UNIVERSITI PUTRA MALAYSIA

MOTION RESISTANCE RATIO, NET TRACTION RATIO AND TRACTIVE EFFICIENCY OF A RICELAND TYPE TYRE

ELWALEED AWAD KHIDIR

MOTION RESISTANCE RATIO, NET TRACTION RATIO AND TRACTIVE EFFICIENCY OF A RICELAND TYPE TYRE

By

ELWALEED AWAD KHIDIR

Thesis Submitted in Fulfilment of the Requirements for the Degree of Master of Science in the Faculty of Engineering
Universiti Putra Malaysia

May 1999

Dedicated

to

My
Mother,
Brothers and Sisters

ACKNOWLEDGEMENTS

I wish to express my profound gratitude and sincere appreciation to Dr. Azmi Yahya, chairman of my supervisory committee for his invaluable guidance, constructive criticisms, suggestions, discussions and patience throughout the research work and during the preparation of this thesis. I am also much indebted and grateful to Assoc. Prof. Dr. Desa Ahmad and Assoc. Prof. Dr. Wan Ishak Wan Ismail, members of my supervisory committee, for their invaluable advice and guidance in supervising this dissertation.

I am especially indebted to Dr. Gizan Saleh for his guidance throughout and after his Advanced Statistical Methods course. I am also indebted to Dr. Faizal, Mr. A/Mutalib, Mr. Mutasim El Tayeb, Mr. Darius El Pebrian. I also acknowledge with gratitude Mr. Mohamad Rushdi, laboratory assistant of Machine Design Laboratory for his generous cooperation and unlimited helping. I also wish to thank Ir. Mesran Rasan, Mr. Mohamad Ikhsan, Mr. Mohamad Kamal Hashim, Mr. Suratman Sulaiman and Mr. Sahat Daud who have been very helpful especially in allowing the use of workshop facilities and developing the rig.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF ABBREVIATIONS

A	tyre contact area, cm^2
a	constant depends on tyre flexibility, dimensionless
Bn	mobility number, dimensionless
B	tyre width, cm
c	soil cohesion, N/cm^2
CI	cone index, N/cm^2
Cn	wheel numeric, dimensionless
Cs	carriage speed, m/s
d	tyre unloaded diameter, cm
d_{rim}	tyre rim diameter, cm
F	maximum tractive force, N
G	sand penetration resistance gradient, N
H	tractive force, N
h	unloaded tyre section height, cm
k	deformation modulus, cm
k_ϕ	frictional moduli of deformation, kN/m^{n+2}
k_c	cohesive moduli of deformation, kN/m^{n+1}
L	tyre contact length, cm
LR	tyre loaded radius, cm
Nc	clay-tyre numeric, dimensionless
Ns	sand-tyre numeric, dimensionless
Nt	tyre rotational speed, rpm

n	index, dimensionless
P	net traction, N
P_c	tyre carcass pressure, N/cm^2
P_i	tyre inflation pressure, N/cm^2
Q	torque, N cm
R_0	rolling radius, cm
s	travel reduction (slip), dimensionless
TE	tractive efficiency, %
TF	towed force, motion resistance or rolling resistance, N
UR	tyre unloaded radius, cm
u	constant depends on tyre flexibility, dimensionless
Va	tyre actual velocity, m/s
Vt	tyre theoretical velocity, m/s
W	tyre vertical load, N
Z	sinkage, cm
τ	shear stress, N/cm^2
σ	normal stress, N/cm^2
ϕ	soil friction angle, degree
α	shear deformation, cm
δ	tyre deflection, cm

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirements for the degree of Master of Science.

MOTION RESISTANCE RATIO, NET TRACTION RATIO AND TRACTIVE EFFICIENCY OF A RICELAND TYPE TYRE

By

ELWALEED AWAD KHIDIR

May 1999

Chairman: Azmi Yahaya, Ph. D.

Faculty: Engineering

A study was conducted to determine the accuracy of Wismer-Luth and Brixius equations in predicting the tyre motion resistance ratio, net traction ratio and tractive efficiency of a Riceland type tyre. The tyre was tested on a sandy clay loam soil in an indoor UPM tyre traction testing facility. The experiment was conducted by running the tyre in two modes; towing mode for the formulation of tyre motion resistance ratio equation and driving mode for the formulation of tyre net traction ratio and tractive efficiency equations.

A total of ninety test runs were involved in the tyre motion resistance ratio determinations at three selected inflation pressures (i.e. 221, 193 and 166 kPa) and selected wheel numerics ranging between 0 to 70. From the analysis of covariance (ANCOVA) it was found that both inflation pressure and wheel numeric has significant effect on the tyre motion resistance ratio. Regression analysis was also conducted to determine the closeness of fit for Wismer-Luth and Brixius equations in predicting the motion resistance ratio of the tested tyre. Finally, 3 new logarithmic models for the tyre motion resistance ratio were formulated. The 193 kPa inflation pressure revealed a lower tyre motion resistance than the nominated pressure (i.e. 221 kPa) and the 166 kPa.

For the tyre net traction ratio and tractive efficiency determinations, 126 test runs were conducted in a combination consisting of three selected inflation pressures (i.e. 221, 193 and 166 kPa) and two wheel numerics (i.e. 19 and 29) representing two extreme types of soil strength under different levels of travel reduction ranging between 0 to 40%. Regression analysis was conducted to determine the prediction equation describing the tyre torque ratio. Marqurdt' s method used by Wismer-Luth for predicting non-linear equation was found not suitable in predicting the torque ratio of the tested tyre for its low coefficient of determination and inadequacy. The logarithmic model was found to be suitable in predicting the torque ratio. From the analysis of covariance (ANCOVA) the mean effect of travel reduction, tyre inflation pressure and wheel numeric were found to be highly significant where as the interaction of inflation pressure and wheel numeric was not significant. The 193 kPa inflation pressure was the best, among the three inflation pressures used, in getting higher net traction ratio and higher maximum tractive efficiency.

Finally, two models were formulated for the tyre net traction ratio; one in terms of wheel numeric and travel reduction and the other in terms of mobility number and travel reduction, to describe the tested tyre performance at different soil strengths. It can be concluded that Wismer-Luth and Brixius models cannot be made common to all agricultural tyres due the differences in their characteristics of width to diameter ratio, deflection to section height ratio, rolling radius to diameter ratio and tyre type.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Master Sains.

NISBAH RINTANGAN GULING, NISBAH TUKISAN BERSIH DAN KECEKAPAN TUKISAN SEBUAH RODA JENIS TANAH SAWAH

Oleh

ELWALEED AWAD KHIDIR

Mei 1999

Pengerusi : Azmi Yahaya, Ph. D.

Fakulti : Kejuruteraan

Kajian telah dijalankan untuk menentukan kejituan persamaan Brixius dan Wismer-Luth dalam meramalkan nisbah rintangan guling, nisbah tukisan bersih dan kecekapan tukisan bagi tayar jenis sawah. Ujian telah dijalankan dengan menggunakan kemudahan makmal ujikaji tukisan tayar di UPM pada tanah jenis loam liat berpasir. Ujikaji telah dijalankan dalam dua mod; mod tunda bagi pembentukan persamaan nisbah rintangan gulingan tayar dan mod pacuan bagi pembentukan persamaan nisbah tukisan bersih dan kecekapan tukisan.

Sebanyak 90 ujian telah dijalankan yang melibatkan penentuan nisbah rintangan guling tayar pada tiga pilihan tekanan tayar (iaitu 221, 193, 166 kPa) dan pilihan bagi pekali roda diantara antara 0 hingga 70. Keputusan daripada analisis kovarian (ANCOVA) menunjukkan tekanan tayar dan pembilang roda mempunyai kesan nyata pada nisbah rintangan guling tayar. Analisis regresi dijalankan bagi menentukan kejituan persamaan Wismer-Luth dan Brixius meramalan nisbah rintangan guling tayar. Jesteru itu, tiga model logaritma baru telah diterbitkan bagi nisbah rintangan guling tayar. Sebanyak 126 ujian telah dijalankan bagi penentuan nisbah tukisan bersih dan kecekapan tukisan dalam kombinasi tiga pilihan tekanan tayar (iaitu 221, 193, 166 kPa) dan dua pekali roda (iaitu 19 dan 29) yang mewakili dua jenis kekuatan tanah yang berbeza pada peringkat pengurangan pergerakan tayar diantara 0 hingga 40 peratus. Analisis regresi dijalankan bagi mendapatkan persamaan yang dapat menerangkan nisbah kilas tayar. Kaedah Marqurdt yang digunakan untuk meramal persamaan tak lelurus oleh Wismer-Luth didapati tidak tepat untuk nisbah tork bagi tayar yang diuji memandangkan pekali penentuannya adalah rendah dan tidak kesesuaian. Model logaritma didapati amat tepat meramal nisbah tork tayar.

Daripada analisis kovarian (ANCOVA), kesan purata pengurangan pergerakan tekanan tayar dan pekali roda didapati mempunyai kesan nyata yang tinggi, manakala interaksi antara tekanan tayar dan pekali roda adalah tidak berkesan. Tekanan tayar pada 193 kPa didapati menunjukan kesan yang terbaik berbanding dengan dua tekanan lain yang diuji bagi mendapatkan nisbah tukisan bersih dan kecekapan tukisan yang maksimum.

Akhir sekali, dua model yang telah dapat diterbitkan bagi nisbah tukisan bersih tayar; satu berdasarkan pekali roda dan pengurangan pergerakan tayar dan yang satu lagi berdasarkan nombor mobiliti dan pengurangan pergerakan tayar untuk menerangkan prestasi tayar yang diuji pada kekuatan tanah yang berbeza.

Ianya dapat disimpulkan bahawa model Wismer-Luth dan Brixius tidak boleh digunakan pada semua jenis tayar pertanian disebabkan perbezaan ciri-ciri nisbah lebar dengan diameter, nisbah pesongan dengan tinggi keratan, nisbah jejari guling dengan diameter dan jenis tayar.

CHAPTER I

INTRODUCTION

Tractors are widely used in farms that perform most of the agricultural field operations. As energy from fossil fuel sources becomes more expensive, the efficient utilization of energy resources becomes a major concern to agricultural production systems. The farm tractors consume approximately 20% of the total onfarm energy requirements (Heichel, 1976).

Tractor power is utilized by transmitting the engine power both through the driving wheels as traction to provide the drawbar power required for draught implements, and through the power take-off shaft - as well as the hydraulic system to provide mobile support for the attached machines. Of these principal ways the least efficient and most used method is the drawbar. Engine power can be converted to drawbar power only if the drive wheels develop traction (Brian, 1988; Liljedahl *et al.* 1989).

Research results throughout the world show that from 20 to 55% of the energy delivered to the drive wheels of the tractors is wasted in the traction elements. This energy is not only wasted but the resulting soil compaction created by a portion of this energy may be detrimental to crop production. This loss of energy by the pneumatic tyre has prompted researchers to search for operational parameters that could improve tractive efficiency (Burt *et al.* 1983).

An understanding of the basic characteristics of the interaction between the running gear and the ground is essential to the study of the performance characteristic and handling the behavior of ground vehicles (Wong, 1993). The running gear of a ground vehicle is generally required to fulfill the following functions:

1. support the weight of the vehicle
2. cushion the vehicle over surface irregularities
3. provide sufficient traction for driving and braking
4. provide adequate steering control and directional stability.

Pneumatic tyres can perform these functions efficiently, thus they are exclusively used in road vehicles and are also widely used in off-road vehicles. The study of the mechanics of pneumatic tyres therefore is of fundamental importance to the understanding of the performance and characteristics of ground vehicles. Two basic types of problem in the mechanics of tyres are of special interest to vehicle engineers; one is the mechanics of tyres on hard surfaces and the other is the mechanics of tyres on deformable surfaces, which is of prime importance to the study of off-road vehicle performance.