別紙４－２（課程博士（和文））

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論文内容の要旨　（博士）

博士学位論文名	自動車用タイヤの接地摩擦特性のモデル化に関する研究

（要旨　1,200 字程度）

自動車と路面の唯一の接点であるタイヤには，車両の支持や操縦安定性といった基本性能，転がり抵抗や車外騒音の低減といった環境性能，乗り心地や静粛性といった車室内快適性等についても考慮した設計が求められる．また，車両開発の短期化が進むにつれ，これらの性能の両立を見据えたタイヤ設計を製品試作前の企画段階に行う事が求められている．タイヤ設計諸元と特性値の力学的な因果関係を理解して設計検討を行う事が肝要となるが，その手段としてタイヤ力学モデルの利用が知られている．しかし，従来モデルには実現象の再現精度や設計検討での実用面において解決すべき課題が残されている．

本研究では，従来のタイヤ力学モデルから得られる接地特性の実測との整合性向上，モデルに含まれる摩擦係数や剛性パラメータとタイヤ設計値の合理的な結び付けを課題として取り上げ，これらの課題を解決することを目的とする．本論文は6つの章で構成され，第1章で緒言を述べた後の各章の概要を以下に示す．

第2章では，従来は矩形と扱われてきた接地形状を楕円とみなすことで，実測の接地特性の再現性を向上させた楕円接地タイヤモデルを構築した．そして，従来モデルに対する提案モデルの優位性を，インサイドドラム型のタイヤ試験機で実測した接地圧分布・横応力分布との比較により示した．

第3章では，ゴム摩擦が粘弾性特性との因果関係を持たず，滑り速度依存性を含まない状態（主に湿潤環境に相当）における接地特性についての課題を取り上げた．Perssonの摩擦理論を組み込んだ楕円接地タイヤモデルを提案し，ゴムの粘弾性から演繹計算したヒステリシス摩擦係数及びその滑り速度依存性と横応力分布を理論的に結び付けた．ただし，モデル計算とタイヤ実験結果が整合するためのスケールパラメータの算出に関して課題が残った．

第4章では，ゴム摩擦が粘弾性特性の因果関係を持ち，滑り速度依存性を含む状態（主に乾燥環境に相当）における接地特性についての課題に取り組んだ．ここでは，ヒステリシス摩擦と粘着摩擦の両方を考慮したXuの摩擦理論を楕円接地タイヤモデルに組み込んだ．そして，摩擦理論のパラメータは試験タイヤと同配合のゴム片の滑り実験から同定した．提案手法により，第3章で課題となったスケールパラメータを用いずに，従来モデルよりも精度良く実測の前後応力分布を再現可能であることを示した．

第5章では, 第2章から4章における接地圧分布のパラメータがタイヤ部材特性と力学的な因果関係を持たない問題，接地圧分布を計算する従来の力学モデルが実験的に確認されている接地圧分布の長さ方向の偏向を合理的に説明できない問題の解決に取り組んだ．ここでは，タイヤ設計諸元から剛性理論に基づき演繹計算したモデルパラメータを接地圧計算モデルに組み込んだ．接地圧計算モデルは，タイヤのヒステリシス特性をトレッドばね要素の可変剛性として定式化して改良した3次元弾性リングモデルを用いた．そして，提案モデルが実測の接地圧分布の偏向を再現可能であることを示した．

第6章では，第2章から第5章で得られた成果を総括し，今後の研究の展望を示した．

別紙４－１（課程博士（英文））

Date of Submission（month day, year）: January 6, 2025

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Abstract（Doctor）

Title of Thesis	Study on modeling for contact friction characteristics of automotive tires

Approx. 800 words

The tire, which is the only contact point between the vehicle and the road surface, must consider basic performance such as handling and stability of vehicle, environmental performance such as reducing rolling resistance and pass-by noise, and comfort such as ride quality and quietness. As the development cycle of vehicles shortens, it is required to design tires that balance these performances at the planning stage before product prototyping. It is essential to understand the mechanical causal relationship between tire design specifications and characteristic values for design consideration, and the use of a "tire mechanical model" is known as a way to achieve this. However, conventional models still have issues to be resolved in terms of the accuracy of reproducing actual phenomena and practical use in design considerations.

This study aims to address the challenges of improving the consistency between the contact characteristics obtained from conventional tire mechanical models and actual measurements, and rationally linking the friction coefficients and stiffness parameters included in the models with tire design values. This paper is composed of six chapters, and after stating the introduction in Chapter 1, the outlines of each chapter are as follows.

In Chapter 2, an "elliptical contact tire model" was constructed by considering the contact shape, which has traditionally been treated as rectangular, as elliptical, thereby improving the reproducibility of the measured contact characteristics. The superiority of the proposed model over conventional models was demonstrated by comparing it with the contact pressure distribution and lateral stress distribution measured with an inside drum-type tire tester.

In Chapter 3, the issue of contact characteristics in a state where rubber friction does not have a causal relationship with viscoelastic properties and does not include slip velocity dependence (mainly corresponding to wet conditions) was addressed. An elliptical contact tire model incorporating Persson's friction theory was proposed, and the hysteresis friction coefficient deduced from the viscoelasticity of rubber and its slip velocity dependence were theoretically linked to the lateral stress distribution. However, there remained an issue in calculating the scale parameter necessary for the model calculations to align with the tire experimental results.

In Chapter 4, the issue of contact characteristics in a state where rubber friction has a causal relationship with viscoelastic properties and includes slip velocity dependence (mainly corresponding to dry conditions) was tackled. Here, Xu's friction theory, which considers both hysteresis friction and adhesive friction, was incorporated into the elliptical contact tire model. The parameters of the friction theory were identified from slip experiments of rubber pieces with the same composition as the test tire. The proposed method demonstrated that it could reproduce the measured longitudinal stress distributions more accurately than conventional models without using the scale parameter, which was an issue in Chapter 3.

In Chapter 5, the issues of the parameters of the contact pressure distribution not having a mechanical causal relationship with the tire component characteristics, and the conventional mechanical model for calculating the contact pressure distribution not being able to reasonably explain the longitudinal deviation of the experimentally confirmed contact pressure distribution were addressed. Here, model parameters deduced from the tire design specifications based on stiffness theory were incorporated into the contact pressure calculation model. The contact pressure calculation model used a three-dimensional elastic ring model, improved by formulating the hysteresis characteristics of the tire as variable stiffness of the tread spring element. The proposed model demonstrated that it could reproduce the deviation of the measured contact pressure distribution.

In Chapter 6, the results obtained in Chapters 2 to 5 were summarized, and the prospects for future research were presented.