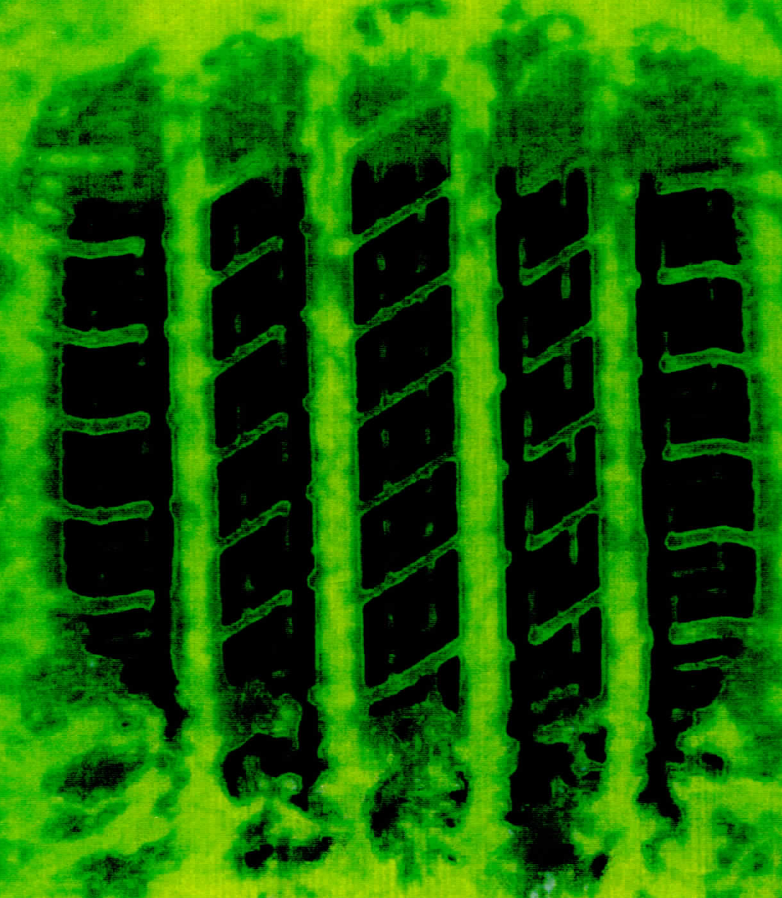
2001

The Tire Society

20th Annual Meeting and Conference on Tire Science and Technology

Radisson Hotel City Centre, Akron, Ohio USA

April 24 & 25, 2001



Abstracts

2001 TIRE SOCIETY CONFERENCE

PROGRAM SUMMARY

DAY 1 – TUESDAY APRIL 24

7:30 Speakers Breakfast (Day 1 speakers only)

8:00 REGISTRATION

8:30 OPENING:
John Luchini, President, The Tire Society

8:35 WELCOME

8:45 KEYNOTE ADDRESS:
Hyung In Shin, President & CEO, Kumho Industrial Co., Inc.

9:30 BREAK

9:35TECHNICAL PROGRAM BEGINS:
Denny Dubs, Gary Zolton, Co-Chairmen

9:35 TECHNICAL SESSION #1
(3 Technical Presentations)

10:55 BREAK

11:00 TECHNICAL SESSION #2
(3 Technical Presentations)

12:20 LUNCH

1:20 PANEL SESSION:
"Tire Society Retrospective", *Joe Walter* will moderate a panel of past presidents: *Dan Livingston, Dick Bauman, Mike Berzins*

2:05 BREAK

2:10 TECHNICAL SESSION #3
(4 Technical Presentations)

3:55 BREAK

4:00 TECHNICAL SESSION #4
(3 Technical Presentations)

5:20 End of Day 1 Technical Sessions

5:25 BUSINESS MEETING

5:30 SOCIAL HOUR

6:30 DINNER BANQUET:
Speaker: Peter Pesch, "Antarctica Expedition"

DAY 2 – WEDNESDAY APRIL 25

7:30 Speakers Breakfast (Day 2 speakers only)

8:15 TECHNICAL SESSION #5
(3 Technical Presentations)

9:35 BREAK

9:40 TECHNICAL SESSION #6
(3 Technical Presentations)

11:00 BREAK

11:05 TECHNICAL SESSION #7
(3 Technical Presentations)

12:25 LUNCH

1:40 SPECIAL LECTURE:
"T.R.E.A.D. Act", Donald B. Shae, President & CEO, Rubber Manufacturers Association

2:25 BREAK

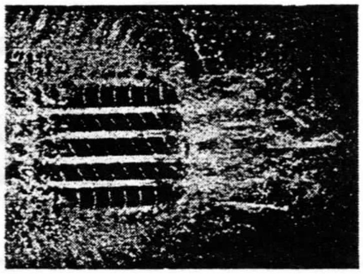
2:30 TECHNICAL SESSION #8
(3 Technical Presentations)

3:50 BREAK

3:55 TECHNICAL SESSION #9
(2 Technical Presentations)

4:50 CLOSING REMARKS

4:55 End of 20th Conference



Visit the Tire Society's website:
http://www.tiresociety.org

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Denny Dubs
Gary Zolton

Technical Papers in Order of Presentation

DAY 1 – TUESDAY APRIL 24, 2001

TECHNICAL SESSION #1 – Fluid Dynamics / Deformable Substrate

1.1 "Hydroplaning and Wet Traction Simulation using CFD", Jonshik Woo, *Kumho Tire LTD.*
1.2 "Tire Models for a Deformable Substrate", S. Shoop, *U S Army Engineer Research and Development Center*, I. Darnell, *University of Michigan*, K. Kestler
1.3 "Application of Finite Element Analysis and Computational Fluid Dynamics to ATV Tire Design", Tim Rooney, Jim Satrape, *Goodyear Tire & Rubber Company*

TECHNICAL SESSION #2 – Design / Optimization

2.1 "Automated Tire Layout Generation With The Goal of Iterative Redesign Using Automatic Meshing and FEM", Brian Murphy, *Kumho Technical Center*
2.2 "Application of STOM to the Optimal Tire Contour Design by Introducing the Aspiration-level Indicator", J.R. Cho, H.S. Jeong, *Pusan National University*, N.J. Kim, K.W. Kim, *Kumho Industries Co.*
2.3 "Surface Shape Optimization of Tire Pattern by Optimality Criteria", Yukio Nakajima, Fumio Takahashi, Akihiko Abe, *Bridgestone Corporation*

TECHNICAL SESSION #3 – Wear / Tread Analysis

3.1 "Vehicle and Course Characterization Process for Indoor Wear Simulation", John L. Turner, David O. Stalnaker, *Bridgestone/Firestone, Inc.*
3.2 "A Correlation between Rolling Tire Contact Friction Energy and Indoor Tread Wear", Sam Knisley, *Hankook Tire*
3.3 "Estimation of Tire Wear and Traumatic Failure Intensities", V. Bagdonavicius, A. Bikelis, V. Kazakevicius, *Vilnius University*
3.4 "Tread Slip Analysis", Hamid Aboutorabi, *Kumho Technical Center*

TECHNICAL SESSION #4 – NVH / Dynamics

4.1 "Tire Vibration Modes and Tire Stiffness", Ben G. Kao, *Ford Motor Company*
4.2 "The Identification of Sound Generating Mechanisms of Tyres", G. J. Kim, T. K. Lee, N. J. Kim, *Kumho Tire R&D Center*
4.3 "Application of Tire Experimental Modal in the Tire Structure Design", Ge Jianmin, Wang Zuomin, Mao Dongxing, *Tongji University*, Rolf Gall, Sun Shiming, *Shanghai Tire and Rubber Group Co.*

DAY 2 – TUESDAY APRIL 25, 2001

TECHNICAL SESSION #5 – Materials / Fracture

5.1 "Non-linear Hysteretic Characterization of Elastomers under Multi-Axial Loading Conditions", Mark R. Gurvich, Archie T. Andonian, Cheng Shaw, *Goodyear Tire & Rubber Company*
5.2 "Energy Dissipation of Rubber from a Classical Thermodynamic and Linear Viscoelastic Point of View", James A. Popio, *Smithers Scientific Services*, Ted A. Conway, *University of Central Florida*, Paul C. Lam, *University of Akron*
5.3 "Deformation and Fracture of SBR Rubber Under Tensile Impact Loading", Ibrahim Bekar, Michelle S. Hoo Fatt, *University of Akron*, Joseph Padovan, *Goodyear Tire & Rubber Company*

TECHNICAL SESSION #6 – Reinforcement / Composites

6.1 "The Influences of Thermal-Mechanical Properties of Polymer Cords on Tires with and without Post-Cure Inflation", Buo Chen, *Cooper Tire and Rubber Company*
6.2 "Anisotropic Composites Reinforced by 4000 Mpa Steel", Amit Prakash, Zhibin Zhang, Gary Tubb, *Goodyear Tire & Rubber Company*
6.3 "Experimental Study of Interlaminar Shear Strain in Cord-Rubber Composites", Doo-Man Kim, Hyun-Seung Yoo, In-Jeong Park, Jin-Yong Yoo, *Hankuk Aviation University*, Bon-Hee Ku, *Hankook Tire Co.*

TECHNICAL SESSION #7 – Vehicle / Handling / F&M

7.1 "New Approach to Tyre Handling Characterization for the Validation of an Extended Range of Maneuvers", F. Mancosu and C Savi, *Pirelli Pneumatici SPA*
7.2 "Energy Considerations in Tire Force and Moment Testing", Randy Jenniges, *MTS Systems Corporation*
7.3 "Road Crown, Tire, and Suspension Effect on the Vehicle Straight-Ahead Motion", J.-H. Lee, J. Lee, S.-H. Mun, *Kumho Tire R&D Center*

TECHNICAL SESSION #8 – FEA / F&M / RCF / Contact

8.1 "An Analytical and Experimental Investigation into Tire Force and Moment Behavior during Side Slip", Ric Mousseau, *University of Toledo*, Ian Darnell, Gregory Hulbert, *University of Michigan*
8.2 "The Finite Element Approach to Predict the Plysteer Residual Cornering Force of Tires", K. Ohishi, H. Suita, K. Ishihara, *Toyo Tire & Rubber Co.*
8.3 "A New Friction Model and Its Implications for the Frictional Energy and the Contact Forces", D.-J. Lee, S.-W. Nahm, H.-Y. Jeong, *Sogang University*, Y.-H. Kim, *Hankook Tire R&D Center*

TECHNICAL SESSION #9 – FEA / Stress Analysis

9.1 "Stress Analysis of the Multi-Layered System of a Truck Tire", X. Zhang, R. Ganesan, S. Rakheja, *Concordia University*
9.2 "Stress Analysis of Radial Tires in Service Conditions by Nonlinear Finite Element Method", F. Niknam Moghadam, K. Hemmatian, Mansour Kamran, *Rubber Industries Engineering and Research Company*

Additional Technical Paper Submitted for Publication

S.1 "Application of Mathematical Methods to Tire Designing", A.B. Nenakhov, L.R. Galperin, S.L. Sokolov, *Start LTD*

Paper Number 1.1

Hydroplaning and Wet Traction Simulation using CFD

*Jonshik Woo**

Computational Fluid Dynamics (CFD) has been employed to simulate tire hydroplaning and wet traction. In the simulation, three dimensional, viscous, unsteady, and turbulent flows are modeled using a finite volume method. These simulations are conducted to evaluate only the tire tread geometry effect whereas hydroplaning and wet traction are complex phenomena caused by tread design, compound, and road surface roughness.

In a hydroplaning simulation, hydrodynamic force called lift force and mass flow rate through grooves are obtained on thick water layer. Lift force is generated as tread blocks move in rotational and downward motions resulting in a squeezing action of water. Moving boundary conditions allow the calculation to initiate a squeeze motion onto the water film. The mass flow rate per second is also calculated by multiplying groove cross areas and corresponding normal velocities of water. For a wet traction simulation, shear stress generated by a rotational motion of a tire and a viscous effect of water between a tire surface and pavement are calculated. At different speeds shear stresses for a tire are computed. Then, the slope of these coefficients is found and used as an indicator of the general wet performance and effect of a tire tread.

The simulation results are compared with experimental data obtained in a proving ground. The correlation between calculations and measurements show very reasonable R-square values. Also, main effective factors for hydroplaning and wet traction are found to be footprint-shapes and void area ratio of the tread.

* Kumho Tire LTD., Kwngju, Korea

Paper Number 1.2

TIRE MODELS FOR A DEFORMABLE SUBSTRATE

S. Shoop[1], I. Darnell[2] and K. Kestler

Vehicle mobility on unpaved surfaces is important to military, agriculture, forestry, mining, construction, and recreation industries. Problems associated with off-road vehicle use can be grouped into two major categories: 1) predicting vehicle performance on various terrain (will it get stuck, how much traction is available to climb or pull, what are the energy requirements); and, 2) estimating the consequences of the vehicle passage (rut formation, shearing/tearing of roots, soil compaction, and the effects of these on vegetation and erosion). To assist in the analysis of complex experimental field data on these topics, a three-dimensional model of a deformable tire on a deformable surface was generated. Such a model can be used for predicting vehicle mobility, terrain deformation under vehicle loads, off-road tire design or tire specification for specific off-road machinery.

The originality of this model is that it accounts for the deformable nature of both the tire and the terrain, and for the three-dimensional nature of the problem. The first improvement is necessary because of the highly deformable nature of both materials, making the rigid approximation of either a gross oversimplification and yielding erroneous contact conditions, which are critical to the solution. Incorporation of the third dimension is crucial since the three-dimensional deformation of the terrain is readily apparent for most conditions. Additionally, tire or track width is an inconsistent factor in empirically derived equations to predict motion resistance (or rolling friction), indicating that it is significant yet not fully understood. To date, three-dimensional simulation of contact between a deformable tire and deformable terrain has been extremely difficult and computationally time consuming. Recent advancements in the contact formulations of general-purpose finite element codes, increases in the speed of computers, and tire model efficiency have brought such a model into the realm of possibility.

The tire model used was based on a formulation proposed by Darnell et al.[3] for efficiently modeling a tire rolling on a hard surface. Darnell's technique models the tire tread area as a single thickness of shell elements. The sidewalls consist of triangular user-defined elements using a look-up table based on modeling the sidewall with inextensible beams. Material properties represent the composite behavior through the tire carcass thickness. The result is an efficient model that enables the tire to accurately roll over obstacles and/or distances of several meters in only minutes of computational time. Simulations of a tire used in off-road performance experiments were generated using the Darnell methodology and called the Shoop-Darnell model. This tire model was compared to a conventional tire model of the same tire, and to experimental tire measurements of deflection, contact area, and contact pressure distribution, and deflected sidewall profile. The Shoop-Darnell tire model was then rolled across soil material modeled using cap Drucker-Prager plasticity.

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[1] US Army Engineer Research and Development Center, Hanover, NH

[2] Dept. of Mechanical Engineering, University of Michigan, Ann Arbor, MI

[3] Darnell, I, G. Hulbert, and C. Mousseau (1997) An Efficient Three-Dimensional Tire Model for Vehicle Dynamics Simulations, Mech. Struct. and Mach., Vol. 25(1), 1-19.

Paper Number 1.3

Application of Finite Element Analysis and Computational Fluid Dynamics to ATV Tire Design

Tim Rooney, Jim Satrape, Steve Liu

Goodyear Tire & Rubber Company

All Terrain Vehicles travel on every imaginable type of surface - from hard pack trails to muddy swamps. ATV tires must provide customer satisfaction in the form of acceptable ride and handling performance, and they must also generate extremely good wet traction characteristics in order to pull the vehicle through the tough stuff. This paper looks at a design tool that is routinely used to achieve one of these goals - optimum mud (wet) traction performance.

Techniques are described to evaluate the self-cleaning ability of tread patterns. Smooth tires are modeled at typical vehicle loads and inflation pressures using Finite Element Analysis. Footprint shapes and pressure distributions are taken from the analysis and used as input to the flow model. Mud is modeled as a viscous Newtonian fluid and is forced through the tread pattern. Flow velocities and pressures are computed using Computational Fluid Dynamics and these responses are used to generate an overall measure of the cleaning efficiency of the tread. By visualizing the results, potential 'clog' areas are identified and the tread pattern is modified to improve flow.

Paper Number 2.1

Automated Tire Layout Generation With The Goal of Iterative Redesign Using Automatic Meshing and FEM

Brian Murphy
Kumho Technical Center, Kumho Tire

A Windows based program has been developed for the automated generation of tire layout (2D cross-sectional) geometry based on parametric data which can be stored and reused. This project is under evaluation for the creation of CAD drawings for engineering use. Additional functions under development include the creation of component and template libraries, automatic generation of manufacturing specification data, automated meshing, and the application of FEM results to reconfigure geometry.

This paper will describe the steps taken to create parametric models of layout geometry, other types of data and databases that must be referenced, and lessons learned from studying current design methods of tire engineers. Forward plans for extending the system and database functions through simulation and tire redesign to final test and manufacturing specifications will then be described, along with potential problems both in system design and production process integration.

Paper Number 2.2

Application of STOM to the Optimal Tire Design

J. R. Cho[1], H. S. Jeong[1], N. J. Kim[2] and K. W. Kim[2]

The contour of internal polyester-cord layer called the tire carcass determines the cord tension distribution and the peak strain energy in the belt-edge region, and these mechanical quantities are directly associated with the major tire performances, automobile maneuverability and tire durability. Therefore, the determination of the tire carcass contour becomes a crucial part in the high-performance tire design.

From the theoretical point of view, the maneuverability improvement requires that the carcass cord tension becomes higher towards the bead, with the minimum value at the belt edge. While, the durability can be improved by minimizing the peak strain energy occurred in the belt edge region. However, these requirements can not achieved by conventional non-interactive multi-objective optimization methods based on mathematical programming, because these exhibit the conflicting behavior with respect to the carcass contour.

In order to obtain a quasi-optimum contour (or called a parete solution), we in this study intend to apply STOM (Satisfying Trade-Off Method). This interactive multi-objective optimization method is not only easy to implement, but also it always provides a unique solution with a minimum load for the designer's decision-making. In this paper, we present the mathematical derivation for applying STOM to the optimal tire design, together with illustrating numerical results.

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[2] Kumho Industries Co. Ltd., Tire R&D Center, Kwangju 506-040, Korea

Paper Number 2.3

Surface Shape Optimization of Tire Pattern by Optimality Criteria

Yukio Nakajima, Fumio Takahashi, Akihiko Abe

Bridgestone Corporation

A new optimization procedure to design the surface shape of tire patterns is proposed in which the optimality criteria are combined with FEM. The effectiveness of this new procedure to control tread element contact pressure distribution was verified via building and testing the rubber block samples. The objective function was the pressure uniformity on the block and the constraint was to keep the contact area in the optimization process. The shape of the optimized surface was round at the edges and concave at the center where the pressure was large in the block with the flat surface. The pressure of the block with the optimized surface became uniform and the friction coefficient increased ten percent on dry compared with the block with a flat surface. Furthermore, this procedure was applied to complicated block shapes such as tire patterns and it was verified that the optimized surface was effective to improve vehicle handling, riding comfort and irregular wear.

Key Words: Tire, Computer Aided Engineering, Finite Element Method, Contact Pressure, Optimization Technique, Optimality Criteria

Paper Number 3.1

VEHICLE AND COURSE CHARACTERIZATION PROCESS FOR INDOOR WEAR SIMULATION

John L. Turner, David O. Stalnaker

Bridgestone/Firestone, Inc, Akron, Ohio

An empirical methodology is described for separately characterizing vehicles and road courses for subsequent combination to predict tire loading histories. By building a library of vehicle and wear course characterizations, indoor wear test simulations can be selectively constructed by using any combination of "virtual" test vehicles and wear courses. A reliable transient record of vertical, lateral and fore-aft forces and inclination angles can be fabricated and supplied to drive the indoor wear tire loading fixture.

Vehicle characterization involves mapping the dynamic load transfer behavior over a range of acceleration, deceleration and cornering maneuvers. A unique indoor vehicle test facility is described for efficiently capturing the tire forces and inclination angles during various maneuvers. All four tire positions can be characterized. Vehicle C.G. accelerations and speeds are also recorded during indoor testing. Empirical equations relating vehicle kinematics to tire loads and inclination angles have been developed and are presented. A method of utilizing these equations together with outdoor wear course measurements for predicting transient load histories is presented. The method is demonstrated and validated with two vehicle case studies.

A wear course can be characterized by measurement of three parameters: the CG lateral and longitudinal accelerations and the longitudinal velocity. Course characterization is illustrated using the DOT's UTQG wear course in the San Angelo, TX area. The full 650km course was characterized and combined with the laboratory characterization of a 1997 Pontiac Grand Am. Four 650km drive files were created, one for each tire position, for an indoor wear machine. These consisted of five, time-based parameters: radial load, lateral load, wheel torque, inclination angle, and velocity. By sequencing a tire through these four drive files, it was "rotated" as it would have been on the actual vehicle. Examples of tire wear rates and irregular wear are shown for a number of tire constructions, comparing the indoor to the outdoor results. Good correlation was achieved.

This simulation technique permits quite complex and lengthy routes to be accurately reproduced in the precisely controlled environment of the laboratory. Each cornering maneuver, each braking and acceleration event, every hill and town can be reproduced in real-time. Only by combining the specific vehicle dynamics of a given vehicle with that of a specific wear route can tire wear be accurately simulated.

Paper Number 3.2

A Correlation between Rolling Tire Contact Friction Energy and Indoor Tread Wear

Sam Knisley
Hankook Tire

In an effort to reduce tire development time and cost, tire companies have developed accelerated indoor wear test technology and are developing modeling methods to conduct tire wear evaluations in a "virtual" sense. Much automotive and tire industry expertise has been devoted to establishing a relationship between outdoor and indoor wear test results. The development of modeling techniques has focused on the prediction of friction energy in rolling tire contact. A successful "virtual" wear test requires an objective link between rolling tire contact friction energy and tire wear. In this paper, a quantitative relationship between experimentally measured rolling contact friction energy and indoor tread wear is established for a specific passenger tire construction. Test equipment and methods for rolling contact measurements and indoor tread wear are described. Laser measurements of tread loss are compared to friction energy results for combined straight-ahead rolling and cornering conditions to establish a reasonable correlation between contact friction energy and tire tread loss on a global and local scale.

Paper Number 3.3

Estimation of Tire Wear and Traumatic Failure Intensities

V. Bagdonavicius, A.Bikelis, V. Kazakevicius
Vilnius University

Failures of tires can be non-traumatic (when wear reaches a specified critical level) or traumatic. Traumatic failures can be of various types.

In the statistical literature tire wear process and traumatic failure-time data are analized separately. In reality, the intensity of traumatic events depends on the wear.

We consider modeling and methods of non-parametric and parametric estimation of various degradation and reliability characteristics, taking into account dependence of traumatic event failure-time and wear data.

In real use conditions environment is dynamic. So the wear depends on various factors (or covariates) such as weight of the load, quality of roads, temperature, etc. Intensities of traumatic events also depend directly or via the wear on these covariates. We give models and methods of estimation for wear and failure-time data with covariates.

Key words:

covariates, failure-time data, hypothesis testing, ideal resource, non-parametric estimation, parametric estimation, regression, reliability, statistical analysis, stochastic process, tire, traumatic events, wear

Paper Number 3.4

Tread Slip Analysis

Hamid Aboutorabi
Kumho Technical Center, Akron, Ohio

Detailed modeling of the interaction between the tire tread and the road surface during rolling of the tire is important for understanding and quantifying several performance parameters. Explicit rolling of a tire model with detailed tread mesh is one way of achieving this, but this tends to be costly both in terms of model generation time and computation time. In this paper, an alternative approach is presented which treats the deformations of the carcass and the tread separately.

First, the steady state rolling solution for a ribbed model of the tire at the specified conditions of camber, speed, and slip is obtained. The material properties of the ribs in the model are adjusted to account for the directional stiffnesses of the tread pattern. Then the time invariant supporting surface of the carcass upon which the tread rolls is extracted. This surface is smoothed, and a detailed mesh of the tread is rolled on it while contact with a moving road surface is maintained. This approach can be thought of as a global/local procedure for tread analysis.

Paper Number 4.1

Tire Vibration Modes and Tire Stiffness

Ben G. Kao

Scientific Research Laboratory, Ford Motor Company

Tire radial stiffness is traditionally calculated from the wheel load deflection measurement. Statically, this stiffness serves to provide the support of the vehicle. However, this stiffness does not provide sufficient understanding of how the tire behaves dynamically: the tire first radial modes, no matter how were they measured, cannot be correlated with this statically measured stiffness. A comprehensive explanation for this phenomenon is needed for better understanding of tire dynamics and building of dynamic tire models.

In this paper, the relationship between the tire static stiffness and the tire radial vibration modes is investigated using the BAT modeling concept [1]. It is found that the tire first radial mode, though it can be of different values through different measuring method, can be explained consistently with this model.

Procedure to obtain consistent tire stiffness for tire model is also proposed as a result of this investigation.

1. B. Kao *"A Three-Dimensional Dynamic Tire Model for Vehicle Simulations"* Tire Science and Technology, **28**, No. 2, 2000

Paper Number 4.2

The Identification of Sound Generating Mechanisms of Tyres

G.J. Kim, T.K. Lee, N.J. Kim

Tyre noise is generated by several mechanisms. With a modern tyre, wall vibration, air pumping and air resonant radiation are all considered to be important. But tyre noise generating mechanisms are still not clear due to the complication of tyre vibration behavior.

Vibrations of the tyre shell are the combination of several different wave types which appear at different frequencies. In a low frequency range, where the tyre behaves like an elastically supported beam, the circular ring model is used to analyze the dispersion relations. Above 300Hz, which is the transition point from one-dimensional to two dimensional waveguide properties of the passenger car tyre, a cylindrical shell model is used to analyze flexural wave propagation. Two important features on the wave propagation, wave-guide behavior and the curvature effect of the tyre wall are analyzed.

In consideration of noise radiation from tyre waves, most of the tyre waves observed in this study are inefficient sound radiators since their wavenumbers are larger than the acoustic wave number. As a result, It is observed that one of the most important features in sound radiation of a tyre shell is acoustically excited wave motion of the tyre wall.

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Paper Number 4.3

Application of Tire Experimental Modal in the Tire Structure Design

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Rolf Gall and Sun Shiming
Shanghai Tire and Rubber Group Co.,Ltd, Shanghai, P.R. China 200072

The tire dynamic properties and noise have influence on the vehicle performance such as passenger comfort and tractive performance etc. This paper studied modal experimental method for tires as a sophisticated mechanical structure. The modal experiment system of tire was built under the radial load, tangential force and side force. Tire modal experiments with hammer and excitation machine under the contact or non-contact were carried out. Experiments of excitation in three directions(radial, tangential and side) were carried out with different types of tires. Eigenfrequencies and modes of tires were extracted in each experiment.

Tire modal experiments under the different radial load(area of contact surface), tangential force and side force were carried out. The relationship between tire modal and vertical load is analyzed. The relationship between tire modal and tangential force is analyzed. The relationship between natural frequencies of lower mode shapes and self-excited vibration (under high slip) is studied. Some parameters and dynamic properties of tire are used by tire company and car companies to simulate the dynamic response of the vehicles.

The relationship between natural frequencies and the inflation pressure. The natural frequency of tire increase with inflation pressure. When inflation pressure increase, damping efficient and rolling resistance of tire decrease.

The relationship between natural frequencies (or modal damping ratio) and tread pattern. When tread groove increase, tread mass and stiffness of tire decrease. The natural frequency of smooth tread tire is lower than that of the tire with pattern. This indicated that the effect of the tread mass is larger than that of the tread stiffness on the natural frequency. The natural frequency of tire decreases with the tread mass.

The relationship between natural frequencies and carcass mass. The natural frequencies of tire increase with carcass mass. This indicated that the effect of the carcass stiffness is larger than that of the carcass on the natural frequency. When the thick of the sidewall rubber decrease, damping coefficient of tire sidewall and rolling resistance of tire decrease. Tire of low rolling resistance increase the amplitude of vibration. However, the ride comfort of vehicle can be improved by the feasible compatibility between the tire and suspension. When the rolling resistance of tire decrease, the decreasing of tire mass influence on the stiffness, natural frequency of tire and the ride comfort of vehicle should be considered.

The relationship between the mode shapes and noise of tire is analyzed. Comparison of Tire Experimental Modal and FEA were carried out. The modal parameters of tires are applied to tire design and tire (or vehicle) simulations successfully.

Key words: Tire Natural frequencies Mode shape Stiffness Damping

Paper Number 5.1

Non-Linear Hysteretic Characterization of Elastomers Under Multi-Axial Loading Conditions

Mark R. Gurvich, Archie T. Andonian, Cheng Shaw

The Goodyear Tire & Rubber Company, Corporate Research, Akron, Ohio

An approach to describe hysteretic energy loss under 3-D cyclic loading is proposed for visco-elastic materials. The approach offers simplicity and high accuracy and can take into account the non-linearity of deformations along with 3-D nature of cyclic loading. It is shown that a two-parameter variant of the approach is, in general, a very good approximation of hysteretic loss even for highly non-linear deformations. Simple relationships between proposed material parameters and classical characteristics of visco-elasticity (storage modulus, loss modulus, and loss factor) are considered as well. Experimental confirmation was provided for a typical elastomeric compound and the statistical reliability of the prediction was found to be very high. The proposed approach may also be used to characterize hysteretic material properties using test results under 2- or 3-D loading.

Paper Number 5.2

Energy Dissipation of Rubber from a Classical Thermodynamic and Linear Viscoelastic Point of View

James A. Popio, Smithers Scientific Services

Ted A. Conway, University of Central Florida

Paul C. Lam, University of Akron

A constitutive model for rubber under dynamic loading has been developed. This model explains the dynamic rubber performance using classical thermodynamics and linear viscoelasticity. A relationship between the coefficients of the model and the loss and storage moduli has been developed to allow application of this method to existing experimental data. The ultimate goal of this work is to provide convenient predictions of energy dissipation, which has major implications in the area of damage.

Paper Number 5.3

Deformation and Fracture of SBR Rubber Under Tensile Impact Loading

Ibrahim Bekar[1], Michelle S. Hoo Fatt[1], Joseph Padovan[2]

Tires can be subjected to strain rates up to 1,000 s^{-1} when they suddenly hit a bump in the road. This paper shows that the deformation and fracture behavior of SBR rubber under such high strain rates are very different from what are observed under quasi-static loading and that the mechanical properties of rubber that are obtained using conventional quasi-static tests will fail to predict the impact response of the rubber.

An experimental study is done to characterize the deformation and fracture of uncracked and cracked SBR rubber specimens under high strain rates. A Charpy Impact test apparatus is modified so that the rubber dumbbell specimens break under tensile impact loading. The experiment is capable of achieving very large strains, on the order of 300%, and strain rates up to 1,000 s^{-1}, in the rubber.

The transient force and deformation response as well as the dynamic force-stretch characteristic for the uncracked and cracked SBR rubber specimens are presented for strain rates between 0.2-350 s^{-1}. Initial and secondary moduli are distinctly observed in the dynamic force-stretch curves. The two moduli are separated by a "knee" in the graph, thus signifying an apparent "yield" or transition point. The initial and secondary moduli as well as the force, at which the knee occurs, increase with increasing strain rate. Failure envelopes for the fracture strain are also given for the cracked and uncracked specimens. The fracture strain of the rubber increases with increasing strain rate until a certain point, at which it begins to decrease with higher strain rates.

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[2] Goodyear Tire & Rubber Company, Akron, OH 44309-3531.

Paper Number 6.1

The Influences of Thermal-Mechanical Properties of Polymer Cords on Tires with and without Post-Cure Inflation

Buo Chen
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Because of the different load histories experienced immediately following the curing process, tires with and without post-cure inflation (PCI) exhibit different behaviors in aspects including dimension and footprint shape, among others. This study thoroughly investigates the influences of the thermal-mechanical properties of polymer cords on tires with and without PCI. First, material characterizations of polyester tire cords with various thermal-mechanical histories are conducted. Both instantaneous and viscoelastic properties of various tire cords are obtained, and a comprehensive understanding of the effects of PCI on cord properties is achieved. Second, experimental tires of a specific size are built with and without PCI, and a series of measurements are made, which include: a) the dimension and footprints for both new and exercised tires with increasing mileage, b) rolling resistance for both new and exercised tires, and c) durability. Through these tests, the influences of PCI on tire performance are established. Both 2D and 3D finite element models are then constructed to analyze the mechanical behaviors of tires with and without PCI quantitatively. In the numerical analyses, both the non-linear instantaneous and viscoelastic behaviors for the tire cords are modeled and the results are consistent with experimental data.

Paper Number 6.2

Anisotropic Composites Reinforced by 4000 MPa Steel

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A composite structure reflects the properties of its constituents, the mechanics of their configuration and the behavior of bonds between various components. The development of a 4000 MPa steel wire, which is claimed to be the strongest engineering material, provides opportunity to design light weight high strength composites with unique properties. In the current study, above wire having 200 GPa modulus has been used in a soft matrix of rubber having a nominal modulus of 5 MPa in conjunction with an organic fiber of modulus 5 GPa. By using the conventional composite mechanics theory, the configuration of reinforcement can be modified to produce composites in a broad property range. Since the adhesion between the reinforcement and the specially formulated rubber matrix is very satisfactory, the composites can be used in a fluctuating stress environment thereby yielding high fatigue life. The anisotropic nature of such composites have shown interesting applications such as in a zero inflation capable 'Run Flat' automobile tires. The bending stiffness results from laboratory samples of 15 cm x 3.8 cm having different reinforcement configuration will be presented.

Paper Number 6.3

Experimental Study of Interlaminar Shear Strain in Cord-Rubber Composites

Doo-Man Kim[1], Hyun-Seung Yoo[1], In-Jeong Park[1], Jin-Yong Yoo[1], Bon-Hee Ku[2]

Cord-rubber composite constituting the belt structure of tire shows great amount of interlaminar shear strains as compared with aircraft composites such as graphite-epoxy and boron-epoxy, because the stiffness ratio of cord/rubber reaches almost from thousands to tens of thousands. This phenomenon is pointed out as a source of failure of belt structure with delamination. So, the experimental study of interlaminar shear strain in cord-rubber composites was performed.

Interlaminar shear strains and in-plane shear strains of the belt specimen cut out from tire were measured from the images which were taken by X-Ray with experimental setup under the various unidirectional extension loading. The effect of cord angle, cord/rubber stiffness ratio and specimen dimension were studied to verify edge effect. The measured results were compared with theoretical analysis, strain gage method and pin method.

In this paper, nonlinear characteristics of interlaminar shear strains and in-plane shear strains were verified. The detail local strains with respect to the position of specimen were measured by X-Ray method.

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Paper Number 7.1

New approach to Tyre Handling Characterization for the validation of an extended range of maneuvers

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The handling behaviour of the tyre is very complex, in particular the linear properties identification is strongly dependent on testing methodology. On the other side, the simulations of the full vehicle behaviour are becoming more critical for the development of new vehicles and tyres, thereby demanding always greater accuracy in a very wide range of maneuvers and testing conditions.

This makes it very difficult to validate a great range of maneuvers at the same level of accuracy with only one tyre identification, even if extremely accurate: the use of different characterizations based on testing methodologies consistent with the actual tyre working conditions of the maneuver concerned become in this way strictly necessary.

This paper describes a characterization methodology supplying different tyre parameter sets referring to different working conditions showing validation examples with several maneuvers covering a wide range of tyre working conditions.

Paper Number 7.2

Energy Considerations in Tire Force and Moment Testing

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Force and moment testing to determine tire properties has been evolving toward larger slip conditions, higher test speeds and larger test loads. Test conditions that produce large slip at the tire patch produce substantial energy that is dissipated as heat and tread wear. This paper looks at the implications the energy dissipation for the testing facilities and test procedures. An analytical comparison of the energy dissipation of various common test types is made in this paper to show how test procedure design can affect the energy dissipation. Ways to minimize energy dissipation by test procedure design are discussed.

Paper Number 7.3

Road Crown, Tire, and Suspension Effect on the Vehicle Straight-Ahead Motion

J.-H. Lee, J. Lee, S.-H. Mun [1]

Drivers are often annoyed by vehicle behavior during straight-ahead motion. A certain vehicle has its own consistent tendency in the lateral direction to the straight-ahead line during a straight-ahead motion. This is called the vehicle pull, steering pull, or vehicle drift. The factors that cause the vehicle pull can be categorized into internal and external factors. Wind and road crowns are known as the determining external factors causing vehicle pull. Among the external factors, road crown pulls a vehicle to the side of the road in one direction under straight-ahead motion. In addition to the external factors, the vehicle itself has it own pull tendency due to design specification of chassis, steering system, suspension system, and tires. Sometimes, these factors interact with each other. Therefore, proper range of the design specification on these factors should be established through the close examination of vehicle pull.
Even though there are some papers available on the effect of tires on the vehicle pull, the mechanism on how these factors causes the vehicle pull is a complex phenoma. The effect of tires on vehicle pull can be characterized by a value of residual aligning torque, abbreviated to RAT [2] [3]. Other than this, more works need to be done for clear understanding the effect from the internal factors like suspension and steering systems.

In this paper, effect of road crown, tire, and front suspension geometry was studied using a full vehicle model in multi-body dynamics software. Here, a sport utility vehicle was modeled and analyzed by a software package called ADAMS (Automated Dynamic Analysis of Mechanical Systems). For the study of tire effect, tire residual aligning torque (RAT) was chosen. Tire models with RAT values from –3 Nm to +3 Nm in a step of 1.5 Nm were selected. For the suspension geometry, scrub radius and caster angle of front wheel geometry were chosen as design variables. The amount of scrub radius varied in the range of –10 to +10 mm in a step of 5 mm from the original design specification. For the caster angle, one degree angle change was applied to the original caster specification.

During simulation, the vehicle model is controlled to follow a preselected straight line with a speed of 80 km/h. Then, the vehicle runs 100m in a free control mode, that is, with a steering wheel released. Lateral deviation from the straight line after 100m run was measured. From the simulation results, vehicle sensitivities to the RAT value of tires and road crown were calculated. Also a possible effect due to the change of scrub radius and caster angle in front suspension was evaluated. Finally a desirable range of RAT value of tires was recommended for a given road crown.

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Paper Number 8.1

An Analytical and Experimental Investigation into Tire Force and Moment Behavior during Side Slip

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This paper describes an investigation on how well a nonlinear finite model predicts tire lateral force and self-aligning moment behavior during sideslip. An efficient 3 D tire finite element model is used to predict spindle forces resulting from large, slow speed (quasi-static) deformations. The simulation, briefly described in the paper, is composed of shell elements that model the deformation of the tread, coupled to special purpose finite elements that model the deformation of the sidewall. The special purpose element uses a pre-computed look-up table to efficiently calculate the sidewall shape, and the forces (and moments) at spindle and tread interfaces. The model is designed to predict the forces at the spindle and ground, and the overall tire shape, as opposed to the internal stress fields. This paper considers the following deformation scenarios: 1) a tire vertically deforming against a flat plate, 2) a vertically loaded tire deforming laterally on a flat surface, and 3) a tire rolling straight ahead under a prescribed slide slip angle. Experimental data is also presented to verify the force predictions.

Paper Number 8.2

The Finite Element Approach to Predict the Plysteer Residual Cornering Force of Tires

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It is well known that the Plysteer Residual Cornering Force (PRCF) of tires plays an important role in assessing the vehicle pull problems and efforts have been made in the tire industry to clarify the underlying mechanisms and to control the phenomenon from the engineering point of view. The magnitude of PRCF of radial tires is affected not only by the belt construction but also by the design of tread pattern for which the experimental evaluations are time- and cost-consuming tasks in the tire development process.

This paper proposes the finite element approach to predict PRCF of tires that is supposed to overcome those difficulties. Results of the finite element predictions are compared with experiments and discussions are also presented.

Paper Number 8.3

A New Friction Model and Its Implications for the Frictional Energy and the Contact Forces

D.-J. Lee[1], S.-W. Nahm[1], H.-Y. Jeong[1], and Y.-H. Kim[2]

A new friction model was developed with consideration of the effect of the contact pressure and the sliding velocity, and the model was implemented as a user subroutine in ABAQUS/Explicit. A smooth tire was simulated for free rolling, driving, braking and cornering situations by using ABAQUS/Explicit along with the user subroutine. The frictional energy and the contact forces were obtained, and they were compared with the results obtained when the Coulomb friction model was used. For the cornering situation, the frictional energy and the cornering force were analyzed with respect to the slip angle. The total frictional energy increases almost linearly as the slip angle increases. However, the cornering force shows its maximum only when the new friction model was used. In addition, the contact area was larger and the frictional energy was distributed more uniformly over the contact area when the new friction model was used.

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Paper Number 9.1

Stress Analysis of the Multi-Layered System of a Truck Tire

X. Zhang, R. Ganesan and S. Rakheja

In this paper, a nonlinear finite element (FE) tire model is developed to analyze the deformation and stress fields within the tire structure, contact patch geometry and contact pressure distribution in the tire-road interface as functions of the normal load and inflation pressure. The model considers the geometry and orientations of the cords in individual layers and the stacking sequence of different layers in the multi-layered system in order to predict the inter-ply interactions in the belts and carcass layers. The study incorporates the nearly incompressible property of the tread rubber block and the anisotropic material properties of the layers. The analysis are performed using the ANSYS® software and the results are presented to describe the influence of normal load and thus the tire deflection on the various stress fields and contact pressure distributions. The computed footprint geometry is qualitatively compared with the measured data to examine the validity of the model. It is concluded that the proposed model can provide reliable predictions about the three-dimensional stress and deformation fields in the multi-layered system and the contact pressure distribution in the tire-road interface, when the material properties and structural parameters are obtainable for the inflated and loaded truck tire.

Keywords: Truck Tires, Tire Model, Finite Element Modeling, Multi-layered System, Contact Pressure, Contact Patch Geometry and Nearly Incompressible material.

Paper Number 9.2

Stress Analysis of Radial Tires in Service Conditions by Nonlinear Finite Element Method

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In this paper a steel belted tire is modeled by finite element to determine the mechanical behavior of the tire under inflation and cornering force in service conditions. The analysis is three-dimensional and geometrical. The carcass region is modeled by shell composite element whereas the covering parts of the tire, including the crown, the sidewall, the shoulders and the bead regions, are modeled by solid elements. The rubber material is assumed to have hyperelastic behavior of Mooney-Rivlin type. However, the carcass layers, which are made of composite steel and cord rubber bonds are assumed to be made of orthotropic laminates. The results are compared with those of experimental tests, which show a close agreement.

Paper Number S.1

Application of Mathematical Methods to Tire Designing

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The mathematical modeling became necessary component in designing modern tires today. However, it is necessary to use not only modeling programs for an effective practical design. Creation of a programs system assisting not only to make calculation, but also to prepare data and to compare various variants of construction of a tire design quickly. In the paper authors give the brief description of similar system, give information about that complex of tire designing methods , which is created and practically used by them for the almost 15-year's period. More than 100 various types of tires were designed using this system.

Key words: tire, 3D FEM analysis, mathematical modeling