# CONSTRUCTION AND EVALUATION OF A MODIFIED MULTICROP THRESHER MODEL IRRI-PAK

WENCESLAUS GEORGE KILASARA

A DISSERTATION SUBMITTED TO SOKOINE UNIVERSITY OF AGRICULTURE MOROGORO, IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE (AGRICULTURAL ENGINEERING)

1987

# DECLARATION

I, Wenceslaus G. Kilasara, hereby declare to the Senate of Sokoine University of Agriculture that this dissertation has not been submitted for any degree award in any other University.

Signature ...[signature]... Date 4th APRIL 1987

## ACKNOWLEDGEMENT

The Author is grateful to the International Rice Research Institute (IRRI) for providing him a conducive environment for his research. The primary advice offered by the Director General, Dr. M. S. Swaminathan, was helpful throughout the days of staying in the Philippines.

The Author wishes to express his deep sense of gratitude and profound appreciation to Dr. Clarence W. Bockhop and Dr. Amir U. Khan. They paid him a lot of patience to understand his research problem. Their fruitful suggestions and guidance enabled him to identify a definite direction of the research. He commends the devotion of Dr. Bockhop, who critically analyzed the research proposal to the acceptable standard. Also, the time spent in reading the thesis drafts, and in the discussion of the thesis ideas is highly acknowledged.

The encouragement from Dr. Khan was immeasurable. The Author is really thankful to the introductions made through different people and institutions, which made the testing activity possible. Without the contribution by Dr. Khan some of the work on the thresher would have been unattainable, and securing of threshing crops would have been very difficult.

Professor G.C. Mrema has been very concerned about the identification of the research problem for the Author.

Also, he has been very dynamic to monitor and correct the setbacks which were to render failure or poor starting. The Author is quite grateful to the advice offered by Dr. Mrema which directed the Research in the line required by the Sokoine University of Agriculture (SUA).

The role taken by Mr. Bent Frederiusen enabled the author to be more critical on his ideas. The author appreciated very much the suggestions given which elaborated his research proposal.

In general, the author is thankful to all of the Engineering Staff of both the IRRI and the SUA. He extends special appreciation to the IRRI Senior Staff who are willing to share their experiences with foreign students; and Mr. John Dumelow (SUA) for his challenging ideas on research identification.

It will be unfair if the Author does not enumerate all the Engineering Staff at IRRI. Since the list will be too long, representatives will be mentioned. He is indebted to Mr. Edison Dungo, the workshop supervisor and his fourteen subordinates who gave the Author the appropriate attention. Mr. Feliciano Jolotjot, technical drawing supervisor with his group showed the maximum concern to the Authors' demands.

The design engineers have all been cooperative. Engineer Miguelito Diestro is thanked for his assistance especially during the first days of the research. Engineer

Rustico Bautista assisted by Mr. Anzoleto Smagula and Mr. Pastor Aldemita contributed a lot during the time of threshing wheat in the Ilocos Norte Region.

Engineers Andy Caballes, Fred Mazaredo and A. Vasallo together with Ms. Imelda Barredo, all of machine testing section contributed much during data collection.

Mr. Nestor Rivera, a store officer, impressed the Author from his consistency in making decisions and follow-ups whenever a spare part was required through him.

Without the Department Secretaries the time spent on the research would have been increased. Ms. Ellen Sunaz, with her ever cool mind typed the final draft of the thesis proposal and the Appendix tables of the thesis. Ms. Ella Castro and Ms. Fe Sunga made the telephone calls, performed typing of some documents and offered guidance to the people/section the Author wanted to contact. Ms. Minerva Bernardino deserves sincere gratitude. She typed several drafts of the thesis; her organization is very much appreciated.

The Author is greatful to the IRRI Assistant Farm Manager, Mr. John Lapis and Mr. Juslado Ramos, the farm garage supervisor. Their leadership enabled the Author to get harvested crop and a tractor whenever requested. Mr. Willy Herrera together with other scientists from the Multicropping section are thanked for offering crops from their experimental plots. Ms. Anabelle Cruz tirelessly assisted in the statistical work.

The Author remembers the ideas from the Tanzanian Engineering Scholars, Mr. Francis F. Mwombeki and Mr. Julius M. Kigalu. Without them the general living in the Philippines would have been difficult.

Finally, the Author reserves special thanks to his parents, brothers and sisters. Their communication and best wishes enabled the Author to concentrate and hence finalize the research.

## ABSTRACT

A modified IRRI-PAK Multicrop Axial-flow thresher has been manufactured at the International Rice Research Institute (IRRI), Engineering workshop, based on the blueprints of the IRRI-PAK-30 Multicrop Axial-flow Thresher from Pakistan.

The modifications include, a piece of hollow shaft to the threshing cylinder shaft; bolted thresher stands; increased area of one of the cleaning screens, and omission of locks and hinges on the observation windows.

Different models of four-wheel tractors were used.

Three of the four crops used -- sorghum variety casor 2; paddy varieties IR38, IR58 and 1917; and yellow corn were obtained from IRRI experimental plots. Wheat was found in Ilocos Region - Northern part of the Philippines.

Settings which included increasing/decreasing aspirator air vents, varying the slope/pitch of the oscillating tray assembly, and varying the cylinder speed/peripheral velocity were the variables for the experiments conducted.

A conveyor was used during sorghum threshing. An output of 1594 kgh$^{-1}$ with 97.65% cleaning efficiency, 98.47% threshing efficiency, 1.27% grain loss were recorded.

The paddy threshed, gave an output range of [illegible]67kgh$^{-1}$ to 1569 kgh$^{-1}$ with cleaning efficiency of 93.39% to 96.01%, and a threshing efficiency of above 99% and total

grain loss of between 1.27% and 2.01%.

The output of wheat varied from 790kgh$^{-1}$ to 2110kgh$^{-1}$ with cleaning efficiency of 76.60% to 96.57%. Threshing efficiency increased with increased speed. The speed of 510rpm [17.81ms$^{-1}$] gave 96.12% and 710rpm [24.79ms$^{-1}$] gave 98.14%.

The results for corn threshing were influenced by the concave bar clearance and or the design of the louvres which resulted to high grain losses from straw thrower (15.94% to 16.98%).

The output ranged from 862 kgh$^{-1}$ to 896 kgh$^{-1}$ with cleaning efficiency of 85.79% to 86.66% and threshing efficiency of above 99%.

## TABLES

## FIGURES

## APPENDICES

## SYMBOLS

A  Area $m^2$ or $mm^2$

b  Crop mixture from aspirator/blower [$kgh^{-1}$]

C  Coefficient of drag

c  Maximum distance to the neutral axis, mm or m

d  Depth or diameter, mm.

F  Foreign material

F ( )  Force; [N]; Ftf; Force of thrower and flange; Fk, force of cutting knives; Fsp1, Force of middle support and outer plate; Fp2, Force of inner plate; Fg, Force of threshing pegs; Fff, Force of flange and flinger; Fn, Force of the fan; F1, Force of pulley assembly and flywheel and driving force; Fr, Drag force

f  Frictional force [N] $f_s$, static froce; $f_k$, kinematic force

GL  Grain loss, $kgh^{-1}$; GLt, loss from straw thrower; GLs, loss from grain bypassing the oscillating screen/tray assembly; GLb, loss from aspirator/blower; GLr, scattered from the feeding hopper or front of the oscillating tray.

g  Gravitational acceleration 9.81 $ms^{-2}$

I  Second moment of area $m^4$

ID and OD; Inside and outside diameters, mm.

J  Polar moment of area $m^4$

l  Length, mm.

M  Moment, Nm.

MC  Moisture content [%] wet basis

OD and ID; Outside and inside diameters, mm.

o  Crop mixture from the output spout $kgh^{-1}$

P  Power, kW.

Q Output, $kgh^{-1}$

QD Damaged grains $kgh^{-1}$; QDo, from output, QDt, from straw thrower; QDb, from blower; QDs, over the screen; QDr, scattered grains

QE Immature grains $kgh^{-1}$; - subscripts can be added as shown with QD

QI Input grain, $kgh^{-1}$ - Subscripts see QD

QM Mature grains $kgh^{-1}$ - Subscripts see QD

QU Unthreshed grains $kgh^{-1}$ - subscripts see QD

r Radius mm or m; subscript defining scattered grains QDr, QEr, QMr, etc, $kgh^{-1}$

s Crop mixture bypassing the oscillating screen, $kgh^{-1}$

T Torsion/Torque [Nm]

t Thickness, mm; crop mixture from straw thrower, $kgh^{-1}$

V Volume $m^3$ or $mm^3$

v Velocity, [$ms^{-1}$]; vt, terminal velocity

W Weight [N]

Z Section modulus, $m^3$

$\zeta$ Percentage damaged grains

$\eta$ Efficiency [%]; $\eta m$, of cleaning mature grains; $\eta mE$, of cleaning mature and immature grains; $\eta T$, of threshing

$\kappa$ Percentage grain recovery; $\kappa o$, from output spout; $\kappa os$, from output spout and over the oscillating screen

$\xi$ Percentage immature grains

$\rho$ Density [$kgm^{-3}$]; $\rho f$, of fluid/air; $\rho p$, of particle

$\sigma$ Tensile stress [$Nmm^{-2}$]; $\sigma t$, ultimate; $\sigma y$, yield

$\tau$ Shear stress [$Nmm^{-2}$]; $\tau y$, yield in shear/torsion

$\omega$ Angular velocity, [radians per second]

#     Sheet gauge

**CONTENTS**

# CHAPTER ONE

# INTRODUCTION

## 1.1 IRRI-PAK THRESHER, BACKGROUND FOR THE DESIGN

In 1972, the development of IRRI portable axial-flow thresher began (Khan, Nicholas and Duff, 1972). The axial-flow principle was favoured because of its integral arrangement of threshing and separation sections. Manufacturers and inventors have claimed the design to be superior to others because of the elimination of straw walkers. Also it has a compact design envelope with a higher throughput capability contrary to the tangential threshing cylinder with straw walkers design which requires increase in its size for more capacity (Quick, 1977).

In Pakistan the IRRI portable axial-flow thresher was further developed. The development resulted in the IRRI-PAK-30, Multicrop Axial-flow Thresher. The model is powered from a 30 HP to 60 HP 4-wheel tractor PTO shaft. Using the blueprints of the model and including some modifications, a Modified IRRI-PAK Multicrop Thresher has been fabricated in the IRRI Engineering workshop.

The modifications included in the IRRI-PAK Multicrop Thresher are: Eliminations of hinges and locks on the observation windows; adopting a hollow threshing cylinder shaft with solid pieces of shafts welded on its ends; provide brackets to the thresher stands which are bolted on to the main frame; and increase the area of the screen on the output spout. With those modifications, the final cost of the machine has been reduced; maintenance and repair of some parts have been simplified; some stresses have been relieved from the main frame; and both cleaning efficiency and grain recovery of some crops have been improved.

Figures 1.1 and 1.2 show respectively the side view and the front view of the thresher. Its dimensions are 1968 mm height, 3240 mm length, 1930 mm width (with hopper opened), and 1346 mm width (with hopper closed). From the ground level to the feeding hopper it measures 1257 mm, and the total weight of the machine is 1090 kg.

Transmission pulleys are concentrated on the front part (Figure 1.2), and the aspirator assembly is fixed at the rear part (Figure 1.1). The threshing cylinder-concave (Figure 1.3) has round pegs for threshing; flat bars for cutting (preparation of bhoosa[1] when the counter knives are included); and straw thrower attachments. The pegs and bars/knives are spirally arranged on the cylinder and they are aided by helically arranged louvres on the cylinder

[1] Fine chops of plant straw used for livestock feed.

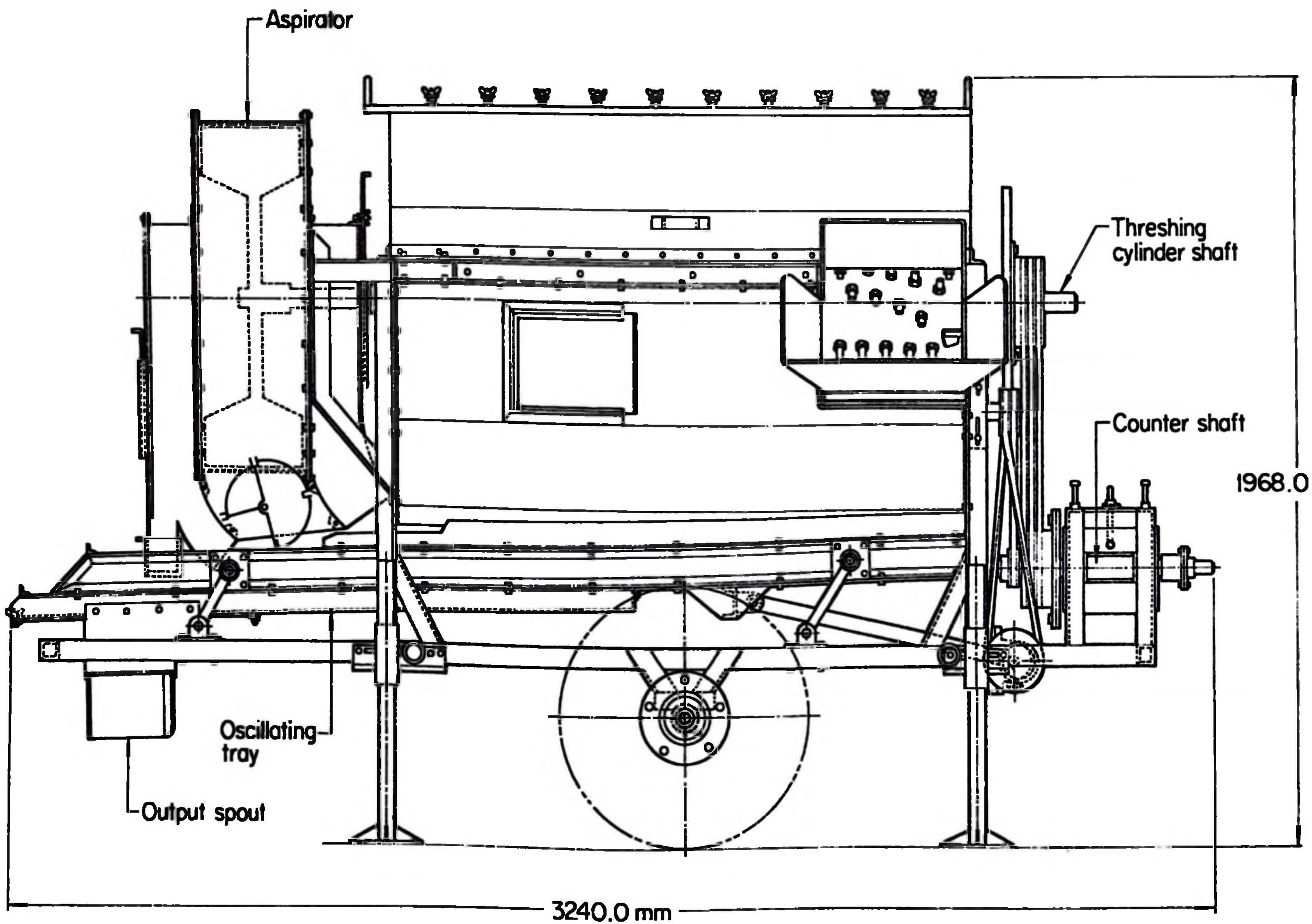



Fig. 1·1. Side view of the modified IRRI-PAK multicrop thresher.

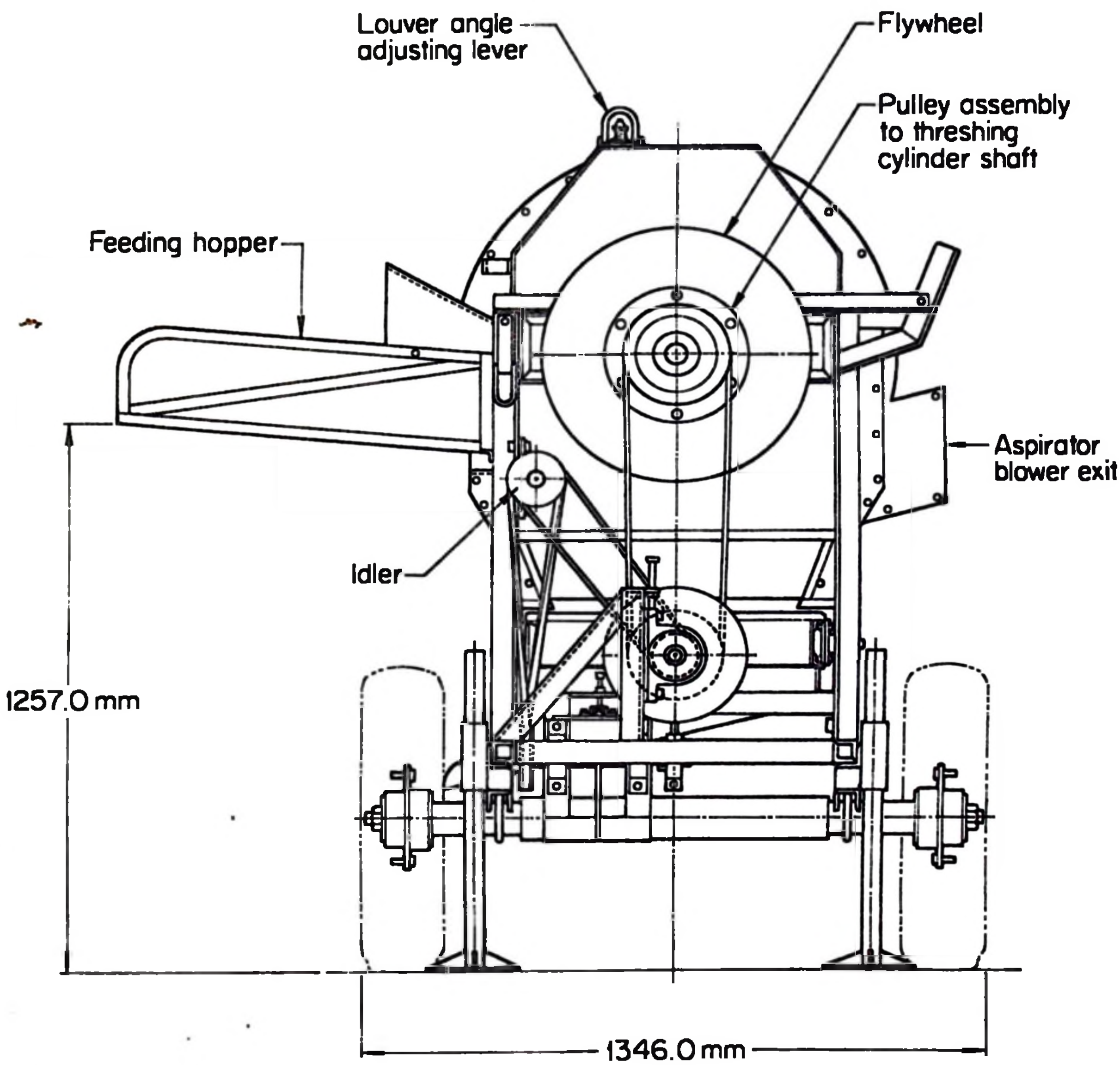



Fig.1·2. Front view of the modified IRRI-PAK multicrop thresher.

RAA 10/29/85

## COMPONENT PARTS LIST

| Ref. | Req'd | Description |
|---|---|---|
| 1 | 1 Assy | [illegible] duct assembly |
| 2 | 1 Assy | Fan blade assembly |
| 3 | 1 Assy | Fan housing assembly |
| 4 | 1 Assy | Front duct assembly |
| 5 | 1 Pc. | Drum shaft |
| 6 | 1 Assy | Threshing drum assy |
| 7 | 1 Assy | Drum cover assembly |
| 8 | 1 pc. | Flywheel, 584.0 mm Ø |
| 9 | 1 pc. | Cylinder drive pulley |
| 10 | 1 Assy | Left side chute assy |
| 11 | 1 pc. | Idler pulley |
| 12 | 1 pc. | Cylinder driven pulley |
| 13 | 1 pc. | Counter shaft |
| 14 | 1 Assy | PTO adaptor |
| 15 | 1 Assy | Throwing concave assy |
| 16 | 1 Assy | Separating concave |
| 17 | 1 Assy | Threshing concave assy |
| 18 | 2 pcs. | Upper front cover |
| 19 | 1 pc. | Front cover |
| 20 | 4 pcs. | Pillow block, 50 mm Ø |
| 21 | 1 Assy | Ghoose heck hitch assy |
| 22 | 1 pc. | Transmission pulley |
| 23 | 1 Assy | Main frame assembly |

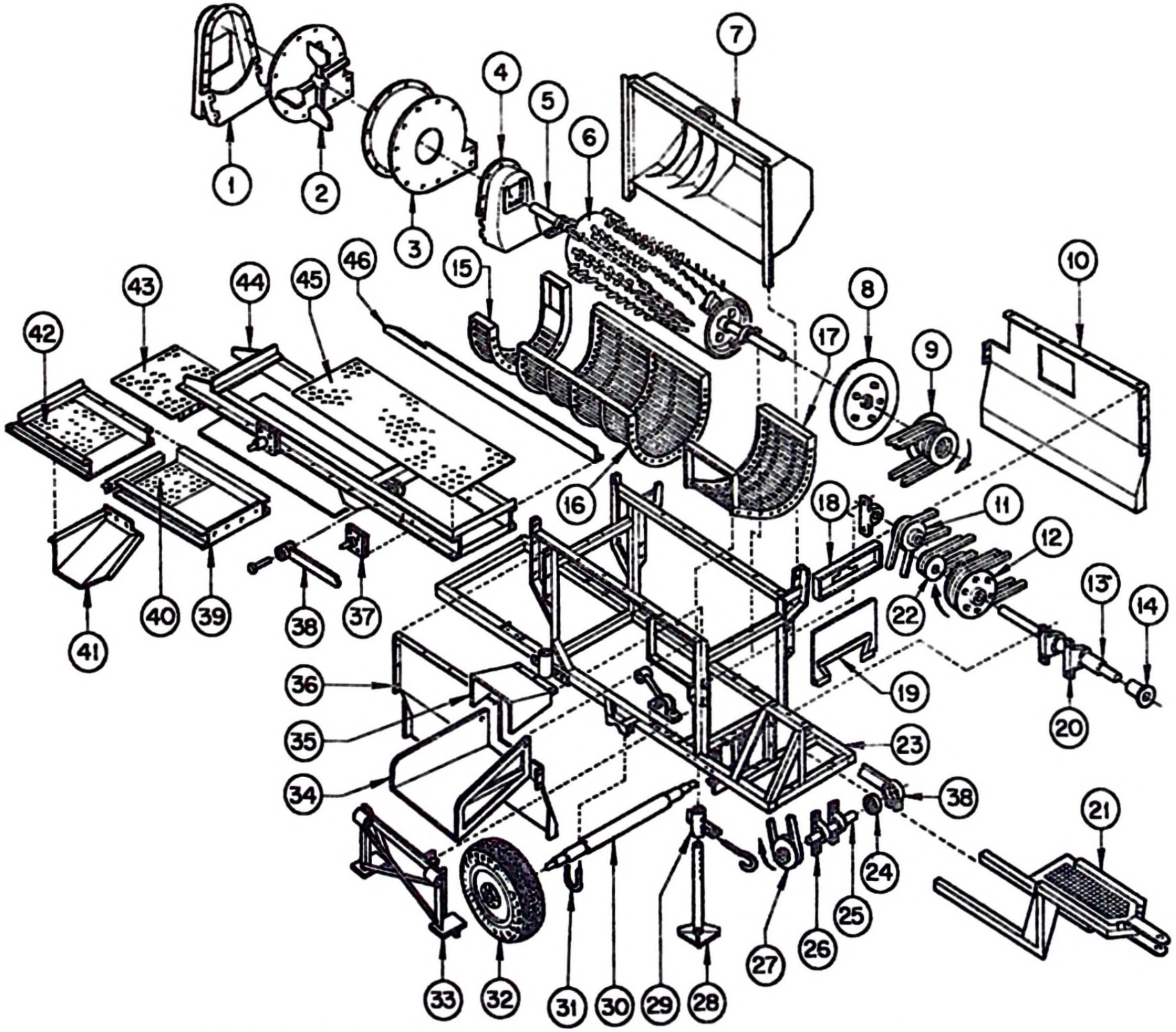


Fig. 1·3. Exploded view of the modified IRRI-PAK multicrop thresher.

| Ref. | Req'd | Description |
|---|---|---|
| 24 | 1 pc. | Cam bearing |
| 25 | 1 pc. | Cam shaft |
| 26 | 2 pcs. | Pillow block, 32 mm Ø |
| 27 | 1 pc. | Cam pulley, 152 Ø B, C.I. |
| 28 | 4 Assy | Stand assembly |
| 29 | 4 Assy | Stand bracket assy |
| 30 | 1 pc. | Wheel axle |
| 31 | 2 pcs. | U-Bolt |
| 32 | 2 pcs. | Tire, size: 5.6x13, 4 ply |
| 33 | 1 Assy | Conveyor attachment |
| 34 | 1 Assy | Feeding tray assembly |
| 35 | 1 pc. | Feeding shield |
| 36 | 1 Assy | Right side chute assy |
| 37 | 4 pcs. | Link mount |
| 38 | 1 pc. | Crank arm assembly |
| 39 | 1 Assy | Seed transfer pan |
| 40 | 1 pc. | Lower screen, 1.5 mm Ø |
| 41 | 1 pc. | Grain spout |
| 42 | 1 pc. | Spout screen 10 mm Ø |
| 43 | 1 pc. | Middle screen 10 mm Ø |
| 44 | 1 Assy | Oscillating tray frame |
| 45 | 1 pc. | Upper screen 16 mm Ø |
| 46 | 2 pcs. | Side panel L and R |

cover to transfer the crop material axially during threshing process.

The aspirator has an enclosed fan which creates air blast for sucking chaff from the oscillating tray.

The oscillating tray assembly has an upper screen with 16 mm diameter holes, a middle screen with 10 mm diameter holes and a lower tray connected to 10 mm and 2 mm diameter holes.

The thresher has been used for threshing[2] paddy, sorghum, wheat and corn. According to tests conducted in Pakistan the machine can also be used for threshing pulses.

## 1.2 AXIAL-FLOW PRINCIPLE

The phenomenon of axial-flow reflects the way the threshed materials are handled/transfered relative to the axis of the threshing cylinder shaft. Basically there are three ways the threshed material can be presented to the threshing cylinder. Figure 1.4 illustrates tangential, radial, and axial-flow of crop material relative to the rotation of the threshing cylinder. Some cylinder designs are conical, which utilizes the advantage of the potential of the progressively increasing centrifugal action as the crop passes over the cylinder.

---

[2] Threshing is used to mean shelling in case of corn.

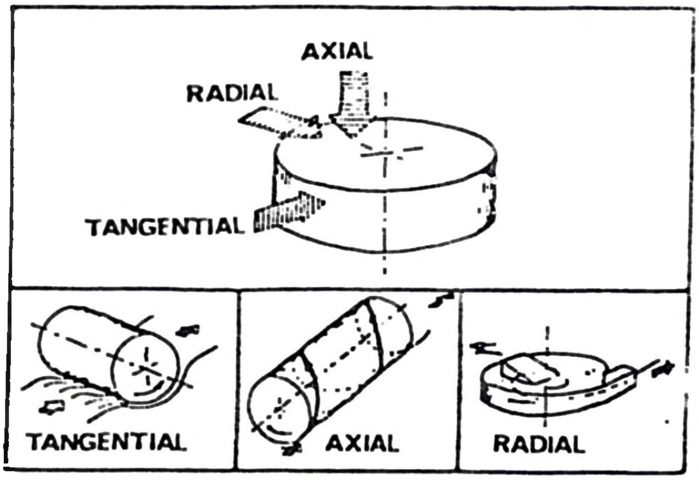



Fig.1.4 (a) Relationship of crop flow along the threshing cylinder.

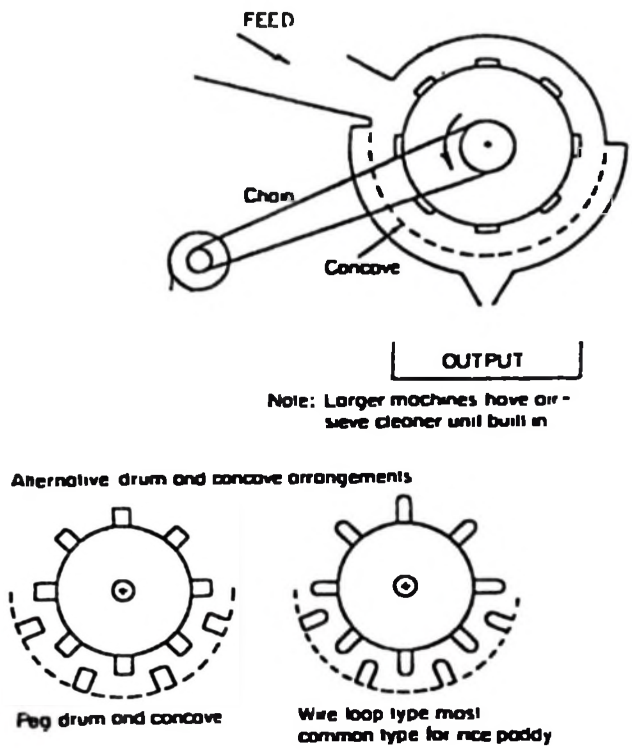



Fig. 1.4 (b) Basic arrangement of the threshing cylinder and concave.

In general the cylinder can be equipped with pegteeth or rasp bars. The axial-flow design favours spike toothed because of the ability of threshing relatively high moisture content crop materials (Buchele, 1964). With axial-flow arrangement, cylinder performs both threshing and separation actions. The pegteeth cylinder threshes and separates the grain from the straw mat by a combination of impact, rubbing and centrifugal actions. The cylinder peripheral velocity, length and diameter, and number of pegteeth affect those actions.

Some versions of axial-flow have cylinders with pegteeth and cutting knives. The knives finalize the threshing, pulverize straw and accelerate the axial movement until expelled by the straw thrower at one end of the cylinder.

On the inside of the cylinder cover louvres are usually fitted spirally. These create a helical path for the crop material which then moves axially with respect to the cylinder axle. The number and the angle of the louvres determines the residence time of the crop in the threshing chamber at a given drum peripheral velocity.

## 1.3 JUSTIFICATION

Threshing is a process of detaching or removing grain from the panicle which can be done either manually or by mechanical means. Separating and cleaning of grain from straw and chaff is also a part of the threshing operation. The operation is among the major post harvest ones. It has also been observed to be among the critical operations in paddy production (Bockhop, 1980). It needs to be performed timely under a given moisture content and and temperature. In paddy production also, the operation together with harvesting are the major labor consuming ones (Ramos, Policarpio and Nicholas, 1973). Also the introduction of double cropping and the increase of the area under crop makes the operation difficult to handle with traditional methods (Khan, 1971). To mechanize the operations of harvesting/threshing is therefore rational for timeliness efficiency and better labor utilization. For the small smale farmers just like large scale farmers threshing is becoming far more important. This is because of the introduction of high - yielding varieties and the increase of irrigated small farms (Zandstra and Carangal, (McMennamy and Policarpio, 1977). Also the introduction of high - yielding varieties and irrigation practice in the tropics will enable some crops to yield more than one crop per year, if all the operations are performed in a timely manner (Bockhop, 1980).

If the crop yield increases, an additional labor and/or machinery also increases which include the threshing machines.

Focusing on the country of Tanzania, there are quite a number of crops cultivated. They range from cash crops to food crops such as corn, wheat, paddy, sorghum, cassava, banana, and millet. Such crops can be found in different categories of farms present in Tanzania. One of the categories (Ministry of Agriculture, 1983) is comprised of Homestead shamba[3], 0.5 ha; Block farms, 100 ha; and communal/village farms, aim is to have these farms with area of more than 100 ha. The decision of undertaking research on the IRRI-PAK Multicrop Thresher considers the need of the farmers in the category mentioned. In general the Ministry of Agriculture (1983), indicated the category to be composed of farmers approaching 90% of the total population. So far there is significant practice of mechanization in this category and some farmers do own tractors. It is also noted country wise, that the population of 4-wheel tractors with power of 44kW and above is increasing at a rate of more than 1500 units per year since 1983. The increase rate started after installation of a Valmet tractor assembly plant which is assembling 1500 tractors per year since 1983 (UNIDO, 1983).

---

[3]Cultivated plot/field.

On the whole the tractors with the small farmers in the developing countries, Tanzania included, are reported to perform the difficult work such as plowing, harrowing, and planting, while the remaining activities are performed manually (UNIDO, 1983). Therefore, it has been suggested that equipment should be introduced to small scale farmers to increase efficiency of some of the manually performed operations. Factors to consider when introducing equipment should include saving crops from climatic threats which require equipments such as threshers, hullers and shellers. Mechanizing of the threshing operation using this particular thresher (IRRI-PAK) has not only been proposed due to the availability of adequate farms but also due to its simplicity and low initial cost of the thresher compared to combine harvesters. Studies have revealed that the combine harvesters are generally costly and call for skilled operators to ensure efficient operation. These factors might not be readily satisfied by small scale farming communities (MacCall, 1925). Finally, the importance of threshing is emphasized because whenever delayed or haphazardly performed, positive loss of yield which has already been recovered by the biological processes of the plant become obvious.

In case the machine is to be fabricated in Tanzania there are many workshops capable of manufacturing it, these include the Mangula workshop the National Engineering Company and the Ubungo Farm Implements. Even the advanced workshops at farm level like the Amboni Group Sisal estates can fabricate the machine. Materials required are similar to the ones supplied by the Steel Rolling Company and the National Steel Corporation.

## 1.4 STUDY OBJECTIVES

1.4.1 To build a Modified PTO (power take off shaft of a tractor) Multicrop thresher for paddy, sorghum, wheat and corn on the basis of the drawings of the IRRI-PAK-30 Multicrop Thresher.

1.4.2 To test the modified sample of the thresher on threshing paddy, sorghum, wheat and on shelling corn.

1.4.3 To evaluate the performance of the modified model compared to the performance of the IRRI-PAK-30 Multicrop thresher on threshing paddy and wheat when tested in Pakistan.

# CHAPTER TWO

# LITERATURE REVIEW

## 2.1 EARLY DESIGNS OF AXIAL-FLOW THRESHER

The axial-flow threshing method is one of the oldest as reported by Ljundgust (Quick, 1977). The same person recalled as far back as 1752 when there was a Swedish grain separator which used centrifugal force to separate whole grain from cracked seed, weed and trash; and also the William Winlow's water powered thresher or rubbing mill of 1785; all were of axial-flow design with axis vertical. The first tangential threshing cylinder was patented by Scotsman, Andrew Meikles in 1788 (Quick, 1977).

## 2.2 IRRI AXIAL-FLOW THRESHERS

Ramos, Policarpio and Nicholas (1983) reported that the original axial-flow thresher consisted of a wire-type wooden threshing drum of 35.56 cm diameter and 126 cm length. It included an upper perforated sheet metal concave and a round bar grill type lower concave with an area of 930 $cm^2$. On the upper concave louvres were fitted positioned spirally to move the material axially to the discharge end.

A blower and a 7.62 cm diameter auger were located under the concave. The auger conveyed the winnowed grain to a rotary screen sieve (Figure 2.1). The grain from the screen sieve dropped to a trough and was then conveyed to a

(a)

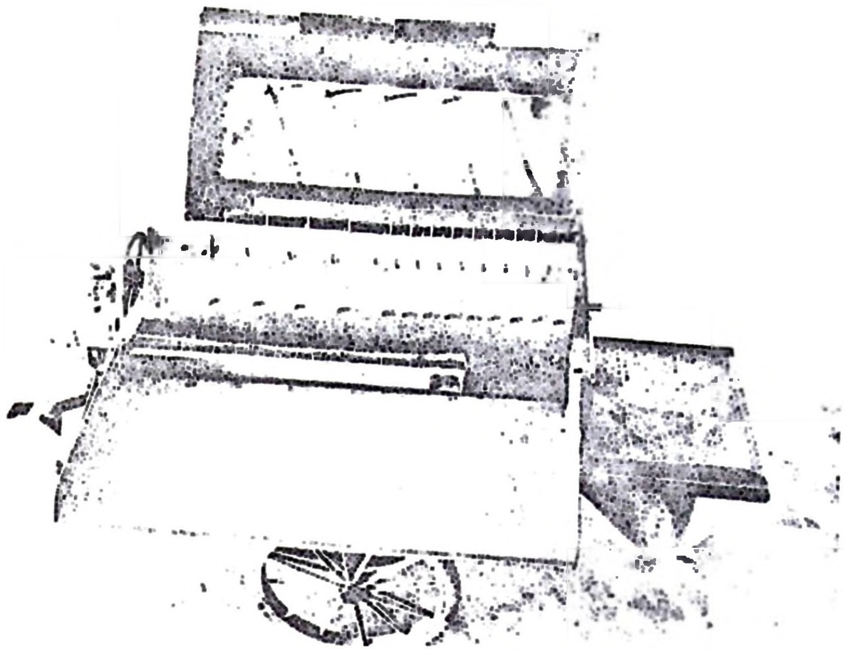


Fig. 2.1. Two of the original designs of the IRRI-PAK axial-flow threshers.

(b)

bag. The machine had a hitch bar which could be hitched to a hand tractor or towed by an animal.

The machine was later amended as follows:

i) Two sets of peg teeth with 51 mm length were installed in the lower concave.

ii) Louvre angle was decreased (to allow the paddy to stay longer in the threshing chamber).

iii) Location of straw ejection was opposite to the feeding hopper.

iv) Provision of platform (to facilitate easy feeding).

Those amendments included, the development of IRRI portable axial - flow threshwer was began (Khan, Nicholas and Duff, 1972). The axial-flow principle received much consideration because of its simplicity and the integral arrangement of threshing and separation sections (Khan, 1971).

A selection of some of more interesting axial and cylindrical rotor devices patented or produced will show that the field of helical flow thresher/separators has well been picked over during the past century (Nicholas, 1974). The main advantages that the inventors and manufacturers have sought and claimed for their designs include:

a) The elimination of the reciprocating straw walkers.

b) More compact design envelope with higher throughput capability contrary to the tangential threshing cylinder and straw walkers design which require increase in its size for more capacity (Quick, 1977).

During the development of the IRRI axial - flow portable threshers different threshing cylinders were developed and tested using combinations of long, short, wet and dry batches of IR36. The open cylinder, had a reduced blow back of material and dust out of the feeding entrance (Progress report, 1978).

## 2.3 IRRI PAK AXIAL-FLOW THRESHER

The Pakistan Agricultural Machinery Division of Pakistan Agricultural Research (PARC) assisted by IRRI personnel succeeded in the developmont of threshers. The IRRI-PAK-30 is one of them. Compared to the traditional ways of threshing with losses ranging from 1% to 2%, the IRRI-PAK threshers on wheat and paddy have losses ranging from 0.5% to 1.0% (Khan, 1981). The IRRI-PAK PTO driven thresher was developed in favor of having a suitable machine of low cost that could be towed and powered by the same tractor (Ceam and Khan, 1967). Also the chances of obtaining an economically priced high speed diesel engine to power threshers in Pakistan were remote (Khan, 1981). Reference to tractor availability, during 1964 to 1978 there were a total of 92,500 units with 19 kw to 52 kw, the importation rate was 1,500 units per year (Khan, Khan and Ahtar, 1979). This implied that the source of power to the threshers was adequate.

In general, wheat threshing in Pakistan requires the straw to be chopped and bruised into fine pieces (bhoosa) used as animal feed (Khan, 1981). For that reason the mini IRRI axial-flow thresher powered from 4.5 HP to 6 HP engine was disliked by farmers because the engine proved to be too small and too costly.

Some of the outstanding features of the IRRI-PAK-30 noted in the instruction manual (IRRI-PAK Agric. Mach. Program, 1980) are length - 4000 mm, height - 1750 mm, weight - 1445 kg, and requires power source from 4-wheel tractor of range of power from 35 HP to 60 HP. Both the threshing pegs and cutting knives are helically arranged on the 5 ft long threshing cylinder. A semi-circular concave made from steel bars is fitted below the threshing drum. The concave has knives folded in for bhoosa making. The concave separates grains from straw where the latter is ejected by straw thrower and the former drops on a screen assembly below the concave. The screened out straw is sucked by an aspirator at the end of the screen.

An output of 550 $kgh^{-1}$ to 750 $kgh^{-1}$ is possible with the machine while making bhoosa. Cleanliness reaches 99% with losses of up to 2%.

On the whole the original prototype of IRRI-PAK thresher had a four feet threshing cylinder. It also used a PTO shaft. use of a PTO shaft eliminates the need of special pulley attachment and long flat belts that are required for powering the conventional wheat threshers (Khan, Akhtar and Ahamad, 1978). After testing the machne on paddy in different districts (Gujranwala and Silkot) in Pakistan the losses were recorded to be 3% to 5%. Further improvement was imposed leading to an increase of the threshing cylinder length to 1524 mm [5 ft.]. With this modification, tests on paddy IR6 recorded output of 900 $kgh^{-1}$ to 1380 $kgh^{-1}$ with mean grain loss of 0.9% (Progressive Report 1976-1981).

The new prototype was also studied by Hundal, Sharma, and Singh, (1981) covering various design parameters on grain chaff separation over the concave, and straw bruising effectiveness for the wheat crop.

Dimensional analysis design was used to develop prediction equations for the above mentioned parameters. Pi-groups containing feed rate, peripheral velocity of threshing cylinder, cylinder concave clearance, concave bar clearance, louvre angle, and axial displacement of grain were used as independent variables. The prediction equations developed can be used to determine the grain chaff separation.

Other tests using the same prototype were reported by Khan, Akhtar, and Ahamad (1978), who showed that an intensive usage of the machine renders the threshing cylinder cover to excessive wear at the corner points due to highly abbrasive action of the paddy.

Manufacturing of IRRI-PAK threshers in Pakistan has been feasible especially with industries located at Faislabad (Lyllapur), for one thing they had been manufacturing textile equipment in early 1970s (Asian Productivity Consultants, 1977) and so they have enough workshop equipment. It was noted that many manufacturers use one oscillating screen (Progressive report, 1978). While other versions for threshing wheat have two screens which run at the same speed and in the same direction. A problem of clogging of the screen holes especially when threshing high moisture material was noted (Progressive report, 1979). The problem could be reduced by using larger diameter holes but this approach decreases grain purity.

Other threshers with two cleaning screens have been reported. The screens extend under the full length of the concave and run at the same speed (320 cycles) with 25 mm stroke but opposite to each other.

## 2.4 AXIAL-FLOW THRESHERS - GENERAL

Pathak and Sharma (Hundal et al, 1981) developed an axial-flow thresher with separating and threshing sections. The threshing cylinder had an overall length of 1530 mm a thre··hing section of 895 mm, and a bruising section of 635 mm. Tests on wheat showed that an appreciable amount of grain was passed on to the bruising section. Therefore, mixing of the grains with the chopped straw could not altogether be avoided. It was also learned that the threshing drum length could not be reduced from 2022 mm without increasing grain separation losses.

Chhabra and Singh (Hundal et al, 1981) observed the optimum results of threshing efficiency, grain damage, feed rate and quality of wheat straw to occur at 700 rpm to 1110 rpm drum speed with peg teeth spacing of 63.5 mm. The observation of Sharma et al (1974) indicated that cylinder speed of 700 rpm [18.5 $ms^{-1}$] and peg spacing of 63.5 mm gave optimum threshing results.

Ahuja, Sharma and Dalwal (1981) suggested the advantages of the axial-flow threshers as being; the integration of threshing and separating system; chances of lesser grain damage, because of much cylinder-concave clearance; capability of threshing high moisture content crop; good threshing efficiency because of large impact area available between the threshing cylinder and concave; and lower power requirement due to lower peripheral speeds.

## 2.5 MULTICROP THRESHER

The design and development of a multicrop thresher was initiated in 1975-76 in Pakistan. For the prototype of the multicrop threshers, separate wheat straw bruising attachment was designed and developed. This could be fixed to the thresher by bolts. The attachment was not used when threshing paddy. The machine consumed power in the range of 35 HP (Sharma, Pathak and Ahiya, 1974).

## 2.6 MACHINE TESTS

Andrew Meikle, a Scotchman, was the first to replace the heavy and laborious threshing work using hand rasp bars by mechanical work with the use of four revolving bars (rasp bars attached to a circumference of drum 250 mm in diameter) driven at 4 $ms^{-1}$ to 6 $ms^{-1}$ peripheral velocity. An American named Tunner in 1835 employed peg teeth on the threshing cylinder and also attached pegs on the concave. With the passage of time these units become the subject of modifications (Kanafojski and Karwowski, 1976). Testing and modifying has resulted in the current threshing machines (Nicholas, 1984). The same person noted that the procedure of designing and testing become more useful when performed in the locality where a machine is expected to be used. MacGregor (1924) also noted that testing and evaluating of machines enables redesigning of the machine for better performance.

However, manufacturers do test and evaluate their machines, and outline their performance before merchandising. Even though Arboleda and Kuether, (1977) pointed out that before a farm machinery is accepted by a farmer its performance has to be counterchecked; i.e., critical examination of the machine under a given set of operating conditions. The advantages of such examination have been referred to by many designers and test engineers.

For example, MacGregor (1924) recalled a combine harvester invented by Ridley in Australia and appeared similar to the ones found in America. Unlike the ones found in America, it had instead of cutting sickle a comb which upon coming into contact with the standing grain allowed the straw to slip through until head was caught and stripped off. The machine performed well in Australia. When exported to America, during the harvesting of wheat in California, the combine was pulling up the plants by the roots or too much grain was left in the heads. This necessitated some design changes.

Another example validating machine examination could be the study by Arboleda and Kuether (1977). They noted that the Japanese grain thresher performing well in Japan has not been well accepted in the tropical countries -- Philippines, because of their poor performance with wet crops and their relatively complicated mechanisms.

It follows, therefore, that evaluating a machine within the zone to be applied is as important as the evaluation done by the manufacturer. For example, the equipment designed by engineers for the developed countries is often made for farmers with large acreages, hence for the small scale farmers such machines may not be effectively utilized (Bockhop, 1980). For the small scale farmers some machines' initial cost could be too high. MacCall (1925) for example, noted the combine harvester thresher to be uneconomical for the small rice farms.

From that, UNIDO (1983) generalized the qualities of equipment that recommended for the small scale farmers as follows:

( i) Should be able to act as a complement to human labor (i.e., as far as possible not substituting it).

( ii) Should correspond to the financial and technical capability of the users.

(iii) Should be able to be maintained and repaired locally so that users benefit from them full time without having to depend on the external suppliers or maintenance services.

## 2.7 CROP THRESHING - GENERAL

Crop mechanization simplifies some of the farm operations and promotes production. Stout (1966) referring to harvest/threshing operations, learned that in rice growing such as in Italy and the United States of America, paddy is harvested entirely with combines. It was estimated that with such machines and others for other operations in the United States of America a man is able to produce 20.4 kg of rice per (5 to 7) minutes compared to (5 to 7) hours expended in S. E. Asia and Far East for the same amount.

Mechanization is therefore essential for most farm operations (Gregg, Law, Virdi and Basis, 1970). With regard to grain threshing and maize shelling, there are machines ranging from the ones operated manually to the self propelled combine harvesters.

For the relatively small machines examples of maize shellers adopted by small scale Indian farmers have been described (Gregg et al, 1970). One of the hand powered maize shellers described has bars that remove seed from the ear and let them drop at the bottom of the machine while the cobs are discharged out from the rear of the sheller. Another maize sheller has a similar configuration except the threshing cylinder has spirally arranged lugs which remove the seed from the cob.

In general the performance of both threshers and shellers is influenced by several factors, e.g., moisture content, crop variety, rate of feeding , threshing device (pegteeth or rasp bars), and the peripheral velocity of the threshing cylinder (McMennamy, 1977, Buchele, 1964, Gregg et al, 1970 and Vas Harrison, 1969).

For example, Gregg et al (1970) found an optimum moisture content for maize shelling as 14% to 16%. He noted the range to be the best for the automatic corn husking equipment attached to the corn combines.

In the case of the moisture content of the wheat crop, Vas and Harrison (1969) related wheat crop behavior to the failure mechanism of soil. They recalled the soil failure which occurs when the soil changes from a plastic to a brittle state They visualized the same behaviour with wheat at 18% moisture content where kernels are quite soft and can deform without exhibiting any visible fracture. As a conclusion, grain damage due to moisture content can go up to 20%. The value is a result of several experiments on different grains with moisture content of up to 38%.

In general, moisture content influences both capacity and power requirement of the threshing machine. In case of a machine capacity, RNAM (1983) have suggested a relationship which utilizes moisture content and grain ratio to obtain corrected capacity. The relationship utilizes standard values of moisture content and grain ratio of a particular crop. The standard values differ from region to region. The relationship for the corrected capacity QC is as follows:

$$QC = \left(\frac{100 - MCm}{100 - MCs}\right)\left(\frac{RsQ}{Rm}\right)$$

where: MCm, MCS - Measured and standard moisture content [%] Wb.

Rm, Rs - measured and standard grain ratio.

Q - quantity of grain [$kgh^{-1}$]

Reference to crop variety the threshing performance is influenced due to the easiness of kernel separation from the kernel pods, tearing and crushing strength of stalks or blades. And in case of rate of feeding when threshing wheat, if the threshing cylinder is consuming 50% of the power input, the amount of power requirement will be four times if rate of feeding is doubled (Buchele, 1964).

When considering threshing cylinders of rasp bars and peg teeth on wheat threshing, assuming the size of working slit and feed rate is same, the pegteeth drum requires less peripheral velocities than rasp bar cylinder but the former exhibit appreciable damaged grains (Buchele, 1964).

## 2.8 THRESHING CYLINDER, CYLINDER COVER, AND CONCAVE

Threshing cylinders can either be conical or circular. The conical threshing cylinders are designed such that the crop material enter the cone at the small end. They travel to the base because of the centrifugal force created by the cylinder. The component of the force parallel to the cone cause the material to undergo a spiral action and move to the base of the cone (Buchele, 1964).

Analysis has been undertaken to outline the behavior of the IRRI axial-flow threshers which possess the design of circular cylinders. From the analysis by Ilyas (1980) he arrived at several conclusions. He noted that, when the louvre angle on the cylinder cover was increased there was an increase in response in unthreshed grain, and grain loss; and a decrease in damaged grain is experienced. An increase in louvre angle produced a rapid decline in the crop retention or dwell time in the thresher which resulted in high threshing and separation losses. Increase in crop feed rate resulted in increase in unthreshed, damaged and high grain losses. An increase in peripheral cylinder velocity resulted in a decrease in unthreshed grain but response in grain loss and grain damage increased.

Bunelle (Buchele, 1964) studied the effect of the peripheral velocity of the cylinder on germination of Alfalfa. A decline from 95% at 25.4 $ms^{-1}$ to 80% at 30-48 $ms^{-1}$ was noted.

Threshability with respect to seed quality shows that with multistage cylindrical threshing mechanism, the highest quality seed gets threshed in the first stage at low cylinder speeds. Usually the grain does not mature evenly in the head and some seeds are more readily threshed than others and the highest quality grain will be threshed first.

The cylinder speed does not only affect grain germination and threshability but also grain separation and grain damage. Buchele (1964), researching on wheat, showed that the threshing efficiency varies from 99.3% to 99.7% as the cylinder rpm was increased from 300 rpm to 600 rpm. And the separation efficiency decreased from 77% to 67% as the speed was increased.

Vas and Harrison (Harrison, 1975) conducted research to determine grain loss from damaged and unthreshed grain. He first defined the loss of grain associated with the threshing cylinder of a combine as the sum of the damaged and unthreshed grain. He pointed out that there is a maximum cylinder speed for every crop variety. A speed less than 800 rpm for the cultivar[4] park with moisture content of 10% wet basis is optimum. But the 800 rpm is less than the recommended by most combine harvester manufacturers. In other experiments conducted on wheat the damage response was similar to all cylinder speeds (Harrison, 1975). In the experiments, by utilizing speeds of (700, 900, and 1100) rpm or (20, 25 and 30) $ms^{-1}$ the maximum grain damage occured at 14% MC for 700 rpm and 900 rpm; and at 16% MC for 1100 rpm level. The minimum unthreshed grain occured with the lowest moisture content 12% whereas the maximum occured at 20% MC. Except for the 18% MC the unthreshed grain

---

[4]The cultivar park is <u>Triticum aestivum</u> L., C. V. Park, an early maturing hard red spring wheat resistant to logging with a mid long straw, developed in 1963 at the Research Station Agriculture, Canada Locombe Alta.

increased with an increase in moisture content. The trend is opposite to that of grain damaged. From this analysis the optimum cylinder speed has been suggested to exceed 800 rpm, may be 1100 rpm at 10% MC for the same wheat crop, cultivar park. Arnold (Kanafojski and Karwowski, 1976) presented different findings that, grain losses can be reduced by an appropriate increase in the number of drum revolutions with a simultaneously elongation of the concave

surface. An approach of computing grain damage when the cylinder speed is increased has been suggested by Vas and harrison (1969). They pointed out that, if the cylinder speed is doubled, the impact time is reduced by half, thus considering the impulse:

$$Ft/2 = 2vm$$

where: v = peripheral velocity [$ms^{-1}$]

m = mass [kg]

F = force [N]

t = time [S]

then: $F = 4\ mv/t$ - - - - - - - - - - - - - - - -2.1

Then they found that, the impact is the square of the change in the cylinder speed. This was verified by quoting values of damaged grains from 700 rpm and 1100 rpm cylinder speed. The values quoted are 0.79% for 700 rpm and 1.82% for 1100 rpm. Then the increase of damage is in the ratio of 1.82/.79 = 2.30 which is equivalent to the square of

$(1100/700)^2 = 2.47$.

The threshing cylinders are usually mounted on circular shafts. The design of (threshing cylinder) shaft diameter has resulted from several theories. The ASME Code for transmission have approaches which have persisted for years (Shigley, 1972). They consider allowable working stress $\tau d = 0.30\sigma y = 0.18\sigma u$. And the maximum shear stress in a shaft subjected to both bending and torsion is found from Mohrs Circle as $\tau max = \{(\frac{\sigma x}{2})^2 + \tau^2_{xy}\}^{0.5}$ - - - - - - - (a)

where: $\sigma_x$ = bending stress = $\frac{Mc}{I}$ - - - (b)

$\tau_{xy}$ = torsional stress = $\frac{T\,c}{J}$ - - (c)

substituting (b) and (c) in (a) we get

$$\tau d = \frac{16}{\Pi D^3} (M^2+T^2)^{0.5}$$

Depending on particular application, shock and fatigue factors Cm and Ct respectively are applied, and the diameter is computed from:

$$D = \left[\frac{16\{(CmM)^2 \quad (CtT)^2\}^{0.5}}{\Pi \tau_d}\right]^{1/3} \quad - - - - 2.2$$

This formula is worth recalling for approximation purposes (Shigley, 1972).

## 2.9 OSCILLATING SCREEN PRINCIPLE

An oscillating conveyor can be defined as a trough or a platform which oscillates sinusoidally in a direction lying in the vertical plane containing the longitudinal axis of the trough and at some mean angle $\theta$ to the vertical (Berry, 1958).

Berry (1958) had several equations, Regimes, and plots which led him to draw some conclusions. Two of the Regimes are:

( i) The particle on the trough will continue with purely slipping motion until a frequency is reached at which the downward vertical acceleration of the trough just equals that due to gravity. At this frequency the particle will begin to lose contact with the surface of the trough. The frequency range, over which pure slip motion without loss of contact can exist is given by:

$$\frac{f_s g}{Xo - f_s Yo} < \omega^2 < \frac{g}{Yo} \qquad \text{------ 2.3}$$

where: $f_s$ = Static coefficient of friction

$Xo$, $Yo$ = horizontal and vertical conveyor amplitude [mm]

$\omega$ = radial frequency [rad $s^{-1}$]

(ii) At greater frequencies the particle will be partly in contact with the trough surface, and slipping; and partly off the trough surface and falling under the influence of gravity. Using non-dimensionless quantities he had.

$$\beta' = \frac{f_s Yo}{Xo} \quad \text{and} \quad \alpha' = \frac{Xo\,\omega^2}{f_s g} \qquad -- 2.4$$

Under normal condition most oscillating conveyors used in agriculture operate on the region of pure slip; hence little has been done on Regime (ii). However, the equation 2.4 does not put limitation on frequency provided that the vertical amplitude - Yo of the trough is correspondingly reduced. After considering the horizontal acceleration of the particles the dimensionless quantities changed to

$$\beta = \frac{fkYo}{Xo} = fk\tan\theta \quad \text{and} \quad \alpha = \frac{Xo\,\omega^2}{fkg}$$

where: $f_k$ - kinematic coefficient of friction

$\theta$ - link angle [radians]

By plotting $\alpha'$ against $\beta'$ , and $\alpha$ against $\Delta X/Xo$ ($\Delta X$= absolute horizontal movement of the particle), and considering the vertical, horizontal, and side forces on the tray for wheat crop, it was concluded that: The conveyance of grain at appreciable depths cannot be expected to conform to same performance curves as that for single grain layers. The grain is being accelerated vertically and horizontally and oscillating forces can be expected to occur at right angles to the motion of the trough. The driving (drag) forces acting on the column of grain being conveyed only exist at the outer surfaces and must be transmitted through the body of the grain by inter granular friction.

The basic advantage of a horizontal oscillating screen for grain cleaning in the IRRI axial-flow threshers is the resulting machine compactness and low position of the output spout for easy operation. Latest models of IRRI axial-flow threshers use a horizontal screen (Diestro, Cabales and Nafziger, 1971).

With regard to oscillating conveyors/screens which integrate stream of cleaning air, their efficiency is influenced by the pitch of the screen, the rate of vibration of the screens, volume of the air blast, and choice of the screens (Gregg et al, 1970). The same people emphasized that wire mesh screens should always be steep since their rough surface retards seed movement enough to give thorough sifting.

## 2.10 ASPIRATION PRINCIPLE

An aspirator has a fan at the air discharge/final point, which creates vacuum or negative pressure within the machine. The air rushing in to fill the vacuum creates a stream of air which is used for grain/straw separation (Gregg et al, 1970).

Bilanski and Lal (1962) conducted experiments determining grain/straw separation. They used a wheat crop of the varieties; Cornell, Genesee, and Ross. They had samples of straw ranging from 25 mm to 250 mm long for which they determined the coefficient of drag, C, and resistance K as:

$$C = 2F_r/A\rho v^2 \quad \text{------------------} \quad 2.5$$

$$K = \rho g/v_t^2 \quad \text{------------------} \quad 2.6$$

where: Fr = Drag force [N]

A = frontal area relative to the motion [$m^2$]

Vt = terminal velocity [$ms^{-1}$]

When the resistance coefficient is plotted against sample length a linear relationship results. Also it was learned that there is no significant difference in the resistance coefficient of the straw having no node and those having the node in the middle. But the resistance with straw with a node at one end was lower than that of the other straw. This is due to the behavior of this straw in the air stream which resulted in higher terminal velocities.

The straw samples about 130 mm long had the highest terminal velocity. All of the samples had velocities ranging from 2.44 $ms^{-1}$ to 30.48 $ms^{-1}$. The range of velocity of straw washigher than that of wheat chaff and heads which were respectively 1.22 $ms^{-1}$ and 2.13 $ms^{-1}$.

Mohsenin (1970) noted that when on air stream is used for separation,knowledge of terminal velocity of all the particles involved would define the range of air velocities affecting separation. Thus, the terminal velocity is used as an important aero - dynamic characteristic of materials in such applications as pneumatic conveying and separation of foreign materials from grains. The terminal velocity derived from the drag force equation gives the following :

$$Fr = m_p g = A_p \rho_p v_t^2/2$$

$$= m_p g \ ( \rho_p - \rho_f)/( \rho_p \rho_f) = (A_p \ \ _p v_t^2/2 \quad - - - - - \quad 2.7$$

$$v_t^2 = 2WC(\rho_p - \rho_f)/ ( \rho_p \ \rho_f)$$

where ( not defined above )

$\rho_f$, $\rho_p$ = density of air and particle (grain) ( $kgm^{-3}$)

C = Coefficient of drag force

W = weight of the grain (N)

This velocity $v_t$ enables one to determine adequate air speed for cleaning/separation of foreign materials from the good/mature grains

# CHAPTER THREE

# METHODOLOGY

## 3.1 CONSTRUCTION OF THE IRRI-PAK THRESHER

Reference to the blueprints for the IRRI-PAK-30 Multicrop thresher from Pakistan, a thresher of similar nature was constructed in the IRRI-Engineering Department Workshop. The fabrication activity took 75 days.

The original drawings which required corrections and/or modification were redrafted. From the draft a final drawing was produced by the drafting section for workshop fabrication.

The quantity and specification of material used is found on the blueprints - not attached. In general, sections used include, angle bars (19.1 x 19.1 x 3.2)*mm to (50.8 x 50.8 x 6.4) mm; flat bars (25.4 x 3.2) mm to (50.8 x 7.9) mm; plates/sheets 16 gage to 19.1 mm thick; shafts/rods (9.5 to 76.2) mm diameter; ball bearings; pillow blocks; screen (1.6, 9.5 and 15.9) mm diameter of holes; pulley (101.6, 127, 152.4, 203.2 and 228.6) mm diameter; and copper bushings.

The procedure of manufacturing the machine was determined by the kind of metal section required for a particular subassembly or part. For example, the assemblies which did not require machined part, like the main frame,

---

*The numbers are converted from inches and approximated to nearest one decimal point.

the pieces of angle bars required were fabricated and assembled by the same person.

The workshop consists of technicians who can independently handle jobs involving metal sheet, fitting and turning, and welding. However, specialization or specific assignments exist whereby machinist, welders and others are distinguished.

All the staff of fourteen members participated in fabricating the IRRI-PAK thresher. The participation ranged from those who made complete or part of the assemblies to those who did precise welding required on some assemblies e.g., the threshing cylinder plates/sheets, cylinder shaft, flanges, etc. and those who participated in the machine assembly and painting.

The standard parts were ordered through the personnel of the engineering part store. And the parts which were fabricated, in general, involved almost all the machines present in the workshop.

The workshop is equipped with almost all the basic handtools which include hacksaw, wrenches, grips, pliers, files, chisels, punches, metal cutting snips, clamps, bench vises and squares.

There are several portable machines which include portable electric drills, jigsaw, hand grinder, sand polisher, and pop riverter.

Of the stationary machines the following were utilized.

( i) Roll type bender. It has three rolls set in a pyramid arrangement in vertical plane. The smooth portion of the rollers measures 1346 mm, while one of the extreme end has groves for rolling circular rods of up to 10 mm.

This machine was used for rolling the threshing cylinder plate, flat bars on the threshing cylinder flanges, and the rods supporting both the threshing and separating concaves.

( ii) Metal sheet benders. They are of various sizes and all are manually operated and can handle sheets of up to 3 mm thick and 1829 mm long.

The semi hexagonal shape of the cylinder cover was made using this machine. Also, the feeding hopper, output spout, side chutes,and covers of the observation windows and air vents had their bendings through these machines.

(iii) Drilling machines. There is a bench mounted sensitive drill and a radial drilling machine. The former has been used to bore holes for pins in the small shafts and spindles viz: camshaft for the oscillating tray, crank pin and the spindle for the oscillating tray idler. Drill bits of up to 14 mm diameter are accomodated by this drill. While drilling holes on the threshing cylinder and the thresher stands for example, the radial drill was used. The machine incorporates a radial arm which swing about the vertical column. The sliding drill is mounted on the arm. The working table can be swinged vertically or horizontally. These features enabled to work on one row of holes on the threshing cylinder before resetting.

( iv) Power hacksaw and Contour band saw. The former has hydraulic mechanism to lower the blade, to lift it on the non-cutting stroke, and rise it after cutting. All pieces of solid and hollow shafts ranging from 25 mm used for oscillating links to 102 mm used for the driving pulley of the oscillating tray assembly, were cut from their blank size shaft by this machine. While the band saw was utilized for many sections. For example, cutting the flat bars used on the cylinder flanges, reinforcement on the oscillating tray and the feeding hopper. Also, the cutting of the circular sections like the plates used for the cylinder flanges/support and the fly wheel utilized the same saw.

( v) Shearing machine. The machine available can cut flat and angle bars of up to 7 mm thick and also rods of up to 10 mm diameter. This machine was extensively used to cut the blank size of all the sections required for the main frame. Also the rods used for the concave and the reinforcement bars used for various subassemblies, e.g., aspirator, oscillating tray, feeding hopper, were primarily cut by this machine.

( vi) Welding equipment. Gas welding has been used to join almost all assemblies which involved pieces of flat/angle bar and a metal sheet of 16 gage. Such assemblies include the reinforcement bars on the feeding hopper and the aspirator. Arc welding has been used extensively to join parts with thickness of more than 3 mm. It follows therefore that all the frame assembly is arc welded. Other welded assemblies include, threshing drum/cylinder sheet/plate; straw thrower; hubs to the flywheel, cylinder flanges/support and pulley flanges.

Rocker arm spot welder was used mostly to join part mates with thickness les than 1.6 mm. Such sections are found on the aspirator;

oscillating tray pan/screen and the output spout.

(vii) Grinding machine. Using a cylindrical grinding wheel, most parts which eventually were not machined or turned were ground to trim off sharp corners for convenient handling. This has been applied to, for example, the flat bars supporting the concave rods; concave rods; reinforcement bars to the feeding hopper, oscillating tray and the brackets to the stands. Also grinding has been applied to the welded joints for smooth finishing. Hand grinders and sand papers were available performing as described above to sections and assemblies which could not be handled by stationary grinder.

(viii) Lathe machine. There are several parts on the thresher which required either solid or hollow circular section. And some of those sections required the outer diameter to be reduced and or the inner diameter to be increased. Some examples include - for diameter reduction; threshing cylinder shaft, counter shaft for PTO, cam shaft for oscillating tray and the flanges/supports to the threshing cylinder - for diameter increment; driving pulley for oscillating tray, hubs to the aspirator fan, flanges/support for cylinder and flywheel, and copper bushes to the oscillating links.

Threads on the threshing cylinder pegs and to the hooks and bolts for pillow block (on the counter shaft and cam shaft) adjustment were achieved by a lathe machine.

( ix) Milling machine. The vertical knee type milling machine with a 900 mm long table has been used for the different sizes of key ways found on the different shafts mentioned above.

( x) Press machine. All key ways of inner diameter, viz: hubs and cam were prepared by either of the press machines by employing a specific key tool. Also one was used for pressing/assembling the universal joints of the PTO shaft.

## 3.2 CORRECTIONS

Corrections on the original IRRI-PAK-30 blueprints were made. Many consisted of parts and subassemblies which were under and over dimensioned. Some of those which were over-dimensioned included; the assemblies of the feeding hopper, cylinder cover, oscillating tray lower screen, rear sucking duct, and the cranking arm. Those under-dimensioned included; ..ft side chute, separating concave, oscillating ray upper screen, flingers and the PTO shaft.

Some of the missing parts were: the observation window on the aspirator; ball bearing on the oscillating tray cam shaft; PTO adopter; brackekt to hold the idler pulley shaft for the oscillating tray; and the bolts for sliding the pillow blocks (on the counter shaft and on the oscillating tray camshaft) for proper belt tension.

Sub-assembly and partmates which required elaboration included cross-section of the oscillating tray (to show the actual relationship of the screens and the output spout); and threshing cylinder and concave (to show the clearances of the pegtooth, cutting knives and straw thrower from the concave).

### 3.3 MODIFICATIONS

3.3.1 Elimination of hinges and locks on the observation windows. Figures 3.1 and 3.2 show respectively observation windows on the side chute and the side of the aspirator. From Figure 3.1 the window opens and closes by sliding now fully closed. Previously two hinges and a lock were used. Currently the price of a hinge (25 mm wide and 50 mm long) is US$0.22, and an assembly of a small lock costs US$0.41. While the extra sheet metal used for the sliding slots of the modified window costs US$0.34 (based on US$33.11 per 2.973 $m^2$ sheet). By comparison there is a net saving of US$0.29 per window or US$1.16 for all the four windows

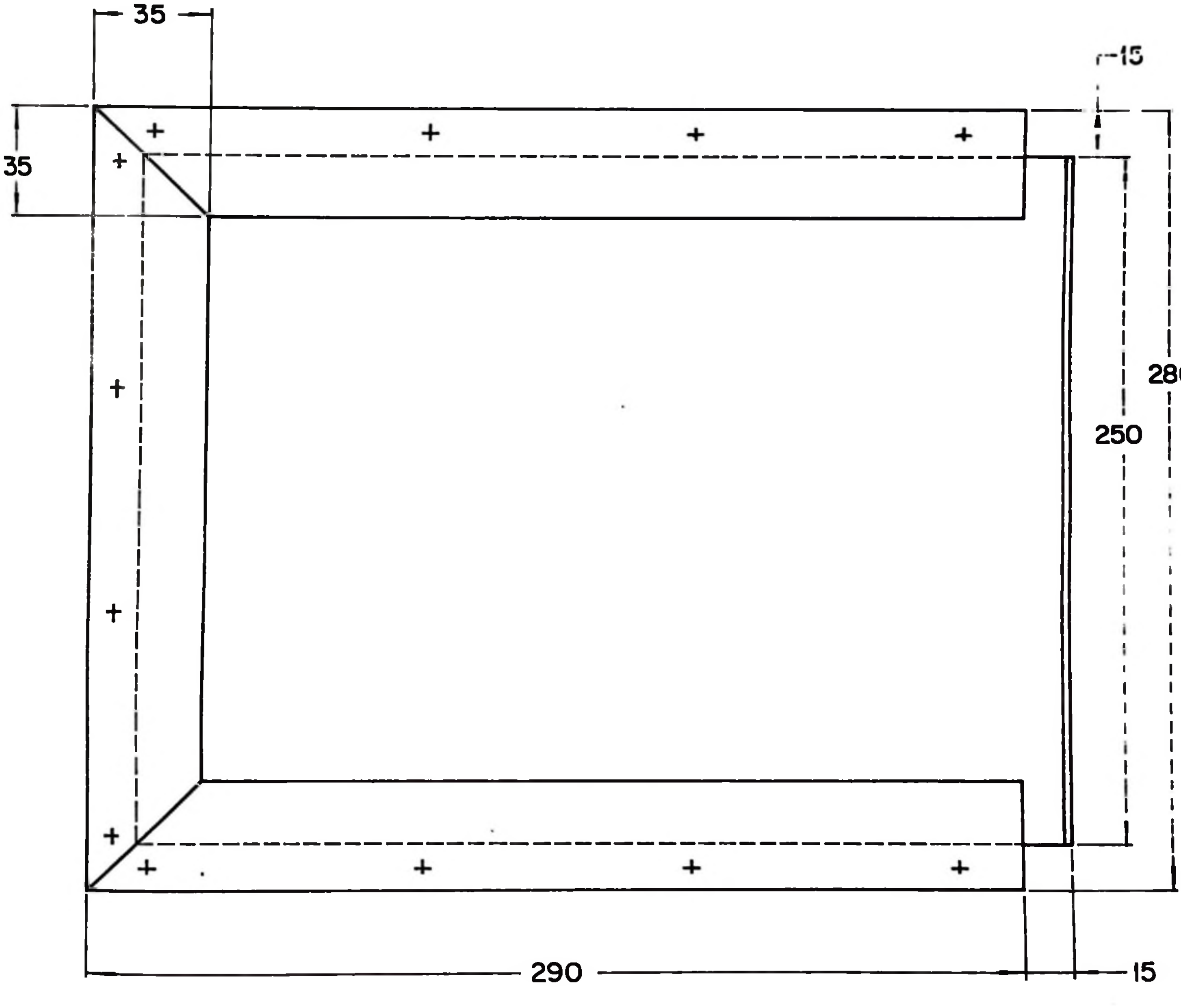



Fig. 3·1 Observation window on the thresher side chute.

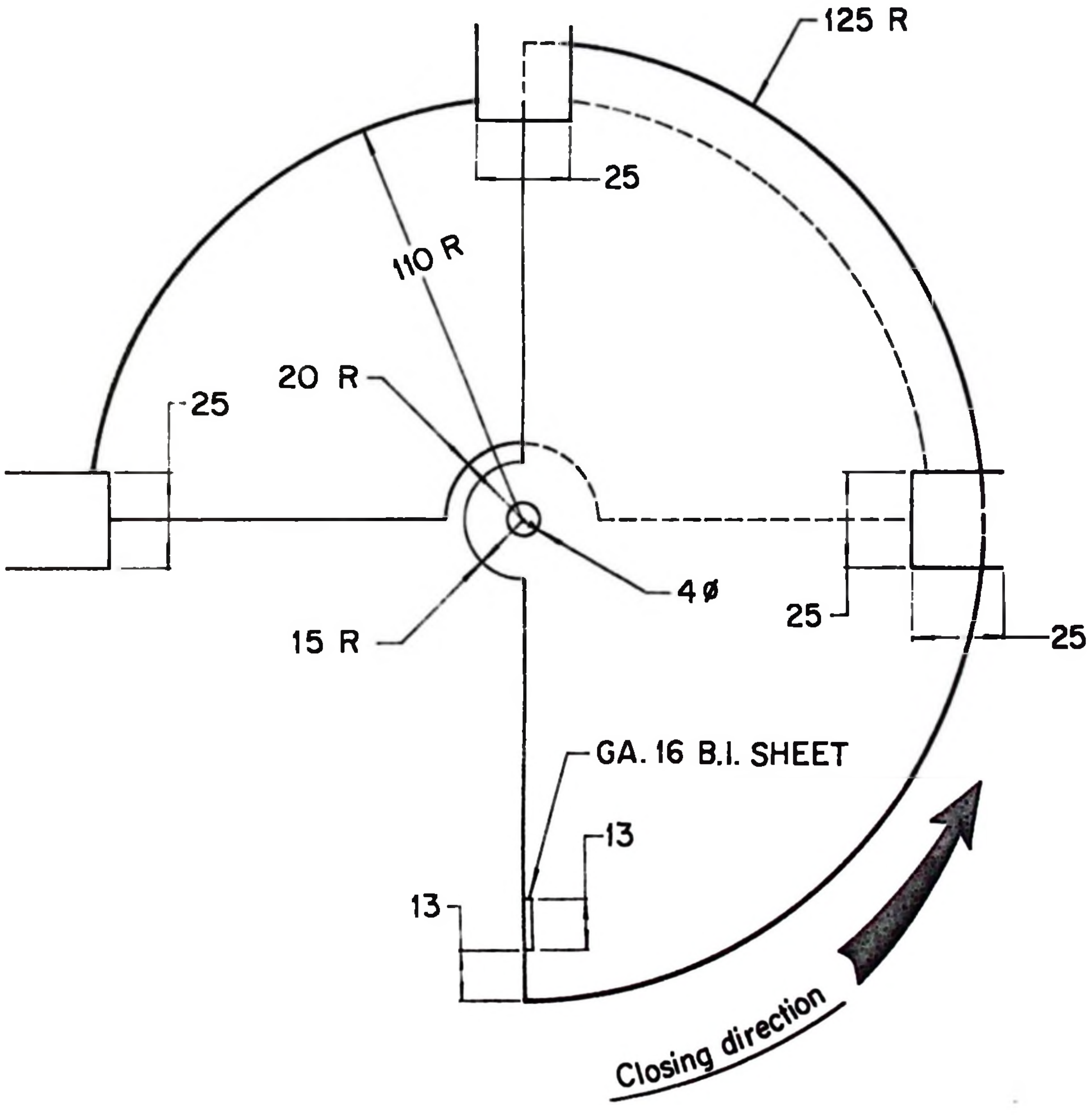



Fig. 3·2. Observation window on the thresher's asperator.

modified.

3.3.2 Adopting a hollow threshing cylinder shaft with pieces of solid shafts on its both ends.

Reasons for selecting such a shaft are:

( i) To make fabrication easier. Since the middle part of the shaft do not require machining, the total length of machined portion is confined only to the end portions of the shaft. These portions were machined independently and press fit on to the middle section of the shaft.

( ii) Cost reduction. A solid shaft 69.95 mm diameter costs US$21.8 per 304.8 mm length. Thus if only such a solid shaft was used with a length of 2247.9 mm a cost of US$160.78 would be required. While a hollow shaft 69.95 mm OD and 50.8 mm ID costs US$17.11 per 304.8 mm length. If pieces of both hollow and solid shafts are utilized (Figure 3.3) the modified shaft will therefore cost US$150.70 hence saving US$10.08.

(iii) Reduction of weight from the main frame. The predominant metal material used for the main frame is mild steel. This has been so in order to have a strong but a cheap machine. Since the machine vibrates during threshing operation, the initial stress in the frame sections should be kept as minimum as possible; and one way of doing so is to relieve the initial weight from the frame. By employing a hollow piece of shaft reduces some of the total weight.

The procedure followed to determine the diameter of the modified shaft is summarized below. According to American Iron and Steel Institute (AISI) standards the properties of the material used is shown in Table 3.1.

The shaft (Figure 3.3) carries the weight of the threshing cylinder assembly (Figure 3.4). The two flanges/supports on the extreme ends shown in Figure 3.4 are the ones supporting the weight of the cylinder assembly on the shaft. Thus, the resultant forces of the cylinder parts are directed on those flanges. Diagramatically, figure 3.5 represents resultant forces from different parts of the cylinder, and the reactions from the flanges.

In general, the weight or force of the different parts has been based on their volume V, and density $\rho$.

Thus weight is given by

$$W = V\rho g \qquad \text{--------- 3.1}$$

Table 3.1. Typical properties of wrought steel.

| Description Wrought Steel C 1045 | Symbol | Value $[kNmm^{-2}]$ |
|---|---|---|
| Modulus of elasticity tension/compression | $E$ | 206.912 |
| Modulus of elasticity shear/torsion | $G$ | 79.316 |
| Ultimate tensile stress | $\sigma_{ut}$ | 0.662119 |
| Yield tensile stress | $\sigma_{ut}$ | 0.406928 |
| Ultimate shear stress | $\tau_u$ | 0.496590 |
| Yield strength shear/ torsion | $\tau_y$ | 0.6 |

Density of the steel is $7.861 \times 10^{-6}$ $kgmm^{-3}$

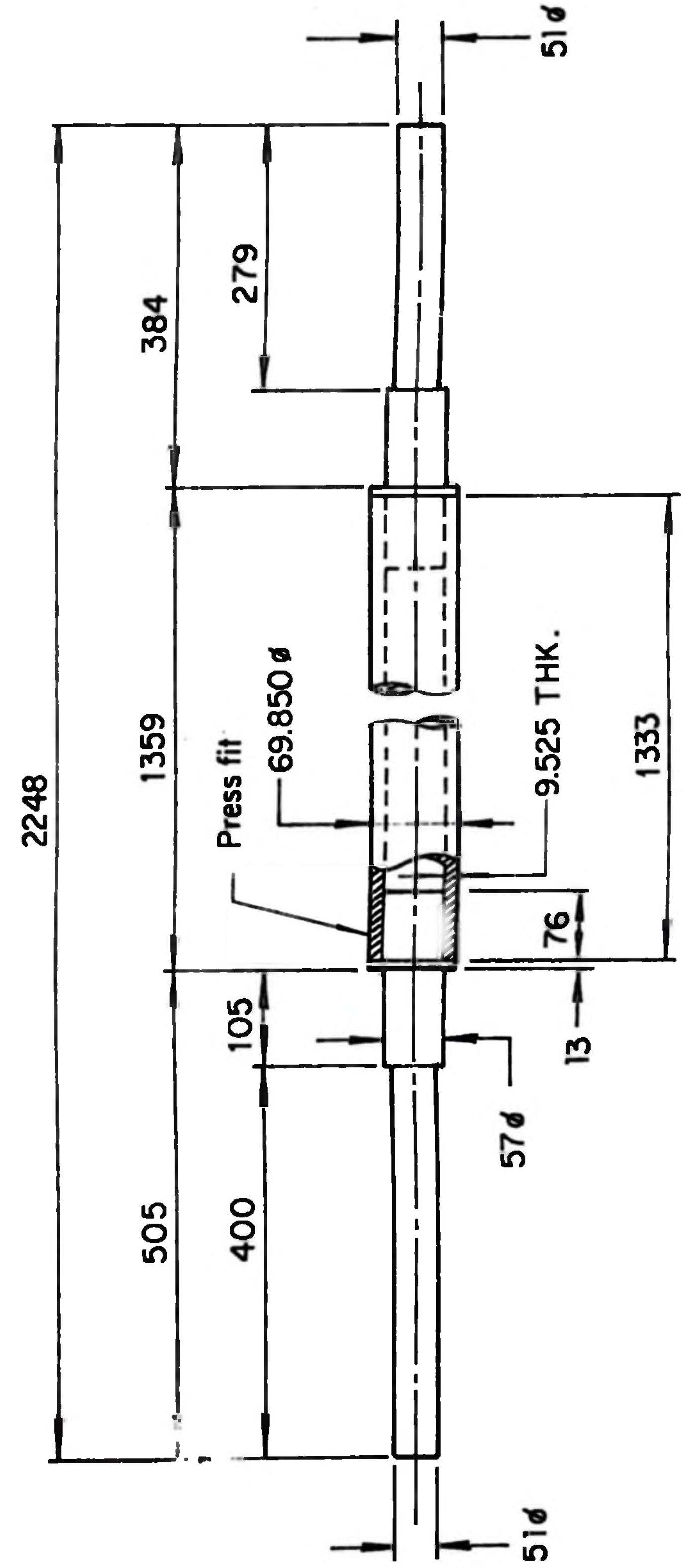



Fig. 3·3 Threshing cylinder shaft.

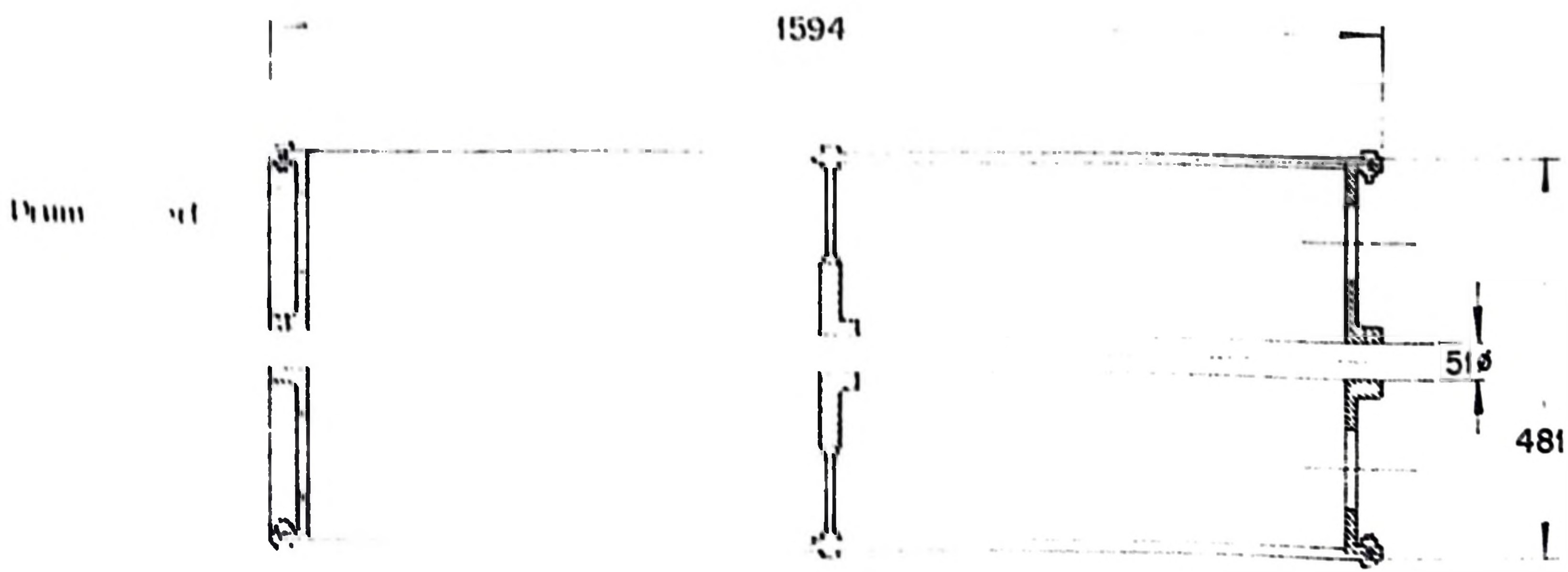



Fig.3-4. Cross-section of the threshing cylinder assembly without pegs, knives and straw thrower.

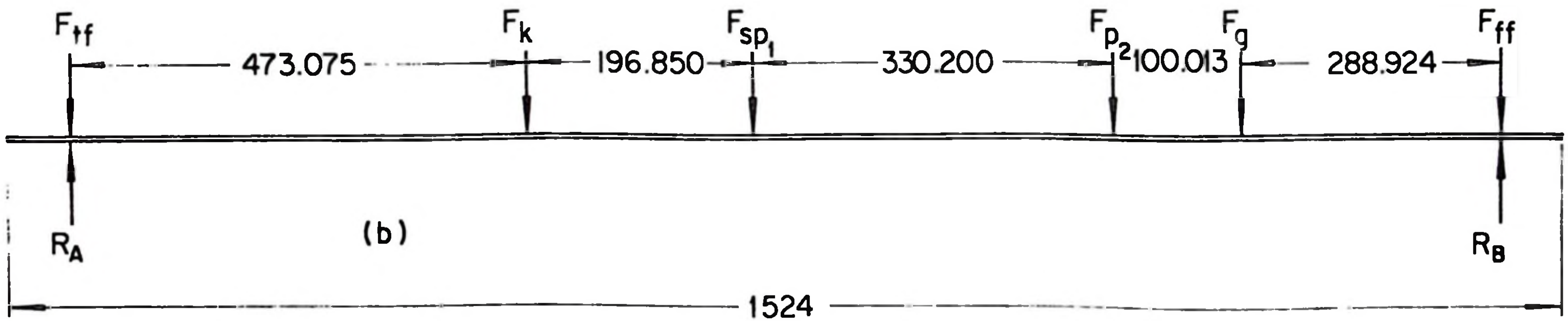



Fig. 3·5. Weight distribution of the threshing cylinder parts.

Care has been taken to deduct the volume occupied by holes and to add the weight of bolts and washers. This resulted to weight distribution of the cylinder on the shaft as shown in Figure 3.6.

It has been assumed that weight of the shaft is not contributing to the other weights/components, and since the supporting bearings for the shaft are self-aligning, the shaft is then simply supported, thus the cylinder assembly weight and the ball bearing reactions are concentrated. The reactions $R_A$ and $R_B$ have been obtained by taking moments about the supporting points. The bending force from the driving pulley attached has been considered. This force results from the force on the tension side F1 and slack side F2 of the driving belts. The sum depends during driving upon F1/F2 which varies with power transmitted and the initial belt tension. A factor of 1.5 can be considered for design purposes[5].

$$\text{Then:} \quad F1 + F2 = F1/F2\ (F1-F2)$$
$$= 1.5\ P/\omega r = 1.5\ F \quad - - - - \quad 3.2$$

---

[5]Suggested by ASME.

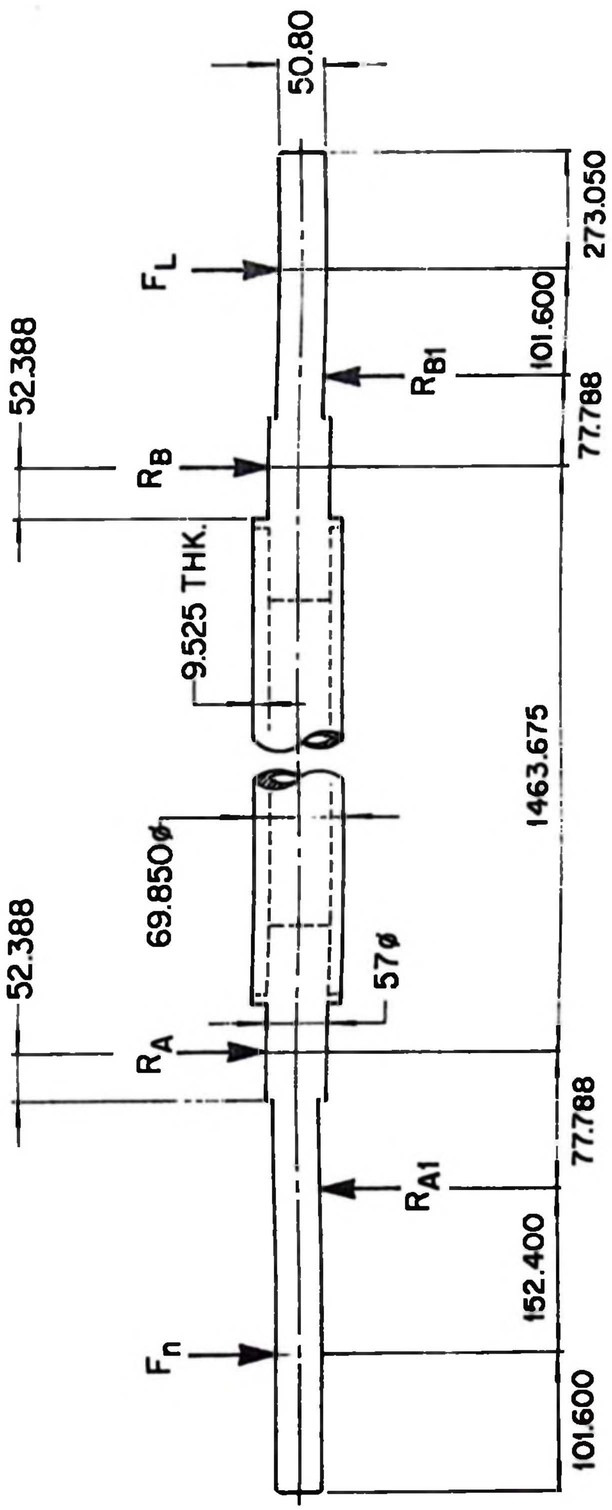



Fig. 3·6. Weight distribution on the threshing cylinder shaft.

Considering power P, from 4-wheel tractor which may go up to 44.45 kw with angular revolution per second, $\omega$ as 63.879 radians per second and the largest pulley to be fitted with a radius, r of 0.114 m, the reactions $R_{A1}$ and $R_{B1}$ from the bearings were computed.

Recalling the values from Table 3.1 together with the derived bending force, the relationship 3.3 was used to determine the diameter of the shaft. The value obtained was 47.773 mm diameter.

$$\frac{1}{N} = \left\{ \left(\frac{\sigma e}{\sigma n}\right)^2 + \left(\frac{\tau e}{\tau n}\right)^2 \right\}^{0.5} \quad - - - - 3.3$$

(See also appendix G for additional information)

3.3.3 Provide brackets to the thresher stands which are bolted on the main frame. This enables easy attachment of the stand, and replacement or repair of the stands whenever bending occurs through traversing levies. Based on the arrangement of the thresher pulleys and the weight distribution on the threshing cylinder, 63% of the total thresher weight is supported by the front stands. The shear stress $\tau$, of the material is 198.635 $Nmm^{-2}$, and the length of the weld applied is 51 mm. The force F, acting upon the bracket is 6743 N. Therefore, the thickness of the weld has been computed from the formula 3.4

$$F = \tau 2tl \qquad \text{--------- 3.4}$$

This resulted to a weld thickness of 17.08 mm.
The forces acting on the bracket are shown on Figure 3.7. Properties of the material used include ultimate tensile and shearing stress of 4.802 MN and 3.583 MN respectively. Assuming only four bolts are supporting the bracket while experiencing weight of the thresher, the resulting stress were obtained by applying formula 3.5.

$$\sigma = \frac{Wt}{l-4d} \qquad \text{------- 3.5}$$

where: t, l - thickness and length of the bracket [mm]

d - diameter of the bolts [mm].

Equation 3.5 gave 7.602 MN. This value is greater than the shearing stress of the bracket hance reinforcement has to be made, and resulted to the assembly seen on figure 3.7c.

3.3.4 Increase the total area of the output spout screen.

This has been initiated so that the threshed grains over the oscillating tray could have more chances of dropping into the output spout. Otherwise a crop with high moisture content had signficant amount of grain by-passing the screen together with large foreign materials. From figure 3.8 a relatinship of output spout and the screen above it is shown. On reversing the screen, the total area of the screen will be increased by 0.035 $m^2$.

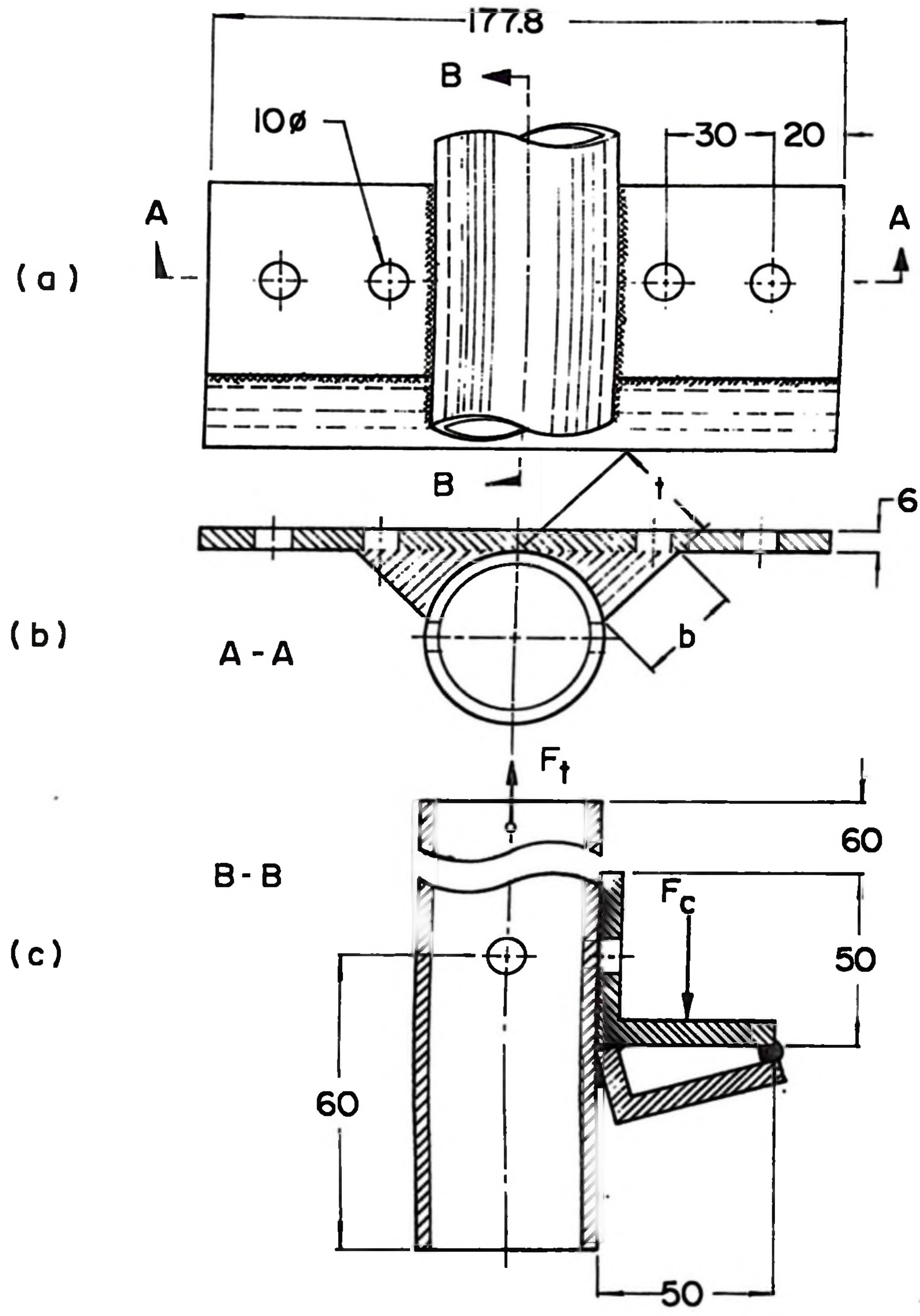



Fig. 3·7. Assembly of the bracket for the thresher stand and forces acting up on.

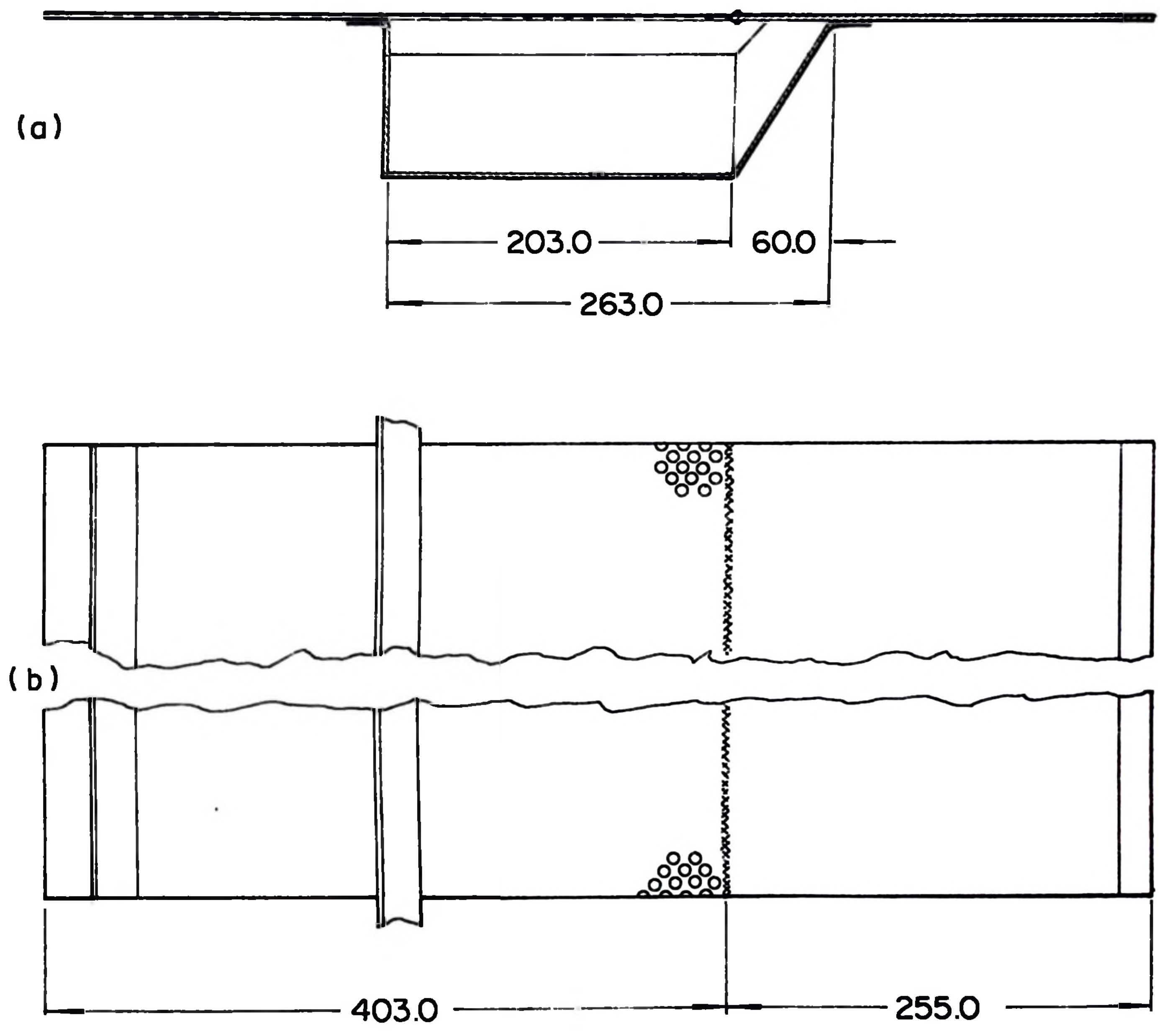



Fig. 3·8. (a). The cross section assembly of the spout screen and the output spout.

(b). Output spout screen.

## 3.4 DESCRIPTION OF THE IRRI-PAK MULTICROP THRESHER DESIGN FEATURES

Figures 1.1, 1.2 were shown in section 1.1. They referred to the length and width of the machine and position of the feeding hopper. In addition, the total weight of the machine is 1090 kg. From the side view a counter shaft could be observed which connects the PTO shaft which transfers power from the tractor. The power from the input shaft is transfered to the threshing cylinder by three B-section V-belts. A single B-section, V-belt transfers power from the input shaft through an idler to the oscillating tray assembly. Three major sub-assemblies make up the IRRI-PAK Multicrop thresher:

( i) Threshing cylinder - concave. Figure 3.9 and figure 3.10 respectively show the threshing cylinder and concave. On the cylinder there are round pegs for threshing, flat bars for cutting, and straw thrower elements. The pegs and bars/knives are arranged spirally. On top of the cylinder a cover is fitted figure 3.11a and figure 3.11b. Inside, it has louvres making an angle of $14^{o}$ with the horizontal plane. Under the threshing cylinder there is a concave, figure 3.10 with three sections --- the threshing, separating, and throwing concaves.

( ii) Aspirator. From figure 3.12 an assembly side view of the aspirator is shown. This consists of a four bladed

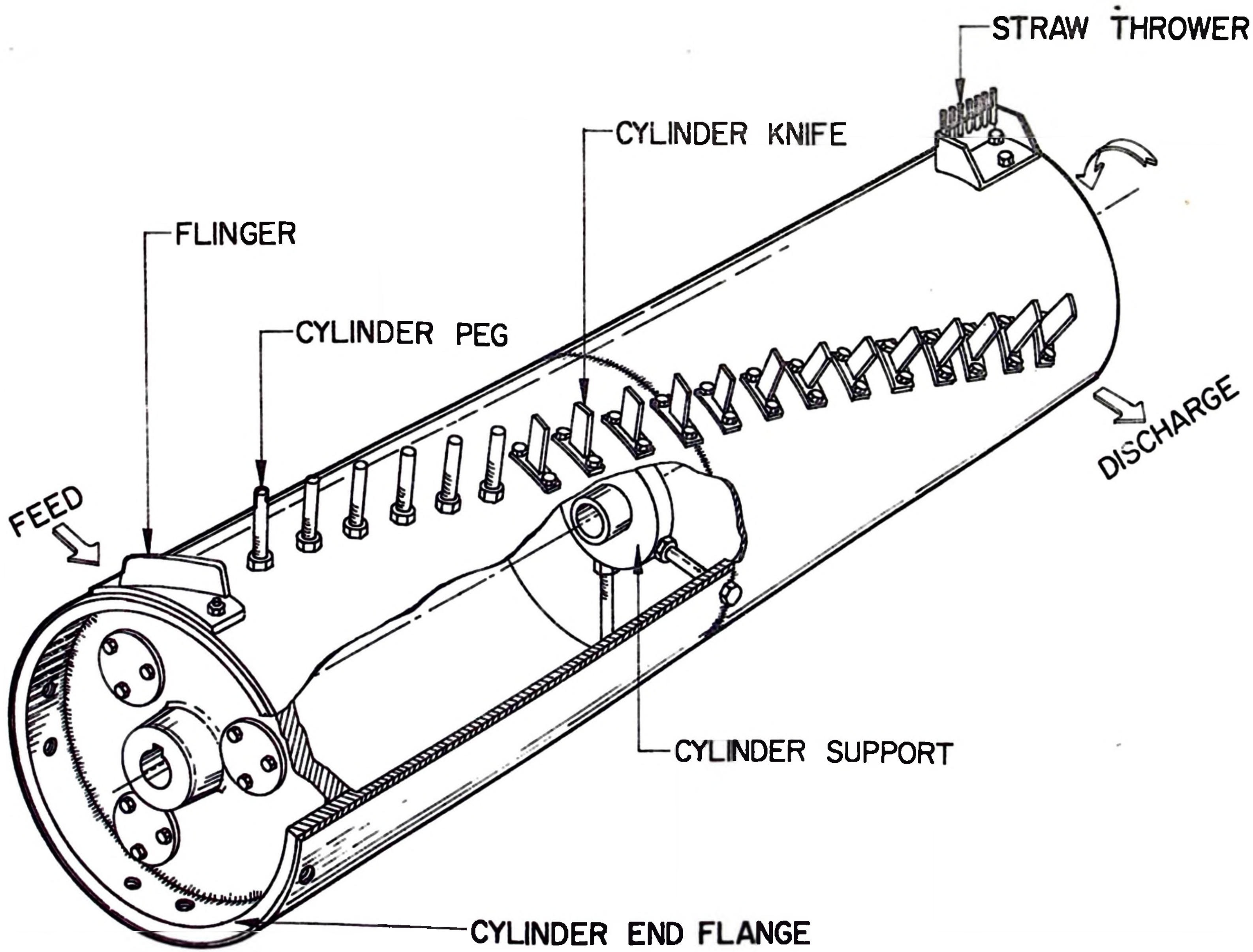



Fig. 3.9 Threshing Cylinder Assembly

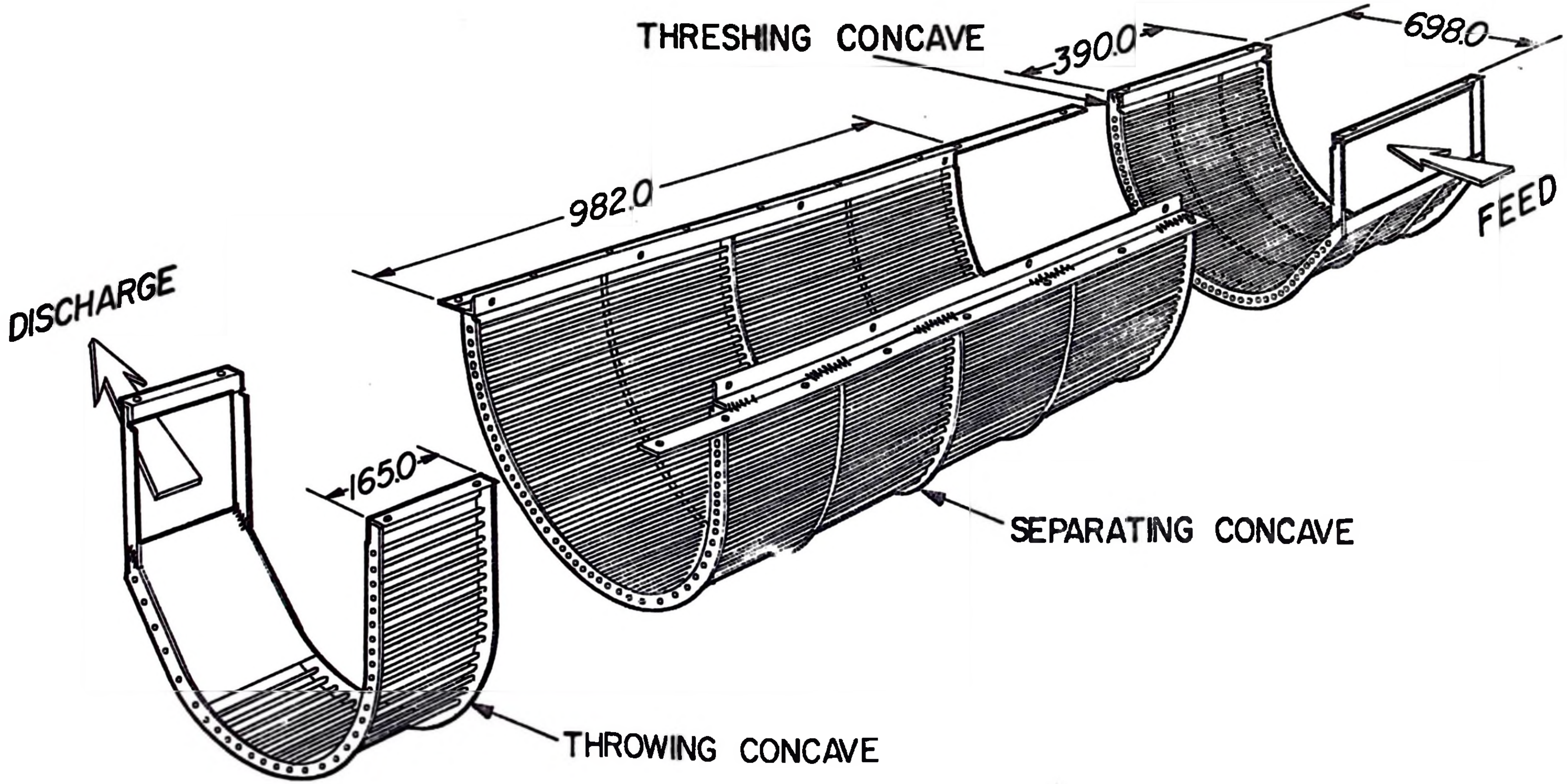



Fig. 3.10 Three portions of concave

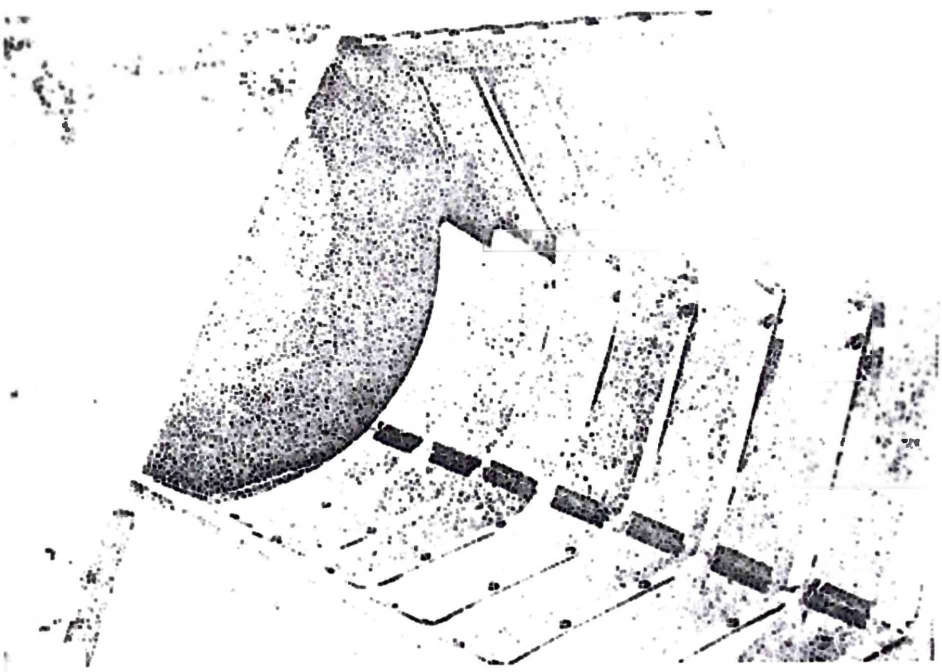


Fig. 3.11a. Adjustable louvres on the threshing cylinder cover.

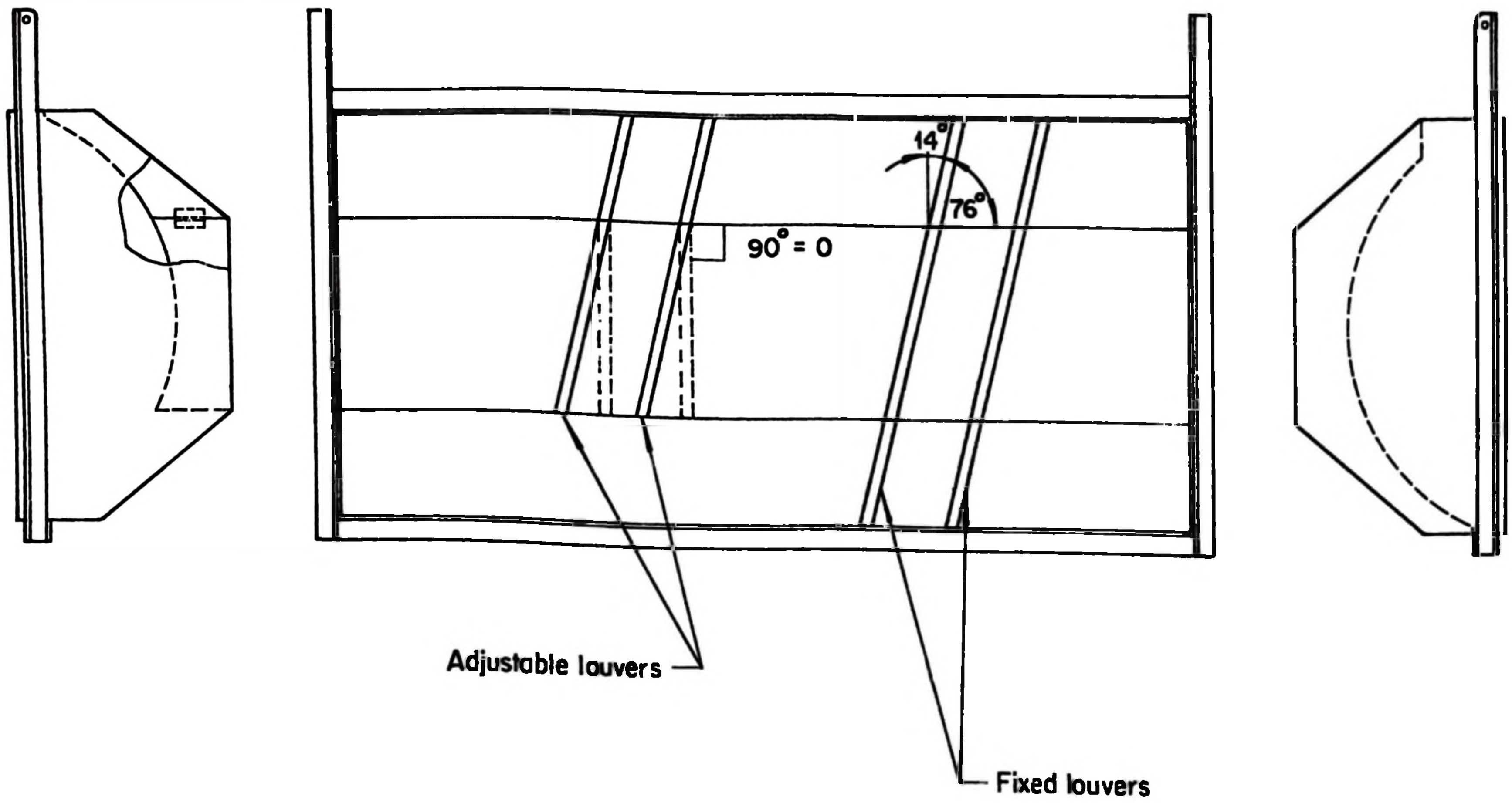



Fig.3·11b. Fixed and adjustable louvers on the threshing cylinder cover.

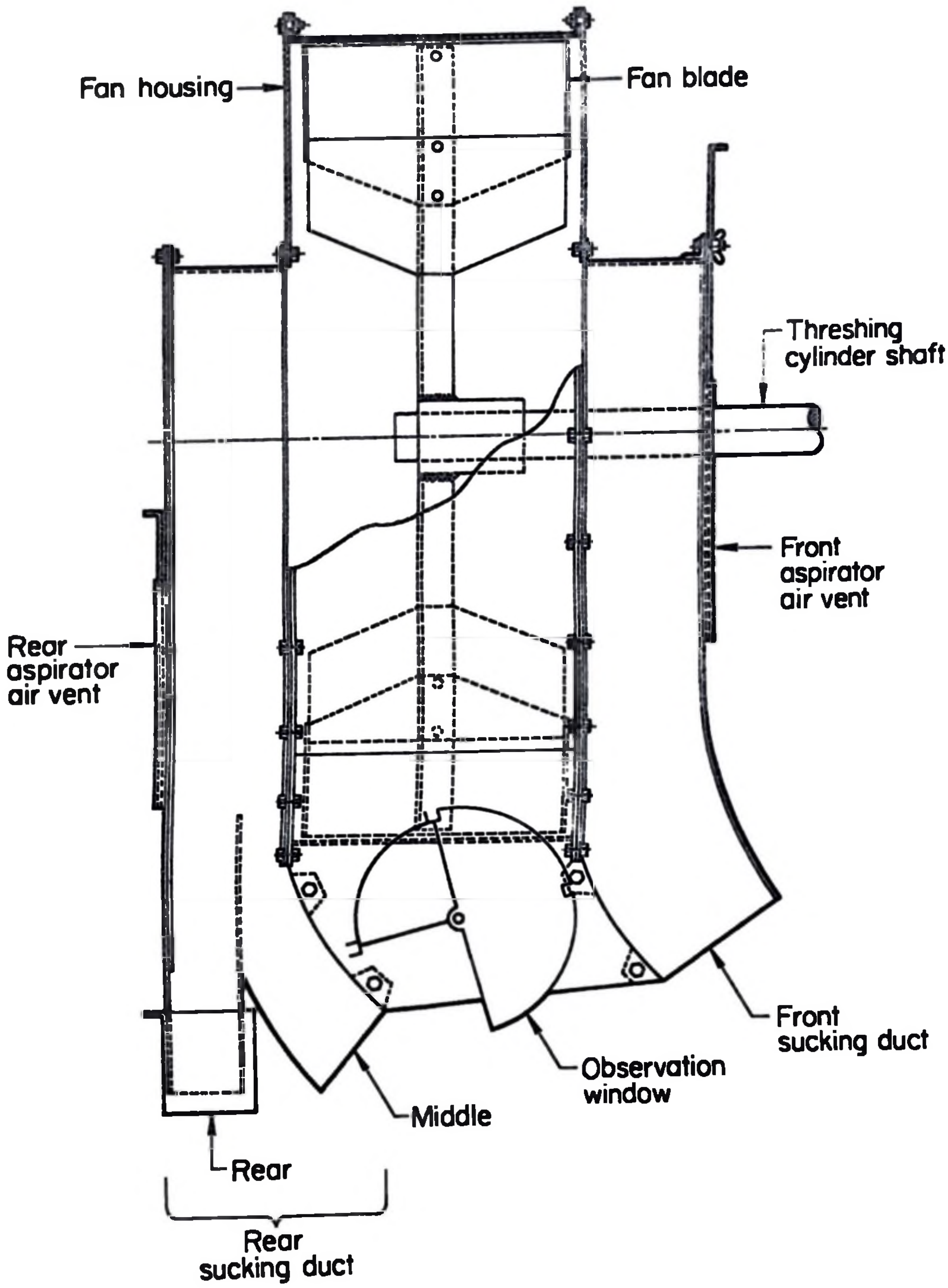



Fig. 3·12. Side view of the aspirator assembly.

fan mounted directly on the threshing cylinder shaft. The fan is enclosed in a housing with two suction ducts the front and rear. The front duct sucks the straw flowing over the upper screen. While the rear duct which is divided into two ducts sucks chaff from the middle and lower screen/pan.

(iii) Oscillating tray. Cross-section of the assembly figure 3.13 show the arrangement of screens and tray pan. The screens have holes of different diameters. The upper screen has 16 mm [5/8 in], middle screen 10 mm [3/8 in], and a pan connected to 2 mm [1/16 in] screen, and 10 mm [3/8 in] screen. The numbers refer to the diameter of holes. The amplitude of the tray is 19 mm with an angular movement of $55^{o}$ to $60.79^{o}$ for the front links and $55^{o}$ to $62.55^{o}$ for the rear links.

## 3.5 PERFORMANCE TEST AND EVALUATION

### 3.5.1 Variables

Several settings were made on the thresher during experiments. More than one setting could be made for one experiment depending on the aim. The various settings made

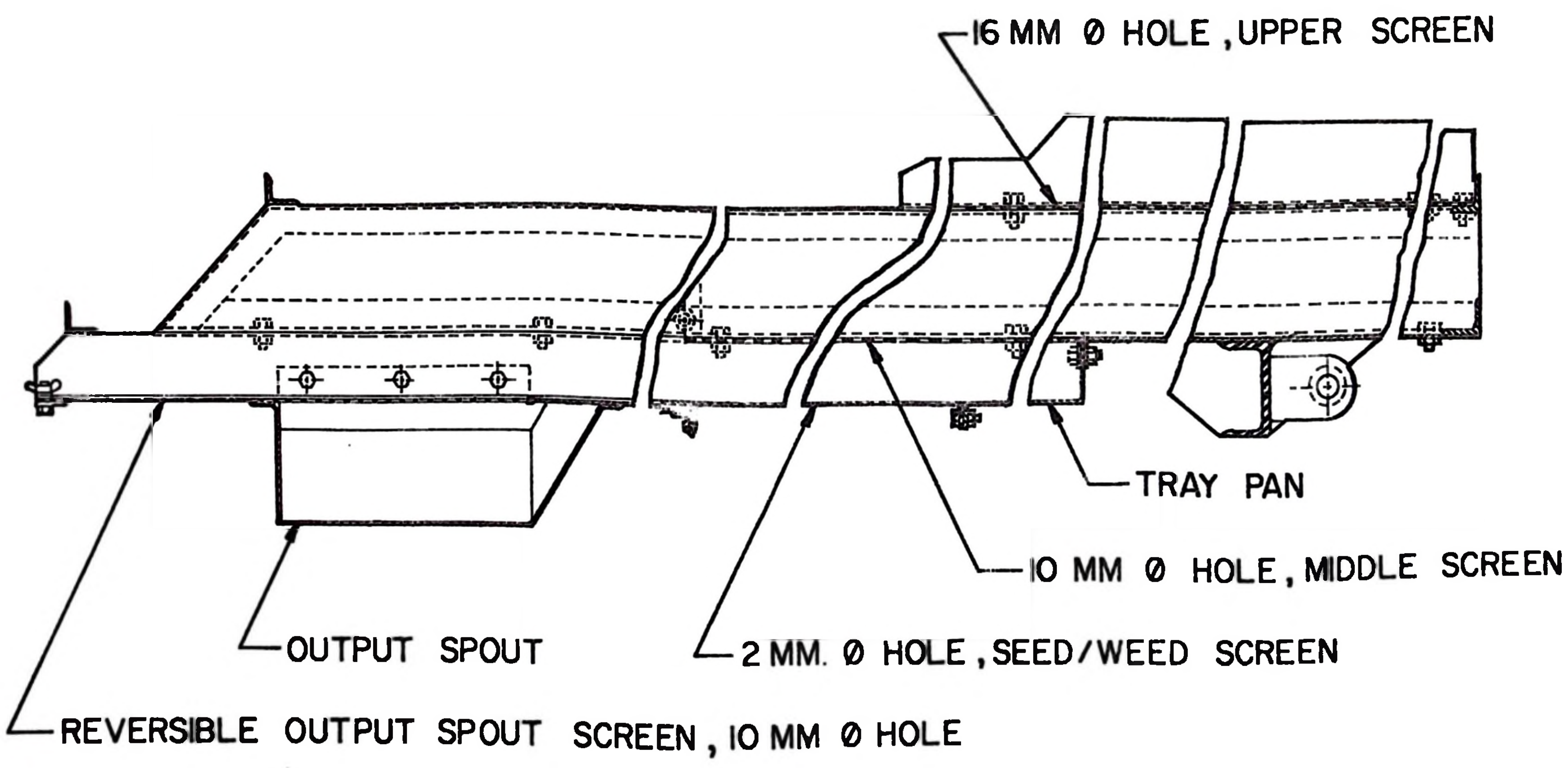



Fig. 3.13 Cross-section of oscillating tray assembly

were as follows:

( i) Threshing cylinder speed/peripheral velocity.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| speed (rpm) | 300 | 380 | 450 | 480 | 510 | 610 | 670 | 710 |
| periph. velo.($ms^{-1}$) | 10.47 | 13.27 | 15.71 | 16.76 | 17.81 | 21.30 | 23.29 | 24.79 |

( ii) Oscillating[6] tray slope, in degrees, this ranged from $-0.56^{o}$ to $3.44^{o}$ at $2^{o}$ interval.

(iii) Number of louvres in the cylinder cover: 5, 10.

( iv) Angle of louvres (Figure 3.11b).

The non adjustable ones had a permanent angle of $14^{o}$ relative to the hexagonal inside the cover. Note from Figure 3.11b that the adjustable piece of the louvre is the one on the middle of the cover. When the piece is set parallel to the side edges of the cover, it is referred to as zero angle. Since the other piece is maintained at $14^{o}$, the zero angle is referred to as $14^{o}-0^{o}$. when the adjustment is $7^{o}$ it is referred to as $14^{o}-7^{o}$.

[6] When the thresher is horizontal the oscillating tray is $1.44^{o}$, leaning to the rear side.

( v) Fan blade area figure 1.14.*

| Description | Minimum | Medium | Maximum |
|---|---|---|---|
| Area exposed [$mm^2$] | 168580 | 191496 | 240984 |
| Percentage area exposed [%] | 70 | 79 | 100 |

*Values are rounded to whole number.

( vi) Aspirator air duct

This is denoted by fractional representation, the numerator and denominator referring to, respectively, the gap in inches exposed on the front and rear air vents.

Figure 3.15 show marking on aspirator air vent and figure 3.16 a and b show the relative sizes of the air vents. The combination used are:

| Combination | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Gap exposed in/in | 0/0 | 1/1.5 | 0/3 | 1/5 |
| Area exposed $mm^2$ | 0 | 8226 | 16451 | 31935 |
| Percentage % | 0 | 15 | 31 | 90 |

( vii) Clearance of pegtooth to concave mm -- 19, 30.

(viii) Aspirator side windows, these were either fully opened or full closed.

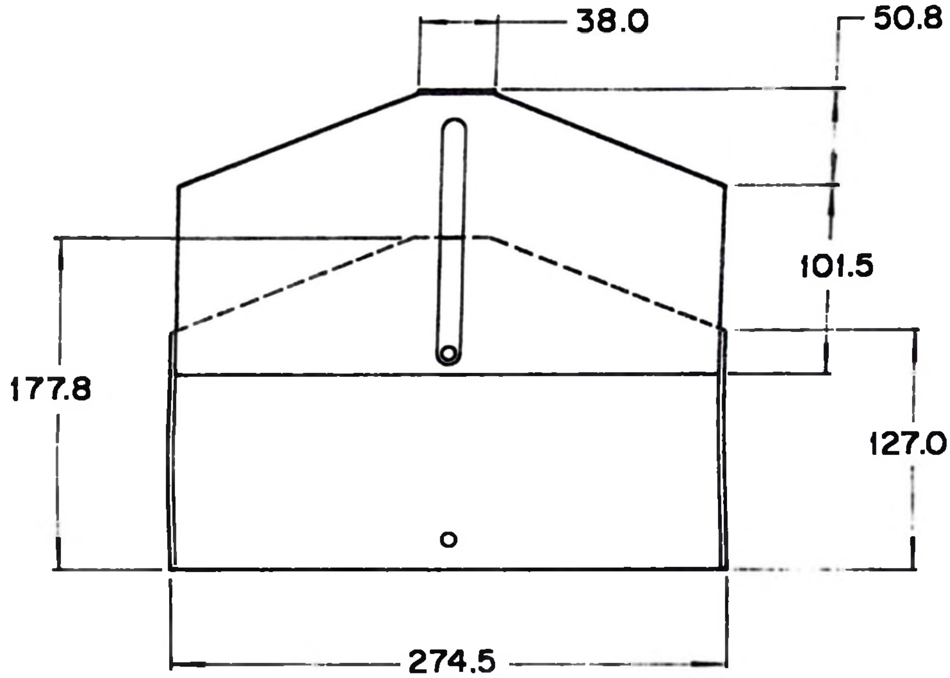



Fig. 3·14. Adjustable blade of the aspirator fan.

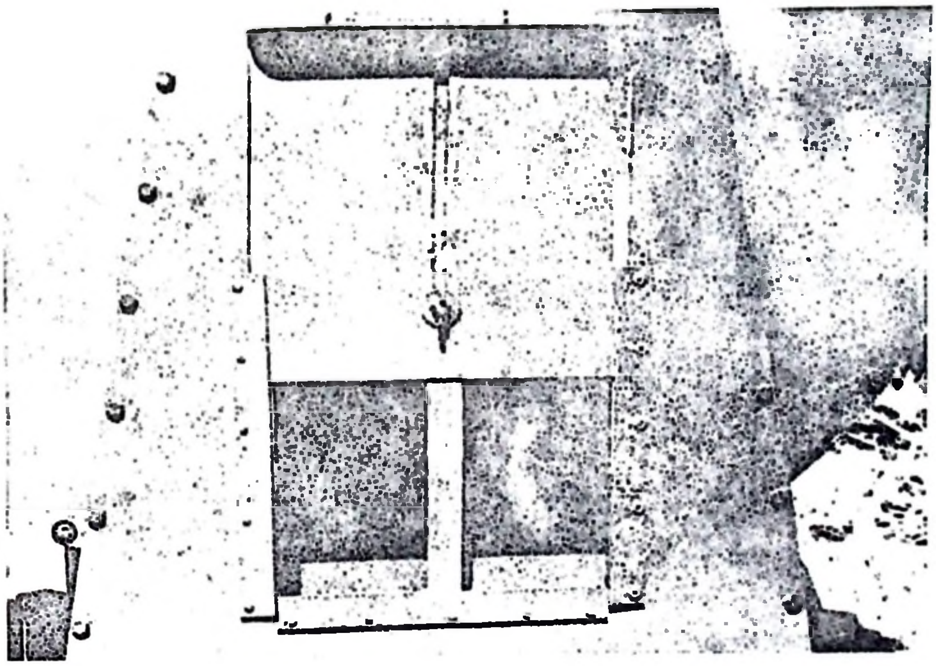


Fig. 3.15. Markings on the air vent.

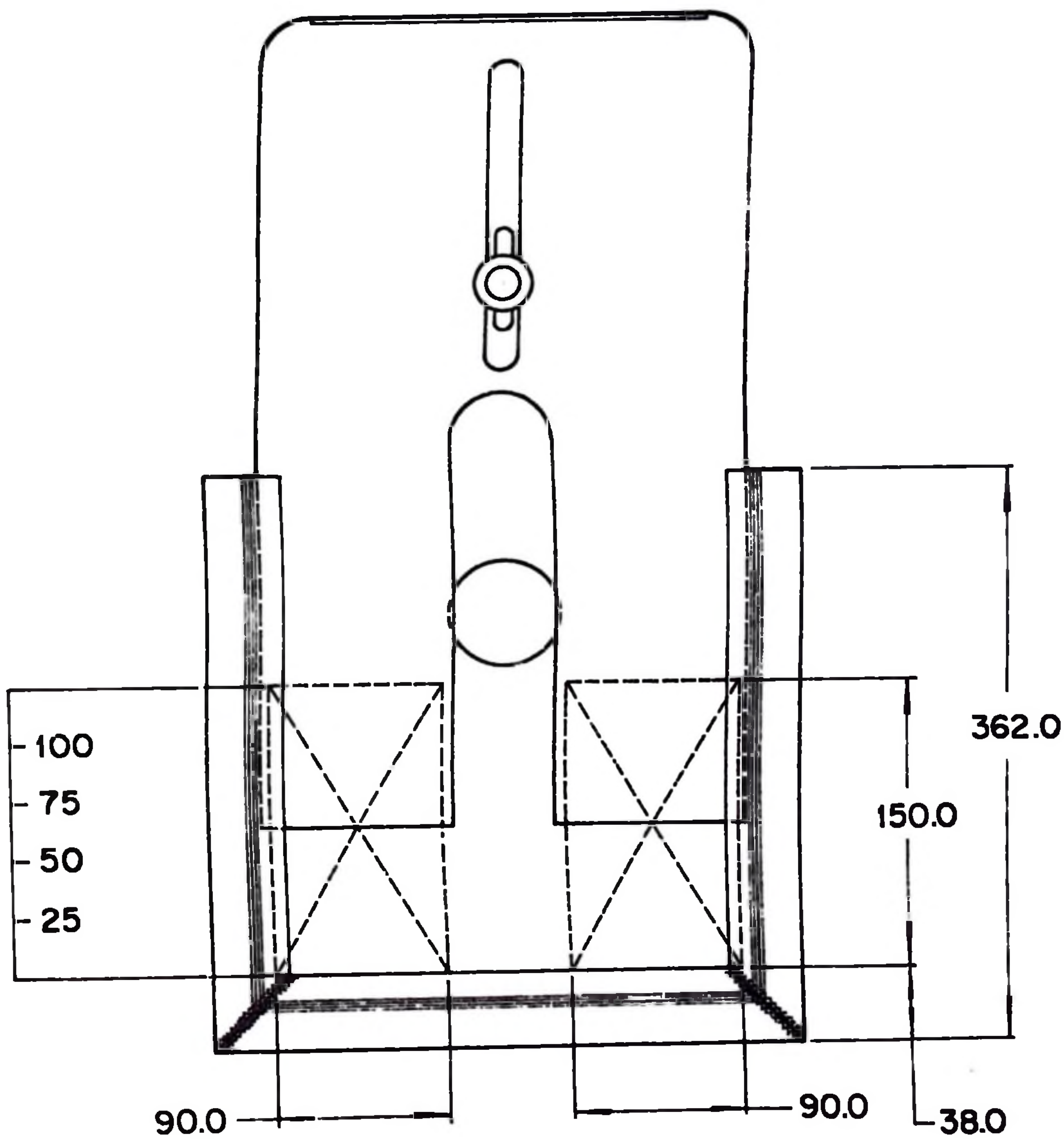



*Fig. 3·16(a)* **Front aspirator air vent.**

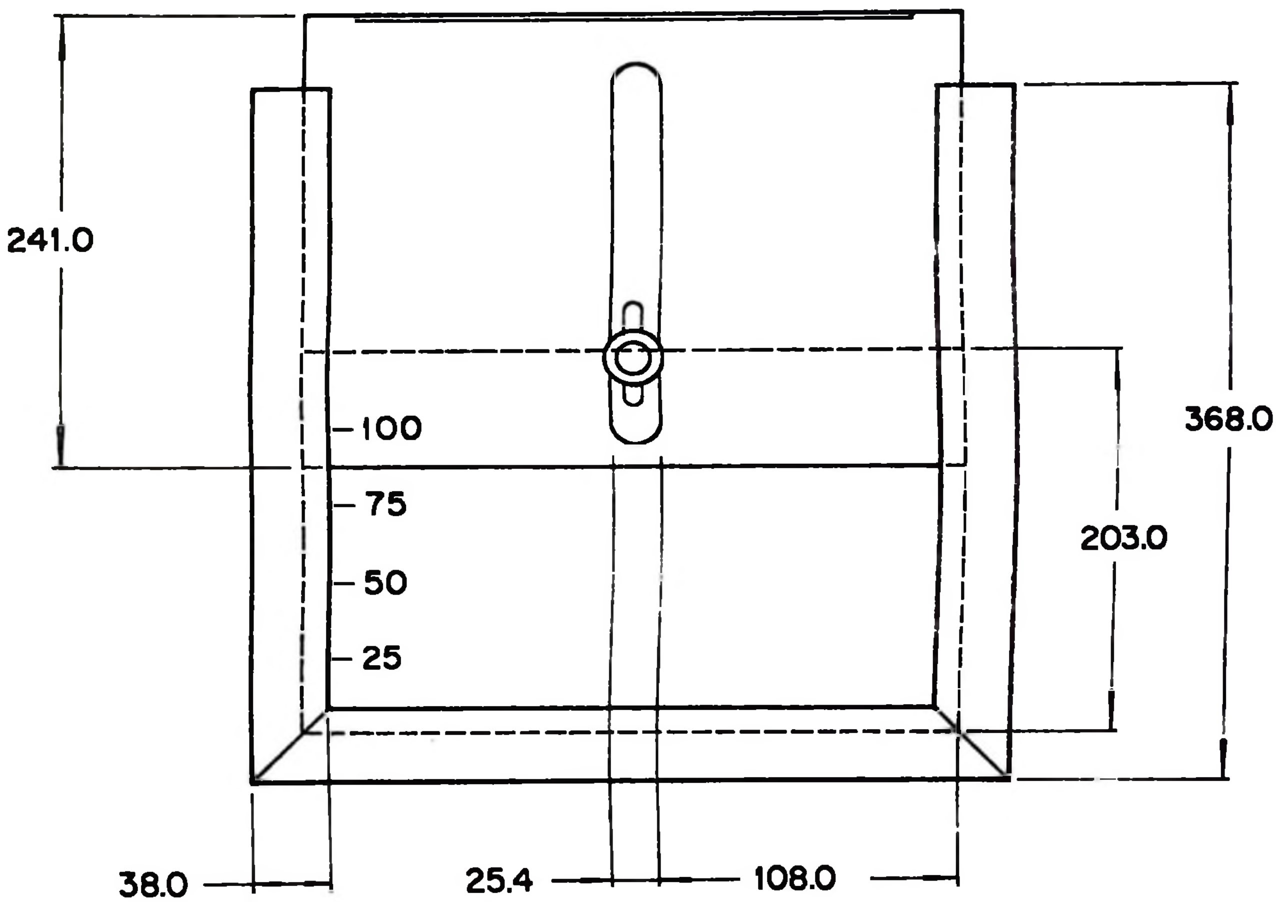



*Fig. 3.16 (b)* Rear aspirator air vent.

### 3.5.2 Crop condition and machine setting

Table 3.2a through table 3.4b show the settings of the machine and the condition of the specific crop.

### 3.5.3 Equipment and application

Number of machines and equipment have been used during the time of different experiments. Below include brief description of the main equipment used.

( i) Tachometer - ONO SOKKI Model HT 322 hand digital tachometer - contact type. It was used to pick up revolutions of the threshing cylinder shaft. An accessory included, KS200 enabled to measure peripheral speed, where the centre of a shaft could not easily be reached, e.g., camshaft of the oscillating tray assembly.

The tachometer displays four digits which are automatically stored for 10 min. and could be recalled as rpm or revolutions per second. It requires 6V with an accuracy of 0.1 m $min^{-1}$.

( ii) Level meter. Figure 3.17 show the kind of level meter used. It has a circular housing with levelling block. It has magnet which enabled it to be attached on various parts of the main frame or the oscillating tray frame.

( iii) Anemometer - KANOMAX - Thermo anemometer. It

Table 3.2a. Variable settings on the thresher during threshing paddy varieties IR38, IR58, and 1917.

| Crop variety | No. of louvre | Louvre angle | Osc. tray slope 1 (degrees) | Osc. tray slope 2 (degrees) | Osc. tray slope 3 (degrees) | Fan blade area (%) | Asp. air vent 1 (%) | Asp. air vent 2 (%) | Cylinder peripheral velocity 1 (ms -1) | Cylinder peripheral velocity 2 (ms -1) | Rear duct adj. (mm) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| IR38 | 5 | 14 | -0.56 | 1.44 | 3.44 | 100.00 | 0.00 | 15.30 | 15.71 | 16.76 | 50 |
| IR58 | 10 | 14 | | 1.44 | 3.44 | 100.00 | 0.00 | 15.30 | | 16.76 | 50 |
| 1917 | 10 | 14 | -0.56 | | | 100.00 | | 15.30 | 15.71 | | 25 |

Table 3.2b. Condition of the paddy used to evaluate the performance of the thresher.

| Crop variety | Length of cut (mm) | Grain percentage (%) | Moisture content (%) | |
|---|---|---|---|---|
| | | | Grain | Straw |
| IR38 | 527 | 31.85 | 28.21 | 64.20 |
| IR58 | 684 | 31.38 | 17.70 | 62.80 |
| 1917 | 609 | 32.45 | 22.13 | 65.88 |

Table 3.3a. Variable settings on the thresher during threshing sorghum variety Casor 2 and Yellow corn.

| Crop | No. of louvre | Settings: Louvre angle 1 | Louvre angle 2 | Osc. tray slope 1 | Osc. tray slope 2 | Fan blade Area 1 | Fan blade Area 2 | Fan blade Area 3 | Asp. air vent 1 | Asp. air vent 2 | Cyl per velocity 1 | Cyl per velocity 2 | Cyl per velocity 3 | Rear duct adj. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | (degrees) | | | | (%) | | | | | (ms-1) | | | (mm) |
| Sorghum Casor 2 | 10 | 14 | 14-7 | 1.44 | 3.44 | 70.00 | | 100.00 | 30.63 | 89.53 | | | 16.76 | 50 |
| Yellow corn | 10 | | 14-7 | | 3.44 | | 79.46 | | 15.30 | | 10.47 | 13.27 | | 25 |

Table 3.3b. Condition of the sorghum variety Casor 2 and yellow corn used to evaluate the performance of the thresher.

| Crop variety | Length of cut (mm) | Grain percentage | Moisture content Grain (%) | Moisture content Straw (%) |
|---|---|---|---|---|
| Casor 2 | 399 | 48.17 | 22.55 | 47.28 |
| Yellow corn | | 64.18 | 14.31 | |

Table 3.4a. Variable settings on the thresher during threshing wheat variety Trigo 1.

| Place of thresh | No. of louvre | Settings: Louvre angle 1 | Louvre angle 2 | Osc. tray slope 1 | Osc. tray slope 2 | Osc. tray slope 3 | Fan blade area | Asp. air vent 1 | Asp. air vent 2 | Cyl per velocity 1 | Cyl per velocity 2 | Cyl per velocity 3 | Rear duct adj. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | (degrees) | | | | | (%) | | | ($ms^{-1}$) | | | mm |
| Pasuquin | 10 | | 14-7 | | | 3.44 | 100.00 | 30.63 | | 17.81 | 21.30 | 24.79 | 50 |
| Batak | 10 | 14 | 14-7 | -0.56 | 1.44 | 3.44 | 70.00 | 89.53 | 100.00 | | 21.30 | 23.39 | 50 |
| Dingras | 10 | | 14-7 | | 1.44 | | 70.00 | 30.63 | | | 21.30 | 23.39 | 102 |

Table 3.4b. Condition of the wheat variety Trigo 1 used to evaluate the performance of the thresher.

| Place of thresh | Length of cut (mm) | Grain percentage | Moisture content Grain (%) | Moisture content Straw (%) |
|---|---|---|---|---|
| Pasuquin | 653 | 31.39 | 13.09 | 15.46 |
| Batak | 577 | 34.33 | 13.11 | 14.56 |
| Dingras | 661 | 25.71 | 12.35 | 14.20 |

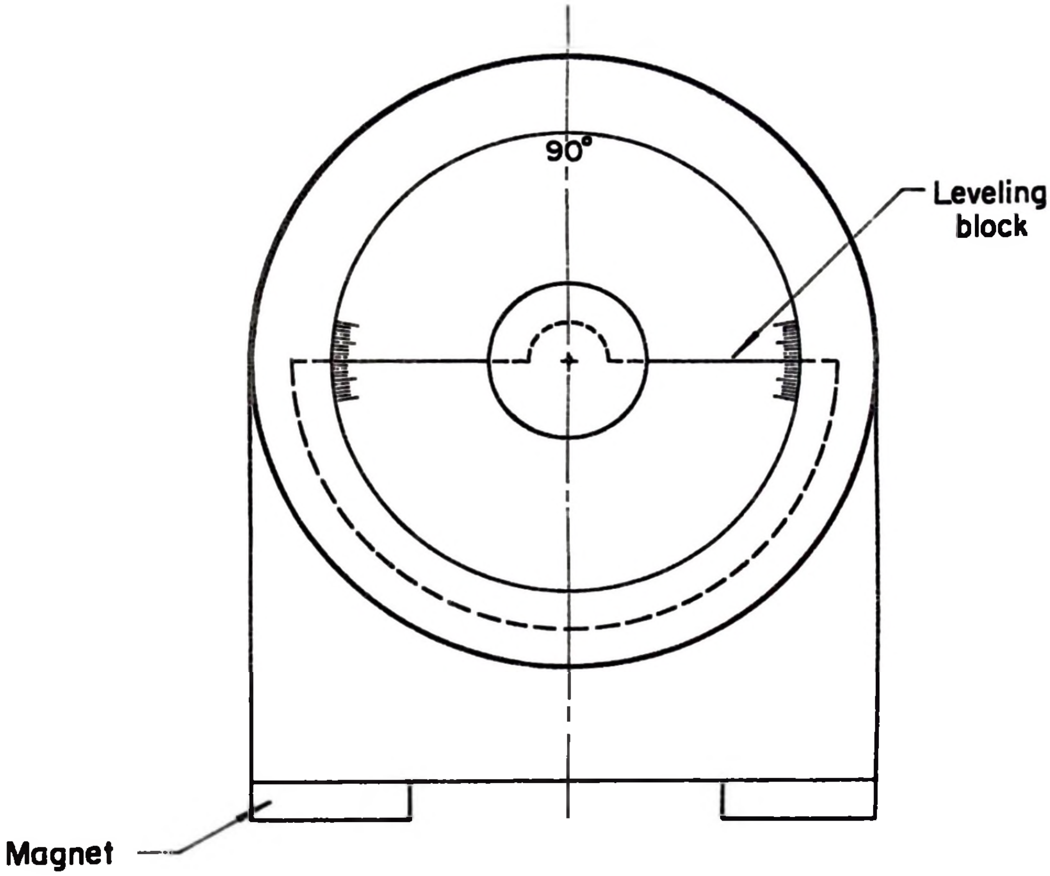



Fig. 3 · 17. Level meter

is composed of wind sensing element and a temperature sensing element which are made of same platinum wire. This enables it, theoretically, to get the automatic compensation for fluctuation of wind temperature. Measuring range of velocity, is in two steps 0 to 10 $ms^{-1}$ and 0 to 50 $ms^{-1}$ and the temperature range is 10$^{o}$C to 40$^{o}$C and 40$^{o}$C to 70$^{o}$C. It utilizes DC current of 6 volts.

The instrument has been used to measure stream of air through various regions of the thresher (Appendix I). From the aspirator air inlets, and the front of the oscillating tray, twelve readings of air velocity were recorded; and also nine readings were recorded from the air outlet of the aspirator for every setting.

( iv) Four-wheel tractor. Since the experiments were conducted at different places the models of tractor available were not the same. The tractors used are noted below:

| Crop | Tractor model | Power hp |
|---|---|---|
| Paddy - IR58 | Iseki 3110 | 30 |
| Paddy - IR38 | MF 135 | 30 |
| Paddy - 1917 | MF 185 | 60 |
| Sorghum - Casor 2 | MF 185 | 60 |
| Wheat - Trigo 1 | Universal | 60 |

( v) Torque transducer - slip Ring type SR/2A. It is capable of measuring up to 2000 kgm and it has brackets for mounting on a machine figure 3.18. It can be observed to have a universal joint which allowed easy alignment to the PTO shaft. Some of its specifications include output voltage sensitivity, 1.5 mV/V, recommended bridge voltage, 6V DC or AC. Input output resistance, 350 ohms; temperature affects on zero, 0.01 FS/$^{o}$C, maximum operating temperature, 60$^{o}$C, allowable load 120% FS, and error due to contact resistance charge, 0.3% FS.

Figure 3.19 show the arrangement of the torgue transducer and the input shaft. The input shaft to the transducer was fitted with strain gages. Wires from the gages transmitted

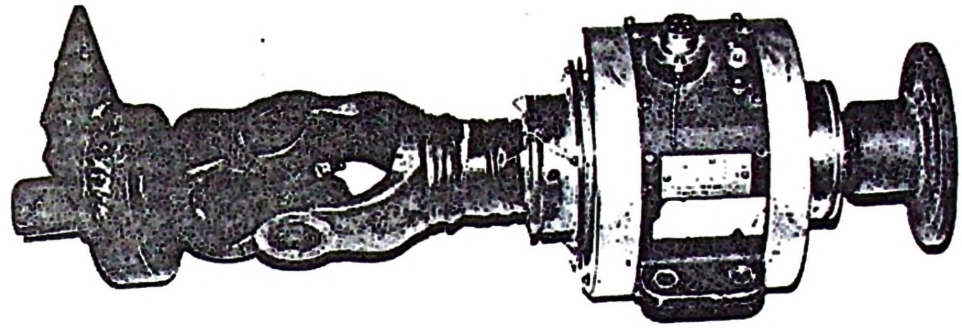
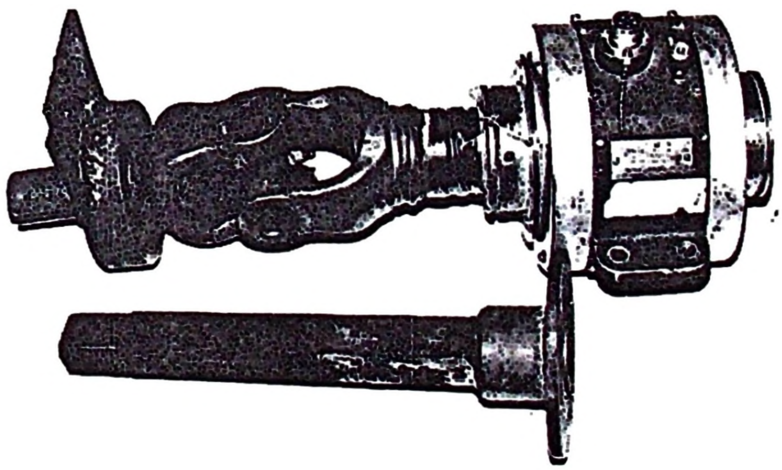


Fig. 3.18. Torque transducer assembly with attaching brackets.



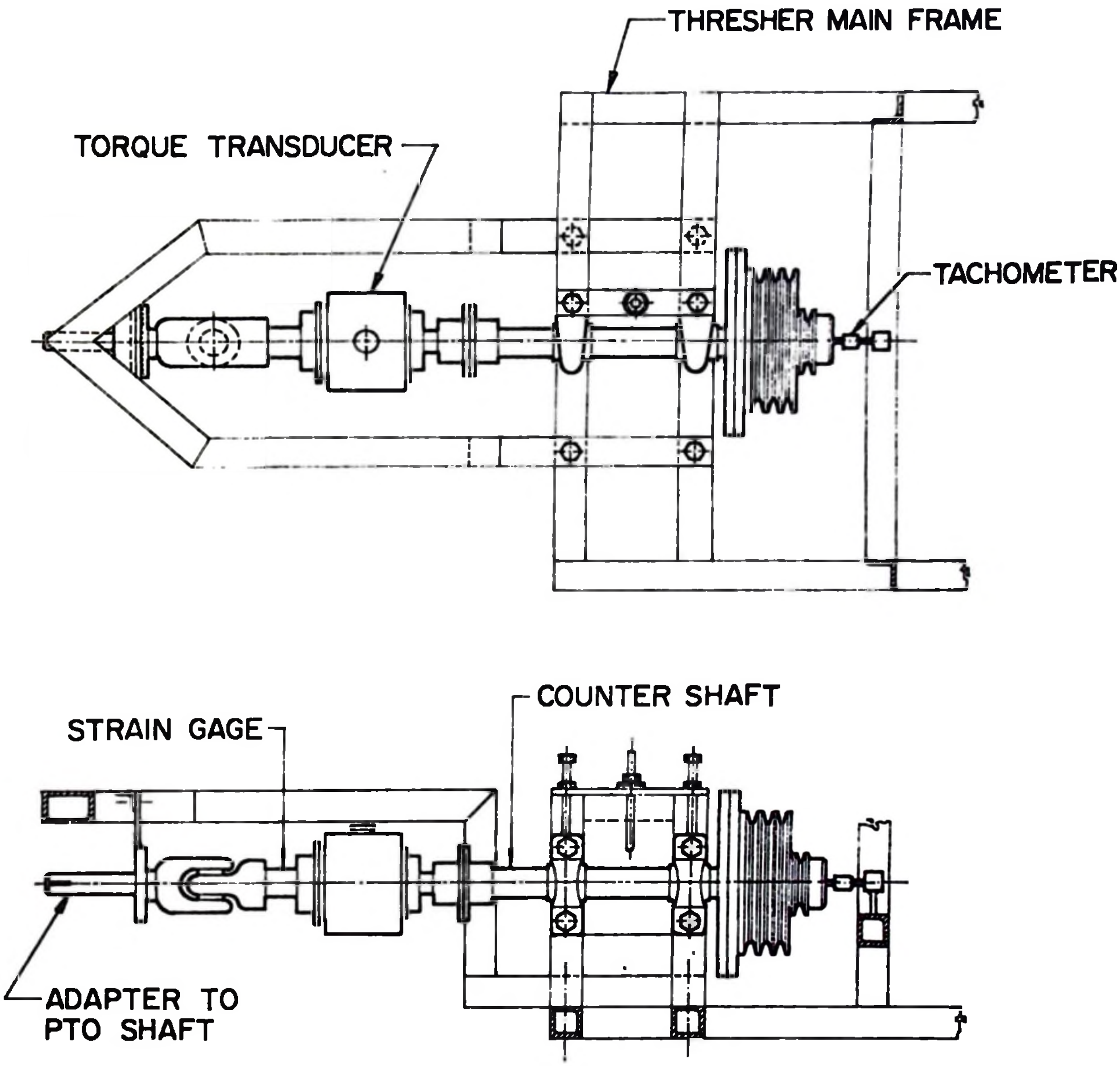



Fig. 3·19. Torque transducer on the thresher.

the torsional quantities proportional to shaft torque into equivalent electrical ones which are brought out by slip rings/brush assembly incorporated. The set up (Figure 3.19) also show a tachometer which picked up the revolution of the shaft with the transducer.

( vi) Hand computer - Polycorder - 516-B. The instrument is capable of data recording, store data collected, perform standard mathematical procedures, monitor and integrate data from other instruments and sensors.

The instrument is pre-programmed but it also accepts new programs up to 52. It uses its own language POLYCODE, wich consists of instructions that can be given to the polycoder in either alphabetic or numeric form to sequence a program.

Some of its specifications include:

Memory - maximum 16 kilobytes which allows storage of 30000 digits or 15000 alphanumeric characters.

Power - six rechargeable Ni-Cad penlight cells, one 9-volt alkaline back up battery.

Accuracy (percentage of full scale) - 0.1% for 5V and 50 mV input range.

This instrument was programmed to record torque and speed of the shaft, integrating them to give power consumed at any one time of recording.

( vii) Moisture meter - Yamamoto Moisture Meter, model YMB-1. It has a cup and sampler. When sample is filled on the cup and inserted on the sampler and pluging a wire from the meter to the sampler, moisture content of the sample can be read directly. It consumes 6VDC or 100VAC. Measuring range dry is 10% to 20% and wet range is 20% to 30%. This instrument was used in the field on wheat crop.

(viii) Weighing scale. A hanging scale with 25 kg range was used in the field to measure weight of bundles fed into the machine and the amount of grain mixture from the output spout.

A triple beam balance was either used in the field for smaller quantities or in the laboratory for larger quantities. Also in the laboratory, a Mattler P 120 with a maximum scale of 120 g, activated by AC current was used for measuring small quantities of materials.

(  ix) Grain cleaner. The bulk of sample collected from the straw thrower required quick cleaning which was supplemented by the machine mentioned.

Other instrument and supporting facilities used include torque arm; oven, while determining moisture content of samples of paddy, sorghum and corn taken into the laboratory the oven was used, operated at 105 $^{o}$C for 24 hours; tape measure/ruler were used in various applications, e.g., measuring the length of the harvested crop; stop watch; pan, for collecting grain from the output spout; buckets; net, tubular net cloth with a diameter of 800 mm and 1000 mm long were used to collect samples from straw thrower and blower, see Figure 3.20; polythene bags; and jute bags.

### 3.5.4 Experiments and data analysis.

#### 3.5.4.1 Experiments

For the paddy varieties IR38 and IR58 the thresher was towed by a 4-wheel tractor to the field with the harvested crop. When threshing paddy variety 1917, and the other two crops sorghum and corn, the activity was performed inside a building.

During wheat threshing the machine was transported 500 km to the northern part of the Philippines (Ilocos Norte

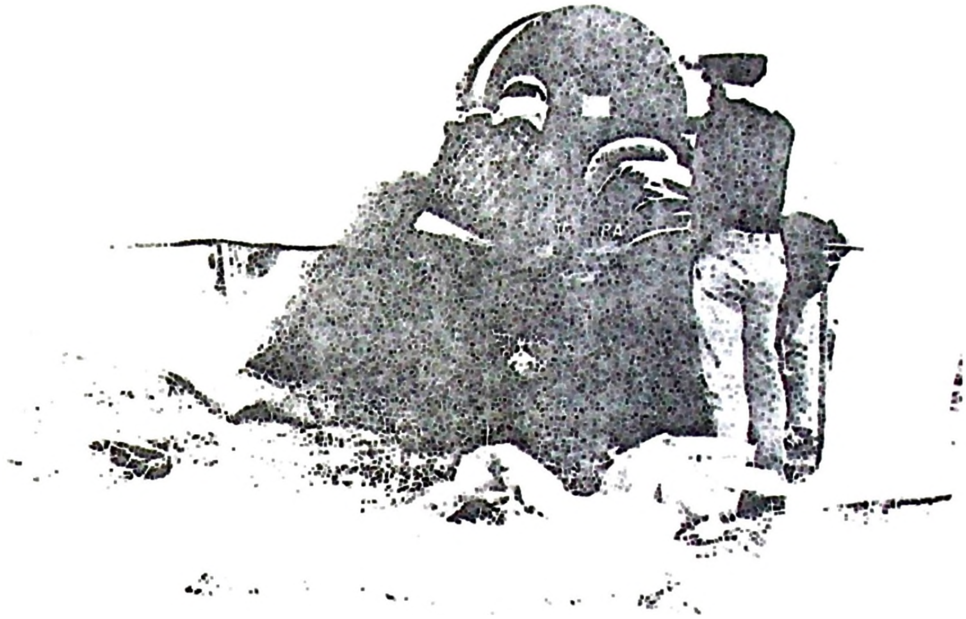
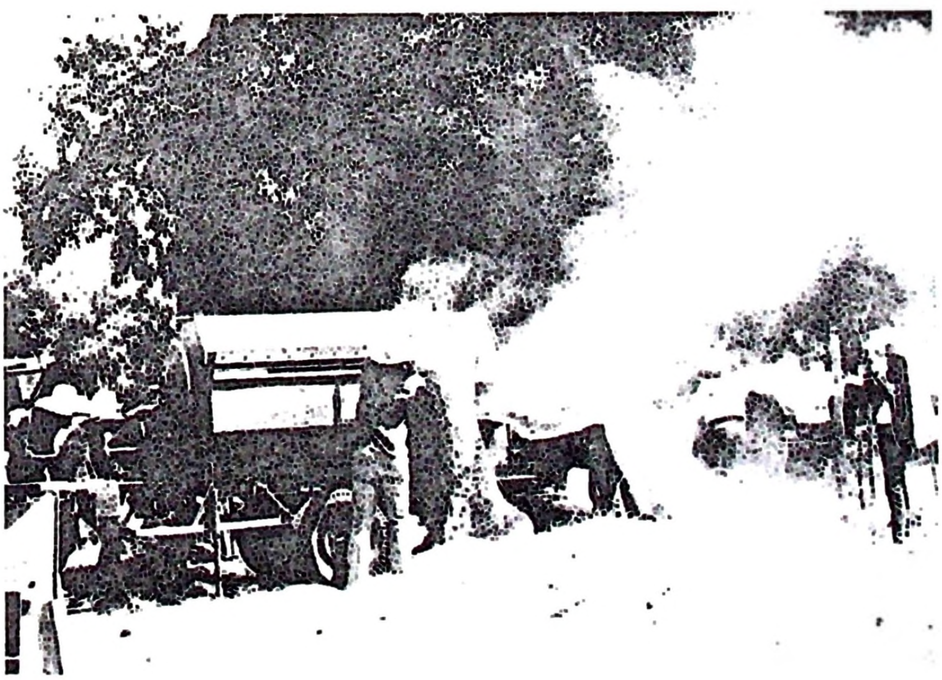


Fig. 3.20. Sample collection using net cloth.



Region). Specific farms with wheat crop were in places known as Pasuguin, Batak and Dingras.

In general, before starting any of the experiments the thresher was anchored on its four stands. then threshing without formal sample collection was conducted for sometime. This enabled preliminary machine setting to suit the crop in question. Some of the settings include, increase or decrease of aspirator air vents and peripheral velocity of the threshing cylinder and louvre angle. After that the experiment designed was conducted.

Duration of one experiment ranged from four hours to 27 hours. Samples of grain mixture were collected from the output spout, the oscillating tray, the blower, and the straw thrower. Also, some grains were forced out of the feeding hopper during feeding. And from the front of the oscillating tray some grains were also being forced out. The grain collected from discharges other than the output spout, oscillating tray blower and straw thrower are referred to as scattered grains. The duration of collecting one sample depended on among other factors, the amount of crop available and the number of trials. However, for all of the output determination experiments three minutes were spent per sample collected. Ten or 20 seconds were spent per sample aimed at other observations viz: cleaning and threshing efficiency grain recovery and grain damage.

A conveyor was used when determining the output of sorghum.

In general, eight to eleven men were involved at any one time of experiment. During output determination three men were feeding, one supplying material to feeders, two collecting grain from output spout and bagging, three collecting samples from the other three outlets, one adjusting the net cloth for the three men, and one timer. The grain forced out of the machine was dropping on to a tarpaulin which was eventually collected.

When looking for parameters other than output, two men were feeding, four collecting samples and one timer. Both cases required a tractor operator.

During feed rate determination, specific bundles of the crop were weighed. Time to thresh the weighed material was monitored.

Before collecting a sample for any trial the machine required "priming". Five bundles of wheat weighing an average of 10.5 kg or 3 bundles of paddy weighing an average of 9.2 kg were enough to have a constant flow of grain into the output spout.

Sequence of experiments were as follows:

( i) Paddy variety IR58. Output determination.

Condition of the crop is on Tables 3.2a and 3.2b.

Settings of the machine were; number of louvres, 10, angle of louvres, $14^{o}$ , slope of oscillating tray $1.44^{o}$; area of fan blades 100%; aspirator air vent 15%; and cylinder peripheral velocity 16.76 $ms^{-1}$.

Another experiment was conducted using the same variety of paddy IR58. The experiment was aimed at locating a better slopefor the oscillating tray in relation to the aspirator air vent. To achieve that, two variables were used:

| | |
|---|---|
| Oscillating tray slope | $1.44^{o}$, $3.44^{o}$ |
| Aspirator air vent | 0%, 15.30% |

( ii) Paddy variety IR38

Tables 3.2a and 3.2b show the condition of crop. The machine setting for this variety was the same as that for the paddy variety IR58, except that the number of louvres were reduced to 5. Also the area of the screen over the output spout was increased from 0.150 $m^2$ to 0.313 $m^2$.

Two experiments were conducted using the variety. The aim of the first experiment was to determine output while the second one was aimed at determining a threshing cylinder speed with minimum grain loss and damage, and high threshing efficiency. The variable factors were:

| | | |
|---|---|---|
| Cylinder peripheral velocity | 15.71 $ms^{-1}$, | 16.76 $ms^{-1}$ |
| Aspirator air vent | 0% | 15.30% |
| Oscillating tray slope | $1.44^{o}$, | $-0.56^{o}$ |

(iii) Sorghum variety casor 2.

Tables 3.3a and 3.3b show the condition of the crop. The crop was harvested in a period of four days. The harvested materials were hauled to a building and spread on a cemented floor. When the last batch of the crop was collected, all the old and newly harvested crop was mixed and dried for another three days.

An experiment was conducted using a conveyor while the settings on the thresher were as follows:

| | |
|---|---|
| Oscillating tray slope | $3.44^{o}$ |
| Number of louvres | 10 |
| Aspirator air vent | 89.53% |
| Fan blade area | 100% |

The settings were varied for another experiment aimed at locating optimum setting for higher cleanliness and grain recovery. The variation were:

| | |
|---|---|
| Oscillating tray slope | $1.44^{o}$, $3.44^{o}$ |
| Louvre angle | $14^{o}$, $(14 - 7)^{o}$ |
| Aspiration air vent | 30.63%, 89.53% |

( iv) Wheat Variety Trigo 1

Tables 3.4a and 3.4b show the condition of the crop. The first experiment conducted, utilized the wheat crop found in Pasuguin. The settings of the thresher for the experiment had louvre angle of $14^{o}$ - $0^{o}$ oscillating tray slope $3.44^{o}$, and aspirator air vent

30.63%. For this experiment, three threshing cylinder speeds were used which are (510, 610 and 710) rpm (17.81, 21.30 and 24.79)$ms^{-1}$.

The wheat from Batak was used to determine the feed rate, the effect of louvre angle when it is at $14^{o}$- $0^{o}$ , and the effect of the output spout screen area when reduced from 0.314 $m^2$ to 0.174 $m^2$. Another experiment was also performed with the following variables:

| | |
|---|---|
| Cylinder velocity | 21.30 $ms^{-1}$, 23.39 $ms^{-1}$ |
| Oscillating tray slope | -0.56 , $1.44^{o}$, $3.44^{o}$ |
| Aspirator air vent | 89.53%, 100% |

In Dingras, an adjustable rear end sucking duct was added on the rear sucking duct and the area of the output spout screen was decreased to $0.150m^2$. The crop condition is on tables 3.4a and 3.4b; and the machine setting was:

| | |
|---|---|
| Oscillating tray slope | $1.44^{o}$ |
| Louvre angle | $14^{o}$ - $0^{o}$ |
| Aspirator air vent | 30.67% |
| Fan blade area | 79.46% |

Two cylinder velocities 21.30 $ms^{-1}$ and 23.39 $ms^{-1}$ were used to determine the effect of the adjustable sucking duct.

( v) Paddy variety 1917.

Tables 3.2a and 3.2b gives the condition of the crop and machine setting. It can be observed (Figure 3.21) the relationship of the adjustable duct and the screen. Two experiments were run using the crop to determine the effect of the adjustable rear end duct and the second one to determine the feed rate of the crop.

( vi) Yellow corn

Tables 3.3a and 3.3b show the crop condition and machine setting. The only variable with the corn experiments was the threshing cylinder speed which was 300 rpm and 380 rpm.

It is worth noting that during wheat threshing which took place at different farms, the thresher was being trailed by either a pick-up or a tractor. One longest trip covered to and fro was 90 km, while the shortest was 50 km.

The bulk of samples collected from the straw thrower and blower were pre-cleaned so that they could be accommodated into 50 kg capacity bag or small polythene bags for further cleaning and hence analysis.

3.5.4.2 Data Evaluation

A sample from each of the harvested crop and its total length of cut was measured. Also the grain and straw weight

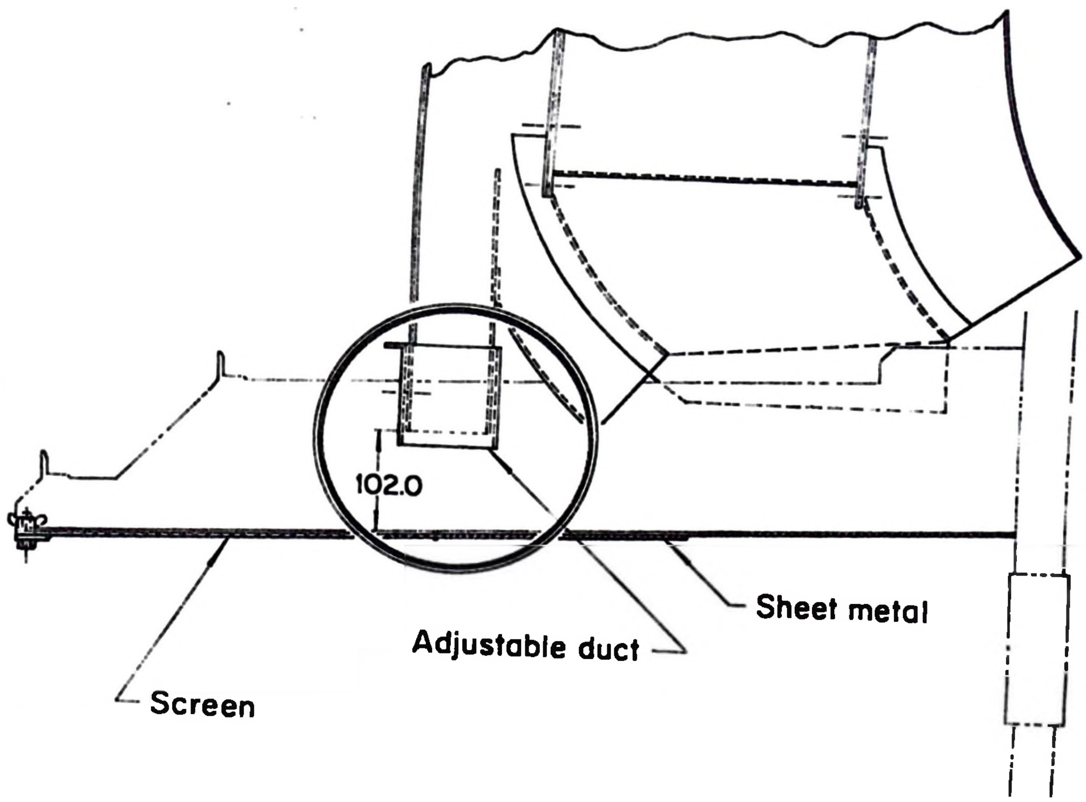



Fig. 3·21. Aspirator adjustable rear duct end of the sample were recorded leading to the determination of percentage grain.

Samples collected from different discharges of the thresher were cleaned, weighed and converted to give an amount per hour, threshing and cleaning efficiency, grain damage and grain recovery, see appendix A to G. The values in the appendix have been arrived at by using the relationships shown below:

Efficiency of cleaning (mature and immature grains)

$$\eta ME = 100\ (QMo + QE)/QI \quad \text{-----------} \quad 3.8$$

Efficiency of threshing

$$\eta T = 100\ (1 - QU/QIo) \quad \text{-----------} \quad 3.9$$

Percentage of grain damaged

$$\zeta = 100\ (QD/QI) \quad \text{--------------} \quad 3.10$$

Grain recovery

$$\kappa_0 = 100\ (QIo/QI) \quad \text{-------------} \quad 3.11$$

Total grain loss

$$GL = 100 - \kappa o \quad \text{------------} \quad 3.12$$

Grain recovery (from output spout and over the oscillating tray)

$$\kappa os = 100\ (QIo + QIs)/QI \quad \text{----------} \quad 3.13$$

Foreign material[7]

$$F = Q - QIo$$

---------------

[7] Foreign material include organic and inorganic material other than grain which includes sand gravel, clay, mud, metal, chaff and straw, weed seeds, and other grains.

# CHAPTER FOUR

# RESULTS AND DISCUSSION

## 4.1 SAMPLE OF THE IRRI-PAK THRESHER

The machine, which took 75 days to build, is represented on figure 4.1a which shows the side view with the feeding hopper removed. Figure 4.1b show the left hand side of the machine with the relative positions of the blower and the straw thrower.

The assemblies which took much of the time are the threshing cylinder and the oscillating tray. The work on the thresher did not end after the 75 days because, just after two experiments with paddy variety IR58 some additions had to be made. The additions included fixing on the adjustable louvres; increasing the size of the screen over the output spout, adding a frame for supporting a conveyor and fixing on brackets for a torque transducer assembly.

The arrangement of pulley and flywheel on the threshing cylinder shaft are seen on figure 4.1a. When analyzing the weight upon the shaft, the shear force and bending diagrams resulted to figure 4.2. When the driving force from the pulley was included, the diagrams changed to the one on figure 4.3. By using the formula in Appendix G and formula 3.3 the diameter was taken to be 50 mm.

From figure 4.1a an additional attachment to the

(a)

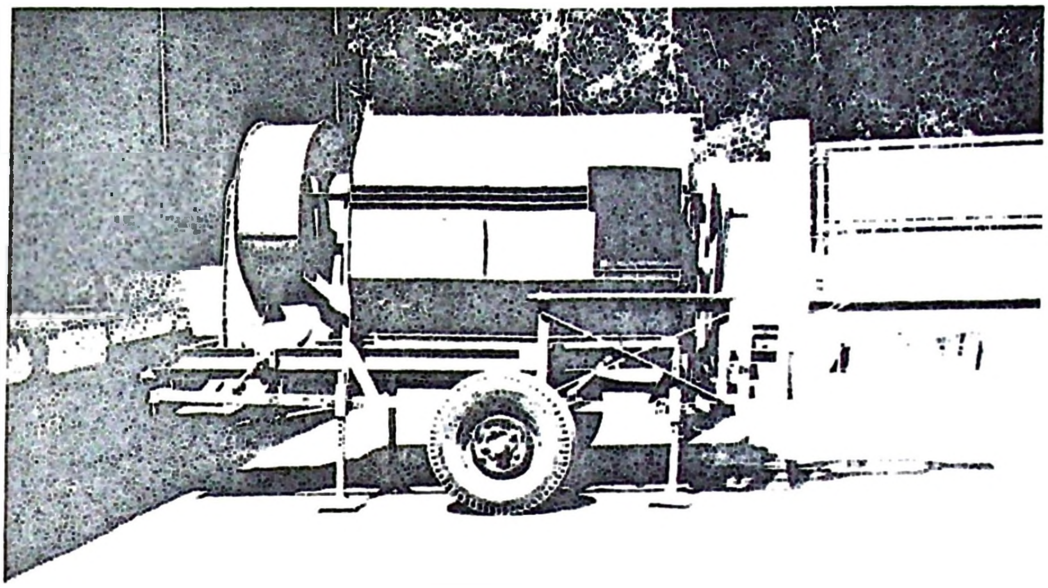


Fig. 4.1a. Side view of the IRRI-PAK thresher, feeding hopper removed.

(b)

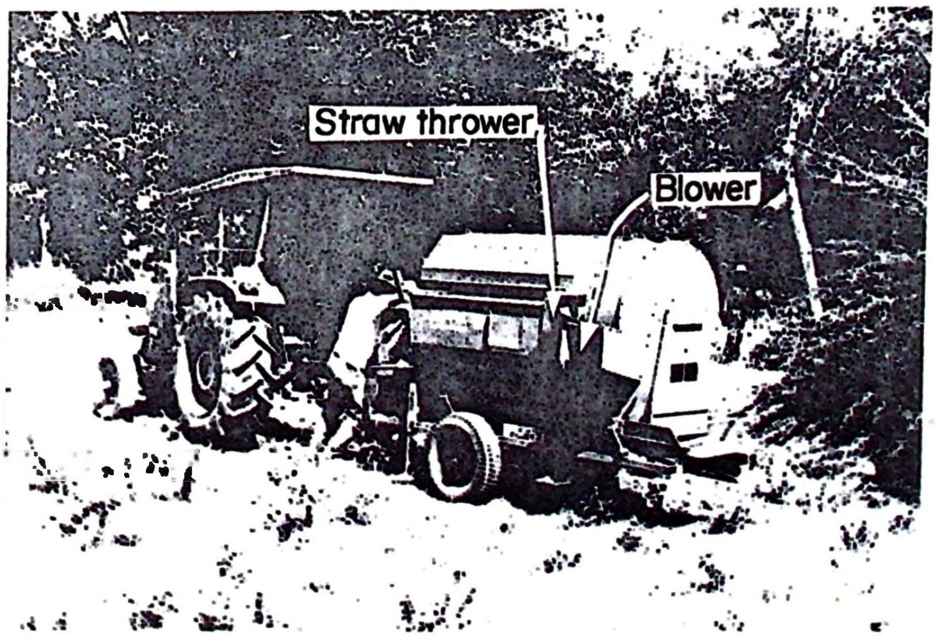
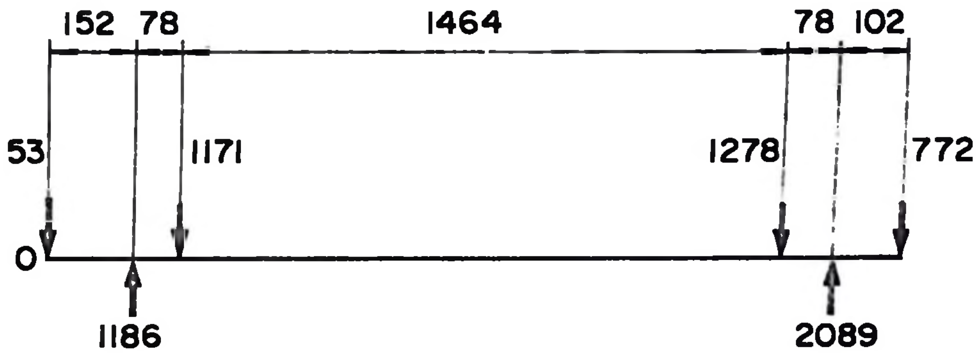
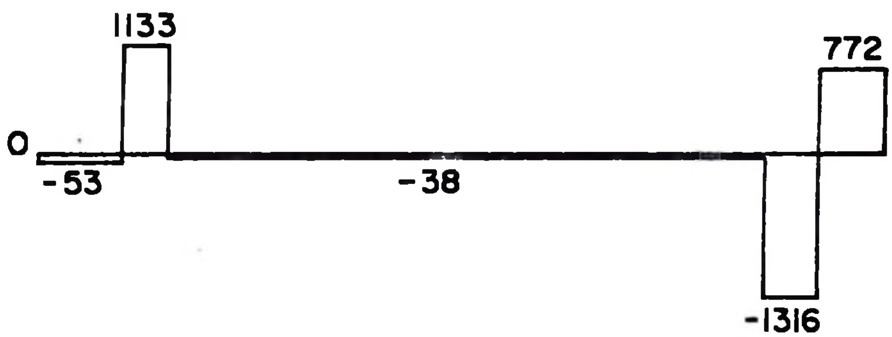



Fig. 4.1b. Side view of the thresher showing relative positions of straw thrower and blower.

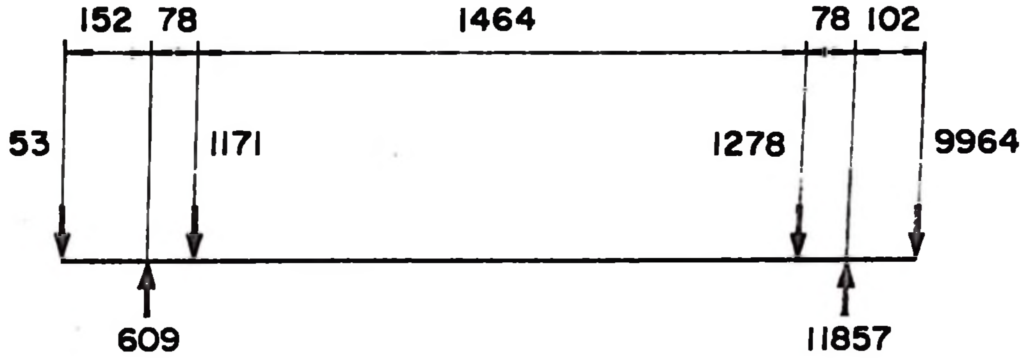



(a) Loading diagram

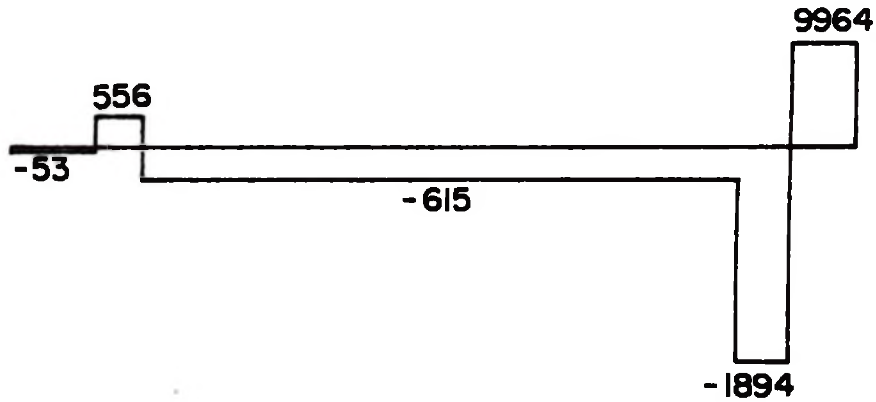



(b) Shearing force diagram

Fig. 4·2. Loading, shear diagrams with dead load on the threshing cylinder shaft.




(a) Loading diagram




(b) Shearing force diagram

Fig. 4·3. Loading, shear diagram with binding force included on the threshing cylinder shaft.

drawbar is observed. This makes it easier for the machine to be hitched to an automobile with a low hitching point.

## 4.2 COST OF PRODUCTION

When we consider labor input, it has been pointed out in chapter three that almost every person in the engineering department participated in one way or the other to manufacture the thresher. For example, without the store officers and attendants, drivers and the secretaries (who made the urgent telephone calls) the fabrication would have taken longer time.

In case of the materials used, usually the metal sections are purchased in large quantities. Thus, gaining the advantages of (discounts) scale.

However, the cost considered has included the current price (in the Philippines) of the materials used and the technical labor utilized (estimated).

From the Appendix Table H1 through H5, the materials used and their respective cost in US dollars are listed. Their total cost is US$1073[8]. Assuming that if a workshop technician is supplied with the materials for a machine fabrication which requires either gas or arc welding to assemble them, he will charge US$3.6 per day spent on the

----------------

[8] The conversion is based on Philippine Currency 1 US$ = ₱18.5

machine. The IRRI-PAK thresher, therefore, if assumed to occupy two people full time for 75 days, US$540 will be required for the labor. Together with the cost of materials used, the total amount of money invested is US$1613. This cost is probably slightly high as the quotations of the materials used has been the maximum alternative offered.

It may sound unrealistic to have two people building the machine but it is possible. Essentially a keen welder who can cut, roll and join sections precisely, and a fitting and turning technician are enough. Extra levers/hands will be required during fixing the threshing cylinder on the main frame. It should be clear that the cost mentioned is only for material used and fabrication labor.

## 4.3 CLEANING AIR

Adjustment of the aspirator air vents coupled with variation of the aspirator fan velocity, resulted to different air blasts through the aspirator sucking ducts and over the oscillating tray assembly. Mean of the air velocity through the different inlets and from the aspirator outlet are in table 4.1.

The values when all the aspirator air vents were fully closed (0% opened area)and fan blade area reduced to minimum (69.995% of the total area) are represented on figure 4.4. From the figure mentioned the behavior of air through the

Table 4.1. Air velocity through the aspirator with different fan peripheral velocity.

| Fan blade area | Fan vel | Front vent gap | Rear vent gap | Air Velocity: Front of osc. tray | Air Velocity: Front suck. duct | Air Velocity: Middle suck. duct | Air Velocity: Rear suck. duct | Outlet |
|---|---|---|---|---|---|---|---|---|
| (%) | ($ms^{-1}$) | (mm) | | $ms^{-1}$ | | | | |
| 69.995 | 13.565 | 0 | 0 | 1.300 | 4.113 | 2.294 | 2.767 | 8.879 |
| | | 0 | 76 | 1.033 | 3.800 | 2.033 | 2.500 | 8.500 |
| | 17.183 | 0 | 0 | 1.681 | 4.314 | 2.814 | 4.976 | 9.913 |
| | | 0 | 76 | 1.275 | 3.900 | 2.500 | 4.000 | 9.300 |
| 69.995 | 20.348 | 0 | 0 | 2.309 | 6.898 | 4.619 | 8.220 | 12.698 |
| 100.00 | 20.348 | 0 | 0 | 2.763 | 7.431 | 5.300 | 11.508 | 15.130 |
| | 20.348 | 0 | 38 | 2.649 | 6.826 | 4.909 | 11.100 | 14.701 |
| 69.995 | 21.705 | 0 | 0 | 2.509 | 7.103 | 4.890 | 9.714 | 13.498 |
| 79.460 | 21.705 | 0 | 0 | 2.778 | 7.492 | 4.968 | 8.763 | 15.600 |
| | | 0 | 127 | 2.158 | 5.611 | 4.402 | 7.094 | 13.013 |
| | | 25 | 127 | 2.085 | 4.986 | 4.109 | 6.567 | 12.222 |
| 100.00 | | 0 | 0 | 2.800 | 7.556 | 5.490 | 12.750 | 16.000 |
| | | 0 | 127 | 2.233 | 6.086 | 4.614 | 9.156 | 14.467 |
| | | 27 | 127 | 2.103 | 5.318 | 4.323 | 7.465 | 12.977 |
| 69.995 | 27.582 | 0 | 0 | 2.979 | 10.780 | 5.506 | 8.985 | 20.791 |
| | | 25 | 127 | 2.713 | 7.533 | 4.300 | 8.814 | 17.571 |
| | | 102 | 165 | 2.013 | 6.461 | 3.098 | 7.582 | 15.556 |
| | 30.296 | 0 | 0 | 3.689 | 12.703 | 6.942 | 9.567 | 26.430 |
| | | 25 | 127 | 2.986 | 9.686 | 4.200 | 8.725 | 21.764 |
| | | 102 | 165 | 2.248 | 8.101 | 3.502 | 7.831 | 19.025 |

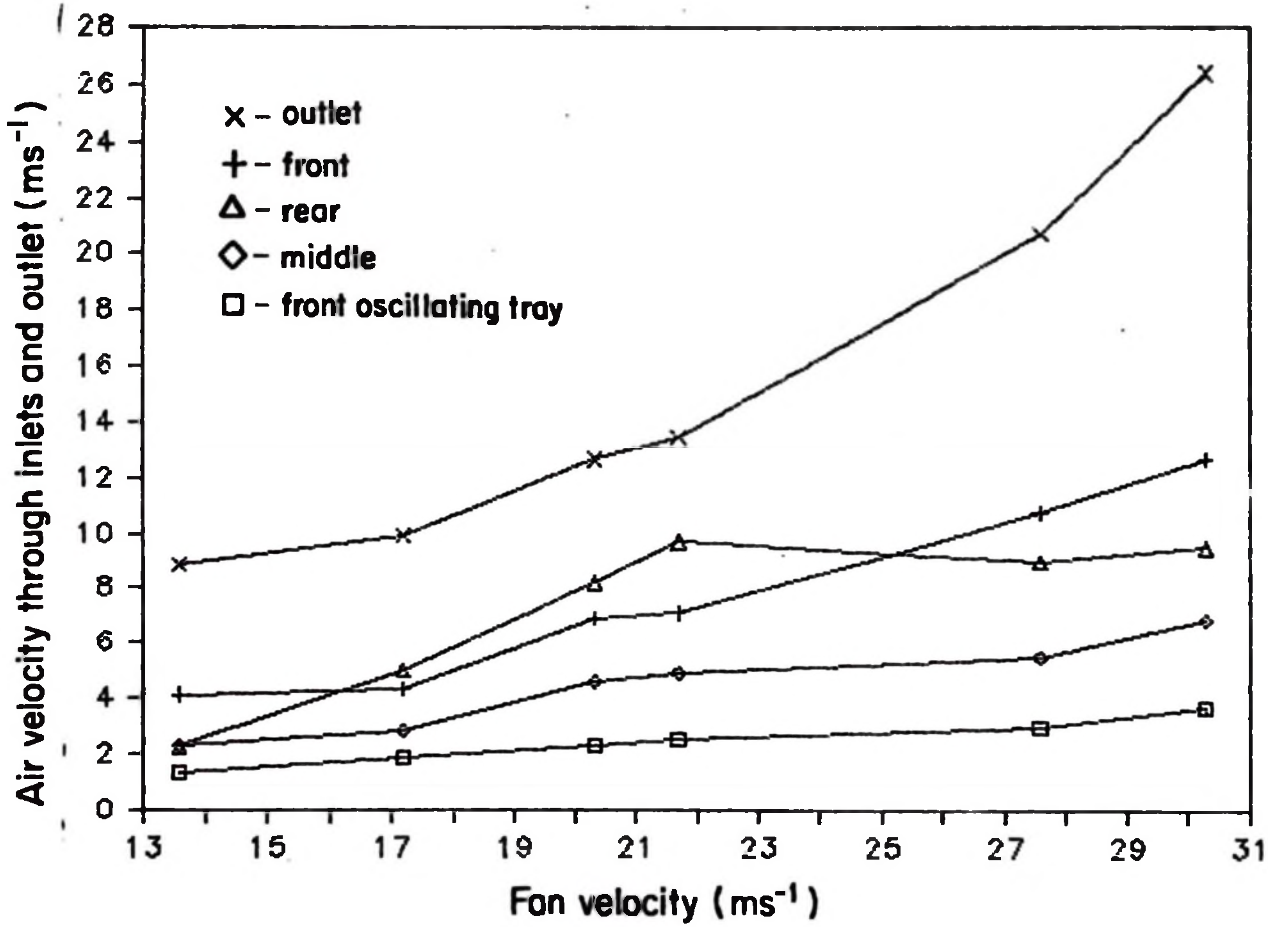



Fig. 4·4. Air velocity through the aspirator with air vents closed (0 % opened area) and fan blade area reduced to minimum (69.995 % of the total area).

front sucking duct and through the aspirator outlet are similar except that the former exhibit lower air velocity than the latter. Air through the middle sucking duct and over the oscillating tray show lower values than the rest, the latter experiencing the least.

The air velocity through the rear sucking duct increase with increasing fan velocity up to 21.7 $ms^{-1}$ fan velocity, then drops below the curve of the air passing over the oscillating tray.

From the trend of the curves, it can be said that the front and the rear sucking ducts picks from the tray most of the foreign material. The middle sucking duct picks only the relatively lighter foreign materials. And the velocity measured from the front of the oscillating tray verify that the transfer of materials over the tray is not only due to the oscillating effect but also due to the air blast created by the aspirator fan.

## 4.4 THRESHER PERFORMANCE - GENERAL

Some measurements on crops' condition are shown in table 4.2a. The maximum values of grain output, grain recovery, cleaning efficiency, and threshing efficiency are in table 4.2b. For paddy, sorghum and corn, a significant amount of grain could be collected from the end of the oscillating tray. Such collection has also been considered as grain recovered. On the whole grain recovery with corn

Table 4.2a. The summary of condition of the crops used to evaluate the performance of the IRRI-PAK thresher.

| Location | Crop | Variety | Length of cut (mm) | Grain percentage | Moisture Content Grain (%) | Moisture Content Straw (%) |
|---|---|---|---|---|---|---|
| IRRI | Paddy | IR32 | 527 | 31.85 | 28.21 | 64.20 |
| " | " | IR58 | 684 | 31.38 | 17.70 | 62.80 |
| " | " | 1917 | 609 | 32.45 | 22.13 | 65.88 |
| " | Sorghum | Casor 2 | 399 | 48.17 | 22.55 | 47.23 |
| Pasuquin | Wheat | Trigo 1 | 653 | 31.39 | 13.09 | 15.46 |
| " | " | " | 653 | 31.39 | 13.09 | 15.46 |
| " | " | " | 653 | 31.39 | 13.09 | 15.46 |
| Batak | " | " | 577 | 34.33 | 13.11 | 14.56 |
| " | " | " | 577 | 34.33 | 13.11 | 14.56 |
| Dingras | " | " | 661 | 25.71 | 12.35 | 14.20 |
| " | " | " | 661 | 25.71 | 12.35 | 14.20 |
| IRRI | Corn | Yellow | | 64.18 | 14.31 | |
| " | " | " | | 64.18 | 14.31 | |

Table 4.2b. The summary of the performance data of the IRRI-PAK Thresher on different crops.

| Location | Crop | Variety | Cylinder Velocity ($ms^{-1}$) | Power1/ (kW) | Output ($kgh^{-1}$) | Grain reco. | Threshing efficiency | Cleaning efficiency |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| | | | | | | (%) | | |
| IRRI | Paddy | IR36 | 16.76 | | 1569 | 98.77 | 99.99 | 93.39 |
| " | " | IR58 | 16.76 | | 1467 | 98.37 | 99.99 | 96.01 |
| " | " | 1917 | 15.71 | 18.95 | 1521 | 98.30 | 99.99 | 97.45 |
| " | Sorghum | Casor 2 | 16.76 | | 1594 | 98.73 | 98.47 | 97.65 |
| Pasuquin | Wheat | Trigo 1 | 17.81 | | 1062 | 99.23 | 96.12 | 88.04 |
| " | " | " | 21.30 | | 1509 | 98.58 | 97.38 | 89.79 |
| " | " | " | 24.79 | | 2110 | 98.77 | 97.78 | 76.60 |
| Latak | " | " | 21.30 | 22.17 | 1725 | 98.97 | 96.46 | 96.57 |
| " | " | " | 23.29 | 25.87 | 1966 | 98.94 | 96.81 | 96.90 |
| Dingras | " | " | 21.30 | | 920 | 99.01 | 96.40 | 93.03 |
| " | " | " | 23.39 | | 1122 | 96.89 | 96.87 | 89.98 |
| IRRI | Corn | Yellow | 10.47 | 5.64 | 862 | 83.42 | 99.98 | 87.84 |
| " | " | " | 13.23 | 5.24 | 896 | 82.36 | 99.98 | 87.13 |

1/ Blank space implies no measurement was taken.

threshing is comparatively the lowest, 82.36%. Much of the grain lost occured through the straw thrower.

The output shown include all the grain passed through the machine, which include, immature, mature, damaged and unthreshed grains. The output of wheat when tested on different cylinder velocities increses with increasing cylinder velocity. With cylinder velocity of 17.81 $ms^{-1}$ and 24.79 $ms^{-1}$, the output from the highest velocity is 1.99 times that of smallest one. The same argument apply for the threshing efficiency which increses 1.02 times. Contrary is the cleaning efficiency which decreases 1.25 times. The low values of cleaning efficiency were obtianed when the screen area over the output spout was $0.314m^2$. But this area contributed to low grain loss from screen and aspirator, hence the overall grain recovery with wide screen area was high. A graphical representation (figure 4.5a) shows the difference of grain recovery from the output spout and from the output spout plus the grain by passing the oscillating screen/tray to be very small. Generally, the grain recovery is shown to decrease with increasing cylinder velocity (figs. 4.5a and 4.5b). This is so because the increased frequencies of the tray limit chances of seed to sift into the output spout and being transfered to the end of the tray. Also the velocity of cleaning air increases which picks together with straws, the less density grains

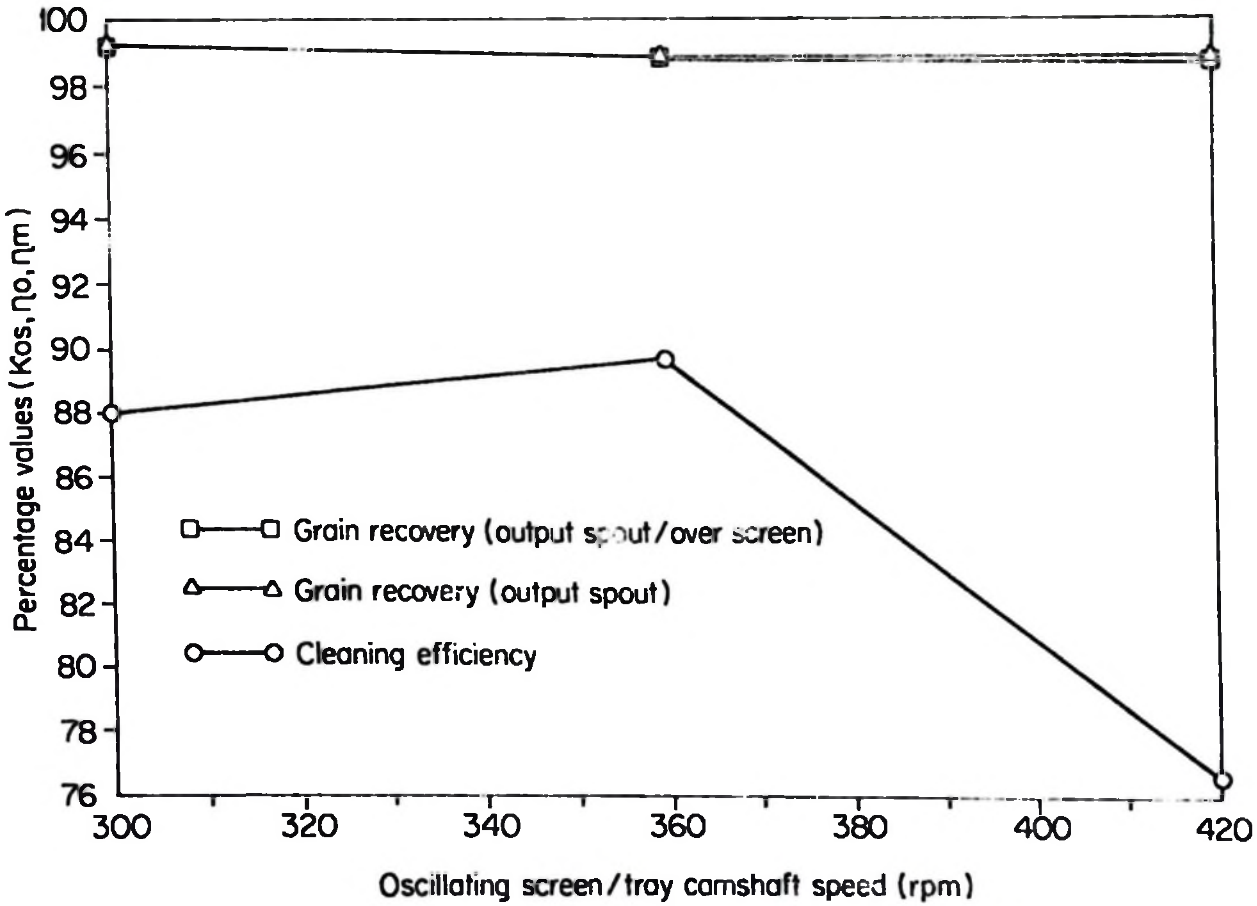



Fig. 4·5 a. The effect of screen area over the output spout when maintained at 0.314 $m^2$ on wheat cleaning efficiency and grain recovery.

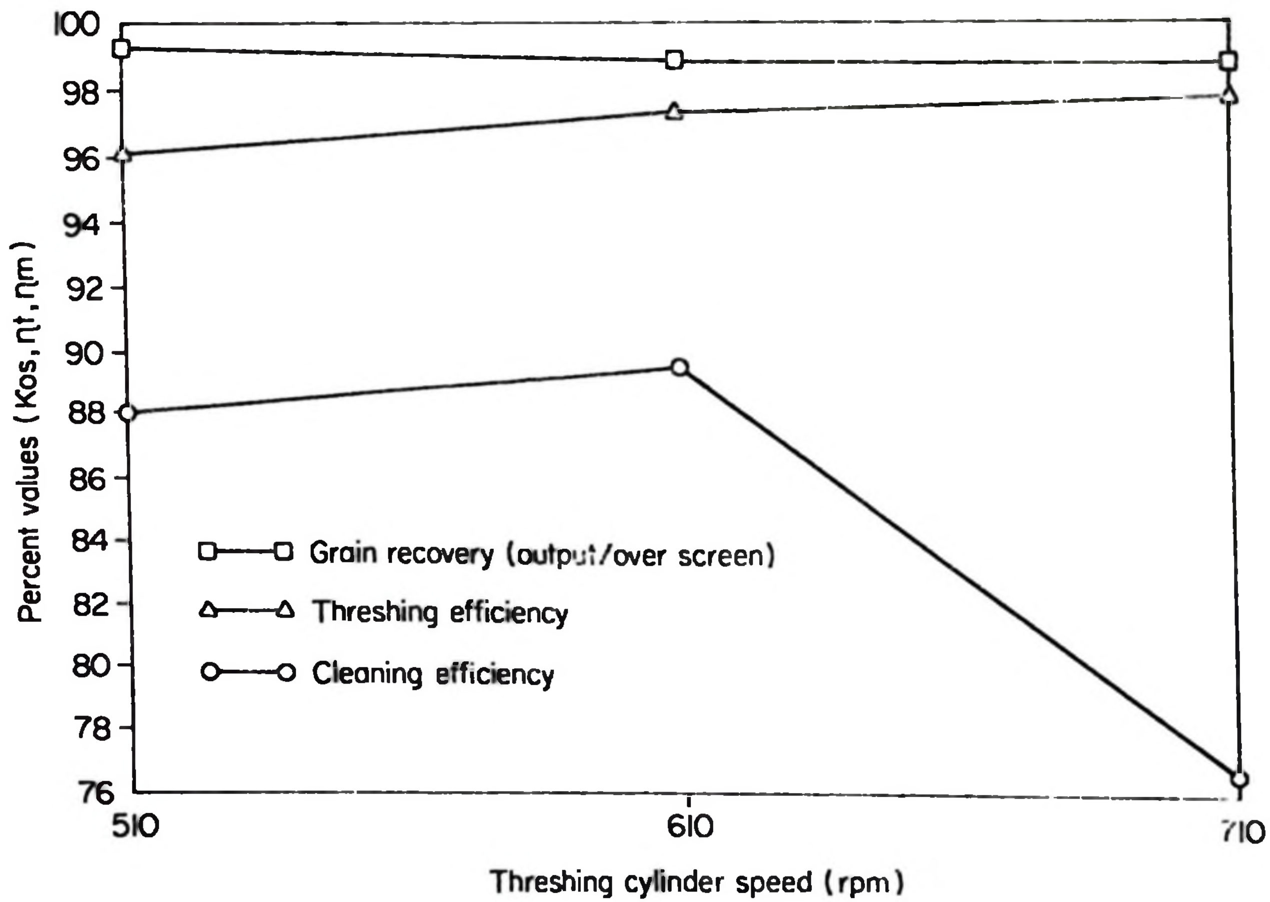



Fig. 4·5 b. The effect of threshing cylinder speed on wheat grain cleaning efficiency, grain recovery and threshing efficiency.

especially the immature ones. Cleanliness decreases because pulverization of the straw becomes high with increased speed and the small straw cuttings can easily sift through the screen to the output spout. Further, since the screen area had been increased to cover a portion between the sucking ducts (where sucking, was not occuring) much of the chaff could sift easily to the output spout, from that portion where sucking was not taking place.

Throughout the discussion, the damaged grains will not strictly be alloted for cylinder losses. It is because almost all the crops used had some grains showing signs of insect or disease damage. Harrison (1975) also cautioned that when assessing damaged grains, the subject becomes complicated, because it cannot readily be defined. The breakage may vary from small cracks in the seed coat which are invisible to the naked eye to the splitting of the kernel into two or more segments.

It can also be pointed here that the length of cut influenced machine output. For example, although the paddy threshed consisted of two varieties IR38 and IR58 their length of cut can be used as a general reference. The length of IR38 was 527 mm compared to the 684 mm of IR58. Their gra[illegible]ercentage were 31.85% and 31.38% respectively. Consequently, the one with shorter straws had a slightly higher output (Table 4.2b). Similar phenomenon has been shown (Progressive Report, 1978) that the capacity of IRRI-PAK threshers decreases by one half, when the straw length increases from 450/600 mm to 700/900 mm.

## 4.5 PERFORMANCE ON PADDY

From Table 4.3 the response of variety IR38 to different settings of the machine is tabulated. The table has been extracted from Appendix B. It can be noted that threshing efficiency is not included because it has been above 99.8% for the two cylinder velocities used; $15.71 ms^{-1}$ and $16.76 ms^{-1}$.

Recalling the design features of the machine, the aspirator fan is fixed on the threshing cylinder shaft. And the oscillating tray gets its drive from the counter shaft connected to the PTO shaft. Moreover, on threshing paddy a pulley 225 mm diameter is fitted on the cylinder shaft. The pulley is driven by one of 200 mm diameter and their configuration result to a speed of 480 rpm for the threshing cylinder and 360 rpm for the oscillating tray cam shaft. By reducing the speed of the threshing cylinder to 450 rpm [$15.71 ms^{-1}$] simply by relaxing the tractor throttle, consequently the fan and the oscillating tray camshaft speeds decrease both of which affect cleanliness of the grains.

It can be learned from Table 4.2a that the three paddy varieties used differ in length of cut, grain percentage, moisture content, and date of harvest. This makes it a bit unrealistic to compare them in every aspects. However, basing on the screen area above the output spout, there is more grain recovery 98.22% Table 4.3 at $0.314m^2$ than at $0.15m^2$ which gives values between 73.06% and 84.25% of grain recovery as shown in Table 4.4a. It means, therefore, if the grain transfered with straw to the end of the oscillating tray/screen is added to the grain lost from the straw thrower and blower the total grain loss will amount to 24%. But grain lossess from the oscillating tray can easily be recovered by adopting either of the following alternatives: one is to increase the size of the screen holes (more than 10mm). Eventually this will allow much of the foreign materials through the output spout than otherwise. Second is to provide a pan into which the mixture by passing the oscillating tray will drop. This is good provided the extra manpower for collecting the mixture and later clean it,will not influence much the total running costs. The third is the one which has been made i.e., to increase the total area of the screen.

One major disadvantage of having a relatively wider screen without considering its relation to the sucking ducts result to poor cleaned grains. This is true when comparing cleaning efficiencies in Tables 4.3 and 4.4a and Figures 4.6

Table 4.[illegible]. Different settings of the thresher and the outcome on paddy variety IR[illegible].

| | Description | Units | Combinations | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Setting | Fan velocity 1/ | ($ms^{-1}$) | 20.35 | 20.35 | 21.71 | 21.71 | 20.35 | 20.35 | 21.71 | 21.71 |
| | Asp. air vent | ([illegible]) | 0 | 0 | 0 | 0 | 15.30 | 15.30 | 15.30 | 15.30 |
| | Osc. tray slope | (degrees) | -0.56 | 1.44 | 1.44 | -0.56 | 1.44 | -0.56 | 1.44 | -0.56 |
| Outcome | Effic. of cleaning | (%) | 93.39 | 92.93 | 92.92 | 93.03 | 91.61 | 92.15 | 91.15 | 91.85 |
| | Grain recovery | | 98.22 | 98.22 | 98.43 | 98.35 | 98.77 | 98.42 | 98.73 | 98.50 |
| | Grain damage | | 0.03 | 0.03 | 0.03 | 0.03 | 0.02 | 0.03 | 0.02 | 0.03 |
| | Blower loss | | 0.59 | 0.50 | 0.26 | 0.38 | 0.05 | 0.41 | 0.01 | 0.26 |
| | Thrower loss | | 1.19 | 1.17 | 1.31 | 1.27 | 1.18 | 1.16 | 1.26 | 1.23 |
| | Screen loss | | 0.23 | 0.38 | 1.27 | 0.33 | 0.51 | 0.03 | 0.58 | 0.10 |

1/ 20.35$ms^{-1}$ and 21.71$ms^{-1}$ correspond to 15.71$ms^{-1}$ and 16.76$ms^{-1}$ cylinder peripheral velocities respectively. The screen area over the output spout was maintained at 0.314$m^2$.

Table 4.4a[1/]. Different settings of the thresher and the outcome on paddy variety IR58.

| | Description | Units | Combinations 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|---|
| Setting | Osc. tray slope | (degrees) | 1.44 | 3.44 | 3.44 | 1.44 |
| | Asp. air vent | (%) | 0 | 0 | 15.30 | 15.30 |
| Outcome | Effic. of cleaning | (%) | 96.01 | 95.60 | 94.98 | 95.10 |
| | Grain recovery | | 77.18 | 73.00 | 77.28 | 84.25 |
| | Grain damage | | 0.02 | 0.02 | 0.01 | 0.02 |
| | Blower loss | | 0.32 | 0.04 | - | 0.12 |
| | Thrower loss | | 1.03 | 1.54 | 1.03 | 1.56 |
| | Screen loss | | 20.87 | 24.[illegible] | 21.0[illegible] | 19.[illegible] |

1/Threshing cylinder peripheral velocity is 16.76 $ms^{-1}$ and screen area over the output spout 0.15 $m^2$.

2/Dash implies negligible value

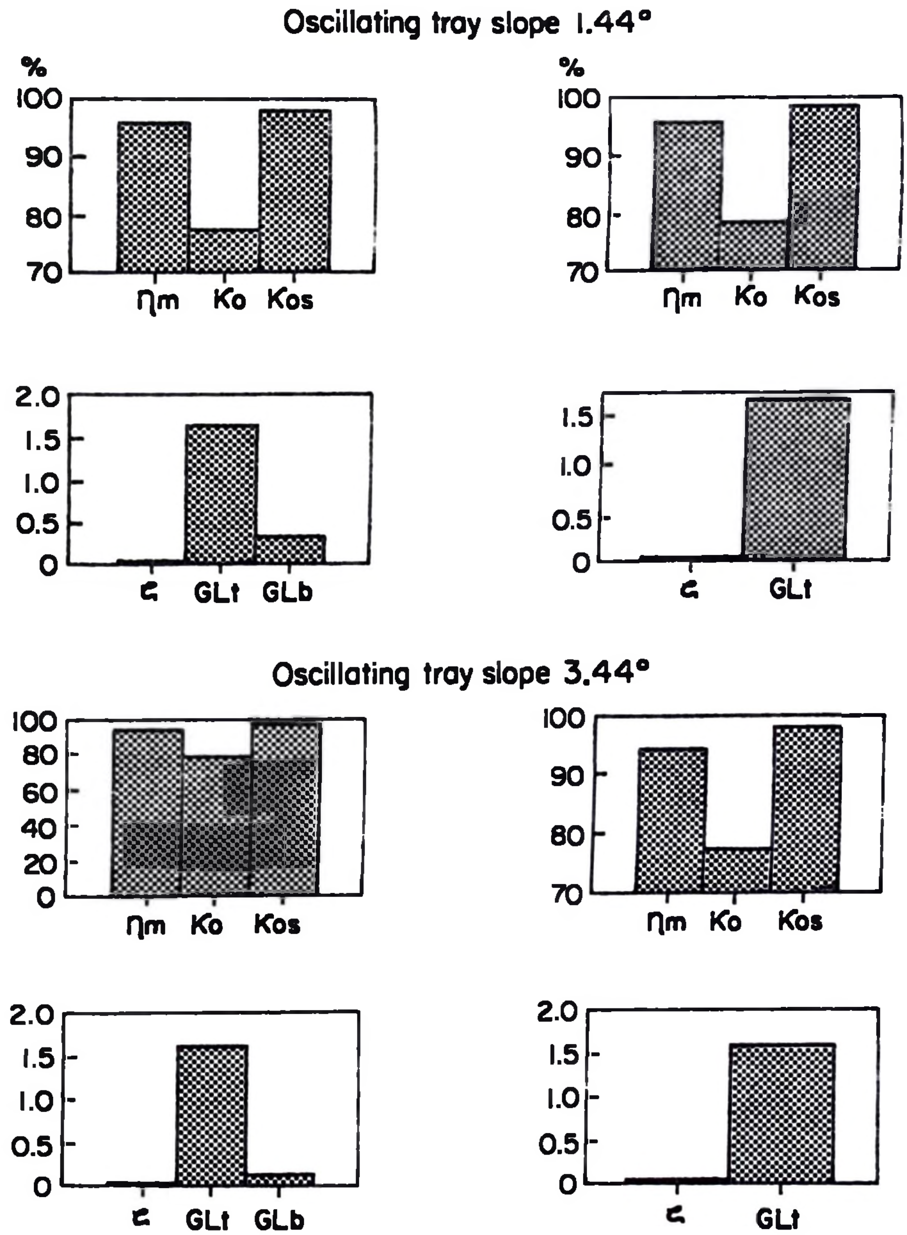



Fig. 4·6. Performance of the thresher on paddy variety IR58.

Note: Cylinder speed is 16.76 $ms^{-1}$. Aspirator air vent 0 % and 15.30 % left hand side and right hand side columns respectively.

and 4.7 shows the maximum cleaning efficiency of 93.39% with screen area increased, and 96.01% with screen area decreased.

Table 4.4b contains data of experiments with paddy variety 1917. During the experiments the rear sucking duct of the aspirator was fitted with an adjustable end duct. This attachment when lowered, limited the transfer of straw together with some grains to the end of the oscillating tray. We can, therefore, note from table 4.4a that the screen grain loss range from 19.68 to 20.87% for variety IR58 and it is 0.48% for the variety 1917. The latter variety had output screen area of $0.157m^2$ and the adjustable duct was maintained at 25mm from the screen. From this it can be concluded that when threshing a crop materials with high moisture content, the screen area should be increased and the adjustable duct should be lowered. The present design includes a reversible screen which enables the screen area to be increased from $0.15m^2$ to $0.185m^2$.

Grain losses from the straw thrower lie between 1.16% to 1.63% for the three varieties. The lower and higher values of the thrower loss occur with cylinder peripheral velocity of $15.71ms^{-1}$ and $16.76ms^{1}$ respectively. Grain damage and immature grains were in small quantities, these can be observed in appendices A, B and C.

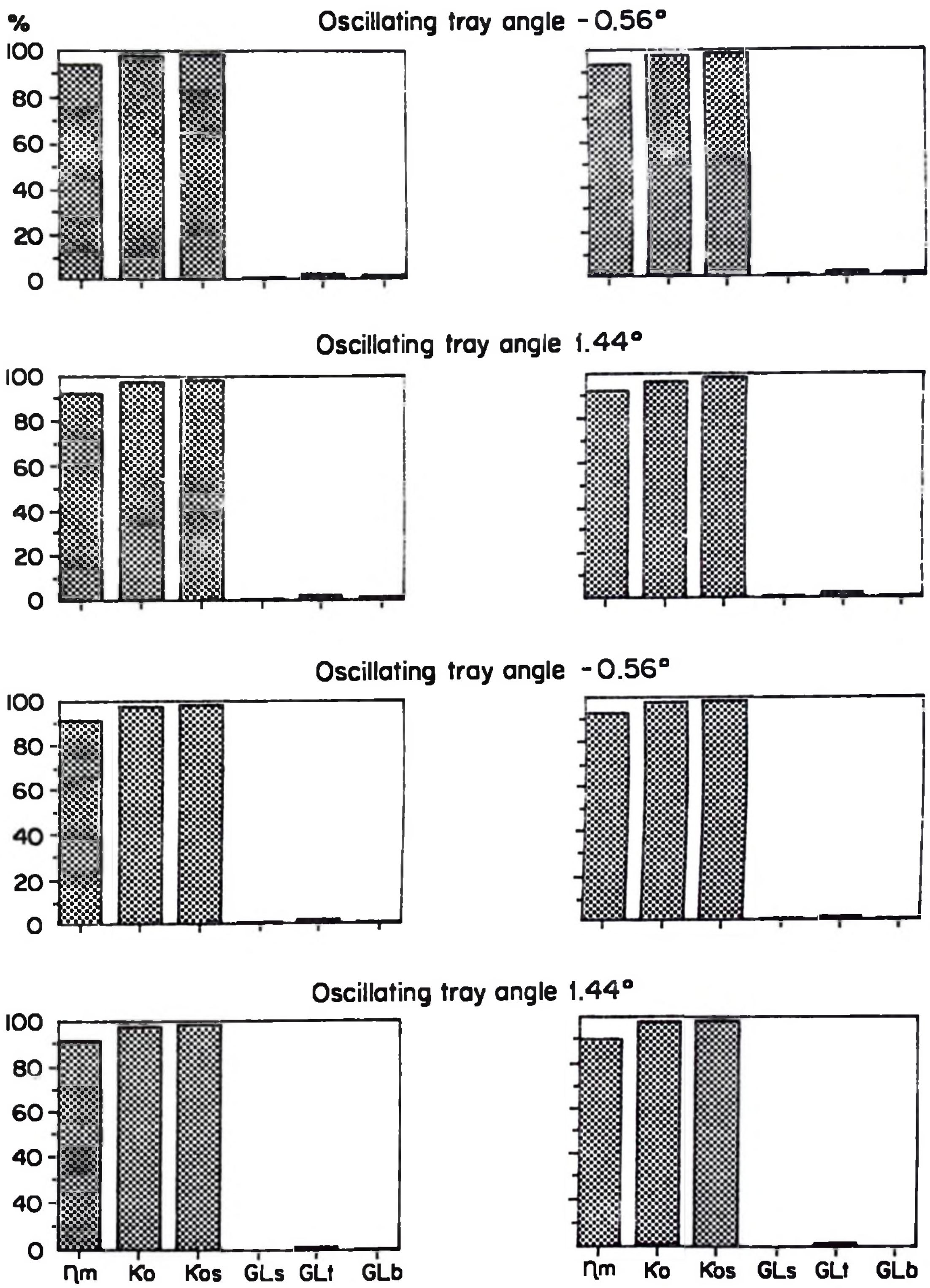



Fig. 4·7. Performance of the thresher on paddy variety IR38.

Note: For right hand side column, fan peripheral velocity is 20-35 $ms^{-1}$ and air vent is 0%; left hand side column fan peripheral velocity is 20-71 $ms^{-1}$ and air vent is 15-30%

Table 4.4b[1]. Thresher performance on paddy variety 1917.

| Description | Units | Value |
|---|---|---|
| Crop fed | kg/10 bundles | 39.38 |
| Threshing time | seconds | 30.24 |
| Feed rate | kgh | 4688 |
| Output | kgh | 1521 |
| Cleaning efficiency | | 97.45 |
| Grain recovery | (%) | 97.88 |
| Blower loss | | 0.27 |
| Thrower loss | | 1.36 |
| Screen loss | | 0.48 |

1/ Threshing cylinder peripheral velocity is 15.71 $ms^{-1}$ and screen area over the output spout is 0.185 $m^2$.

## 4.6 PERFORMANCE ON SORGHUM

A conveyor was used to determine output per time of the machine, it was found to be 1594 $kgh^{-1}$ (Table 4.2b). Further application of the conveyor was not encouraging. This is because apart from being self-propelled, it had a limited conveyor belt length of 3.5m and it required three to four people to arrange the crop material on. This proved difficult especially with the designed experiment of sixteen treatments.

The experiment which followed was aimed at observing, threshing, and cleaning efficiency, grain recovery and also output per time. Results from the experiment are in table 4.5 which also contain the different settings of the thresher. From the table it can be said that combination nine is the best for high threshing efficiency and grain recovery which is 98.36% and 98.12% respectively. The combination is composed of 10 louvres making an angle of $14^{o}-7^{o}$, oscillating tray tilted at $1.44^{o}$ (or the thresher main frame should be horizontal to the ground), fan blade area, 70% (or reduced to minimum), the aspirator air vents exposed at 30.63% of its full area, and the screen area over the output spout should be $0.314m^{2}$. Also combination seven is the best when only cleaning efficiency is considered.

The conclusions are not only limited to sorghum variety casor 2 but also to the kind of crop (sorghum) condition outlined in table 3.3a. Then assuming only the factors shown are influencing the machine performance, therefore the high threshing efficiency is the result of louvre angle (combination 9, table 4.5). Combinations 9 to 16 bear the same louvre angle $14^{o}-7^{o}$, and their threshing efficiency, are higher than the rest of the combinations. Why combination 9 has been one with the highest value of cleaning efficiency no special reason can be established so far. Moreover small louvre angle has shown higher threshing efficiency in other experiments. For example Ilyas (1980), Hundal, Sharma, and Singh (1981) independently showed that small louvre angle offers more retention time or dwell time of the crop in the threshing zone thus increasing the threshing efficiency.

The high percentage of grain recovery combination 9 was contributed by small area of the fan blades which imply low air velocity hence sucking less grain. And the small pitch or screen slope, offers more sifting chances of the grain to the output spout. While the small louvre, angle decreases losses of grain through the straw thrower. But keen observation of table 4.5 combination number 15 should have been for the highest grain recovery because of the large air vent area and minimum fan blade area exposed which imply less air velocity and thus less grain loss. Maybe this did not apply because the low air velocity offered enabled more

Table 4.5 1/. Different settings of the thresher and the outcome on sorghum variety casor 2.

| Combination | Louvre Angle (degrees) | Oscillating tray slope (degrees) | Aspirator air vent | Fan blade area | Cleaning efficiency (%) | Threshing efficiency (%) | Grain recovery (%) | Grain 2/ recovery (%) | Highest value |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 14 | 1.44 | 89.53 | 100 | 96.26 | 97.87 | 96.47 | 98.39 | |
| 2 | 14 | 1.44 | 30.63 | 70 3/ | 95.90 | 97.45 | 96.02 | 98.30 | |
| 3 | 14 | 3.44 | 89.53 | 70 | 93.78 | 97.40 | 95.97 | 98.26 | |
| 4 | 14 | 3.44 | 30.63 | 70 | 94.80 | 97.63 | 96.26 | 98.42 | |
| 5 | 14 | 3.44 | 89.53 | 100 | 96.19 | 97.81 | 96.50 | 98.50 | |
| 6 | 14 | 3.44 | 30.63 | 100 | 97.36 | 97.61 | 96.32 | 98.44 | |
| 7 | 14 | 1.44 | 30.63 | 100 | 97.65 | 98.01 | 96.65 | 98.10 | *Cleaning |
| 8 | 14 | 1.44 | 89.53 | 70 | 95.90 | 97.71 | 96.24 | 98.26 | efficiency |
| 9 | 14-7 | 1.44 | 30.63 | 70 | 95.95 | 98.36 | 97.12 | 98.73 | *Threshing |
| 10 | 14-7 | 3.44 | 89.53 | 70 | 93.91 | 98.09 | 96.62 | 98.48 | efficiency |
| 11 | 14-7 | 1.44 | 30.63 | 100 | 97.23 | 98.16 | 96.73 | 98.11 | and grain |
| 12 | 14-7 | 3.44 | 30.63 | 100 | 96.92 | 98.06 | 95.86 | 98.09 | recovery |
| 13 | 14-7 | 1.44 | 89.53 | 100 | 96.10 | 98.17 | 96.42 | 98.30 | |
| 14 | 14-7 | 3.44 | 30.63 | 70 | 95.40 | 98.11 | 96.42 | 98.57 | |
| 15 | 14-7 | 1.44 | 89.53 | 70 | 96.09 | 98.05 | 96.63 | 98.50 | |
| 16 | 14-7 | 3.44 | 89.53 | 100 | 95.90 | 98.10 | 96.55 | 98.59 | |

1/ Threshing cylinder peripheral velocity 16.76 $ms^{-1}$.

2/ This includes grain collected from the output spout and grain bypassing the oscillating tray assembly.

3/ These values are approximated to nearest whole number.

straw together with some grains to be transferred to the end of the tray/screen than with combination nine. Majority of the grains dragged by the straw and dropped at the end of tray include the insect or disease damaged grains (figs. 4.8a and 4.8b).

With reference to cleaning efficiency figure 4.5 combination seven, appears rational. This has the maximum fan blade area, and the minimum air vent within the combination. This combination favors high cleaning air velocity, which eventually sucks most of the foreign materials. Together with the mentioned settings, the large louvre angle $14^{o}$ has contributed to the high cleanliness. It is so because with large angles the crop straw is less pulverized but also their retention time is minimized and can be transfered to the straw thrower before sifting to the screen.

The output per hour which include all the sorghum grain passed through the thresher, ranged from 1101 $kgh^{-1}$ to 1594 $kgh^{-1}$ (see Appendix D). The output values were statistically analyzed and concluded that under 5% significance level, the output from the 16 combinations do not differ significantly.

It could be worthwhile to compare the machine performance on paddy and sorghum because they have shared the same cylinder velocity $16.76ms^{-1}$. But since the percentage

(a)

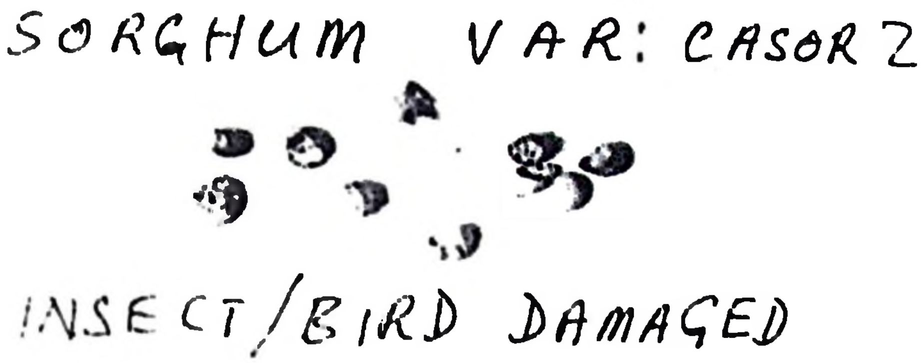
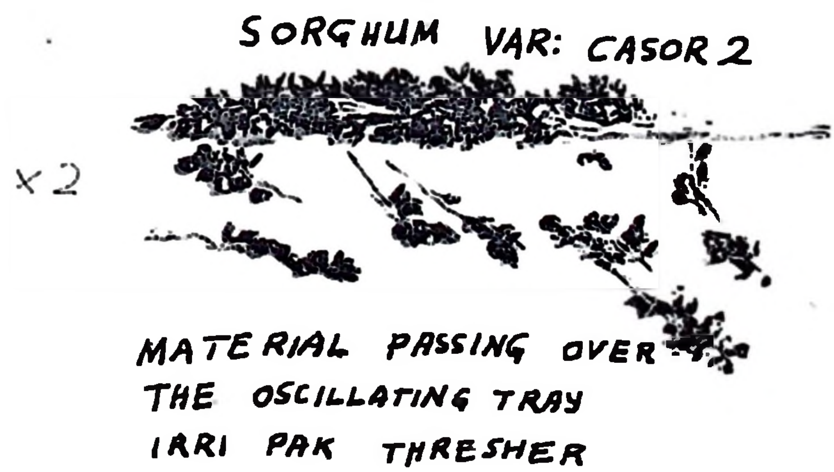



Fig. 4.8(a). Insect/bird damaged grains.

(b). Immature, insect/bird damaged grains collected from the end of the oscillating tray.

(b)



and outputs shown are computed from the mass of the grains, the comparison cannot be straight forward without considering the densities of the grains. In general, observation, however, one could argue that the output of sorghum is higher than that of paddy (1594 vs 1569) $kgh^{-1}$. And the high output of sorghum has probably resulted from the short length of cut, 399mm (compared to 527mm of paddy) variety IR38. Also sorghum has higher percentage of grain 48.17% compared to 31.85% of paddy variety IR38. Kanafojski and Karwowski (1976) studied the grain ratio or grain percentage from harvested crop. They found that the shorter the ear stalks the more easily it is to achieve a higher threshing efficiency with appropriate grain sifting.

## 4.7 PERFORMANCE ON WHEAT

The machine has been designed to thresh wheat at a cylinder peripheral velocity of $21.30ms^{-1}$. Several scientists have noted the optimum cylinder velocity lie betwee $25ms^{-1}$ and $36ms^{-1}$ (Buchele, 1974; Gasparetto, Zen and Guadagnin, 1977). But they all cautioned that wheat threshing depends on variety, moisture content and the type of cylinder used, i.e., one with rasp bar or pegtooth.

With that idea in mind, an experiment was performed varying the threshing cylinder velocity. The results have been described in section 4.4 referring to figures 4.5a and 4.5b and table 4.2b.

Reference to output (table 4.2a) by increasing the cylinder velocity from 17.81ms$^{-1}$ to 24.79ms$^{-1}$ the output increases 1.99 times but cleanliness becomes 1.51 times inferior. With low cylinder velocity and high feeding rates the tractor engine stalled. The reason for this could be due to low fuel supply since by achieving 17.81ms$^{-1}$ the throttle has to be relaxed. In the case of 24.79ms$^{-1}$ the tractor engine was operating above the rated engine revolutions for a PTO shaft. Under the mentioned limitations experiments were further conducted with the threshing cylinder rotating at 610rpm [21.30ms$^{-1}$] and 670rpm [23.39ms$^{-1}$].

Using the two speeds an experiment was performed in Batak - Northern part of the Philippines - to determine feed rate. Table 4.6 show the results. An attempt to use a conveyor for this experiment failed. The failure was due to presence of awns on the wheat (figure 4.9) which became stuck on a stationary sheet which bridged the crop material from the rotating conveyor to the rotating cylinder/concave. Also the tapering of the feeding hopper limted the crop movement especially when the material tended to be dragged laterally. From table 4.6 an average weight of ten bundles is shown together with the time used to thresh them. It can be noted from the same table that the higher the cylinder velocity the less the threshing time used per bundle. Also

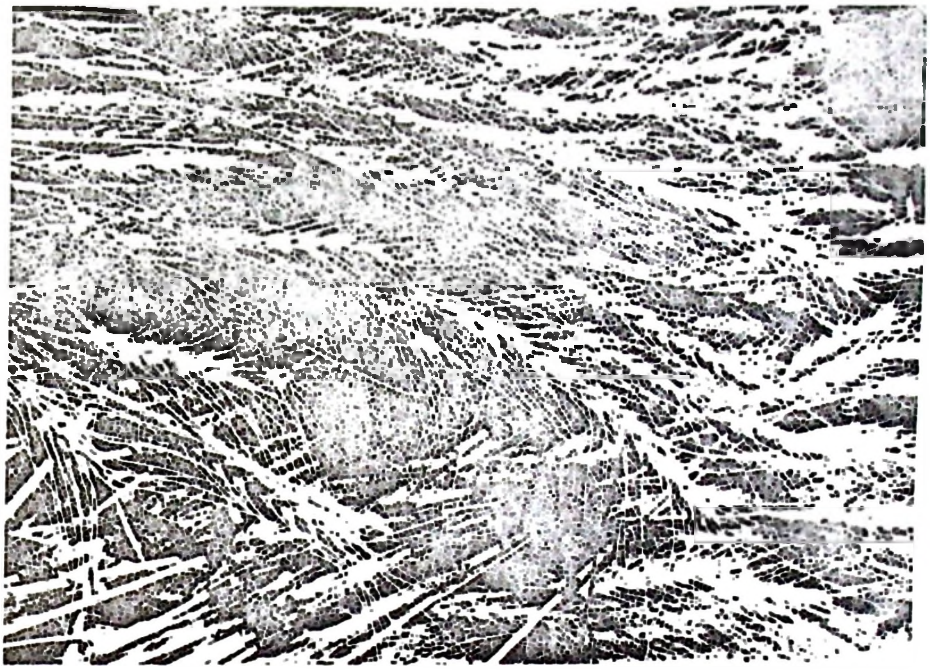


Fig. 4.9. Wheat variety Trigo 1 showing presence of awns.

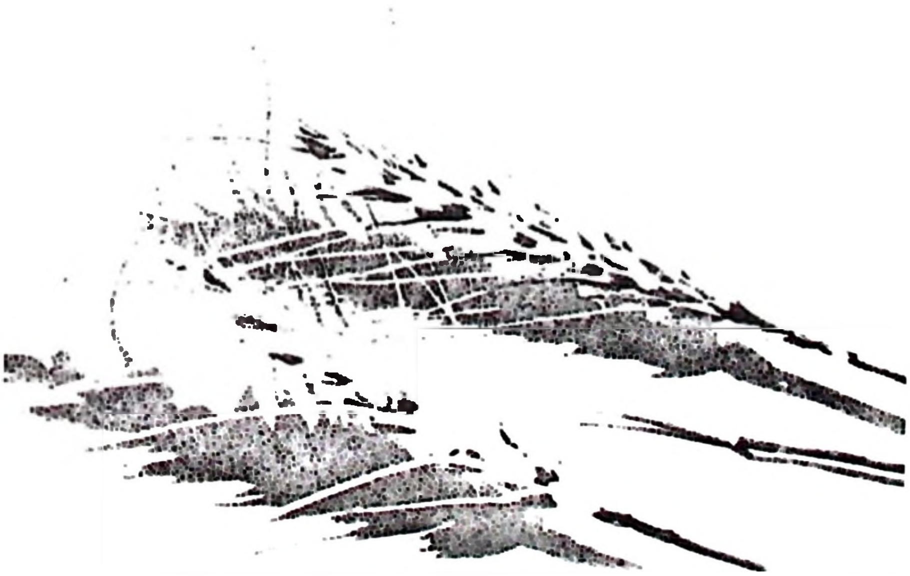


Table 4.C. Feed rate and output per one hour on wheat variety Trigo 1.

| Cylinder velocity ($ms^{-1}$) | Amount (kg/10 bundles) | Threshing time (s) | Feed rate ($kgh^{-1}$) | Output/ time ($kgh^{-1}$) |
|---|---|---|---|---|
| 21.297 | 20.80 | 14.90 | 5026 | 1725 |
| 23.391 | 20.20 | 12.70 | 5726 | 1966 |

when this feed rate is compared to the feed rate found with paddy variety 1917 (figure 4.4b), the latter has a lower figure 4688 $kgh^{-1}$ than 5026 $kgh^{-1}$ and 5726 $kgh^{-1}$. The difference could be because of the high moisture content found with paddy 65.88% vs 14.20% to 15.46% of wheat.

The same wheat used for feed rate determination was used for another experiment aimed at cleanliness determination. The total number of 12 combinatios used are found in Table 4.7.

It is worth noting that unlike paddy and sorghum neither of the combinations used for wheat threshing resulted in great amounts of straw/grain transferred to the end of the oscillating tray. Appendix E show the total amount of materials collected from the end of the tray.

References to cleanliness (Figures 4.10 and 4.11) show the results of two cylinder velocities and three different slopes of the oscillating tray. What can be concluded generally is that the cleanliness decreases with the increase of the oscillating tray slope. For this crop one could postulate that the slope checks the material velocity on the tray and gives the aspirator more chances of sucking off the foreign material. This depended on the prevailing air velocity. Buchele (1964) pointed out that the cleaning air should be adjusted to match the density of the grains.

From Figures 4.10 and 4.11, both the threshing

Table 4.7. Adjustments on the thresher which yield same results under 5% significance level; on threshing wheat variety Trigo 1.

| Treatment | Cylinder per. velocity (ms ) | Oscillating tray slope (degrees) | Aspirator air vent (degrees) | Cleaning efficiency (%) | Grain recovery 1/ (%) | Threshing efficiency (%) |
|---|---|---|---|---|---|---|
| 1 | 21.297 | -0.56 | 100 | 96.49C | 98.85 2/ | 96.45 |
| 2 | 21.297 | 1.44 | 100 | 96.99 | 98.94 G1 | 96.45 |
| 3 | 21.297 | 3.44 | 100 | 95.36 | 99.06 | 96.43 |
| 4 | 21.297 | -0.56 | 89.257 | 96.57C | 98.83 | 96.45 |
| 5 | 21.297 | 1.44 | 89.257 | 96.38 | 98.93 G1 | 96.46 |
| 6 | 21.297 | 3.44 | 89.257 | 95.46 | 98.94 | 96.44 |
| 7 | 23.391 | -0.56 | 100 | 96.90 | 98.90 G | 96.82 |
| 8 | 23.391 | 1.44 | 100 | 96.35 | 98.93 G1 | 96.80 |
| 9 | 23.391 | 3.44 | 100 | 95.66 | 98.99 | 96.80 |
| 10 | 23.391 | -0.56 | 89.257 | 97.00 | 98.85 | 96.81 |
| 11 | 23.391 | 1.44 | 89.257 | 96.56C | 98.89 | 96.81 |
| 12 | 23.291 | 3.44 | 89.257 | 95.76 | 98.92 G | 96.79 |

1/ The number 1 implies superiority.

2/ Similar letters imply that there is no difference at 5% significant level.

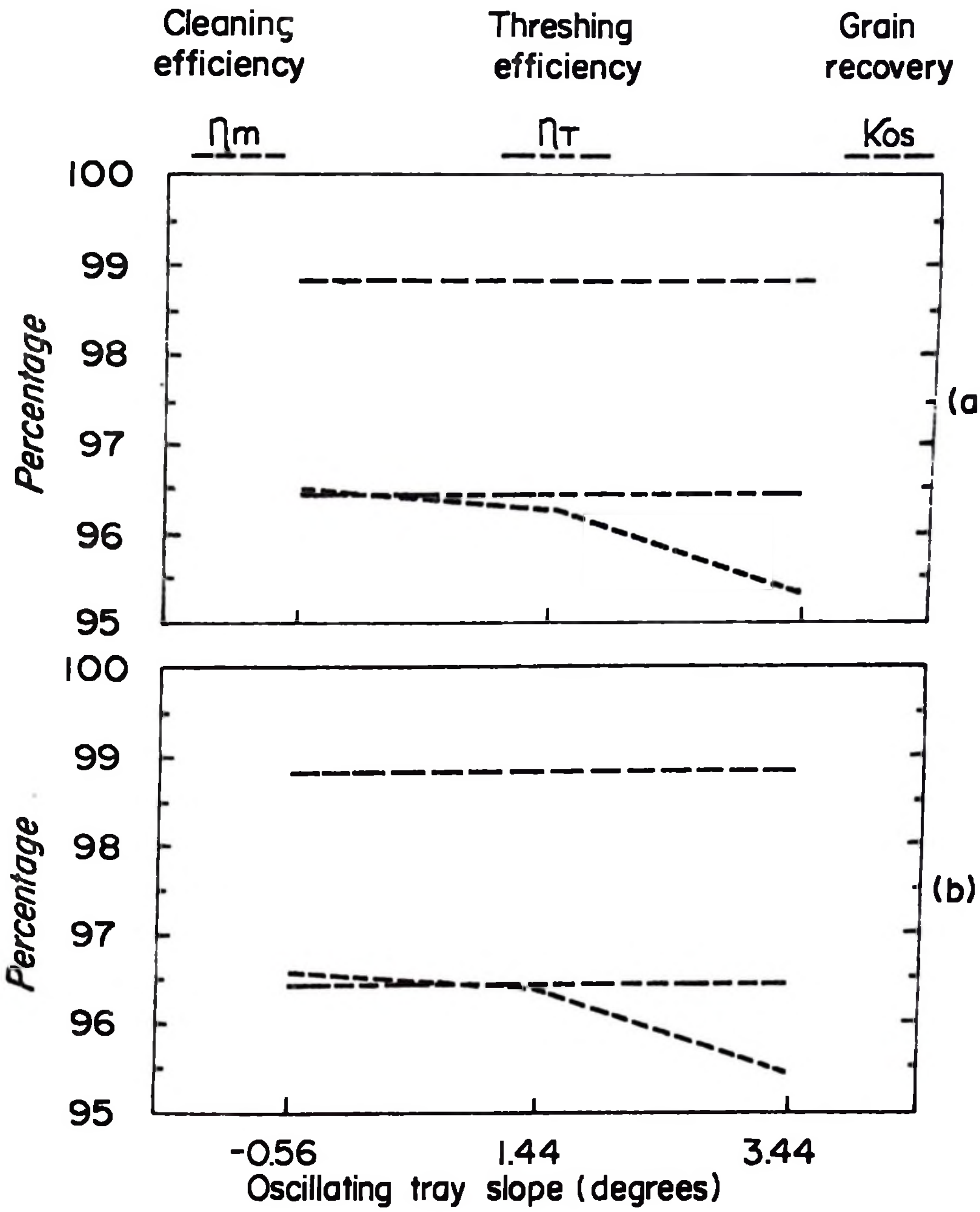



Fig. 4.10 Effect of oscillating tray slope on wheat grain cleanliness.

**Note: Cylinder velocity 21.30 $ms^{-1}$.**
**Aspirator air vent 100 % and 89.26 % for (a) and (b) respectively.**

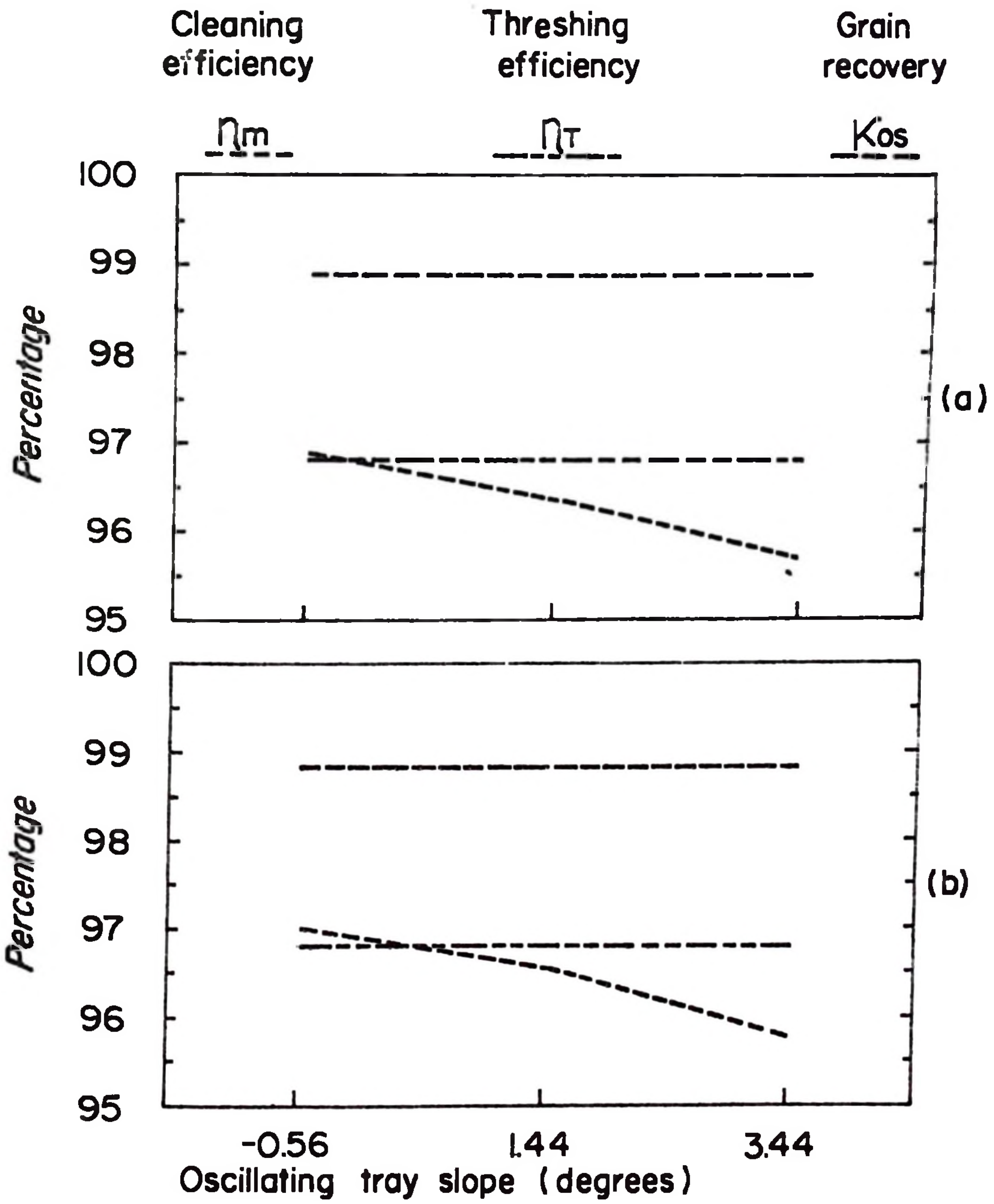



Fig. 4.11 Effect of oscillating tray slope on wheat grain cleanliness.

Note: Cylinder velocity 23.39 $ms^{-1}$.

Aspirator air vent 100 % and 89.257 for (a) and (b) respectively.

efficiency and grain recovery seem to be stable. The cleaning curves decrease with increasing tray angle. A point is seen where the curve for cleaning efficiency crosses the one of threshing efficiency. This point might be of interest to argue that it is the optimum point for the tray slope. The point is proportional to the cylinder/cleaning air velocity. The less the cylinder velocity the more the point of crossing moves to the negative slope of the tray. It could therefore be concluded that while threshing wheat of similar conditions as ones shown in table 3.4a the tray pitch should be around zero. Gregg et al (1970) stressed that the screen pitch/slope should be steepened to make chaff move down the screen. The pitch should be flattened when cleaning round seed to prevent them from gaining too much momentum and bouncing over the screen without being properly graded.

Statistically, grain recovery, cleaning efficiency, and threshing efficiency have been analyzed by comparing their means.

It has been found that with reference to cleaning efficiency at 5% significance level, there is no significant difference of cleaning efficiency from treatments 1, 4 and 11. The treatments have respectively; cylinder velocity, 21.297ms$^{-1}$; oscillating tray slope, -0.56$^{o}$; aspirator vent, 100%; and cylinder velocity, 21.297ms$^{-1}$; oscillating tray slope, -0.56$^{o}$; aspirator air vent, 89.257%; and cylinder velocity,

$23.391ms^{-1}$; oscillating tray slope, $1.44^{o}$; aspirator air vent, 89.257% (table 4.7). At the same significance level there is no difference of threshing efficiency within a single stage of cylinder velocity. It is also noted (table 4.7) that the $23.39ms^{-1}$ velocity has slightly higher values than the $21.30ms^{-1}$.

With reference to grain recovery at 5% significance level either of the cylinder velocities can be opted for, with $1.44^{o}$ tray slope and 100%/89.257% aspirator air vent for $21.30ms^{-1}$, or $1.44^{o}$ tray slope and 100% aspirator air vent for $23.39ms^{-1}$. Such combinations are represented by treatments 2, 5 and 8 (table 4.7). The same table include letters which refer to the combinations which are not significantly different.

Using wheat found in Batak another experiment was performed to determine the effect of louvre angle (see table 4.8).

By increasing the louvre angle from $14^{o}$-$0^{o}$ to $14^{o}$ the losses from the straw thrower increases 1.25 times and the threshing efficiency decreases slightly.

Other samples of wheat were found in Dingras (northern part of the Philippines). These were used to determine the effect of the adjustable sucking rear duct. The adjustable duct regulates the amount of air/chaff sucked from the oscillating tray/screen. Therefore, the duct adjustment is related to blower/aspirator losses.

From table 4.9 the losses due to aspirator (blower) are 0.48% and 0.50% with cylinder velocity of 21.30ms$^{-1}$ and 23.39ms$^{-1}$ respectively. Without the adjustable duct, the aspirator (blower) losses were recorded to exceed 0.50%, see Appendix E.

As a point of notation, tables 4.8 and 4.9 reveal that the latter exhibit losses more from the straw thrower than the first. Yet the louvre angle of the latter was $14^{o}$-$0^{o}$. Such differences were due to the variability of wheat condition found from one farm to another. As a result the conclusions arrived at are specific to the place/farm the experiment was conducted. Reference tothe wheat variability, some samples had significant amount of immature grains (figure 4.12)and presence of weed seeds. In Dingras, for example, the percentge of immature grains ranged from 31% to 40% (Appendix E), table E 10). The high percentage of immature grains to mature ones influenced the grain/chaff separation process. In general the amount of grain lost from the aspirator/blower increased with the amount of immature grains in the sample. But irrespective of the place the wheat was found, a close look of tables in Appendix E some trend can be observed. For example, the amount of damaged grains has been stable, not exceeding 0.066%. Also,

Table 4.8. The effect of louvre angle on wheat variety Trigo 1 at 21.30ms$^{-1}$ cylinder velocity.

| Louvre angle (degrees) | Cleaning efficiency (%) | Threshing efficiency (%) | Thrower loss (%) |
|---|---|---|---|
| 14 - 0 | 96.32 | 96.40 | 0.45 |
| 14 | 96.41 | 96.25 | 0.57 |

Table 4.9. The effect of adjustable sucking rear duct end on wheat variety Trigo 1 (louvre angle maintained at 14$^{0}$ - 0$^{0}$.

| Threshing cylinder velocity (ms ) | Cleaning efficiency (%) | Blower loss (%) | Screen loss (%) | Thrower loss (%) |
|---|---|---|---|---|
| 21.30 | 93.03 | 0.48 | 0.06 | 0.51 |
| 23.39 | 89.98 | 0.50 | 0.10 | 0.61 |


Figure 4.12. Insect or disease damaged and immature grains of wheat variety Trigo 1.

the theory postulated by Vas and Harrison (1969) of estimating the percentage of damaged grains has proved true to some trials. The theory works when the percentage damaged grain of one of the cylinder speed being tested is known, the theory is :

$$\frac{\text{Damaged \% (higher speed)}}{\text{Damaged \% (lower speed )}} = \left(\frac{\text{higher speed}}{\text{lower speed}}\right)^2$$

When this is applied to Appendix E tables E2 and E 4 the values obtained are near to the ones found in the mentioned tables.

## 4.8 PERFORMANCE ON YELLOW CORN

During corn shelling two cylinder velocities have been used 10.47 $ms^{-1}$ (300 rpm) and 13.27 $ms^{-1}$ (380 rpm). The lowest cylinder speed rated for the machine is 480 rpm for paddy threshing. When this proved to be too high for corn shelling, a decision of going lower by 100 rpm was taken. TOgether with this the lowest working cylinder speed the tractor could offer under the given pulley size and configuration was located to be 300 rpm. The two velocities facilitated the values on Table 4.10.

It can be observed from Table 4.10 that losses from the straw thrower are high - 16.98%. Similarly cleanliness is poor - 85.79%. But threshing efficiency for the two cylinder velocities used was greater than 99%. See Appendix F table F. This suggests that the speed can still be

Table 4.10. Cleaning efficiency, grain damage and losses for yellow corn.

| Threshing cylinder velocity ($ms^{-1}$) | Cleaning efficiency | Grain damage | Blower loss | Screen loss | Thrower loss |
|---|---|---|---|---|---|
| | | | (%) | | |
| 10.47 | 86.66 | 7.22 | 0.03 | 0.41 | 15.94 |
| 13.27 | 85.79 | 7.44 | 0.04 | 0.69 | 16.98 |

decreased. Decreasing the cylinder speed decreases also the speed of the aspirator fan. This eventually worsens the cleanliness. The best way could be employing another set of pulleys. During operation the oscillating tray was moving at a speed of 225rpm. This appeared to be very slow. The layer of grain mixture on the tray was thick but did not cause clogging of the screen holes because the crop moisture content was low.

It can be learned from the study objectives (section 1.4) that the evaluation of the IRRI-PAK Multicrop thresher included sorghum, wheat, corn and paddy. More than one experiment were conducted for every crop except corn. This is because the machine requires some modifications to suit the crop. For example, preliminary studies of the size of corn grain available was necessary. This would enable one to determine an adequate separating concave bar clearance which is now maintained at 10mm. Such a study would have included all the other crops in order to have an average concave bar clearance suitable for all. More to that, the pitch and frequencies of the oscillating tray requires further study in relation to corn grains.

To complete such studies and, hence, include the modifications, an appreciable amount of time would be required. The time would have resulted in missing the peak season of corn harvesting. Also the time set to conduct the experiments for the four mentioned crops would have been offset.

After considering all that, an experiment was performed after making all the possible adjustments to suit the shelling process. The results of the experiment were briefly discussed above. The detailed data for the experiment is found in Appendix F table F. It is also worth noting that the IRRI-PAK-30 Multicrop threshers found in Pakistan are being used for paddy, wheat pulses and sunflower (Progressive Report, 1978). Then, it seems that much has not been done on the original prototype to suit corn shelling. Therefore, from the experiment performed together with some recommendations outlined below there can be points of departure to some fundamental changes on the IRRI-PAK Multicrop thresher. The changes should result into a machine threshing several small grain crops, and successfully shelling corn.

## 4.9 LABOR REQUIREMENT AND CROP SUITABILITY

Generally labor requirement refered to in this case, are the people who will be working direct with the machine. Five people will be enough, two feeding in the crop; two, bagging; and a tractor operator. With these people it is assumed that the harvested crop is bundled and possibly accumulated in piles, two per hectare. With too many piles in a field much time will be consumed for moving the thresher, and anchoring it on its four stands.

4.10 MAINTENANCE AND OTHER OBSERVATIONS

During threshing, vibrations from both the threshing cylinder and the oscillating tray are experienced. They are exaggerated when the machine is not resting fully on a level ground thus causing an uneven weight distribution onto the four stands. These vibrations resulted in loosening of set screws on the pulley/cylinder hubs and the PTO adapter.

Other maintenance required was observed to follow that of other farm machines like tightening/checking the nuts and bolts, e.g., for the pillow blocks before commencing an operation; applying oil to the oscillating tray links; applying grease to all fittings viz: on the pillow block and to the universal joints.

The behavior of some parts observed include the cylinder knives' attachment. Each knife is attached to the cylinder by two tempered 8mm diameter bolts and nuts. During the entire operation two knives dropped off. It will be a premature conclusion to claim that the attachment is weak. However, some pictures on some reports from Pakistan show the knives welded on the cylinder. Such attachment forecast a difficulty in changing the knives whenever they are worn out.

Another observation comes when the straw piles on the exit of the straw thrower to the extent of reentering the exit. When this happens the quantity of straw which enters, encounter the straw thrower which draws and 'squeeze' them at the upper tip of the thrower concave causing an excessive impact. If this is not checked out immediately the straw thrower fingers will bend.

Finally, the thresher was lent to farmers who continued threshing their wheat for a period of one month. During this period the machine experienced failure of one of the threshing concave frame bars. Also two stands, one from rear was broken and repaired and one from front was excessively bent.

## 4.11 PERFORMANCE OF THE MODIFIED SECTIONS

Eventually no bending/failure was experienced from the threshing cylinder shaft.

The bolted stand assembly has proved quite beneficial for repair and replacement purposes. In more than one case the tractor driver pulled the thresher without raising the stands. This caused excessive bending to the stand that could be repaired easily and quickly when the stand was detached from the machine.

The observation windows are occassionally used and primarily they are only affected by the machine vibration during working and transportation. Therefore, after the testing period they still appeared intact.

Sections 4.5 and 4.6 for respectively sorghum and paddy have discussed in detail the performance of the screen on the output spout with its total area increased. In general with this kind of screen modification cleanliness of the wheat grains was not good. But with sorghum and paddy it is highly encouraging. These qualities have influenced a design with reversible screen which is maintained in the final drawings. With this, the screen area will be increased or decreased depending on the kind of crop being threshed.

The screen had poor performance on wheat because the harvested crop straw had comparatively the lowest moisture content (less than 16%), contrary to more than 47% for sorghum and paddy. This factor among others enabled the wheat straw to be pulverized and sifted to the tray in large volume which could not be sucked promptly by the aspirator before being sifted to the output spout. For the other crops most of the straw that sifted from the concave was too heavy to suck and too big to sift into the output spout thus being transfered and thrown from the end of the oscillating tray.

## 4.12 IRRI-PAK-30 FABRICATED IN PAKISTAN AND IRRI-PAK FROM IRRI WORKSHOP

There are noticeable differences of the IRRI-PAK-30 threshers fabricated by the different manufacturers in Pakistan. Some manufacturers tend to add or deduct some minor details suitable for their working conditions and material availability. For example from the Progressive Reports (1978 and 1982) from Pakistan and the instruction manual of the IRRI-PAK-30, have several pictures of the IRRI-PAK-30 Multicrop Thresher. The pictures should have shown a thresher similar to the IRRI-PAK manufactured in the IRRI workshop without the modification described in section 3.3. Instead there are other differences observed from the pictures, which include; attachment of the cylinder knives by welding absence of pulley flanges, presence of pillow block with replaceable bearings, absence of PTO adapter, presence of idler double sheave pulley of the oscillating tray with different diameters, just to mention a few externally observed from the photographs. Apart from the additions/deductions made by the different manufacturers it will, therefore, be justifiable to say that the IRRI-PAK Multicrop Thresher is similar to the IRRI-PAK-30 Multicrop Thresher. The basic difference lie on the modifications described in section 3.3.

With regard to performance, the IRRI-PAK-30 has been reported to thresh the crop shown below (Instruction Manual IRRI-PAK-30 thresher).

| Crop | Cylinder Speed [rpm] |
|---|---|
| Wheat barley and oats | 600 to 620 |
| Paddy dwarf or Basmati | 450 to 500 |
| Sunflower and Pulses | 400 |

The output and different efficiencies are as follows:

| Crop1/ | Output $kgh^{-1}$ | Cleaning efficiency % | Grain loss % |
|---|---|---|---|
| Wheat barley | 550 to 750 | 98 to 99 | 1 to 2 |
| Basmati paddy | 550 to 750 | 98 to 99 | 1 to 2 |

1/Threshing operation involved preparation of bhoosa.

The modified IRRI-PAK has the following performance without bhoosa making.

| Crop1/ | Output $kgh^{-1}$ | Cleaning efficiency % | Grain loss 2/ % |
|---|---|---|---|
| Paddy | 1260-1560 | 91.05-97.45 | 1.27- 2.01 |
| Sorghum | 1000-1590 | 94.80-97.65 | 1.27- 1.90 |
| Wheat | 790-2110 | 76.60-96.57 | 0.94- 1.55 |
| Corn | 860- 890 | 85.79-86.66 | 15.97-17.02 |

1/ The machine is not modified for corn shelling.
2/ The grain loss from the oscillating tray/screen is not included.

Since no substantial data was found to show the performance of the IRRI-PAK-30 thresher without bhoosa making it becomes improper to drawout comparisons. Even though reference to wheat, the cleaning efficiencies are slightly higher from Pakistan than ones observed by the IRRI-PAK. In case of grain loss the thresher manufactured at IRRI seem to be superior.

# CHAPTER FIVE

# CONCLUSION AND RECOMMENDATIONS

## 5.1 TEST AND EVALUATION

The modified IRRI-PAK Multicrop Thresher weighs 170 kg less than the weight of the orignal machine, the IRRI-PAK-30 Multicrop Thresher. Such a weight decrease has relieved some stresses within the main frame. This agrees with the hypothesis that the IRRI-PAK Multicrop thresher will weigh less than 1260 kg.

The modified parts on the IRRI-PAK Multicrop thresher were generally assessed. From that the threshing cylinder shaft did not show bending or failure. Also neither failure due to shear nor tearing were observed from the brackets of the four stands. Instead it is now easy and less time consuming to repair and replace the stands whenever subjected to bending during the operation or careless driving/trailing. The performance of the screen over the output spout was good for paddy and sorghum. The straw of the wheat crop was highly pulverized during threshing, making it easier for it to sift through the concave on to the screen. In this case, the aspirator could not handle the volume sifted. When this was coupled with the increased area of the screen over the output spout, the output was not thoroughly cleaned.

A general trend for all experiments shows that the quality of the output and efficiency of threshing has been affected by crop moisture content, addition of green matter (random seeds or weeds), grain percentage, cylinder peripheral velocity, concave bar clearance, slope of the oscillating tray assembly, and the velocity of the cleaning air.

In case of comparison, the grain thresher requirement in Pakistan is also to produce good bhoosa. The process demands extra energy and may influence the output per time. With bhoosa making the IRRI-PAK-30 in Pakistan yields per one hour 550 kg to 750 kg of wheat and Basmati paddy. Cleaning efficiency and grain loss of the mentioned crops ranges from 98% to 99% and 1% to 2% respectively.

The modified IRRI-PAK Multicrop Thresher has been tested on four crops -- paddy, sorghum, wheat and corn. With an exception of corn grain breakage due to machine was lower than 0.55% The machine exhibited losses from the straw thrower, aspirator/blower, oscillating tray/screen. Also during feeding process some amount of grain was forced out of the thresher through the feeding hopper due to the initial impact from the cylinder to the material being fed. Due to the machine vibration and screen oscillation effect some grain were droping off the machine through the front of the oscillating tray. the grain loss which resulted from the latter two ways explained was referred to as scattered grains. Such loses were recorded up to 0.62% for corn but negligible for the other crops. Losses from the straw thrower were present for all crops. Paddy had 1.16% to 1.63%; sorghum, 0.19% to 0.58%; wheat 0.45% to 1.19% and corn, 16% to 17%. The minimum grain losses from the straw thrower of the different ranges shown above, can be acceptable for the experiments performed. This is because the values were obtained after the thresher adjustments were set to allow minimum losses. The settings included reduction of the louvre angle to the minimum level available, and using the minimum possible threshing cylinder speed.

Losses from the screen can be recovered easily simply by collecting the grain mixture being transfered and discharged over the tray end. By increasing the area over the output spout to 0.314m these losses were kept in the region of 0.01% to 1.27% for paddy, 1.02% to 2.28% for sorghum and 0.04% to 0.10% for wheat. The original screen area 0.15$m^2$ with paddy exhibit losses of up to 24.92% (Appendix A table A3).

Three varieties of paddy used, IR38, IR58 and 1917, were obtained from the IRRI experimental plots. The three varieties differed in length of cut, moisture content and time of harvest. More still the experiments designed on them were not alike. But from their outputs 1570$kgh^{-1}$ for

IR38 and 1470kgh$^{-1}$ for IR58, it can be concluded that the length of cut influences output. This follows because the IR58 had 1.3 times the length of cut than the IR38. For all the three varieties the threshing efficiency was above 99% (Appendix A and B) with cleanliness range of 93.39% to 96.01% and grain loss range of 1.27% to 2.01%. Here the screen loss is considered as recovered.

A conveyor was employed during threshing sorghum and wheat. It could only be satisfactorily used with sorghum, and the output is 1590kgh$^{-1}$ with losses of up to 1.27%. Threshing efficiency was recorded up to 98.5%. Much of the unthreshed included the immature grains and the bird/insect damaged.

Wheat crop was found in farms located in the Northern province of the Philippines - Ilocos Norte Region. The variety is Trigo 1 but the quality of the crop found in other farms was not good due to grain disease infestation, weed contamination, uneven maturing, and uneven dryness. Four cylinder speeds were used viz: 510rpm [17.81ms$^{-1}$], 610rpm [21.30ms$^{-1}$], 670rpm [23.39ms$^{-1}$], and 710rpm [24.79ms$^{-1}$]. The speeds resulted to output ranging from 790kgh$^{-1}$ to 2110kgh$^{-1}$ and cleaning efficiency from 76.60% to 96.57%. Grain loss ranges from 0.94% to 1.55%. Much of the losses were recorded from the straw thrower.

On yellow corn the threshing efficiency of the two cylinder speeds used (300 and 380) rpm was above 99%. The concave bar clearance and/or the design of the louvres has resulted in high grain loss from the straw thrower which went up to 16%, and contributed to a total grain loss of 17.02%. The low percentage of cleaning efficiency resulted from the low velocity of the cleaning air and low screen oscillations.

One of the major advantages of this machine should be looked at further for shelling corn, there is no need of dehusking before feeding, and even pieces of the stem together with the cob are acceptable by the machine.

## 5.2 ACCEPTABILITY

The IRRI-PAK Multicrop Thresher is quite robust. It has been transported 1000km in a truck and within the trip there was unloading and loading using facilities at farm level. That rough handling ended up in a bending of the aspirator housing which was repaired by a local craftsman. The machine was trailed to cover an average distance of 200km. The distance included the narrow/rough farm roads and the levied fields. This handling caused breakage of one rear stand and bending of one of the front stand. In a period of one month the machine was lent to farmers many of whom had the first experience with such a machine. When the machine was returned, the threshing concave lower frame joint was rewelded, and the feeding hopper was twisted. The frame failure could be due to initial weak welding or due to the the result of impact forces from the pegteeth during threshing. Twisting of the hopper could be due to negligence in folding it during trailing.

The machine is not affected by the ropes which tie crop bundles. Any size of crop bundle that can enter the feeding mouth will be threshed without damaging the machine. The only limitation is the tractor power and belt slippage due to overloading. Pieces of wood/stick or metals which may be fed into the machine, like hand sickles are only detrimental to the operator.

Mobility of the machine and easiness of operating has proved useful to wheat/paddy farmers in the Northern province of Philippines. Its multicrop handling ability makes it one of the farm units that are recommended for communities like the ones found in most of the Tanzanian Ujamaa[8] villages.

## 5.3 RECOMMENDATIONS

5.3.1 An optional threshing cylinder with less or no cutting knives could be designed.

---

8 Group of people living together.

If there are farmers who are not interested in both threshing and preparation of livestock feed (bhoosa) can utilize the optional cylinder. Such a cylinder will not only simplify part of the assembly work but also will cause less straw pulverization and thus promote cleanliness.

5.3.2 An auger conveyor to be included, to convey the grains to an appreciable height for bagging.

The present design requires at least two people for bagging or one person with a bag strainer. Also the output spout is oscillating in the same maner the tray does. For safety purposes it is dangerous to work so close with a moving part.

5.3.3 Further research should be devoted to determining the minimum length of the upper screen in the oscillating tray assembly.

Close observation shows that crop materials sifting from the concave fall some 150mm from the edge of the upper screen. This implies an area of about $0.09m^2$ is being under utilized.

5.3.4 A set of different pulleys, say 150mm diameter, for the PTO countershaft and 270mm diameter for the cylinder shaft should replace the present set during corn shelling.

The set will decrease the cylinder velocity but maintain enough frequencies for the oscillating tray assembly.

5.3.5 A hanging guard to be added at the end of the feeding hopper.

This will limit the small amount of grain forced out of the concave/cylinder during feeding/threshing process.

## REFERENCES


ARBOLEDA, J.R. and D.O. KUETHER. 1977. Test and Evaluation: A necessary component of farm machinery development. Paper presented at the Philippine Society of Agricultural Engineers. April 28-29.

ASIAN PRODUCTIVITY CONSULTANTS. 1977. Thresher Manufacturing Industry in Pakistan. IRRI-PAK Agricultural Machinery Program, Pakistan.

BERRY, P.E. 1958. Research on oscillating conveyors. J. Agric. Eng. Res. 3(3):249-259.

BILANSKI, W.K. and R. LAL. 1962. Behavior of Threshed Materials in Vertical Wind Tunnel. Trans. of the ASAE. 411-413, 416.

BILANSKI, W.K., S.H. COLLINS and P. CHU. 1962. Aerodynamic properties of Seed Grains. Agricultural Engineering. 43(4): 216-129.

BOCKHOP, C.W. 1980. The need for small scale agricultural machinery in the tropics. Paper presented at the 1980 Annual Meeting of Chinese Society of Agricultural Machinery Beijing, China, October 15-17.

BUCHELE, W.F. 1964. The principle of threshing small grains. NATO Mechanization Field Experiments Paper No. 18.

CASEM, E.O. and A.U. KHAN. 1967. Development work on threshing and grain cleaning equipment at IRRI. Paper presented at the Philippine Society of Agricultural Engineers. UP College of Agriculture, Los Banos, Laguna. December 11-12.

DIESTRO, M.S. 1983. IRRI Axial-Flow Threshers. Handout sheet Agricultural Engineering Training Course - IRRI.

DIESTRO, M.S., A.L. CABALLES and M.L. NAFZIGER. 1981. Design Parameters for Horizontal Oscillating Screen. Paper presented at the 31st Annual Convention of the Philippine Society of Agricultural Engineers. UP Los Banos. April 20-30, 1981.

ESMAY, M.C. 1978. Local Manufacturing for Small Farms in Asia. Paper presented at the meeting of the Philippine Society of Agricultural Engineers. 1978.

FAIRES, V.M. 1967. Design of Machine Elements Ltd. The MacMillan Company, New York/Collier MacMillan Ltd. London. 624p.

GASPARETTO, E., M. ZEN, A. GUADAGNIN. 1977. Ultra Hish Speed Movie Observation of a Conventional Threshing Mechanism (Cylinder Concave Rear Beater) Working on Wheat Grain and Forage Harvesting. The Proceedings of the International Grain and Forage Harvesting Conference ASAE Publication 1-78. 104-111.

GORYACHKIN, V.P. 1968. Theory of threshing drum. Collected work in three volumes. Vol. III. 140-22. Translated from Russian. Published for the US Dept. of Agric. and the National Science Foundation, Washington, DC, by the Israel Program for Scientific Translations.

GREGG, B.R., A.G. LAW, S.S. VIRDI and J.S. BASIS. 1970. Seed Processing Printed and bound in India in 1970 by AVION printers I, ARAM NAGAP. New Delhi - 55, 336p.

HARRISON, H.P. 1975. Effects of Moisture Content on Wheat Threshing. Canadian Agricultural Engineering. Vol. 17, No. 1 June, 1975. pp. 55-58.

HUNDAL, S.S. V.K. SHARMA and C.P. SINGH. 1981. Studies in the selected parameters affecting grain chaff separation and buising effectiveness of straw in Axial-flow Thresher for Wheat Crop. Paper presented at the 18th Annual Convention of India. SAE. 1981.

ILYAS, M. 1980. A response surface analysis of the IRRI Axial-flow threshers. Paper submitted to the Faculty of graduate school, University of the Philippines, Los Banos, Laguna, in partial fulfillment of the requirements for the degree of MSc. Ag. Eng.

IRRI-PAK. Agricultural Machinery Program. 1980. Instruction Manual Multicrop Thresher Model. IRRI PAK-30. Agricultural Machinery Division, Pakistan.

KANAFOJSKI, C.Z. and T. KARWOWSKI. 1976. Agricultural Machines Theory and Construction. Published for the USA Dept. Ag. and National Science Foundation, Washington D.C. by the Foregin Scientific Publ. Dept. of Nat. Center for Scientific Tech. and Econ. Inf. Warsaw, Polland, 1976. 1046p.

KHAN, A.U. 1971. Harvesting and Threshing of Paddy. Paper presented at the IRRI Conference Los Banos, Laguna, Philippines. April, 1971.

KHAN, A.U. 1981. IRRI-PAK Agricultural Machinery Program. Report July, 1976 to June, 1981. Agricultural Machinery Division, Pakistan.

KHAN, A.U., A.S. KHAN and J. AKHTAR. 1979. Mechanization of Wheat Cultivation in Pakistan. Paper presented at the National Seminar on Wheat Research and Poduction. Aug. 6-9, 1979.

KHAN, A.U., J. AKHTAR and I.S. AHMAD. 1978. Development of Axial-flow threshers in Pakistan. Paper presented at the Second Annual Convention of the Pakistan Society of Agricultural Engineers. June, 1978.

KHAN, A.U., F.E. NICHOLAS and B. DUFF. 1972. Semi-Annual Progressive Report No. 14. Contract No. AID/CSD - 2541. Ag. Eng. Dept. Res. for Tropical rice cultivation. IRRI Los Banos, Laguna, Philippines.

MacCALL, M.A. 1925. Some factors to be considered in Extending the use of combine harvester. Paper presented for the meeting of Farm Power and Mechanization Division of ASAE, December 1, 88-90.

MacGREGOR, W.F. 1924. The Combine Harvester Thresher. Paper presented at the meeting of the Farm Power and Machinery Division of the ASAE. 100-103.

McMENNAMY, J.A. and J.S. POLICARPIO. 1977. Development of a Portable Axial-Flow Thresher. Paper presented at the International Grain and Forage Harvesting Conference. Ames. Iowa, September 25-29. 1978.

MINISTRY OF AGRICULTURE. 1983. The Agricultural Policy of Tanzania. Printed by the Government Printer Dar Es Saloam. 35p.

MOHSENIN, N.N. 1970. Physical Properties of Plant and Animal Materials. Gordon and Breach Science Publishers, New York, 742p.

NICHOLAS, F.E. 1974. Is Testing and Evaluation Different from Local Manufacturer in Developing Countries? Expert Consultation meeting on the Mechanization of Rice Productivity. IITA 1974 report. 214-223.

PROGRESS REPORT. 1978. Rice Machinery Development and Industrial Extension. Semi-annual Progressive Report No. 26, Jan. 1 - June 30, 1978. AID/ta-C-1208.

PROGRESSIVE REPORT. 1979. Rice Machinery/development and industrial extension. Semi-annual progressive report No. 29, July 1 - Dec. 31, 1979. AID/ta-C-1208.

QUICK, G.R. 1977. Development of Rotary and Axial Thresher/Separations. The Proceedings of the International Grain and Forage Harvesting Conference. ASAE 151-164.

RNAM. 1983. (Regional Network for Agricultural Machinery) Code and Procedure for Power Corn Threshers. RNAM Test Codes and Procedures for Farm Machinery. 246p.

SHARMA, V.K., B.S. PATHAK and S.S. AHUJA. 1974. Design Development and Evaluation of Multicrop thresher. J. Ag. Eng. Vol. 20, 3 and 14, 16-25.

SHIGLEY, J.E. 1972. Mechanical Engineering Design 2nd. MacGraw-Hill Book Company, New York, Johanesburg. London. Toronto. 753p.

STOUT, B.A. 1966. Equipment for rice production FAO Agricultural Development paper No. 84, FAO-Rome.

UNIDO. 1983. Agricultural Machinery and Rural Equipment in Africa. New Approach to Growing Crisis. Sectorial studies series No. 1, Ditr. Ltd. UNIDO/IS 377.25. March, 1983.

VAS, F.M. and H.P. HARRISON. 1969. The effects of Selected Mechanical Threshing Parameters on Kernel Damage and Threshability of Wheat. Can. Agri. Eng. 11(2):83-87.

## APPENDIX A

### A1

Machine performance on paddy variety IR58.

Table A1. Amount of grain collected from the different discharges of the thresher with maximum* feeding of the paddy variety IR58.

| Description | QM | QE | QD | QU [$kgh^{-1}$] | QI | F | Q |
|---|---|---|---|---|---|---|---|
| o | 1131.875 | .219 | .098 | 0.000 | 1132.193 | 57.374 | 1189.567 |
| t | 13.378 | 10.200 | .137 | .035 | 23.751 | | |
| b | .023 | .033 | .013 | .000 | .070 | | |
| s | 289.450 | 21.060 | .007 | .017 | 310.534 | | |
| r | .039 | 0.000 | | .000 | .039 | | |
| Total | 1434.766 | 31.513 | .255 | .052 | 1466.587 | | |

| | | | |
|---|---|---|---|
| $\eta_M$ | 95.15 | GLt | 1.62 |
| $\eta_T$ | 99.99 | GLb | Negligible |
| $\xi$ | 2.01 | GLs | 21.17 |
| $\zeta$ | .016 | GLr | Negligible |

*Maximum feeding involved five men throwing bundles of the crop into the machine until the cylinder speed reduces by a factor of 50 rpm.

A2

Table A2. The effect of changes of velocity of the aspirator sucking air when the oscillating tray slope is maintained at 1.44° on paddy variety IR58.

| Description | QM | QE | QD | QU [kgh$^{-1}$] | QI | F | Q | Remarks |
|---|---|---|---|---|---|---|---|---|
| o | 974.094 | .180 | .074 | .006 | 974.354 | 17.218 | 1014.572 | Air duct area exposed 0% |
| t | 12.43 | 7.94 | .132 | .018 | 20.523 | | | |
| b | 1.674 | 2.345 | .025 | .003 | 4.047 | | | |
| s | 243.417 | 20.016 | .013 | .022 | 263.468 | | | |
| r | .038 | .000 | .000 | .00 | .038 | | | |
| Total | 1231.653 | 30.495 | .244 | .049 | 1262.441 | | | |
| o | 1031.727 | .181 | .060 | .003 | 1031.972 | 38.954 | 1084.926 | Air duct area exposed 15.30% |
| t | 13.719 | 7.823 | .169 | .017 | 21.728 | | | |
| b | .702 | .850 | .023 | .000 | 1.575 | | | |
| s | 249.377 | 20.216 | .016 | .014 | 269.623 | | | |
| r | .011 | .000 | .005 | .000 | .016 | | | |
| Total | 1295.536 | 29.070 | .273 | .034 | 1324.914 | | | |

| Air duct area | ηM | ηT | ξ | ζ [%] | GLt | GLb | GLs | GLr |
|---|---|---|---|---|---|---|---|---|
| 0 | 96.01 | 99.99 | 2.42 | .019 | 1.63 | .321 | 20.87 | - |
| 15.30 | 95.10 | 99.99 | 2.19 | .021 | 1.59 | .115 | 19.68 | - |

A3

Table A3. The effect of changes of velocity of the aspirator sucking air when the oscillating tray slope is maintained at 3.44° on paddy variety IR58.

| Description | QM | QE | QD | QU [$kgh^{-1}$] | QI | F | Q | Remarks |
|---|---|---|---|---|---|---|---|---|
| o | 1006.736 | .169 | .069 | .000 | 1006.974 | 46.105 | 1053.079 | Air vent |
| t | 13.127 | 7.769 | .143 | .021 | 21.060 | | | area ex- |
| b | .278 | .210 | .005 | .006 | .499 | | | posed 0% |
| s | 243.724 | 97.673 | .014 | .019 | 341.430 | | | |
| r | .035 | .000 | .000 | .000 | .035 | | | |
| Total | 1263.899 | 27.822 | .231 | .046 | 1369.998 | | | |
| o | 990.373 | .174 | .066 | .003 | 990.616 | 52.347 | 1042.720 | Air vent |
| t | 12.909 | 7.810 | .159 | .013 | 20.891 | | | area ex- |
| b | .020 | .007 | .007 | .004 | .038 | | | posed |
| s | 249.764 | 20.492 | .004 | .003 | 270.263 | | | 15.3% |
| r | .004 | .000 | .003 | .000 | .007 | | | |
| Total | 1253.070 | 28.483 | .239 | .023 | 1281.815 | | | |

| Air duct area | $\eta_M$ | $\eta_T$ | $\varepsilon$ | $\zeta$ [%] | GLt' | GLb | GLs | GLr |
|---|---|---|---|---|---|---|---|---|
| 0 | 95.60 | 99.99 | 2.03 | .017 | 1.54 | .036 | 24.92 | - |
| 15.30 | 94.98 | 99.99 | 2.22 | .019 | 1.63 | - | 21.06 | - |

# APPENDIX B

## B1

### Machine performance on paddy variety IR38.

Table B1. Amount of grain collected from the different discharges of the thresher with maximum* feeding of the paddy variety IR38.

| Description | QM | QE | QD | QU [kgh$^{-1}$] | QI | F | Q |
|---|---|---|---|---|---|---|---|
| g | 1536.323 | 2.237 | .109 | .027 | 1538.696 | 148.641 | 1687.337 |
| t | 13.830 | 7.725 | .177 | .000 | 21.732 | | |
| b | .003 | .051 | .053 | .027 | .134 | | |
| s | 2.644 | 5.803 | .034 | .047 | 8.528 | | |
| r | .093 | .009 | .000 | .000 | .102 | | |
| Total | 1552.893 | 15.825 | .373 | .101 | 1569.192 | | |

| | | | |
|---|---|---|---|
| $\eta_M$ | 91.05 | GLt | 1.38 |
| $\eta_T$ | 99.99 | GLb | Negligible |
| $\xi$ | 1.01 | GLs | .543 |
| $\zeta$ | .024 | GLr | Negligible |

*Maximum feeding involved five men throwing bundles of the crop into the machine until the threshing cylinder speed reduces by 50 rpm.

B2

Table B2. The effect of changes of peripheral velocity of the cleaning fan on paddy variety IR 38 when the oscillating tray slope is maintained at -0.5° and the aspirator air vent fully closed.

| Description | QM | QE | QD | QU [kgh$^{-1}$] | QI | F | Q | Remarks |
|---|---|---|---|---|---|---|---|---|
| o | 1245.366 | 3.132 | .168 | .000 | 1248.666 | 84.894 | 1333.560 | Fan per. |
| t | 7.290 | 7.740 | .138 | .00 | 15.168 | | | velocity |
| b | 2.196 | 5.148 | .078 | .054 | 7.476 | | | 20.348ms$^{-1}$ |
| s | .786 | 2.124 | .012 | .006 | 2.928 | | | |
| r | .096 | .000 | .000 | .00 | .096 | | | |
| Total | 1255.734 | 18.144 | .396 | .060 | 1274.334 | | | |
| o | 1248.630 | 5.640 | .060 | .000 | 1254.330 | 87.846 | | Fan per. |
| t | 7.794 | 8.280 | .174 | .000 | 16.248 | | | velocity |
| b | 1.302 | 3.300 | .120 | .084 | 4.806 | | | 21.705ms$^{-1}$ |
| s | .696 | 3.684 | .042 | .054 | 4.476 | | | |
| r | .132 | .000 | .000 | .000 | .132 | | | |
| Total | 1258.554 | 20.904 | .396 | .138 | 1279.992 | | | |

| Fan per. velocity [ms-1] | ηM | ηT | ξ | ζ [%] | GLt | GLb | GLs | GLr |
|---|---|---|---|---|---|---|---|---|
| 20.348 | 93.390 | 99.995 | 1.423 | .031 | 1.190 | .587 | .230 | - |
| 21.705 | 93.030 | 99.489 | 1.633 | .031 | 1.269 | .375 | .330 | - |

B3

Table B3. The effect of changes of peripheral velocity of the cleaning fan on paddy variety IR38 when oscillating tray slope is maintained at 1.44° and the aspirator air vent fully closed.

| Description | QM | QE | QD | QU [kgh⁻¹] | QI | F | Q | Remarks |
|---|---|---|---|---|---|---|---|---|
| o | 1245.744 | 2.160 | .114 | .000 | 1248.018 | 92.490 | 1340.508 | Fan per. |
| t | 6.762 | 7.980 | .138 | .000 | 14.880 | | | velocity |
| b | 2.196 | 4.056 | .024 | .084 | 6.360 | | | 20.348ms$^{-1}$ |
| s | 1.056 | 3.660 | .084 | .060 | 4.860 | | | |
| r | .096 | .000 | .000 | .00 | .096 | | | |
| Total | 1255.800 | 17.856 | .360 | .144 | 1274.160 | | | |
| o | 1246.866 | 1.860 | .084 | .000 | 1248.810 | 94.494 | 1343.304 | Fan per. |
| t | 8.502 | 8.112 | .186 | .000 | 16.800 | | | velocity |
| b | .318 | 2.940 | .024 | .030 | 3.312 | | | 21.705 ms$^{-1}$ |
| s | 7.848 | 8.268 | .096 | .114 | 16.326 | | | |
| r | .072 | .000 | .000 | .000 | .072 | | | |
| Total | 1263.606 | 21.180 | .390 | .144 | 1285.320 | | | |

| Fan per. velocity [ms$^{-1}$] | ηM | ηT | ξ | ζ [%] | GLt | GLb | GLs | GLr |
|---|---|---|---|---|---|---|---|---|
| 20.348 | 92.931 | 99.989 | 1.401 | .028 | 1.167 | .499 | .381 | - |
| 21.704 | 92.821 | 99.969 | 1.648 | .030 | 1.307 | .258 | 1.270 | - |

B4

Table B4. The effect of changes of peripheral velocity of the cleaning fan on paddy variety IR38 when the oscillating tray slope is maintained at -0.56° and the aspirator air vent area is 15.30% opened.

| Description | QM | QE | QD | QU [$kgh^{-1}$] | QI | F | Q | Remarks |
|---|---|---|---|---|---|---|---|---|
| o | 1250.586 | 2.700 | .138 | .000 | 1253.424 | 103.710 | 1357.134 | Fan per. |
| t | 6.762 | 7.860 | .138 | .000 | 14.760 | | | velocity |
| b | .558 | 4.560 | .042 | .096 | 5.256 | | | 20.348$ms^{-1}$ |
| s | .126 | .078 | .018 | .036 | .258 | | | |
| r | .114 | .000 | .000 | .00 | .114 | | | |
| Total | 1258.146 | 15.198 | .336 | .132 | 1273.812 | | | |
| o | 1256.652 | 5.370 | .078 | .000 | 1262.100 | 106.020 | 1368.120 | Fan per. |
| t | 7.458 | 8.160 | .186 | .000 | 15.804 | | | velocity |
| b | .618 | 2.664 | .012 | .030 | 3.324 | | | 21.705$ms^{-1}$ |
| s | .210 | .852 | .114 | .108 | 1.284 | | | |
| r | .096 | .012 | .000 | .000 | .108 | | | |
| Total | 1265.034 | 17.058 | .390 | .138 | 1282.620 | | | |

| Fan per. velocity [$ms^{-1}$] | $\eta M$ | $\eta T$ | $\xi$ | $\zeta$ [%] | GLt | GLb | GLs | GLr |
|---|---|---|---|---|---|---|---|---|
| 20.348 | 92.149 | 99.990 | 1.193 | .026 | 1.159 | .413 | .020 | - |
| 21.705 | 91.852 | 99.989 | 1.330 | .030 | 1.232 | .259 | .100 | - |

B5

Table B5. The effect of changes of peripheral velocity of the cleaning fan on paddy variety IR36 when the oscillating tray slope is maintained at 1.44° and the aspirator air vent area is 15.30% opened.

| Description | QM | QE | QD | QU [$kgh^{-1}$] | QI | F | Q | Remarks |
|---|---|---|---|---|---|---|---|---|
| o | 1246.710 | 1.968 | .114 | .000 | 1248.792 | 112.092 | 1360.884 | Fan per. |
| t | 7.104 | 7.740 | .132 | .000 | 14.976 | | | velocity |
| b | .134 | .456 | .034 | .054 | .678 | | | 20.348$ms^{-1}$ |
| s | 2.076 | 4.380 | .018 | .102 | 6.576 | | | |
| r | .018 | .000 | .000 | .000 | .018 | | | |
| Total | 1256.042 | 14.544 | .298 | .156 | 1271.040 | | | |
| o | 1247.502 | 2.268 | .102 | .000 | 1249.872 | 118.752 | 1368.624 | Fan per. |
| t | 8.052 | 7.800 | .138 | .000 | 15.990 | | | velocity |
| b | .000 | .060 | .024 | .048 | .132 | | | 21.705$ms^{-1}$ |
| s | 1.644 | 5.640 | .024 | .078 | 7.386 | | | |
| r | .060 | .000 | .000 | .000 | .060 | | | |
| Total | 1257.258 | 15.768 | .288 | .126 | 1273.440 | | | |

| Fan per. velocity [$ms^{-1}$] | $\eta M$ | $\eta T$ | $\xi$ | $\zeta$ [%] | GLt | GLb | GLs | GLr |
|---|---|---|---|---|---|---|---|---|
| 20.348 | 91.610 | 99.988 | 1.144 | .023 | 1.178 | .053 | .513 | - |
| 21.705 | 91.150 | 99.990 | 1.238 | .022 | 1.256 | .010 | .580 | - |

APPENDIX C

Machine performance on paddy variety 1917.

Table C. The effect of adjustable rear duct when maintained at a clearance of 25 mm from the oscillating tray pan when threshing paddy variety IR 1917.

| Description | QM | QE | QD | QU* [kgh$^{-1}$] | QI | F | Q | Remarks |
|---|---|---|---|---|---|---|---|---|
| o | 1419.012 | .160 | .050 | .000 | 1419.223 | 36.922 | 1456.145 | Thresh. |
| t | 19.553 | .088 | .132 | .007 | 19.780 | | | cyl. |
| b | 3.559 | .322 | .008 | .091 | 3.980 | | | at 14° |
| s | 6.815 | .085 | .000 | .017 | 6.918 | | | |
| r | .026 | .008 | .000 | .000 | .034 | | | |
| Total | 1448.965 | .663 | .190 | .115 | 1449.934 | | | |

| nM | nT | ξ | ζ | GLt [%] | GLb | GLs | GLr |
|---|---|---|---|---|---|---|---|
| 97.450 | 99.99 | .046 | .013 | 1.364 | .274 | .477 | – |

*Unthreshed but immature.

# APPENDIX D

## D1

### Machine performance on sorghum variety Casor 2.

Table D1 The amount of sorghum grain variety Casor 2 collected from the different discharges of the thresher with conveyor feeding.

| Description | QM | QE | QD | QU [kgh$^{-1}$] | QI | F | Q |
|---|---|---|---|---|---|---|---|
| o | 1539.361 | 6.130 | .227 | .690 | 1546.408 | 36.438 | 1582.846 |
| t | .205 | 4.885 | 3.932 | .528 | 9.550 | | |
| b | .504 | 9.009 | 1.947 | 8.824 | 20.283 | | |
| s | 2.390 | 6.033 | .183 | 8.609 | 17.215 | | |
| r | .217 | .170 | .223 | .000 | .610 | | |
| Total | 1542.677 | 26.227 | 6.512 | 18.651 | 1594.066 | | |

| $\eta M$ | $\eta T$ | $\xi$ | $\zeta$ [%] | GLt | GLb | GLs | GLr |
|---|---|---|---|---|---|---|---|
| 97.640 | 98.829 | 1.645 | .409 | .559 | 1.272 | 1.080 | .038 |

Table D2[1/] The effect of changes of louvre angle on sorghum variety Casor 2 when the smallest fan blade area (69.995%) and 30.631% of the aspirator air vent area are exposed.

| Description | QM | QE | QD | QU [kgh$^{-1}$] | QI | F | Q | Remarks |
|---|---|---|---|---|---|---|---|---|
| o | 1111.209 | 3.903 | .351 | .891 | 1116.354 | 46.432 | 1162.786 | Louvre |
| t | 1.995 | 2.343 | .021 | 2.400 | 6.759 | | | angle set |
| b | 1.695 | 1.911 | 4.974 | 3.411 | 11.991 | | | at 14° |
| s | 2.115 | 1.410 | .039 | 22.977 | 26.541 | | | |
| r | .516 | .144 | .351 | .000 | 1.011 | | | |
| Total | 1117.530 | 9.711 | 5.736 | 29.679 | 1162.656 | | | |
| o | 1273.255 | 3.516 | .357 | .339 | 1277.467 | 52.919 | 1330.386 | Louvre |
| t | .761 | 1.335 | .000 | .369 | 2.465 | | | angle set |
| b | 1.674 | 4.560 | 2.895 | 4.293 | 13.422 | | | at 14°-7° |
| s | 2.262 | 2.041 | .276 | 16.581 | 21.160 | | | |
| r | .618 | .000 | .222 | .000 | .840 | | | |
| Total | 1278.570 | 11.452 | 3.750 | 21.582 | 1315.354 | | | |

| Louvre angle (degrees) | $\eta M$ | $\eta T$ | $\xi$ | $\zeta$ [%] | GLt | GLb | GLs | GLr |
|---|---|---|---|---|---|---|---|---|
| 14 | 97.640 | 98.829 | 1.645 | .409 | .559 | 1.272 | 1.080 | .038 |
| 14-7 | 95.970 | 98.359 | .871 | .285 | .187 | 1.020 | 1.609 | .064 |

1/The oscillating tray slope angle set at 1.44°.

Table D3[1/] The effect of changes of louvre angle on sorghum variety Casor 2 when the smallest fan blade area (69.995%); and 30.631% of the aspirator air ven area are exposed.

| Description | QM | QE | QD | QU [$kgh^{-1}$] | QI | F | Q | Remarks |
|---|---|---|---|---|---|---|---|---|
| o | 1129.352 | 3.967 | .282 | .765 | 1134.366 | 61.118 | 1195.484 | Louvre |
| t | 1.925 | 1.974 | .216 | 2.199 | 6.314 | | | angle set |
| b | 1.554 | 2.718 | 4.368 | 2.847 | 11.487 | | | at 14° |
| s | 2.298 | 1.137 | .063 | 22.122 | 25.620 | | | |
| r | .432 | .000 | .356 | .000 | .788 | | | |
| Total | 1135.561 | 9.796 | 5.285 | 27.933 | 1178.575 | | | |
| o | 1127.194 | 3.912 | .359 | .432 | 1131.898 | 53.748 | 1185.646 | Louvre |
| t | 1.578 | 1/699 | .560 | .625 | 4.462 | | | angle set |
| b | 1.407 | 3.997 | 2.670 | 3.034 | 11.108 | | | at 14°-7° |
| s | 2.201 | 4.562 | .336 | 18.084 | 25.184 | | | |
| r | .262 | .558 | .456 | .000 | 1.276 | | | |
| Total | 1132.642 | 14.728 | 4.381 | 22.175 | 1173.928 | | | |

| Louvre angle (degrees) | n M | nT | ξ | ζ [%] | GLt | GLb | GLs | GLr |
|---|---|---|---|---|---|---|---|---|
| 14 | 94.800 | 97.630 | .831 | .448 | .535 | .975 | 2.173 | .067 |
| 14-7 | 95.400 | 98.111 | 1.255 | .374 | .380 | .946 | 2.145 | .109 |

1/ The oscillating tray slope set at 3.44°.

D4

Table D4 1/ The effect of changes of louvre angle on sorghum variety Casor 2 when the largest fan blade area (100%); and 30.631% of the aspirator air vent area are exposed.

| Description | QM | QE | QD | QU [$kgh^{-1}$] | QI | F | Q | Remarks |
|---|---|---|---|---|---|---|---|---|
| o | 1071.535 | 4.380 | .237 | .894 | 1077.046 | 24.761 | 1101.807 | Louvre |
| t | 1.302 | 1.767 | .282 | .606 | 3.957 | | | angle set |
| b | 2.328 | 4.623 | 2.454 | 7.248 | 16.653 | | | at 14° |
| s | 1.872 | .714 | .075 | 13.455 | 16.116 | | | |
| r | .336 | .000 | .261 | .000 | .597 | | | |
| Total | 1077.373 | 11.484 | 3.309 | 22.208 | 1114.369 | | | |
| o | 1225.134 | 4.404 | .213 | .498 | 1230.249 | 34.317 | 1264.566 | Louvre |
| t | 1.386 | 1.839 | .354 | .591 | 4.170 | | | angle set |
| b | 2.703 | 5.334 | 3.324 | 7.716 | 19.077 | | | at 14°-7° |
| s | 2.166 | .822 | .030 | 14.550 | 17.568 | | | |
| r | .360 | .378 | .000 | .000 | .738 | | | |
| Total | 1231.490 | 12.777 | 3.921 | 23.355 | 1271.802 | | | |

| Louvre angle (degrees) | nM | n T | ξ [%] | ζ | GLt | GLb | GLs | GLr |
|---|---|---|---|---|---|---|---|---|
| 14 | 97.650 | 98.007 | 1.031 | .297 | .355 | 1.494 | 1.446 | .054 |
| 14-7 | 97.230 | 98.164 | 1.004 | .308 | .327 | 1.500 | 1.381 | .058 |

1/ The oscillating tray slope set at 1.44°.

D5

Table D5[1/] The effect of changes of louvre angle on sorghum variety Casor 2 when the largest fan blade area (100%) and 30.031% of the aspirator air vent area are exposed.

| Description | QM | QE | QD | QU [kgh$^{-1}$] | QI | F | Q | Remarks |
|---|---|---|---|---|---|---|---|---|
| o | 1156.713 | 4.389 | .186 | 1.027 | 1162.315 | 30.271 | 1192.586 | Louvre |
| t | 1.827 | 1.743 | .168 | 2.412 | 6.150 | | | angle set |
| b | 1.839 | 3.030 | 4.200 | 2.988 | 12.057 | | | at 14° |
| s | 1.902 | 1.003 | .216 | 22.467 | 25.588 | | | |
| r | .222 | .054 | .336 | .000 | .612 | | | |
| Total | 1162.508 | 10.219 | 5.106 | 28.894 | 1206.722 | | | |
| o | 1219.536 | 4.464 | .102 | .525 | 1224.627 | 38.270 | 1262.897 | Louvre |
| t | 1.284 | 2.067 | 1.167 | .462 | 4.980 | | | angle set |
| b | 2.832 | 6.237 | 3.261 | 6.846 | 19.176 | | | at 14°-7° |
| s | 5.736 | 5.412 | .354 | 16.947 | 28.449 | | | |
| r | .195 | .000 | .105 | .000 | .300 | | | |
| Total | 1229.583 | 18.180 | 4.989 | 24.780 | 1277.532 | | | |

| Louvre angle (degrees) | ηM | ηT | ξ [%] | ζ | GLt | GLb | GLs | GLr |
|---|---|---|---|---|---|---|---|---|
| 14 | 97.360 | 97.606 | .846 | .423 | .510 | .999 | 2.120 | .051 |
| 14-7 | 96.920 | 98.060 | 1.423 | .391 | .340 | 1.501 | 2.003 | .023 |

1/ The oscillating tray slope set at 3.44°.

DG

Table DG[1/] The effect of changes of louvre angle on sorghum variety Casor 2 when the the lowest fan blade area (69.995%); and 89.527% aspirator air vent area are exposed.

| Description | QM | QE | QD | QU [kgh$^{-1}$] | QI | F | Q | Remarks |
|---|---|---|---|---|---|---|---|---|
| o | 1085.274 | 4.302 | .528 | .723 | 1090.827 | 45.331 | 1136.158 | Louvre |
| t | 1.800 | 2.283 | .255 | 2.253 | 6.591 | | | angle set |
| b | 1.923 | 4.116 | 2.919 | 3.186 | 12.180 | | | at 14° |
| s | 1.686 | 1.077 | .297 | 19.791 | 22.851 | | | |
| r | .270 | .270 | .396 | .000 | .936 | | | |
| Total | 1090.953 | 12.048 | 4.425 | 25.953 | 1133.385 | | | |
| o | 144.728 | 4.602 | .783 | .567 | 1150.680 | 45.417 | 1196.097 | Louvre |
| t | 1.734 | 2.034 | .492 | 1.608 | 5.868 | | | angle set |
| b | 1.959 | 3.915 | 2.838 | 2.007 | 10.719 | | | at 14°-7° |
| s | 1.893 | 1.113 | .252 | 19.068 | 22.326 | | | |
| r | .258 | .306 | .672 | .000 | 1.236 | | | |
| Total | 1150.572 | 11.970 | 5.037 | 23.250 | 1190.829 | | | |

| Louvre angle (degrees) | ηM | ηT | ξ [%] | ζ | GLt | GLb | GLs | GLr |
|---|---|---|---|---|---|---|---|---|
| 14 | 95.900 | 97.710 | 1.063 | .390 | .582 | 1.075 | 2.016 | .083 |
| 14-7 | 96.090 | 98.048 | 1.005 | .423 | .493 | .900 | 1.875 | .103 |

1/ The oscillating tray slope set at 1.44°.

Table D7[1] The effect of changes of louvre angle on sorghum variety Casor 2 when the lowest fan blade area (69.005%); and 89.257% aspirator vent area are exposed.

| Description | QM | QE | QD | QU [$kgh^{-1}$] | QI | F | Q | Remarks |
|---|---|---|---|---|---|---|---|---|
| o | 1005.072 | 4.039 | .405 | .706 | 1010.822 | 65.859 | 1076.681 | Louvre |
| t | 1.775 | 1.922 | .369 | 2.079 | 6.145 | | | angle set |
| b | 1.426 | 2.844 | 3.843 | 3.426 | 11.539 | | | at 14° |
| s | 1.878 | .979 | .000 | 21.183 | 24.040 | | | |
| r | .381 | .000 | .294 | .000 | .675 | | | |
| Total | 1011.132 | 9.784 | 4.911 | 27.394 | 1153.221 | | | |
| o | 1059.939 | 3.717 | .399 | .588 | 1064.643 | 67.990 | 1132.633 | Louvre |
| t | 1.731 | 1.899 | .057 | 1.608 | 5.295 | | | angle set |
| b | 1.566 | 2.043 | 4.932 | 1.998 | 10.539 | | | at 14°-7° |
| s | 2.094 | 1.410 | .222 | 16.806 | 20.532 | | | |
| r | .474 | .000 | .450 | .000 | .224 | | | |
| Total | 1065.804 | 9.069 | 6.060 | 21.000 | 1101.933 | | | |

| Louvre angle (degrees) | ηME | ηT | ξ [%] | ζ | GLt | GLb | GLs | GLr |
|---|---|---|---|---|---|---|---|---|
| 14 | 93.760 | 97.399 | .929 | .466 | .583 | 1.096 | 2.282 | .064 |
| 14-7 | 93.910 | 98 094 | .823 | .550 | .481 | .956 | 1.863 | .084 |

[1] The oscillating tray slope set at 3.44°.

D8

Table D8[1/] The effect of changes of louvre angle on sorghum variety Casor 2 when the largest fan blade area (100%); and 89.527% aspirator vent area are exposed.

| Description | QM | QE | QD | QU [$kgh^{-1}$] | QI | F | Q | Remarks |
|---|---|---|---|---|---|---|---|---|
| o | 1112.009 | 3.987 | .462 | .572 | 1117.030 | 38.184 | 1155.214 | Louvre |
| t | 1.851 | 1.906 | .183 | 1.452 | 5.482 | | | angle set |
| b | 1.617 | 3.259 | 3.523 | 3.518 | 11.917 | | | at 14° |
| s | 1.843 | .870 | .276 | 19.182 | 22.171 | | | |
| r | .219 | .696 | .363 | .000 | 1.278 | | | |
| Total | 1117.539 | 10.808 | 4.807 | 24.724 | 1157.878 | | | |
| o | 1258.776 | 4.470 | .570 | .402 | 1264.218 | 45.643 | 1309.861 | Louvre |
| t | 1.599 | 2.274 | .342 | .549 | 4.764 | | | angle set |
| b | 3.615 | 4.500 | 2.496 | 6.192 | 16.803 | | | at 14°-7° |
| s | 5.796 | 1.023 | .384 | 16.818 | 24.021 | | | |
| r | .384 | .000 | .325 | .000 | .709 | | | |
| Total | 1270.160 | 12.867 | 4.117 | 23.961 | 1311.115 | | | |

| Louvre angle (degrees) | ηME | ηT | ε [%] | ζ | GLt | GLb | GLs | GLr |
|---|---|---|---|---|---|---|---|---|
| 14 | 96.260 | 97.865 | .933 | .415 | .473 | 1.029 | 1.914 | .110 |
| 14-7 | 96.100 | 98.172 | .981 | .314 | .363 | 1.232 | 1.878 | .054 |

[1/] The oscillating tray slope set at 1.44°.

Table D9[1] The effect of changes of louvre angle on sorghum Casor 2 when the largest fan blade area (100%); and 89.27% aspirator vent area are exposed.

| Description | QM | QE | QD | QU [kgh$^{-1}$] | QI | F | Q | Remarks |
|---|---|---|---|---|---|---|---|---|
| o | 1122.108 | 4.110 | .480 | .660 | 1127.358 | | 1166.554 | Louvre |
| t | 1.887 | 2.199 | .150 | 1.644 | 5.880 | | | angle set |
| b | 1.596 | 3.273 | 3.030 | 3.444 | 11.343 | | | at 14° |
| s | 2.229 | 1.056 | .219 | 19.851 | 23.355 | | | |
| r | .093 | .000 | .225 | .000 | .318 | | | |
| Total | 1127.913 | 10.638 | 4.104 | 25.599 | 1168.254 | | | |
| o | 1071.064 | 4.848 | .642 | .573 | 1077.147 | | 1116.876 | Louvre |
| t | 1.836 | 2.127 | .348 | .243 | 4.554 | | | angle set |
| b | 1.974 | 3.672 | 3.945 | .984 | 10.575 | | | at 14°-7° |
| s | 2.199 | 1.182 | .048 | 19.314 | 22.743 | | | |
| r | .265 | .000 | .378 | .000 | .643 | | | |
| Total | 1077.358 | 11.829 | 5.361 | 21.144 | 1115.662 | | | |

| Louvre angle (degrees) | ηME | ηT | ξ [%] | ζ | GLt | GLb | GLs | GLr |
|---|---|---|---|---|---|---|---|---|
| | 96.190 | 97.809 | .911 | .351 | .503 | .971 | 1.909 | .027 |
| | 95.894 | 98.105 | 1.060 | .481 | .408 | .948 | 2.034 | .029 |

[1] The oscillating tray slope set at 3.44°.

E1

Machine performance on wheat variety Trigo 1.

Table E1[1/] The effect of the changes of the threshing cylinder peripheral velocity on wheat variety Trigo 1 when the oscillating tray slope is -0.56°.

| Description | QM | QE | QD | QU | QI | Chaff | F Weed | Stones | Q | Remarks 2/ |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | [$kgh^{-1}$] | | | | | | |
| o | 1038.396 | 304.740 | .096 | 42.156 | 1385.388 | 6.432 | .000 | .168 | 1391.988 | Thresh. |
| t | .834 | 2.592 | .042 | 3.138 | 6.606 | | | | | periph. |
| b | 1.050 | 3.288 | .078 | 4.440 | 8.862 | | | | | vel. |
| s | .030 | .168 | .000 | .000 | .198 | | | | | 21.297 $ms^{-1}$ |
| r | .228 | .450 | .000 | .000 | .678 | | | | | |
| Total | 1040.544 | 311.238 | .216 | 49.734 | 1401.732 | | | | | |
| o | 1047.096 | 301.920 | .000 | 36.672 | 1385.736 | 6.276 | .000 | .192 | 1394.111 | Thresh. |
| t | .582 | 2.760 | .078 | 3.060 | 6.480 | | | | | periph. vel. |
| b | .612 | 2.580 | .420 | 4.560 | 8.172 | | | | | 23.391 $ms^{-1}$ |
| s | .000 | .024 | .000 | .312 | .336 | .028 | .000 | .084 | | |
| r | .684 | .180 | .000 | .000 | .864 | | | | | |
| Total | 1048.974 | 307.464 | .498 | 44.604 | 1401.540 | | | | | |

| Thresh. Cyl. periph. speed $ms^{-1}$ | $\eta_{ME}$ | $\eta_T$ | $\xi$ | $\zeta$ | GLt | GLb | GLs | GLr |
|---|---|---|---|---|---|---|---|---|
| | | | | [%] | | | | |
| 21.297 | 96.490 | 96.452 | 22.20 | .015 | .471 | .632 | .014 | .048 |
| 23.391 | 96.90 | 96.818 | 22.201 | .036 | .462 | .583 | .024 | .062 |

1/ The aspirator air vent area opened was 100%.
2/ Threshing cylinder peripheral velocity.

E2

Table E2[1] The effect of the changes of the threshing cylinder peripheral velocity on wehat variety Trigo 1 when the oscillating tray slope is -0.56°.

| Description | QM | QE | QD | QU [kgh$^{-1}$] | QI | F Chaff | F Weed | F Stones | Q | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|
| o | 1036.278 | 303.528 | .054 | 42.216 | 1382.076 | 5.202 | .000 | .162 | 1387.394 | Thresh. |
| t | .636 | 2.880 | .144 | 3.000 | 6.660 | | | | | periph. |
| b | 1.188 | 3.300 | .096 | 4.440 | 9.024 | | | | | vel. |
| s | .000 | .168 | .000 | .000 | .168 | .036 | .000 | .348 | | 21.297 ms$^{-1}$ |
| r | .420 | .156 | .084 | .000 | .660 | | | | | |
| Total | 1038.522 | 310.032 | .378 | 49.656 | 1398.588 | | | | | |
| o | 1055.184 | 309.708 | .018 | 37.290 | 1402.200 | 4.644 | | .276 | 1407.105 | Thresh. cyl. |
| t | 1.080 | 2.880 | .120 | 2.640 | 6.720 | | | | | periph. vel. |
| b | .432 | 2.940 | .408 | 4.980 | 8.760 | | | | | 23.391 ms$^{-1}$ |
| s | .024 | .030 | .024 | .408 | .486 | .078 | | .252 | | |
| r | .702 | .204 | .000 | .000 | .906 | | | | | |
| Total | 1057.422 | 315.762 | .570 | 45.318 | 1419.072 | | | | | |

| Thresh. Cyl. periph. speed ms$^{-1}$ | $\eta_{ME}$ | $\eta_T$ | $\xi$ | $\zeta$ [%] | GLt | GLb | GLs | GLr |
|---|---|---|---|---|---|---|---|---|
| 21.297 | 96.570 | 96.449 | 22.168 | .027 | .476 | .645 | .012 | .047 |
| 23.391 | 97.000 | 96.807 | 22.251 | .040 | .473 | .617 | .034 | .064 |

[1] The aspirator air vent set at 89.257% opened.

E3

Table E3[1] The effect of the changes of the threshing cylinder peripheral velocity on wheat variety Trigo 1 when the oscillating tray slope is 1.44°.

| Description | QM | QE | QD | QU | QI | Chaff | F Weed | Stones | Q | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | [kgh$^{-1}$] | | | | | | |
| o | 1034.784 | 304.296 | .084 | 42.600 | 1381.764 | 8.676 | .066 | .174 | 1390.680 | Thresh. |
| t | .666 | 2.700 | .054 | 2.2940 | 6.360 | | | | | periph. |
| b | 1.068 | 2.850 | .060 | 4.020 | 7.998 | | | | | vel. |
| s | .246 | .360 | .000 | .048 | .654 | .096 | .012 | .240 | | 21.297 ms$^{-1}$ |
| r | .186 | .318 | .000 | .000 | .504 | | | | | |
| Total | 1036.950 | 310.524 | .198 | 49.608 | 1397.280 | | | | | |
| o | 1045.356 | 302.220 | .096 | 37.104 | 1384.776 | 13.710 | .000 | .174 | 1398.660 | Thresh. |
| t | .510 | 2.640 | .090 | 3.180 | 6.420 | | | | | periph. vel. |
| b | .570 | 3.240 | .138 | 4.200 | 8.148 | | | | | 23.391 ms$^{-1}$ |
| s | .036 | .056 | .040 | .372 | .504 | | | | | |
| r | .252 | .120 | .000 | .000 | .372 | | | | | |
| Total | 1046.724 | 308.276 | .364 | 44.856 | 1400.220 | | | | | |

| Thresh. Cyl. periph. speed ms$^{-1}$ | nME | nT | ξ | ζ | GLt | GLb | GLs | GLr |
|---|---|---|---|---|---|---|---|---|
| | | | | [%] | | | | |
| 21.297 | 96.289 | 96.450 | 22.223 | .014 | .455 | .572 | .047 | .036 |
| 23.391 | 96.348 | 96.797 | 22.016 | .026 | .458 | .582 | .036 | .027 |

[1] The aspirator air vent set at 100% opened.

E4

Table E4 1/ The effect of the changes of the threshing cylinder peripheral velocity on wheat variety Trigo 1; when the oscillating tray slope is 1.44°.

| Description | QM | QE | QD | QU | QI | F Chaff | F Weed | F Stones | Q | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | $[kgh^{-1}]$ | | | | | | |
| o | 1039.452 | 303.780 | .096 | 42.576 | 1385.904 | 6.924 | .000 | .792 | 1393.620 | Thresh. |
| t | .816 | 2.640 | .084 | 2.880 | 6.420 | | | | | periph. |
| b | .690 | 3.180 | .078 | 4.020 | 7.968 | | | | | vel. |
| s | .000 | .300 | .012 | .180 | .492 | .096 | .120 | .420 | | 21.297 $ms^{-1}$ |
| r | .372 | .144 | .000 | .000 | .516 | | | | | |
| Total | 1041.330 | 310.044 | .270 | 49.656 | 1401.300 | | | | | |
| o | 1054.176 | 308.868 | .066 | 37.050 | 1400.160 | 11.250 | .000 | .198 | 1411.608 | Thresh. |
| t | .344 | 2.640 | .102 | 3.318 | 6.404 | | | | | periph. vel. |
| b | .864 | 3.390 | .198 | 4.452 | 8.904 | | | | | 23.391 $ms^{-1}$ |
| s | .048 | .030 | .012 | .372 | .462 | .096 | .000 | .333 | | |
| r | .246 | .156 | .000 | .000 | .402 | | | | | |
| Total | 1055.678 | 315.084 | .378 | 45.192 | 1416.332 | | | | | |

| Thresh. Cyl. periph. speed $ms^{-1}$ | $\eta ME$ | $\eta T$ | $\xi$ | $\zeta$ | GLt | GLb | GLs | GLr |
|---|---|---|---|---|---|---|---|---|
| | | | | [%] | | | | |
| 21.297 | 96.384 | 96.456 | 22.125 | .019 | .458 | .569 | .031 | .037 |
| 23.391 | 96.560 | 96.809 | 22.246 | .027 | .452 | .629 | .033 | .028 |

1/ The aspirator air vent set at 89.257% opened.

E5

Table E5[1/] The effect of the changes of the threshing cylinder peripheral velocity on wheat variety Trigo 1 when the oscillating tray slope is 3.44°.

| Description | QM | QE | QD | QU | QI | Chaff | F Weed | Stones | Q | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | [kgh⁻¹] | | | | | | |
| o | 1038.078 | 302.760 | .084 | 43.224 | 1384.146 | 21.606 | .192 | .144 | 1406.088 | Thresh. |
| t | .558 | 2.820 | .102 | 2.880 | 6.360 | | | | | periph. |
| b | .750 | 2.400 | .126 | 3.180 | 6.456 | | | | | vel. |
| s | .132 | .456 | .084 | .648 | 1.320 | | | | | 21.297 $ms^{-1}$ |
| r | .126 | .192 | .000 | .000 | .318 | | | | | |
| Total | 1039.644 | 308.628 | .396 | 49.932 | 1398.600 | | | | | |
| o | 1059.438 | 306.060 | .102 | 38.664 | 1404.264 | 23.136 | .000 | .012 | 1427.412 | Thresh. |
| t | .864 | 2.640 | .096 | 2.760 | 6.360 | | | | | periph. vel |
| b | 1.506 | 2.640 | .102 | 3.540 | 7.788 | | | | | 23.391 $ms^{-}$ |
| s | .108 | .132 | .012 | .420 | .672 | .132 | .036 | .768 | | |
| r | .204 | .000 | .000 | .000 | .204 | | | | | |
| Total | 1062.120 | 311.472 | .312 | 45.384 | 1419.288 | | | | | |

| Thresh. Cyl. periph. speed $ms^{-1}$ | η ME | ηT | ξ | ζ | GLt | GLb | GLs | GLr |
|---|---|---|---|---|---|---|---|---|
| | | | | [%] | | | | |
| 21.297 | 95.359 | 96.430 | 22.067 | .028 | .455 | .462 | .094 | .023 |
| 23.391 | 96.662 | 96.802 | 21.946 | .022 | .448 | .549 | .047 | .014 |

1/ The aspirator air vent set at 100% opened.

E6

Table E6[1] The effect of the changes of the threshing cylinder peripheral velocity on wheat variety Trigo 1 when the oscillating tray slope is 3.44°.

| Description | QN | QE | QD | QU | QI | F Chaff | F Weed | F Stones | Q | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | [kgh$^{-1}$] | | | | | | |
| o | 1039.284 | 304.860 | .084 | 42.906 | 1387.1[illegible] | 21.070 | .000 | .000 | 1408.204 | Thresh. |
| t | .924 | 2.640 | .096 | 2.940 | 6.600 | | | | | periph. |
| b | .804 | 2.760 | .090 | 3.900 | 7.554 | | | | | vel. |
| s | .000 | .000 | .162 | .162 | .028 | .000 | 1.032 | .420 | | 21.297 ms$^{-1}$ |
| r | .408 | .282 | .000 | .000 | .690 | | | | | |
| Total | 1041.420 | 310.542 | .270 | 49.908 | 1402.140 | | | | | |
| o | 1061.834 | 034.752 | .078 | 38.292 | 1405.056 | 22.062 | .000 | .042 | 1427.160 | Thresh. |
| t | .768 | 2.856 | .096 | 2.880 | 6.600 | | | | | periph. vel. |
| b | 1.060 | 3.336 | .108 | 4.080 | 8.604 | | | | | 23.391 ms$^{-1}$ |
| s | .193 | .072 | .035 | .360 | .660 | .312 | .018 | .726 | | |
| r | .138 | .030 | .000 | .000 | .168 | | | | | |
| Total | 1064.113 | 311.046 | .317 | 45.612 | 1421.088 | | | | | |

| Thresh. Cyl. periph. speed ms$^{-1}$ | nME | nT | $\xi$ | $\zeta$ | GLt | GLb | GLs | GLr |
|---|---|---|---|---|---|---|---|---|
| | | | | [%] | | | | |
| 21.297 | 95.459 | 96.441 | 22.148 | .019 | .471 | .539 | .012 | .049 |
| 23.391 | 95.763 | 96.790 | 21.888 | .022 | .464 | .605 | .046 | .012 |

1/ The aspirator air vent set at 89.257% opened.

E7

Table E7[1/] The amount of wheat grain variety Trigo 1 collected from the different discharges with maximum* feeding and cylinder velocity of 17.805 $ms^{-1}$ and 21.297 $ms^{-1}$.

| Description | QM | QE | QD | QU [$kgh^{-1}$] | QI | F Chaff | F Weed | F Stones | Q | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|
| o | 1016.036 | .229 | .039 | 37.245 | 1053.549 | 100.390 | .249 | .133 | 1154.321 | Thresh. |
| t | 3.519 | .169 | .297 | 2.998 | 6.983 | | | | | cylinder |
| b | .021 | .101 | .318 | .948 | 1.389 | | | | | velocity |
| s | .000 | .000 | .000 | .000 | .000 | | | | | 17.805 $ms^{-1}$ |
| r | .009 | .015 | .000 | .000 | .025 | | | | | |
| Total | 1019.585 | .514 | .654 | 41.191 | 1061.945 | | | | | |
| o | 1456.182 | .263 | .049 | 35.690 | 1492.185 | 129.384 | .257 | .103 | 1622.128 | Thresh. |
| t | 12.137 | .285 | .153 | 2.608 | 15.182 | | | | | cylinder |
| b | .014 | .629 | .062 | 1.057 | 1.762 | | | | | velocity |
| s | .013 | .010 | .020 | .144 | .277 | 1.586 | .259 | .031 | | 21.297 $ms^{-1}$ |
| r | .021 | .032 | .000 | .000 | .053 | | | | | |
| Total | 1468.367 | 1.219 | .284 | 39.499 | 1509.369 | | | | | |

| Thresh. Cyl. velocity $ms^{-1}$ | $\eta_{ME}$ | $\eta_T$ | $\varepsilon$ | $\zeta$ | GLt [%] | GLb | GLs | GLr |
|---|---|---|---|---|---|---|---|---|
| 17.805 | 88.020 | 96.121 | .048 | .061 | .658 | .131 | .000 | - |
| 21.297 | 89.770 | 97.383 | .081 | .019 | 1.006 | .117 | .018 | - |

*Maximum feeding involved five men throwing bundles of the crop into the machine until the cylinder speed reduces by a factor of 50 rpm.

E8

Table E8. The amount of wheat grain variety Trigo 1 collected from the different discharges with maximum* feeding and cylinder velocity of 24.788 $ms^{-1}$.

| Description | QM | QE | QD | QU [$kgh^{-1}$] | QI | F Chaff | F Weed | F Stones | Q | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|
| o | 2046.927 | .340 | .087 | 35.067 | 2082.420 | 589.187 | .520 | .113 | 2672.240 | |
| t | 22.060 | .453 | .240 | 2.480 | 25.233 | | | | | |
| b | .320 | .140 | .207 | 1.480 | 2.147 | | | | | velocity |
| s | .013 | .040 | .006 | .220 | .280 | 2.987 | .293 | .047 | | 17.805 $ms^{-1}$ |
| r | .020 | .040 | .000 | .000 | .060 | | | | | |
| Total | 2069.340 | 1.013 | .540 | 39.247 | 2110.140 | | | | | |

| nME | nT | ξ | ζ | GLt [%] | GLb | GLs | GLr |
|---|---|---|---|---|---|---|---|
| 76.600 | 98.14 | .048 | .026 | 1.196 | .102 | .013 | - |

*Maximum feeding involved five men throwing bundles of the crop into the machine until the cylinder speed reduces by a factor of 50 rpm.

E9

Table E9. The effect of louvre angle on wheat variety Trigo 1 at a cylinder peripheral velocity of 21.297 $ms^{-1}$

| Description | QM | QE | QD | QU [$kgh^{-1}$] | QI | F Chaff | F Weed | F Stones | Q | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|
| o | 1027.116 | 296.760 | .102 | 43.020 | 1366.998 | 6.924 | .228 | .276 | 1374.4226 | Louvre |
| t | .774 | 2 .670 | .090 | 2.736 | 6.270 | | | | | angle |
| b | .672 | 3.582 | .090 | 3.714 | 8.058 | | | | | 0°–14° |
| s | .000 | .258 | .030 | .258 | .546 | .276 | .072 | | | |
| r | .312 | .211 | .012 | .000 | .535 | | | | | |
| Total | 1028.874 | 303.481 | .234 | 49.728 | 1382.407 | | | | | |
| o | 1020.516 | 290.64 | .102 | 41.840 | 1353.098 | 6.660 | .156 | .078 | 1359.992 | Louvre |
| t | .372 | 2.658 | .042 | 4.650 | 7.722 | | | | | angle |
| b | .078 | 3.030 | .078 | 4.188 | 7.974 | | | | | 14° |
| s | .186 | .252 | .024 | .558 | 1.020 | .192 | .180 | .036 | | |
| r | .156 | .228 | .000 | .000 | .384 | | | | | |
| Total | 1021.908 | 296.808 | .246 | 51.236 | 1370.198 | | | | | |

| Louvre angle (degrees) | $\eta ME$ | $\eta T$ | $\varepsilon$ | $\zeta$ | GLt [%] | GLb | GLs | GLr |
|---|---|---|---|---|---|---|---|---|
| 0 - 14 | 96.322 | 96.403 | 21.953 | .017 | .453 | .583 | .039 | .039 |
| 14 | 96.409 | 96.252 | 21.662 | .018 | .565 | .582 | .0744 | .028 |

E10

Table E10. The effect of adjustable rear duct when maintained at a clearance of 76 mm from the oscillating tray pan when threshing wheat variety Trigo 1 at different cylinder velocities.

| Description | QM | QE | QD | QU | QI | Chaff | F Weed | Stones | Q | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | [kgh$^{1}$ | | | | | | |
| o | 737.745 | 21.122 | .243 | 26.128 | 785.238 | 30.302 | .149 | .039 | 815.7276 | Threshing |
| t | 1.379 | 2 .486 | .160 | .045 | 4.071 | | | | | cylinder |
| b | .676 | .904 | .077 | 2.124 | 3.781 | | | | | velocity |
| s | .024 | .143 | .043 | .244 | .453 | .398 | .000 | | | 21.297 ms$^{-1}$ |
| r | .000 | .000 | .000 | .000 | .000 | | | | | |
| Total | 739.824 | 24.655 | .523 | 28.541 | 793.543 | | | | | |
| o | 1035.094 | 39.862 | .394 | 30.389 | 1105.739 | 88.779 | .167 | .018 | 1194.702 | Threshing |
| t | 2.685 | 3.838 | .249 | .075 | 6.848 | | | | | cylinder |
| b | .310 | 1.232 | .048 | 3.978 | 5.569 | | | | | velocity |
| s | .257 | .198 | .011 | .687 | 1.153 | 2.329 | .519 | .000 | | 23.391 ms$^{-1}$ |
| r | .000 | .012 | .000 | .000 | .012 | | | | | |
| Total | 1038.346 | 45.142 | .702 | 35.129 | 1119.319 | | | | | |

| Thresh. cyl. velocity ms$^{-1}$ | ηME | ηT | ε | ζ | GLt [%] | GLb | GLs | GLr |
|---|---|---|---|---|---|---|---|---|
| 21.297 | 93.030 | 96.403 | 31.070 | .066 | .513 | .476 | .057 | .000 |
| 23.391 | 89.977 | 96.871 | 40.330 | .063 | .612 | .498 | .1034 | - |

# APPENDIX F

Machine performance on yellow corn.

Table F. Yellow corn grain from different discharges of the machine at 10.474 ms-1 and 13.267 ms-1 cylinder peripheral velocities.

| Description | QM | QE | QD Machine | QD Insect Disease [$kgh^{-1}$] | QU | QI | F 1/ | Q | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| o | 647.340 | 9.288 | 52.800 | 6.474 | .000 | 715.902 | 31.638 | 747.540 | Threshing |
| t | 123.762 | 2.691 | 9.390 | 1.491 | .138 | 137.472 | | | cylinder |
| b | .000 | .066 | .078 | .069 | .000 | .213 | | | velocity |
| s | 1.908 | 1.380 | .030 | .216 | .000 | 3.534 | | | 10.474 $ms^{-1}$ |
| 2/ r | 2.682 | 1.740 | .000 | .927 | .000 | 5.349 | | | |
| Total | 775.892 | 15.165 | 62.298 | 9.177 | .138 | 862.470 | | | |
| o | 658.254 | 10.272 | 55.290 | 8.031 | .000 | 731.847 | 35.415 | 767.262 | Threshing |
| t | 136.908 | 3.318 | 10.845 | .870 | .192 | 152.133 | | | cylinder |
| b | .006 | .156 | .054 | .168 | .000 | .384 | | | velocity |
| s | 4.581 | 1.026 | .480 | .081 | .000 | 6.168 | | | 13.267 $ms^{-1}$ |
| r | 4.440 | .420 | .000 | .708 | .000 | 5.568 | | | |
| Total | 804.189 | 15.192 | 66.669 | 9.858 | .192 | 896.100 | | | |

| Thresh. cyl. velocity $ms^{-1}$ | ηM | ηT | ξ | ζ | GLt [%] | GLb | GLs | GLr 2/ |
|---|---|---|---|---|---|---|---|---|
| 10.474 | 86.660 | 99.984 | 1.758 | 7.223 | 15.939 | .025 | .410 | .620 |
| 13.267 | 85.792 | 99.979 | 1.695 | 7.439 | 16.977 | .043 | .688 | .621 |

1/ Great amount is of cob pieces.

2/ Resulted from grains thrown out of the feeding hopper.

G1

## APPENDIX G

Information on threshing cylinder shaft design.

The typical properties of steel are found on Table 3.1. The area occupied by different holes of bolts was calculated ($A = \pi d^2/4$, where d is the diameter of respective holes) and eliminated.

thus: area occupied by threshing pegs $= 2.394 \times 10^{-2*}\ m^2$

area for knife bolts $= 9.550 \times 10^{-3}\ m^2$

flange, support, and thrower bolts $= 4.630 \times 10^{-3}\ m^2$

Total $3.807 \times 10^{-2}\ m^2$

Net area of the outer plate = total area of plate minus area of holes

$= (2.323 - 3.807 \times 10^{-2})m^2$

$= 2.285\ m^2$

Area of holes on the inner plate $= 2.444 \times 10^{-2}\ m^2$

Net area of the plate = total area minus area of holes

$= (1.161 - 2.444 \times 10^{-2})m^2$

Then: Weight of the inside plate = 322.222 N

Weight of the outer plate = 647.541 N

Total 969.763 N

---

*All values and number to follow are approximated to the nearest three decimal digits irrespective of the exponential sign.

G2

The weight of the parts on the threshing cylinder viz: flanges, threshing pegs, and knives was computed and presented on Table G.1.

Table G1. Forces of the threshing cylinder parts.

| Description | Symbol | Magnitude (N) |
|---|---|---|
| Thrower and flange | Ftf | 392.697 |
| Cutting knives | Fk | 347.949 |
| Middle support and outer plate | Fspl | 779.746 |
| Inner plate | Fp2 | 322.222 |
| Threshing pegs | Fg | 265.506 |
| Flinger and flange | Fff | 341.702 |
| Total weight | W* | 2449.822 |

*Weight and force mean the same.

Taking moments about the thrower side we have the reaction $R_B$ from the feed side as:

$$R_B = (1389.062\ Fff + 1100.138\ Fg + 1000.125\ Fp2 + 669.925\ Fspl + 473.075\ Fk)/1389.062 \quad \text{........G.1}$$

All numbers in equation G.1 are measurements in mm.

Then $R_B$ = 1278.545 N

And $R_A$ = reaction from feed side

$= W - R_B$

G3

$= 1171.277$ N

When the weight of fan, threshing cylinder assembly, flywheel, and driving pulley are added on the threshing cylinder shaft the weight distribution resulted the values on Table G.2 (also represented on Figure 4.2).

It is assumed that:

( i) The weight of the shaft is not contributing to the other components.

(ii) Since the bearings are self-aligning the shaft is then simply supported and the weight and bearing reactions are concentrated.

Table G.2. Forces on the threshing cylinder shaft.

| Description | Symbol | Component (N) |
|---|---|---|
| Cylinder reaction thrower side | $R_A$ | 1171.277 |
| Cylinder reaction feed side | $R_B$ | 1278.545 |
| Fan assembly weight | Fn | 52.890 |
| Pulley and flywheel weight | Fl | 771.938 |
| Total weight | Ws1/ | 3274.800 |

1/ Weight on the shaft.

Taking moments about the thrower side we have the reaction $R_{B1}$ on the shaft from the feed side as:

$M_{RB1} = 1619.251 R_{B1} + 152.400 \text{ Fn} - 1720.851 \text{ Fl} -$

G4

$$1541.463\ R_B - 77.788\ R_A = \emptyset \quad \text{............G.2}$$

All numbers in equation G.2 are in mm.

Then $R_{B1}$ = 2088.787 N

$R_{A1}$ = reaction from the feed side

= Ws - RB1

= 1185.813 N

Considering the bending force from the pulley on the shaft, it is contributed by the force F1 on the tension side of the pulley and the force on the slack side F2. The sum depends during driving upon F1/F2. This ratio is for V-belt drive after neglecting the centrifugal forces, thus:

$$\ln \frac{F1}{F2} = f\theta$$

where

f = frictional force

θ = angle of lap

The ratio vary with power transmitted and the initial belt tension. For design purposes 1.5* may be used.

Then F1 + F2 = F1/F2 (F1 - F2)

F1 - F2 = F (net driving force)

then F1 - F2 = 1.5 F ............................ G.3

Assuming a tractor with power P = [60 hp] 44.45 kw

---------------

*Suggested by ASME.

G5

$$F = \frac{P}{\omega r} \qquad \text{.......................... G.4}$$

where

$\omega$ = angular velocity (rad $s^{-1}$)

$r$ = radius of the pulley [m]

Taking the maximum cylinder speed expected [610rpm] 63.879 rad $s^{-1}$ and a pulley of 0.114 m radius and substituting the numbers in the equation G.3 and G.4 we get F=9191.830 N (Bending force). When this force is added to the force contributed by the pulley and flywheel the result is F1 = 9963.768 N. By substituting this new value in equation G..2 we get new values of reactions as RA1 = 609.135 N and RB1 = 11857.295 N. This value and the others listed in Table G.2 resulted to the loading and shear diagram on Figure 4.3.

The point where the shear force crosses the line is the area of maximum bending. In both shear force diagrams the crossing occur at the same point. On this point the diameter is computed as follows:

From Figure 4.3 bending moment M = 1012.319 Nm

Recalling the values in Table 3.1 the following is computed:

Endurance limit $\sigma n = \sigma u/2$ - - - - - - - G.5

Endurance strength $\tau n = 0.6\sigma n$ - - - - - - - G.6

G6

Design $\tau y$, $\tau yd = 0.6\sigma y$ - - - - - - - G.7

Strength reduction factor Kf considered is 1.6. And the alternating component of total stress for respectively shear and tensile is noted by $\tau a$ and $\sigma a$ and the mean stress by $\tau m$ and $\sigma m$. The Equivalent Stress in tensile is given by the following relationship.

$$\sigma e = \frac{\sigma n}{\sigma y} \sigma m + K_f \sigma a \qquad \text{- - - - - - - - - - G.8}$$

$$\sigma m = \frac{F}{A}$$

In this case $\sigma m = 0$

$$\sigma a = \frac{Mc}{I} = \frac{(1012.319)(32)}{\pi D^3} \qquad \text{- - - - - - - - - - (a)}$$

Also Equivalent Stress in shear

$$\tau e = \frac{\tau n}{\tau y} \tau m + K_f \tau a \qquad \text{- - - - - - - - - - G.9}$$

with a steady torque $\tau a = 0$

$$\tau m = \frac{Tc}{J} = \frac{(700.417)(16)}{\pi D^3} \qquad \text{- - - - - - - - - - (b)}$$

Safety/design factor considered N = 1.8

Then by utilizing the equivalent stress we have

$$\frac{1}{N} = \{(\frac{\sigma e}{\sigma n})^2 + (\frac{\tau e}{\tau n})^2\}^{0.5} \qquad \text{- - - - - - - - - - G.10}$$

## G7

If the values obtained from equation G.5 to G.9 are plunged in equation G.10 and reducing the endurance limit by a factor of 0.85 the dimension of the shaft diameter obtained will be 47.775 mm. A 50 mm diameter shaft has been used.

H1

# APPENDIX H

Table H1. Cost of shafts/rods, and sheet metal used for IRRI-PAK Thresher

| shaft/rods | | | flat bar and sheet | | | |
|---|---|---|---|---|---|---|
| Diameter (m) | Length | Cost (US$) | Width | Thickness ($m^2$) | Length | Cost (US$) |
| 0.010 | 109 | 45.01 | 0.025 | 0.006 | 1.07 | 0.83 |
| 0.019 | 13 | 38.54 | 0.032 | 0.006 | 8.69 | 7.55 |
| 0.025 | 0.61 | 2.03 | 0.038 | 0.006 | 27.00 | 27.05 |
| 0.044 | 0.14 | 0.72 | 0.051 | 0.006 | 1.70 | 2.18 |
| 0.076OD | | | | | | |
| 0.051ID | 0.38 | 19.25 | 0.070 | 0.006 | 1.02 | 1.72 |
| 0.095OD | | | | | | |
| 0.070ID | 0.08 | 4.93 | | | | |
| 0.070OD | | | | | | |
| 0.051ID | 1.33 | 75.31 | | | | |
| 0.051 | 1.64 | 114.78 | | 16# | 9.40** | 103.51 |
| 0.114 | 0.13 | 15.31 | | 0.004 | 2.35** | 33.36 |
| 0.127 | 0.06 | 7.83 | | 0.006 | 0.28** | 6.88 |
| 0.152* | 0.06 | 10.00 | | 0.019 | 0.93** | 50.45 |
| 0.203* | 0.18 | 20.00 | | | | |
| 0.229* | 0.13 | 20.00 | | | | |
| | | 371.71 | | | | 233.53 |

\# Symbol for gauge of a sheet
* Cast iron.
** The values refer to area $m^2$ .

Table [illegible]. Cost of angle bar and screen used for IRRI-PAK thresher.

| Angle bar | | | | | Screen | | |
|---|---|---|---|---|---|---|---|
| Width | Depth | Thickness (m) | Length | Cost (US$) | Hole diameter (m) | Area ($m^2$) | Cost (US$) |
| 0.025 | 0.025 | 0.003 | 10.10 | 6.04 | 0.002 | 0.225 | 3.25 |
| 0.038 | 0.038 | 0.006 | 0.75 | 1.33 | 0.010 | 0.806 | 11.60 |
| 0.051 | 0.051 | 0.006 | 26.36 | 66.40 | 0.016 | 0.968 | 13.92 |
| | | | | 73.77 | | | 28.77 |

Table H3. Cost of bearings and pillow blocks.

| Amount | Descripstion | | Cost (US$) |
|---|---|---|---|
| | Part No. | Size (mm) | |
| 4 | SKF6310 | 110 OD 50 ID 27W (pillow blocks) | 103.78 |
| 5 | SKF ELS10 | 2 3/4" 1 1/4" ID 11/16" ID (ESW) | 56.97 |
| 2 | SKF6309 | 100 OD 45ID 45W | 28.11 |
| 2 | SKF6312 | 130 OD 60ID 31W | 35.14 |
| | | | 224.77 |

## H4

Table H4. Standard part used for IRRI-PAK Thresher.

| Amount | Description | Size (mm) | Cost (US$) |
|---|---|---|---|
| 4 | Cotter pin | 3.18D x 38.1L | 0.03 |
| 10 | Split pin | 4.76D x 38.1L | 0.08 |
| 30 | Reverts | 4.76D | 0.16 |
| | key | 6.35W x 305L | 0.16 |
| | key | 9.53W x 914L | 0.61 |
| 16 | Set screws | 6.35D x 25L | 0.45 |
| 4 | Set screws | 9.35D x 38L | 3.11 |
| 1 | B-V-belt | 62L | 5.24 |
| 1 | B-V-belt | 52L | 4.11 |
| 3 | B-V-belt | 82L | 6.49 |
| 8 | Copper bush | 6.35OD 1ID | 4.67 |
| 2 | Rubber tires | 6-16, 4 ply | 35.68 |
| 2 | Rim | 6-16 | 27.03 |
| | | Total | 87.82 |

Table [illegible]. Standard parts (Bolts, nuts and washers).

| Amount | Hexagon head Bolt Diameter (mm) | Length | Cost US$ | Nut Diameter (mm) | Cost US$ | Washer Spring Diameter (mm) | Cost US$ | Flat Diameter (mm) | Cost US$ |
|---|---|---|---|---|---|---|---|---|---|
| 22 | 6 | 13 | 0.18 | | | | | | |
| 116 | 6 | 13 | 0.94 | 6 | 3.14 | 6 | 0.13 | 6 | 0.94 |
| 20 | 6 | 38 | 0.23 | 6 | 0.54 | 6 | 0.02 | | |
| 97 | 8 | 9 | 1.00 | 8 | 3.67 | 8 | 0.26 | | |
| 90 | 8 | 25 | 1.17 | 8 | 3.41 | 8 | 0.24 | | |
| 18 | 10 | 19 | 0.30 | 10 | 0.88 | 10 | 0.08 | | |
| 2 | 10 | 19 | 0.03 | | | | | | |
| 8 | 10 | 50 | 0.26 | | | | | | |
| 8 | 10 | 25 | 0.16 | 10 | 0.30 | 10 | 0.03 | | |
| 5 | 13 | 25 | 0.14 | | | | | | |
| 4 | 13 | 50 | 0.18 | 13 | 0.14 | 13 | 0.02 | 13 | 0.03 |
| 6 | 13 | 57 | 0.56 | | | | | | |
| 8 | 13 | 76 | 0.55 | 13 | 0.56 | 13 | 0.06 | 13 | 0.14 |
| 16 | 16 | 30 | 2.46 | | | | | | |
| 168 | | | | 19 | 18.16 | 19 | 1.91 | 19 | 4.27 |
| | | | 8.86 | | 30.16 | | 2.75 | | 5.38 |

# APPENDIX I

## I1

Figures for specific air inlets and outlet of the aspirator.

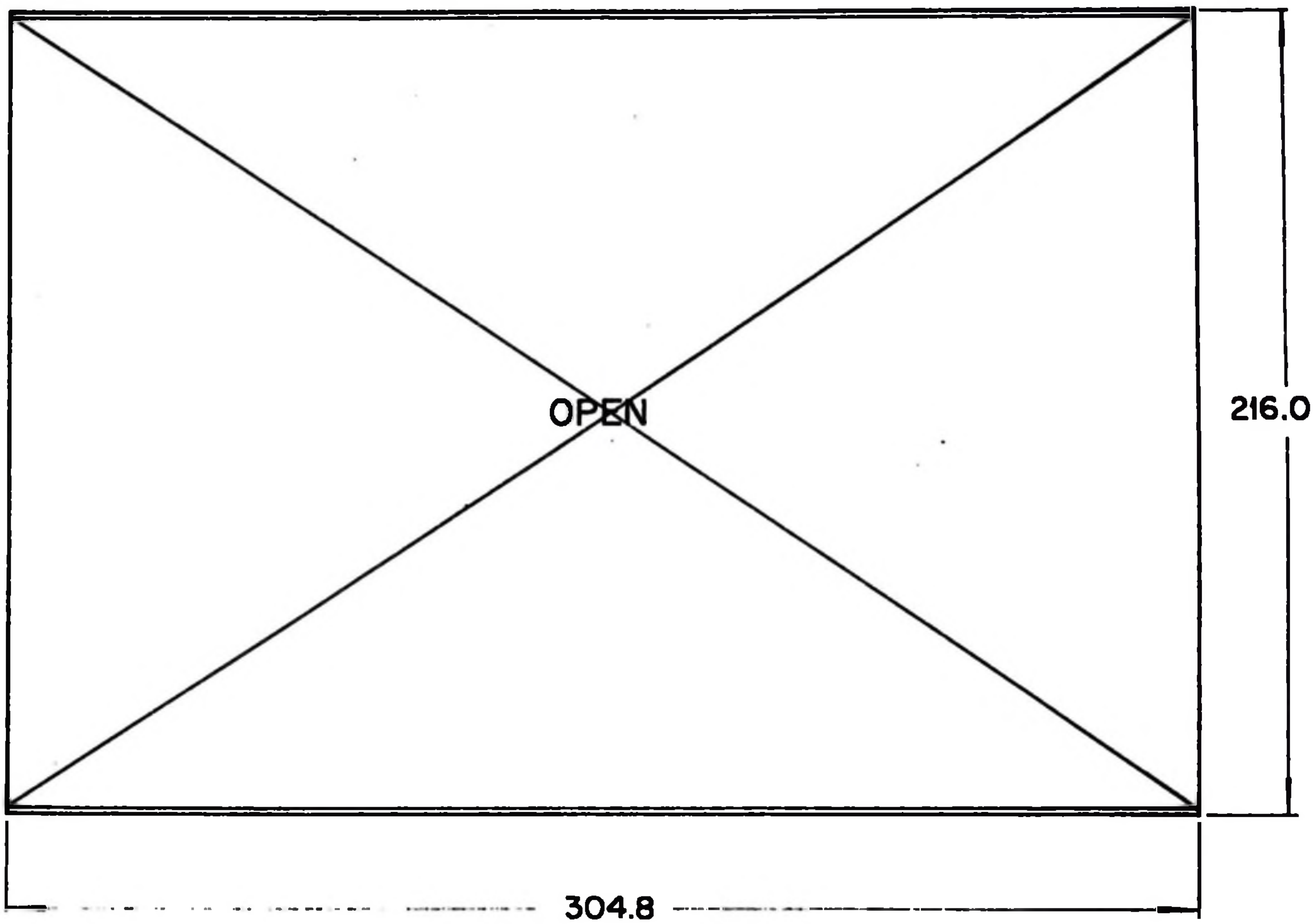



Fig. I1. Air outlet of the aspirator.

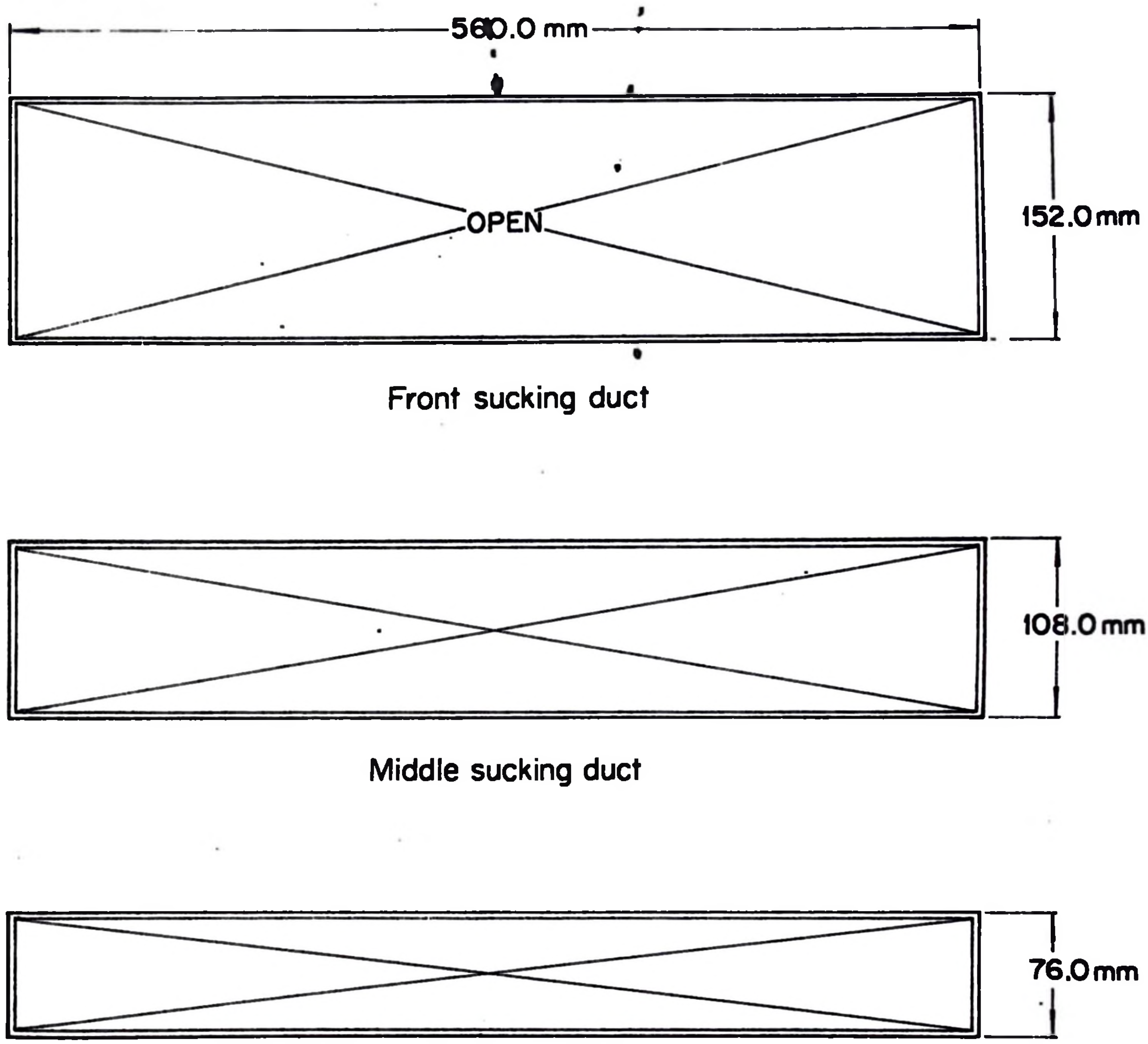



**Fig. I2. Air inlets of the aspirator.**

I3

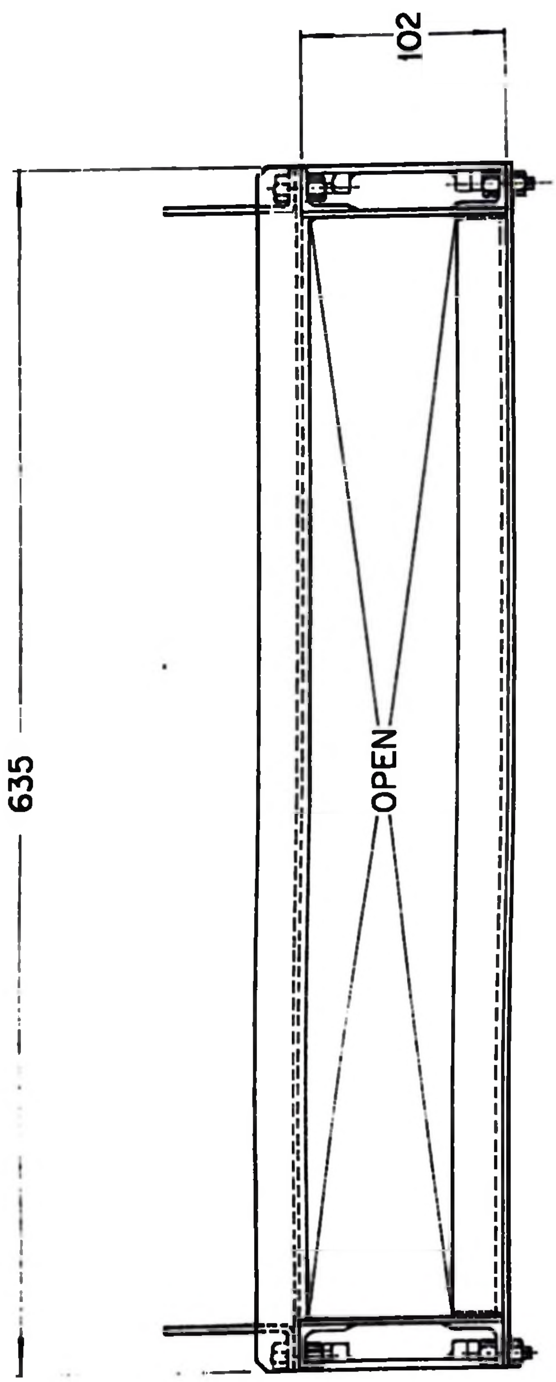



Fig. I3. Air inlet, front of the oscillating tray assembly.