UNIVERSITI PUTRA MALAYSIA

DESIGN AND DEVELOPMENT OF KENAF HARVESTING MACHINE

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By

OMID GHAHRAEI

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

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Dedicated to

To my family members especially my beloved wife, my dear son, and my ever-encouraging parents

for their love

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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

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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

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(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.

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Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

REKABENTUK DAN PEMBINAAN MESIN PENUAI KENAF

Oleh

OMID GHAHRAEI

Ogos 2011

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

Fakulti: Kejuruteraan

Serat gentian panjang yang terhasil dari batang kenaf amat diperlukan oleh industri untuk menghasilkan tekstil dan panel biokomposit. Jentera penuai kenaf sediaada yang diubahsuai dari jentera seperti jentuai tebu, "forage harvesters", "choppers", "reaper binder", "mower conditioner" dan "pedestrian harvester" memotong batang kenaf kepada ukuran pendek, menghancurkannya atau tidak berupaya untuk memotong batang kenaf yang tebal. Justeru itu sebuah jentera penuai kenaf amat diperlukan untuk memotong batang kenaf dalam ukuran yang panjang tanpa merosakkan serat gentian. Buat masa ini proses memotong batang kenaf dilakukan menggunakan tenaga buruh yang memakan masa serta kurang ekonomik.

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

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sudut tepi bilah berkesan (ANE) dan kelajuan putaran memotong. Dalam kajian ini daya pemotongan tentu (SCF) dan tenaga pemotongan tentu (SCE) di ukur dengan mengambilkira 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 penuaian satu baris (dengan 75 cm jarak tanaman

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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 garispusat, 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).

Berdasarkan kajian ini keupayaan ladang berkesan maksimum mesin mampu mengatasi 370 pekerja sehari sekiranya dilaksanakan secara manual. Berdasarkan analisis kos, kos penuaian secara manual adalah 32 kali ganda lebih tinggi berbanding kos penuaian secara mekanikal apabila menuai 1,500 hektar tanaman kenaf untuk pengeluaran serat bagi tahun 2010.

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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 awarded the Doctor of Philosophy.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted in fulfilment of the requirements for the degree of **Doctor of Philosophy**. Members of the Supervisory Committee were as follows:

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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.

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Date: 25 August 2011

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