available finite element code ABAQUS.

We begin with the steady state transport tire analysis schematics in which steady state deformations are captured by a two stage ALE like formulation in which the Lagrangian material point rotates through a fixed Eulerian tire mesh representing the steady state configuration. The deformation map is split into two parts in which the first part is a rotational rolling tire step which maps the initial configuration to the reference configuration and the second part applies the mapping from the reference domain to the steady state tire deformation domain. The derivation of the acceleration of a material point for straight rolling conditions is cast into the virtual work integral via D'Alembert's dynamic equilibrium principle.

In our particular case, the non-axisymmetric attachments to the tire structure are located near the bead area and virtually follow a circular path. Under these conditions the virtual work integration domain can be split into two domains, namely a region containing the nonaxisymmetric attachments and the rest of the tire domain in which the traditional steady state transport analysis is carried out. It is shown that the virtual work integral in the first domain reduces to the virtual work done by the pure centrifugal forces. This allows us to apply centrifugal inertial forces in the first domain and perform the consistent standard steady state transport analysis in the second domain. The inertial representation of non-axisymmetric attachments is within the static standard capability of ABAQUS that can be invoked in a steady state transport analysis. The structural attachment to the tire can be accomplished by using the tied contact approach or by using the embedded element technology approach.

An example of performing such a modified steady state rolling analysis is demonstrated for a tire with an attachment under free-rolling conditions.

Starting from the free rolling conditions an explicit analysis is performed with the initial velocity field equal to the transport velocity. The advantages of this approach are demonstrated using several examples, highlighting a more efficient analysis together with increased accuracy.

Advances in Modeling Rolling Tires

Stephen Vossberg
Hans Dorfi

As in all fields of science and engineering the exponential growth of computing power has facilitated tremendous advances in modeling pneumatic tires. These advances now allow the modeling of complex 3D geometries, the time-dependence of the rolling tire response and a wide range of physical phenomena such as the nonlinear descriptions of deformations, materials and contact behavior. The evolution of the various modeling techniques enabled with these greatly expanded resources will be presented here.

One early modeling technique was the use of carefully constructed boundary conditions along with a static FEA analysis to obtain rolling tire solutions. More rigorous steady-state solutions were then developed and found wide usage. Various implicit and explicit dynamics codes with detailed tread patterns are now run routinely. The advantages of simulating different boundary conditions with respect to solution efficiency will be discussed.

However, in spite of these advances the pneumatic tire still cannot be modeled with as much fidelity as desired. Even with results of the most sophisticated simulations the tire engineer is still required to direct a great deal of experience and judgment to compensate for what these models lack. It is still beneficial to develop and apply analytical and mechanistic tire models. Although such models are not extensively developed these days they should not be abandoned. They provide information and valuable insight that is not easily obtained from the multi-million-degree-of-freedom FEA models. One such mechanistic model of tire cornering behavior will be described, which serves to identify fundamental mechanisms of the radial ply tire, which in turn lead to the development of tire design tools.

Impact of Initial Thermal Strain and Viscoelasticity of Hybrid/Merged Cords on Tire Performance

Xianwei Meng
Mahmoud Assaad

Hybrid / Merged cords made by blending dissimilar yarns into a single cord are commonly used in tire applications (Overlay, carcass ply, stiffener…). This concept is used to capture the desirable properties of each component. In the Nylon (PA66) / Kevlar (K19) cord constructions, the Kevlar is used for its superior strength and thermal stability. The Nylon is used for its durability and high elongation.

In tire numerical modeling, the overlay component requires two types of input data related to the initial thermal strain: Thermal Coefficient of Expansion (CTE), and growth / creep viscoelastic response: Creep Factor (CF).

The following paper provides a summary of the laboratory measurements of these material properties for the commonly used hybrid / merged cords. A consumer tire with overlays was analyzed under high speed. The impact on the individual cord's axial force and axial strain were reported. In addition, the impact on the tire footprint characteristic was also shown to be dependent on the type of cord materials used in the overlay, its initial thermal strain, and its viscoelastic behavior.

Design and Analysis Paradigm for Gauging Thermomechanochemical Aging of Tires

Joseph Padovan

In both stored and operating tires, thermomechanical fields and highly temperature-dependent resident chemical reactions jointly interact to induce various levels of progressive product aging. Depending on the severity of a given operational duty cycle, such Thermomechanochemical (chemophysical) behavior can range over several primary chemistries. As time progresses, such conditions may cause significant irreversible degradation in both strength and crack propagation rates. The predominating dilatory chemistries include oxidative and a variety of sulfidic reactions that collectively lead to backbone and cross-link schisms along with a growing number of side branches. Many secondary reactions are also possible. These are associated with HO groups, various surfactant type impurities among the fillers and blended rubbers as well as other additives - processing oils among several. On the positive side, antioxidant chemistries are added to partially mitigate the onset of direct product oxidation.

The paper will develop the requisite Thermomechanochemical (chemophysical) representation and concomitant Chemophysics FEA simulation paradigm. This involves the formulation of the several layers of problem definition, in particular:

- Individual species diffusion characteristics - the species include oxygen, antioxidants, sulfur, HO among many - Some of the chemical reaction kinetics are strongly diffusion limited
- The evolving duty cycle induced mechanical fields
- Evolving Thermomechanical environment induced by the heat generation aspects of transient mechanical fields – significant effect on chemical reaction rates and start points
- Primary species reaction kinetics along with all required chemo-coupling
- Evolving Chemophysical effects on mechanical properties – along with hierarchical birth/death option modeling in cracking zones where properties fall below threshold levels
- All appropriate Chemophysical coupling.

For the primary chemistries, the individual specie level kinetics is gauged in terms of the appropriate defining variable, for example:

- The individual amounts of oxygen separately consumed in both the antioxidant and aging oxidative reactions
- The change in polysulfidic state during sulfur reactions, namely the evolution of the distribution of cross links (mono, di, so on).

Note oxygen consumed and the polysulfidic state are the primary drivers of property losses. Overall, the methodology enables the ongoing evaluation of the critical mechanical properties (strength and crack propagation rates). This is achieved through a state space type treatment of the key chemical factors, namely the primary gauges of the oxygen consumed and polysulfidic state. The experimentally generated parameters defining the mechanical properties reflect the appropriate thermomechanical history and chemistry state. The generality and efficiency of the scheme is such that essentially any single duty cycle or a combination of several cycle types can be handled. The formulation of the multichemophysics is such that it can be incorporated into any of the commercially available FEA codes, namely, ABAQUS-Simulia, MARC-MSC, and so on. This is possible through only modest changes incorporated through user interfaces/subroutines.

As a design paradigm, the overall methodology can be employed to parametrically tailor all critical chemophysical interactions so as to improve overall tire performance. Because of the scope of the model, both storage and road/user induced duty cycles can be handled. To round out the design process, modeling assessments should be undertaken to gauge/optimize product performance under government-mandated tests – for example the accelerated road wheel type endurance test.

Day 2, Paper 6

Evaluation of the Sidewall Crack Life By Fatigue Test of Sidewall Compound and Finite Element Method

Min Sung Kang
Seong Rae Kim
Ki Deug Sung
Myung Kug Cho
Chang Sung Seok

The tire is an important part of the automobiles because it acts as both a load support and a breaking and driving force generator. Recently, there has been an increased demand for the ultra-high performance (UHP) tires that have high efficiency and high performance and that can be used at high speeds.

The UHP tire is installed mainly on vehicles that undergo high-speed driving and the sidewall is a narrow structure because of the tire's low aspect ratio. Therefore, the possibility of sidewall crack initiation for UHP tires is higher than for other tires because bending and stretching by the rolling of the tire and resistance force by traction and braking are delivered directly to the sidewall. Also, greater stress concentration occurs at the sidewall due to the vertical loads.

However, an official standard test method that can evaluate the sidewall crack life through endurance test does not exist. Such a laboratory method for evaluating sidewall cracking would be time-consuming and expensive.

In this study, the fatigue characteristics of sidewall compound were evaluated by a uni-axial fatigue test and fatigue crack growth test in accordance with the international standard test method of ASTM D. The finite element analysis method is used to analyze the mechanism of sidewall crack initiation and damage concentration behavior in tire rolling states. Finally, amethod is suggested to predict the sidewall crack life of a UHP tire using the fatigue test result and FEA simulation.

Aging Mechanisms Involving Oxygen and Strain in the Tire Beltcoat Compound

Ed Terrill

Tire durability involves a combination of aging and degradation processes. Two key degradation processes are oxidation and mechanical softening. To understand how these processes interact during aging, an experimental approach was taken to measure chemical and physical property changes during aging under various loading conditions.

To understand the mechanisms and interactions in natural rubber, black-filled, sulfur–vulcanized compounds, the belt coat compound was extracted from a new passenger tire and subsequently, oven aged three different ways – no strain, static strain, and dynamic strain. The chemical and physical properties were measured as a function of time to understand the effect of strain on oxidation. Furthermore, preliminary work to model these chemical and physical property changes was initiated.

A New Methodology for Tire Wear Prediction
Part I – Mathematical Derivation

Saied Taheri

Vehicle characteristics have a profound effect on tire wear due to vehicle suspension/steering characteristics and dynamic load transfer. To characterize this influence, the vehicle response over a range of acceleration, deceleration and cornering maneuvers are mapped showing differences in driven and non-driven positions, steered and non-steered positions, as well as effects of suspension type, alignment, stiffness and kinematic properties.

Vehicle modeling with commercially available software has progressed to the point that it can be used in place of an actual vehicle to provide the necessary characterization. A new mathematical model has been developed and has been used to augment the commercially available software, Carsim. Using this new model, a new methodology has been developed for predicting tire wear. In this presentation, the mathematical derivation and some preliminary results are presented.

Wireless Structural Health Monitoring of a Tire Under Steady-State Free-Rolling

Vijaykumar Krithivasan
Robert L. Jackson
Russell W. Green
Song-yul Choe

The main objective of this work is to predict the operating conditions or the state of a tire based on a wireless sensor suit. First a three dimensional finite element model of a standard reference test tire (SRTT) was developed to better understand the tire deformation under separate cases of static loading, steady-state free-rolling and steady-state rolling conditions. A parametric study of normal loading, slip angle and slip ratio was carried out to capture the influence of these parameters. A numerical model that correlates the said parameters to the load on the tire is also proposed.

A wireless sensor suite comprised of analog devices (strain, pressure, and temperature sensors) was developed to capture the tire deformation under loading conditions similar to those used in the finite element model. This sensor suite formed the basis for experimentally verifying the trends captured by the finite element model on a custom-built tire test stand with capabilities of mimicking real-time conditions (under static loading scenario) of a tire in contact with road and steady state conditions on a Flat Trac test bed.

Using the results from the experiments and the finite element model, an empirical model was developed that demonstrates how the strains measured on the inner surface of the tire could be used to quantify desired parameters such as slip angle, lateral force, slip ratio, longitudinal force, and normal load. The resulting empirical equations relate measured strains to the normal load; slip angle, slip ratio, lateral force, and longitudinal force.

Effect Of Conicity and Ply Steer On Long Combination Vehicle Yaw Plan Motion

James Patterson

The demand for heavy trucking capacity in the United States continues to grow, but the interstate highway infrastructure and the legislation regarding vehicle size and weight have not changed for several decades. One possible solution is Long Combination Vehicles (LCV), which can carry more freight using fewer resources than a traditional tractor-trailer. Concerns regarding the safety and lateral stability of LCV's exist, in particular with respect to the tires, which are highly non-linear and load-dependent components. Tires can also exhibit conicity and ply steer, which are residual lateral forces and aligning moments at zero slip angle. This implies a possible lateral motion in straight line driving, raising a concern regarding units of the vehicle leaving the intended lane of travel.

A system of differential equations was derived for the triple trailer LCV system. These equations considered the mass and dimensions of the vehicle units, as well as simplified tire stiffness coefficients. The eigenvalues and eigenvectors of the system were determined, allowing a general assessment of the vehicle stability. A forced vibration analysis was then performed, applying the conicity forces and moments as a loading vector, with the lateral displacement at the end of the last trailer as the response of interest. Parametric studies were performed to assess the impact of variations of the force/moment location, the vehicle forward velocity, the vehicle mass, and the tire properties. The lateral displacement was affected by each of these, but the response for the cases examined was small relative to the width of the travel lane.

Tire Transient Lateral Force Generation: Characterization and Contribution to Vehicle Handling Performance

Terence Wei
Hans Dorfi

Tire force generation is often described in terms of a steady-state force response, which is considered independent of the tire and a function of the kinematic roll conditions such as slip angle. In addition to the steady-state response, the tire also exhibits a time-dependent transient force response, which in the lateral direction is a delay in the buildup of the cornering force. This delay is often characterized by the so called tire relaxation length (Ly), a tire performance characteristic often thought to have a strong effect on handling performance.

The definition and mechanistic interpretation of tire lateral relaxation length is discussed and different methods for measuring and interpreting lateral relaxation length are compared. The measurement methods include different types of flat belt as well as static stiffness measurements. Because of different levels of measurement uncertainty, the repeatability and benefits of the different measurement methods are demonstrated.

To determine the effect of including tire transient response in tire / vehicle system models a handling study has been performed. The study included a series of CarSim handling simulations with tires of different transient F&M characteristics as well as an analysis of outdoor subjective handling ratings. The result show the relatively small contribution of tire transient characteristics to vehicle handling performance compared to the tire steady-state force response.

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32nd Annual Meeting and Conference on Tire Science and Technology
September 10 - 11, 2013

Brief Schedule Overview (detailed schedule inside)

Day 1 - Tuesday, September 10, 2013

7:30 AM	**Registration**
8:55 AM	**Welcome:** Ric Mousseau, President
9:00 AM	**Keynote Address:** Chuck Yurkovich, Cooper Tire & Rubber Company
9:40 AM	**Opening:** Mohammed Sobhanie, Conference Chair
9:45 AM	**Session 1 - Wear Mechanisms:** Two Presenters
10:35 AM	**Break/Refreshments**
10:45 AM	**Session 2 - Properties of Tire Materials** Four Presenters
12:30 PM	**Lunch**
	Distinguished Technical Achievement Award – Dr. Hans. Pacejka
1:30 PM	**Session 3 - Heavy Truck Tires** Three Presenters
2:50 PM	**Break/Refreshments**
3:00 PM	**Session 4 - New Light on Tire Technology:** Three Presenters
4:20 PM	**Break/Refreshments**
4:35 PM	**Session 4 - New Light on Tire Technology:** Three Presenters
5:50 PM	**Day 1 Technical Sessions End** Grand Ballroom - South Section
6:45 PM	**Awards Banquet**
7:30 PM	**Awards Presentation**
7:40 PM	**Dinner Speaker:** Dr. Tim Joseph, University of Alberta
8:30 PM	**End of Day One**

Day 2 - Wednesday, September 11, 2013

7:30 AM	**Registration**
8:00 AM	**Opening:** Mohammad Sobhanie, Conference Chair
8:05 AM	**State of the Society:** Ric Mousseau, President
8:25 AM	**Session 6 - Modeling and Simulation:** Four Presenters
10:10 AM	**Break/Refreshments**
10:20 AM	**Plenary Lecture:** Bill Langer, MTS Fellow, Ground Vehicles
11:15 AM	**Session 7 - Durability** Three Presenters
12:35 PM	**Lunch:** On Your Own
1:35 PM	**Session 8 - Intelligent Tire Technology** Three Presenters
2:30 PM	**Break/Refreshments**
2:40 PM	**Session 9 - Various Topics** Four Presenters
3:35 PM	**Conference Closing Remarks**

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