DESIGN AND DEVELOPMENT OF KENAF HARVESTING MACHINE

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FK 2011 107
DESIGN AND DEVELOPMENT OF KENAF HARVESTING MACHINE

By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

August 2011
Dedicated to

To my family members especially my beloved wife, my dear son, and my ever-encouraging parents for their love
DESIGN AND DEVELOPMENT OF KENAF HARVESTING MACHINE

By
OMID GHAHRAEI

August 2011

Chair: Professor Desa Ahmad, PhD, P.Eng.

Faculty: Engineering

Kenaf whole-stem having long bast fibres is more suitable for industries to produce textile and bio-composite panels. Current modified harvesters (sugarcane harvesters, forage harvesters, choppers, reaper binders, mower conditioners, pedestrian harvesters) normally chop the kenaf stems to small segments and/or crash the fibres or unable to cut the thick stems. So, a kenaf harvesting machine is required to cut the thick intact whole-stems having high capacity and satisfactory cutting quality with no damage on the bast fibres. Currently manual whole-stem harvesting which is a labour-intensive, time-consuming, and less profitable process, is being practiced in Malaysia.

In this study, a new pull-type four-row whole-stem kenaf harvesting machine with a rotary impact cutting system was designed, developed and evaluated. The machine cutting system design was based on effective cutting knife edge angle (ANE) and cutting rotational speed. In this research, specific cutting force (SCF) and specific
cutting energy (SCE) were measured by considering knife edge angle (ANE), shear angle (SA), knife approach angle (ANA), knife rake angle (ANR), and the cross-sectional area of plant stems. In addition, an experimental impact cutting machine was manufactured and tested in the field. The rotational speed obtained with this machine had the lowest cutting torque. Kenaf stems of the V36 variety were used as the experimental material. An analysis of variance of the SCF and SCE values of the kenaf stems showed that the effects of all the above-mentioned angles (considering a broad range) on SCF and SCE were significant. Moreover, the preferred values of ANE, SA, ANA, and ANR were 25°, 40°, 40°, and 40°, respectively, according to Duncan's multiple range test (DMRT). Based on the impact cutting test, the rotational cutting speed had a significant effect on the specific cutting torque. Increasing the rotational speed from 308 to 788 rpm decreased the cutting torque by 26.3%. The preferred rotational speed with a minimum cutting torque used in designing the cutting system was 712 rpm. The experimental impact cutting machine had an estimated effective field capacity of 0.56 ha/8 h day. The average moisture content of cut samples from the lower area of the stems was 70.78% (dry basis).

The harvesting machine operated best at the field speeds of 3-6 km/h resulted from the cutting quality tests and recommended by DMRT. In preliminary field tests, the average values of the effective filed capacity (EFC), field efficiency (FE), and material capacity (MC) of the machine were found to be 1.68 ha/8 h day, 70.6%, and 114.8 t/8 h day for single-row harvesting (with 75 cm row spacing and about 20 stems/m of row) and 3.37 ha/8 h day, 74%, and 241.9 t/8 h day for 2-row harvesting.
(with 75 cm row spacing and about 20 stems/m of row), respectively at recommended speeds of 3-6 km/h. The average expected values of EFC, FE, and MC of the machine for 4-row harvesting (with 30 cm row spacing and 10 stems/m of row) were foreseen to be 2.92 ha/8 h day, 77%, and 249 t/8 h day, respectively at recommended speeds of 3-6 km/h in standard field conditions (planted by an accurate planter, proper watering and fertilization, and with no weed or grass). Maximum height, average diameter, average cutting height, and average moisture content of the kenaf stems at the harvesting time were measured as 3.10 m, 21.8 mm, 20 cm, and 71.8% (dry basis), respectively.

The highest recommended machine effective field capacity evaluated in this study was capable of replacing up to 370 persons per day when harvesting by traditional hand methods. Based on cost analysis results, the total manual harvesting operation cost was 32 times more than the total mechanical harvesting operation cost for harvesting 1,500 hectares of Malaysia kenaf fields for fibre production for one time plantation a year in 2010.
Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

REKABENTUK DAN PEMBINAAN MESIN PENUAI KENAF

Oleh

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Sebuah mesin penuai batang kenaf jenis tarik yang berupaya memotong empat baris batang kenaf menerusi sistem pemotong impak berputar telah direkabentuk, dibangunkan dan diuji. Rekabentuk sistem pemotong mesin adalah berdasarkan
sudut tepi bilah berkesan (ANE) dan kelajuan putaran memotong. Dalam kajian ini
daya pemotongan tentu (SCF) dan tenaga pemotongan tentu (SCE) di ukur dengan
genambilkira sudut tepi bilah (ANE), sudut ricih (SA), sudut tuju bilah (ANA),
sudut sadak bilah (ANR), dan luas keratan rentas batang pokok. Sebuah mesin ujian
pemotongan impak turut dibina dan diuji di ladang. Penggunaan mesin ujian
menunjukkan kelajuan putaran yang dicapai memberikan nilai kilasan terendah.
Batang kenaf dari jenis V36 telah digunakan sebagai bahan kajian. Analisis varian
bagi nilai SCF dan SCE menunjukkan bahawa kesan kesemua sudut yang dinyatakan
adalah signifikan. Berdasarkan ujian julat berbilang Duncan (DMRT), nilai ANE,
SA, ANA dan ANR adalah 25˚, 40˚, 40˚ dan 40˚.

Berdasarkan ujian pemotongan impak, kelajuan pemotongan putaran memberi kesan
yang signifikan ke atas nilai kilasan pemotongan. Peningkatan kelajuan putaran dari
308 hingga ke 788 psm akan menurunkan nilai kilasan potongan sebanyak 26.3%.
Kelajuan putaran yang dipilih dalam merekabentuk sistem pemotongan adalah 712
psm. Mesin ujian pemotonagn impak berkeupayaan untuk mengerjakan 0.56 ha/8
jam sehari. Kelembapan sampel dari bahagian bawah batang kenaf yang dipotong
adalah 70.78% (asas kering).

Pencapaian terbaik mesin adalah pada kelajuan 3-6 km/jam semasa ujian kualiti
pemotongan dan berdasarkan ujian julat berbilang Duncan (DMRT). Pada ujian
awal, purata nilai keupayaan ladang berkesan (EFC), kecekapan ladang (FE), dan
keupayaan bahan (MC) mesin adalah masing-masing 1.68 ha/ 8 jam sehari, 70.6%
dan 114.8 ton/8 jam sehari bagi penuaiain satu baris (dengan 75 cm jarak tanaman
dan 20 batang/m). Bagi penuaian 2 baris, nilai yang diperolehi adalah masing-masing 3.37 ha/8 jam sehari, 74% dan 241.9 t/8 jam sehari. Jangkaan nilai EFC, FE, dan MC bagi pemotongan 4 baris (dengan 30 cm jarak tanaman dan 10 batang/m) adalah masing-masing 2.92 ha/8 jam sehari, 77% dan 249 t/8 jam sehari pada kelajuan 3-6 km/jam dengan andaian ladang yang bersih dari rumpai dan benih tanaman ditanam pada jarak yang tepat beserta penjagaan yang rapi. Ketinggian maksimum, purata garis pusat, purata ketinggian pemotongan dan purata kelembapan batang kenaf ketika penuaian dijalankan adalah masing-masing 3.10 m, 21.8 mm, 20 cm dan 71.8% (asas kering).

ACKNOWLEDGMENTS

I wish to express my deepest gratitude to the numerous people who have walked with me along the journey of this thesis. First and foremost I would like to express my deep gratefulness to my supervisor Professor Ir. Dr. Desa Ahmad, the chairman of the supervisory committee for his kind assistance, strong support, critical advice, encouragement, suggestions and direction throughout my research and preparation of this thesis. I would also like to express my gratitude towards Dr. Jamarei Othman and Dr. Khalina Abdan, the members of supervisory committee for their supervision, helpful advice and fruitful discussions that made an invaluable contribution to this dissertation. My appreciation is addressed to Dr. Hadi Suryanto, the former UPM lecturer to encourage and guide me at the onset of design procedure and his valuable advice on cutting system design. I appreciate Associate Professor Dr. Farrokh J. Sharifi (Department of Mechanical and Industrial Engineering, Ryerson University, Toronto, Canada), Professor Dr. Abbas Hemmat (Department of Mechanics of Agricultural Machinery, Isfahan University of Technology, Isfahan, Iran) for their helpful advice and discussion in mechanical design of the present kenaf harvesting machine, and Professor Dr. Ken Giles (Department of Biological and Agricultural Engineering, University of California Davis, USA) for reviewing the research methodology and results of the published full-length paper in Transactions of The ASABE.
This research was funded by the Ministry of Higher Education (MOHE, Malaysia), FRGS Top-Down Project No. 5523501-10201. The author is grateful to Malift Sdn. Bhd (Selangor, Malaysia) for fabricating the prototype cutting machine and the kenaf harvesting machine. My special thankfulness is for Universiti Putra Malaysia (UPM) to support me during my thesis and for granting access to the test field and for providing all the necessary equipment. My special appreciations are extended to Associate Professor Dr. Azmi Yahya, Head of Machinery Design Laboratory for the guidance and cooperation in the cutting tests. My special appreciation is for all staff of the Department of Biological and Agricultural Engineering, UPM who contribute in the completion of this study. Thanks are extended to staff of Institute of Tropical Forestry and Forest Products (INTROP) and Malaysian Agricultural and Research Development Institute (MARDI) for granting us the permission to conduct the field test and evaluation in their plantations. My sincere appreciation also goes to all the people who have helped and supported me.

Last but not the least, my heart-full gratitude and love to my wife and my son, my mother and my father, and siblings whose unconditional support and love has made this dream comes true to me.
I certify that a Thesis Examination Committee has met on 25 August 2011 to conduct
the final examination of Omid Ghahraei on his thesis entitled "Design and
Development of Kenaf Harvesting Machine" in accordance with Universities and
University College Act 1971 and the Constitution of the Universiti Putra Malaysia
[P.U.(A) 106] 15 March 1998. The Committee recommends that the student be
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DECLARATION

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously and is not concurrently submitted for any other degree at Universiti Putra Malaysia or other institutions.

OMID GHAHRAEI

Date: 25 August 2011
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