Harvesting crops
WHEAT: Post-harvest Operations

• Although post-production operations vary from country to country and region to region throughout the world, procedures are similar among the developing countries.

• Operations diversify with farm size such as small landholders, medium scale farmers and progressive growers.

• Operation are harvesting, transportation, threshing, cleaning, drying, storage, packaging and marketing
1. Harvesting

• A major proportion of the crop in Asia is harvested manually using sickles (over 70 percentage in Pakistan, India and Bangladesh or with types of knives leaving 3-6 cm wheat straw above the ground level.
• In South Asia wheat is harvested in the dry summer months from March to May.
• Farmers are conscious of the fact that the harvested wheat should be dry enough for threshing and storage.
• The manually harvested wheat crop is tied into small bundles and stacked in bunches of 10 - 15 bundles, which are left in the field for one to three days to dry. Combine or mechanical harvesters
Woman harvesting wheat manually

Manually harvested crop left to dry on the field
A reaper cutting rye in Germany 1949

Drawing of a "Gallic header"
Hussey's reaping machine, 19th century

McCormick's reaper at a presentation in Virginia 1831
Champion reaper, 
**trade card** from 1875

Typical 20th century reaper, a tractor-
drawn **Fahr** machine
Adriance reaper, late 19th century
Mechanical harvester

Animal transport to threshing floor
### Effect of moisture on grain quality

#### Effect of moisture on wheat

<table>
<thead>
<tr>
<th>Grains MC (%)</th>
<th>Effect on Wheat</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 or over 20</td>
<td>Grains are soft in feel, may be easily pressed between teeth, grains start germinating if a store as such for over three days and they have little value as food or feed.</td>
</tr>
<tr>
<td>Between 16 and 20</td>
<td>Grains may be pressed easily between teeth, do not germinate but are attacked by moulds and bacteria. These grains change color, taste and nutritive value very fast and are injurious when consumed as food or feed.</td>
</tr>
<tr>
<td>Between 13 and 16</td>
<td>Grains may be crushed between teeth with some pressure, they are not safe for storage as they lose lustier becomes susceptible to pest damage and they may develop sour taste along with bad smell at high temperature. Such grain lose weight at 3 to 5 percent month due to high rate of respiration.</td>
</tr>
<tr>
<td>Between 10 and 13</td>
<td>Grains may be easily crushed between teeth. They are not attacked by mould or bacteria but they become susceptible to store insect pest and pesticidal measure become essential for their safe storage.</td>
</tr>
<tr>
<td>Between 8 and 10</td>
<td>Grains are hard to be crushed between teeth; they are resistant to insect attacks. Such grains retain their weight, taste, germination and nutritive values for longer period. The grains gain weight due to absorption of water especially during wet season. They are very safe for storage.</td>
</tr>
</tbody>
</table>

Prof. Dr. Muhammad Iqbal, Department of Farm Machinery & Power, University of Agriculture, Faisalabad
2. Threshing

• The sheaves of wheat are carried to the threshing floor manually or on the backs of animals like camel donkeys and bullock.

• Tractor trolleys and bullock carts are mostly used for transporting harvested wheat crop to the threshing floor where they are spread out to dry in the sun and wind for a few days.

• Conventional threshing: Animals may be used to draw a wheat bundle/stone roller over the thick layer of harvested wheat crop. Or, an implement consisting of a series of steel disks may be used. In some locales, a tractor may be repeatedly driven over the wheat stack spread on the threshing floor.

• The tractor-drawn thresher has a revolving drum with projecting teeth that strip off the grain when a sheaf of wheat is held against the moving surface.
Threshing

• Self-propelled harvester combine threshes, separates, cleans and stores grains in its storage bin which then are unloaded in a trailer.

• After threshing, the straw (*bhoosa*) is stacked around the threshing floor and used as animal feed, bedding, cooking fuel, to make sun-dried bricks, or compost. The wheat grain will be contaminated with pieces of straw chaff, broken grains, stones, and dirt when it is spread on the threshing floor for further drying.
Tractor-drawn thresher

Straw stacks around the threshing floor
Combine harvester
3. Transport

1. Labor-intensive systems of grain movement serve to minimize capital investment in countries where the cost of labor is low. Most wheat is manually loaded and unloaded from wagons, trucks, railroad cars, and barges between farm and mill.

2. In South Asia post-harvest handling, transport and storage of grains at the farm level is done partially in bulk.

   • The transportation of grain to primary markets by the farmers is also done in bulk using bullock carts, tractor trolleys or lorries.

   • At the market yard, the grain is displayed in bulk, auctioned, cleaned, bagged, weighed and delivered to consumers in bags.
Transport (Cont...) 

3. The food grain trade depends upon labor. Therefore, handling, transport and storage of marketed grains in bags is common. Availability of cheaper jute bags in these countries also encourages handling, storage and marketing of grain in bags.

4. From farms in Pakistan, wheat is mainly transported in animal driven carts or carried on camelback. Large farmers use tractor driven trolleys and trucks. Mostly 100-kg bags are used which are cumbersome to carry.

5. Highly efficient bulk handling systems exist in developed countries to load loose wheat into trucks. Using an auger, wheat is moved to the grain-processing centre in a single trip, dumped into a receiving bin, carried by a mechanical conveyor through the cleaning and drying processes and into storage.
4. Drying

• The most critical decision in harvesting is the timing of the harvest. If the harvest starts late, the grain becomes too dry and rate of grain shattering is high. The longer a ripe crop is left in the field or on the threshing floor, the higher will be the loss from natural calamities including hailstorm, fire, birds, or rodents. The moisture content of the grain will be high, making drying difficult if the harvest start too early.

• The moisture content of wheat grain is a crucial factor from harvest until milling. Moisture content of 25 percentage is not uncommon in newly harvested grain in humid areas but it must be dried immediately to protect it against mould. At 14 percentage moisture grain can be safely stored for 2 to 3 months. For longer periods of storage from 4-12 months, the moisture content must be reduced to 13 percentage or below.
Drying (Cont…)

- Drying in many wheat-growing countries of Asia, Africa, and Latin America is done by spreading a thin layer of grain in the sun, on the threshing floor or on rooftops. Mechanical drying of wheat grain is not practiced in most of the developing countries. It is mostly sun dried. Sun drying is risky because it depends on weather conditions leading to dirty grain, spillage loss and bird attack.

- As the weather is quite warm at harvest, the moisture content of the grain (Pakistan) is below 10 percentage. During the rainy season moisture content slowly increases to 15 percentage. Deterioration of grain is closely related to the moisture content which is key to safe storage.

- The wheat delivered from the farm at harvest to the village market or to a government food corporation presents different challenges. Since mills need to be able to hold sufficient grain for 30 to 60 days of milling this wheat may be kept in sheds, large steel bins, concrete silos, or in the holding bins of a flour mill.
5. Cleaning

• After threshing, the straw, chaff, immature grains, sand, stones, and other substances are separated from the grain by sieving, winnowing or hand picking. In traditional manual winnowing, a shallow basket containing grain is held overhead, and the grain is tossed during periods of fast winds. Lighter weight broken grain, straw, and weed seed are carried by the wind to one side, as the whole grain falls to the bottom of the winnowing device. The winnowing device may stand on a stool to give the falling grain longer exposure to the wind. Manual winnowing requires a continuous brisk wind and several repetitions. Even then, the results are erratic producing grain, which is far from satisfactory. Wheat cleaning is most often done manually by women, occasionally by professionals.
Cleaning (Cont...)

• Simple, low-cost appliances that use hand-driven or motorized blowers have been developed that are more efficient and less time consuming than hand winnowing. A FAO publication on processing and storage of food grains by rural families describes grain mills, flourmills and sophisticated grain cleaners. Lending agencies that finance grain storage facilities can provide advice on appropriate cleaning equipment.
6. Storage

- In South Asia and most of the developing countries, farmers for their own use for food, cattle feed and seed retain about 50-80 percentage of the grain produced.
- The farmers generally store their grain in simple granaries constructed from locally available materials like paddy straw, split bamboo, reeds, mud and bricks. A majority of wheat is stored in bags in a room, bin, drum or container for family consumption or is piled in farm buildings lacking proper flooring, closed doors and windows. Some conventional storage structures used by the farmers in Asia are:
  - 1. Mud structures mostly bins or pots
  - 2. Wood or Bamboo structures
  - 3. Metallic drums, bins or containers
  - 4. Kothis (small rooms)
Prof. Dr. Muhammad Iqbal, Department of Farm Machinery & Power, University of Agriculture, Faisalabad
Lecture 2

Combine harvesting
## Harvesting with a combine harvester

<table>
<thead>
<tr>
<th>According to threshing and separation</th>
<th>According to power source</th>
<th>According to topography</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional (transverse flow design)</td>
<td>Self propelled</td>
<td>Hillside (for hilly area)</td>
</tr>
<tr>
<td>Rotary (axial flow design)</td>
<td>PTO driven but pulled by tractor draw bar</td>
<td>Prairie (for plain area)</td>
</tr>
<tr>
<td></td>
<td>Pulled by tractor but powered by an auxiliary engine</td>
<td></td>
</tr>
</tbody>
</table>
### Combine size and area of different components

<table>
<thead>
<tr>
<th>Threshing cylinder size</th>
<th>Header width, m</th>
<th>Average separating area, cm²/mm cyl width</th>
<th>Total separating area, cm²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dia, m</td>
<td>Length, m</td>
<td>Walker</td>
</tr>
<tr>
<td></td>
<td>0.48-0.6</td>
<td>0.757</td>
<td>3.35</td>
</tr>
<tr>
<td></td>
<td>0.48-0.6</td>
<td>0.983</td>
<td>3.87</td>
</tr>
<tr>
<td></td>
<td>0.48-0.6</td>
<td>1.212</td>
<td>4.02</td>
</tr>
<tr>
<td></td>
<td>0.48-0.6</td>
<td>1.461</td>
<td>3.96</td>
</tr>
</tbody>
</table>

---

Prof. Dr. Muhammad Iqbal, Department of Farm Machinery & Power, University of Agriculture, Faisalabad
Grain separation area at various threshing cylinder length

- T.AREA = 715x - 15, $R^2 = 0.9$
- W.AREA = 412x - 8645, $R^2 = 0.97$
- S.Area = 303x - 6272, $R^2 = 0.9$

Prof. Dr. Muhammad Iqbal, Department of Farm Machinery & Power, University of Agriculture, Faisalabad
Cutting and windrowing method

- Reaper harvesting and windrow and allowed to sun drying
- Reel and cutter bar header of combine replaced by pick-up attachment
- Combine pick up attachment collects crop from windrow and thresh
## Functional process of a combine

<table>
<thead>
<tr>
<th>Units</th>
<th>Parts</th>
<th>Functions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Header</td>
<td>Reel, cutter bar, platform auger,</td>
<td>To gather, harvest, and convey crop to throat of feeder</td>
</tr>
<tr>
<td>Feeder house</td>
<td>Under shoot conveyor</td>
<td>To convey crop from header to threshing unit</td>
</tr>
<tr>
<td>Threshing unit</td>
<td>Cylinder and concave</td>
<td>Thresh crop for separating grain and straw</td>
</tr>
<tr>
<td>Separating unit</td>
<td>Straw walkers and grain pan</td>
<td>Separating grain from straw by tossing action and allow grain to fall onto grain pan</td>
</tr>
<tr>
<td>Cleaning unit</td>
<td>Chaffer sieve, radial centrifugal air fan</td>
<td>Clean grain from chaff</td>
</tr>
<tr>
<td></td>
<td>Shoe sieve, radial centrifugal air fan</td>
<td>Clean grain from fine chaff</td>
</tr>
<tr>
<td>Grain conveying unit</td>
<td>Auger, elevator</td>
<td>Collect and convey clean grain to tank</td>
</tr>
<tr>
<td>Tailings conveying unit</td>
<td>Auger, elevator</td>
<td>Collect and convey tailings to thresher for re-threshing</td>
</tr>
<tr>
<td>Grain tank</td>
<td>Grain tank, auger</td>
<td>To store clean grain</td>
</tr>
<tr>
<td>Grain unloading unit</td>
<td>Unloading auger</td>
<td>To unload clean grain from tank into a trailer</td>
</tr>
</tbody>
</table>

Prof. Dr. Muhammad Iqbal, Department of Farm Machinery & Power, University of Agriculture, Faisalabad
Axial Flow Combine Harvester

Prof. Dr. Muhammad Iqbal, Department of Farm Machinery & Power, University of Agriculture, Faisalabad
Lecture 3

Reel Kinematics and Platform auger
Gathering, cutting, pick up, and feeding

• Reel types:
  – Pick up reel – for tangled/lodged crop
  – Bat type reel – for straight erect standing crop

• Reel axis ahead of cutter bar: 230 – 300 mm

• Crop cutting height: 150 – 250 mm

• Reel teeth be clear from cutter bar: 50 - 75 mm

• Reel speed w.r.t. machine forward speed: 25% fast for wheat; 50% faster for barley
Reel Kinematics

- The bats/fingers of reel execute both translatory and rotary motion.
- Let, $V$ = field velocity of combine, m/s
- $U$ = linear velocity of bat at the tip of reel, m/s
- $\omega$ = angular velocity of reel, rad/s
- $R$ = radius of reel, m
- $\Theta_0$ = origin of co-ordinate system at the center of shaft of reel
- $x$-axis is +ve in the direction of travel of combine
- $y$-axis is +ve directed downward into crop
- $A_0$ = extreme point on the bat be initially on the $x$-axis
Let, after an interval ‘t’ the axis of shaft is displaced to a new position ‘\( \Theta_1 \)’

During time interval ‘t’, the bat turns an angle ‘\( \phi=\omega.t \)’ and shaft axis moved a distance along x-axis as, \( x=V.t \)

New co-ordinates of A are:

\[
X_A = V.t + R \cos \omega.t
\]
because, $\lambda = \frac{U}{V}$  
OR  
$V = \frac{U}{\lambda} = \frac{R. \omega}{\lambda}$

therefore,  
$X_A = \frac{U. t}{\lambda} + R \cos \omega. t$

or,  
$X_A = \frac{R. \omega. t}{\lambda} + R \cos \omega. t$

or  
$X_A = R \left[ \frac{\omega. t}{\lambda} + R. \cos \omega. t \right]$

$Y_A = R. \sin \omega. t$
Velocity of a point on the bat of reel is found by differentiating equations 1 & 2.

\[
\frac{dX_A}{dt} = U_X = V - \omega \cdot R \cdot \sin \omega \cdot t = V - \omega \cdot \sin \omega \cdot t = V - U \cdot \sin \omega \cdot t
\]

Therefore, \[U_X = V - U \cdot \sin \omega \cdot t\]  

and, \[\frac{dY_A}{dt} = U_Y = \omega \cdot R \cdot \cos \omega \cdot t = \omega \cdot \cos \omega \cdot t = U \cdot \cos \omega \cdot t\]

\[U_Y = U \cdot \cos \omega \cdot t\]

Now the absolute velocity of a point of bat

\[V_{ABS} = \sqrt{(U_X)^2 + (U_Y)^2}\]
\[ V_{\text{ABS}} = \sqrt{(V - U \cdot \sin \omega \cdot t)^2 + (U \cdot \cos \omega \cdot t)^2} \] -- 6

\[ V_{\text{ABS}} = \sqrt{U^2 + V^2 - 2UV \cdot \sin \varnothing} \] -- 7

\[ V_{\text{ABS}} = \sqrt{\frac{U^2}{V^2} + 1 - \frac{2UV}{V^2} \cdot \sin \varnothing} \] -- 8
• For Cycloid for $\lambda > 1$, up to point Ao, the bat bends the stalks away from the cutter bar and, thereafter, towards it.

• The absolute velocity at Ao is directed vertically downward and the horizontal velocity component becomes zero.
\[ U_{ZA} = V - U \cdot \sin \omega \cdot t = 0 \]

or, \[ \frac{V}{V} = \frac{1}{\sin \omega \cdot t} \]

or, \[ V = U \cdot \sin \omega \cdot t \]

or, \[ \lambda = \frac{1}{\sin \omega \cdot t} \]

or, \[ \sin \omega \cdot t = \frac{1}{\lambda} \]

insert this into equation 7,

\[ V_{ABS \ at \ Ao} = V \sqrt{1 - 2\lambda \cdot \sin \theta + \lambda^2} = V \sqrt{\lambda^2 - 1} \]
This is the velocity at which the bat enters downward into the crop. Let $U_1$ is the critical grain shattering velocity, then to avoid shattering loss

\[ V_{ABS \ at \ Ao} \leq U_1 \]

or, \[ \frac{u_1}{u_1} \geq \sqrt{\lambda^2 - 1} \]

or, \[ \left(\frac{u_1}{v}\right)^2 + 1 \geq \lambda^2 \]

or, \[ \lambda \leq \sqrt{\left(\frac{u_1}{v}\right)^2 + 1} \]

or, \[ U \leq \sqrt{\left(U_1\right)^2 + V^2} \]
This indicates that for a constant value of $U_1$, the $U$ and $V$ may correspondingly be adjusted. Assignment: Draw the cycloids for $\lambda \leq 1$ and $\lambda > 1$,

<table>
<thead>
<tr>
<th></th>
<th>$\lambda &gt; 1$</th>
<th>$\lambda = 1$</th>
<th>$\lambda &lt; 1$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$U$, m/s</td>
<td>1.25</td>
<td>1</td>
<td>0.9</td>
</tr>
<tr>
<td>$V$, m/s</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>$R$, m</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>$U = R \cdot \omega$</td>
<td>$\omega = \frac{U}{R} = \frac{1.25}{0.5} = 2.5 \text{ rad/s}$</td>
<td>$\omega = \frac{U}{R} = \frac{1}{0.5}$</td>
<td>$\omega = \frac{U}{R} = \frac{0.9}{0.5} = 1.8 \text{ rad/s}$</td>
</tr>
<tr>
<td>$\phi = \omega \cdot t$</td>
<td>$t = \frac{\phi}{\omega} = \frac{2\pi}{2.5} = 2.537 \text{ s}$</td>
<td>$t = \frac{\phi}{\omega} = \frac{2\pi}{2} = 3.141 \text{ s}$</td>
<td>$t = \frac{\phi}{\omega} = \frac{2\pi}{1.8} = 3.49 \text{ s}$</td>
</tr>
</tbody>
</table>
Cycloid data for $\lambda < 1$

<table>
<thead>
<tr>
<th>S.No</th>
<th>$t$</th>
<th>$X = V \cdot t$</th>
<th>$\omega \cdot t$</th>
<th>$\phi$</th>
<th>$-X_a$</th>
<th>$-Y_a$</th>
<th>$U_x$</th>
<th>$U_y$</th>
<th>$V_{abs}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>-0.500</td>
<td>0.000</td>
<td>1.000</td>
<td>0.900</td>
<td>1.345</td>
</tr>
<tr>
<td>2</td>
<td>0.436</td>
<td>0.436</td>
<td>0.785</td>
<td>45.000</td>
<td>-0.790</td>
<td>-0.354</td>
<td>0.364</td>
<td>0.636</td>
<td>0.733</td>
</tr>
<tr>
<td>3</td>
<td>0.873</td>
<td>0.873</td>
<td>1.571</td>
<td>90.000</td>
<td>-0.873</td>
<td>-0.500</td>
<td>0.100</td>
<td>0.000</td>
<td>0.100</td>
</tr>
<tr>
<td>4</td>
<td>1.309</td>
<td>1.309</td>
<td>2.356</td>
<td>135.000</td>
<td>-0.955</td>
<td>-0.354</td>
<td>0.363</td>
<td>-0.636</td>
<td>0.733</td>
</tr>
<tr>
<td>5</td>
<td>1.745</td>
<td>1.745</td>
<td>3.141</td>
<td>180.000</td>
<td>-1.245</td>
<td>0.000</td>
<td>0.999</td>
<td>-0.900</td>
<td>1.345</td>
</tr>
<tr>
<td>6</td>
<td>2.181</td>
<td>2.181</td>
<td>3.926</td>
<td>225.000</td>
<td>-1.827</td>
<td>0.353</td>
<td>1.636</td>
<td>-0.637</td>
<td>1.756</td>
</tr>
<tr>
<td>7</td>
<td>2.618</td>
<td>2.618</td>
<td>4.712</td>
<td>270.000</td>
<td>-2.617</td>
<td>0.500</td>
<td>1.900</td>
<td>-0.001</td>
<td>1.900</td>
</tr>
<tr>
<td>8</td>
<td>3.054</td>
<td>3.054</td>
<td>5.497</td>
<td>315.000</td>
<td>-3.407</td>
<td>0.354</td>
<td>1.637</td>
<td>0.636</td>
<td>1.756</td>
</tr>
<tr>
<td>9</td>
<td>3.490</td>
<td>3.490</td>
<td>6.282</td>
<td>360.000</td>
<td>-3.990</td>
<td>0.001</td>
<td>1.001</td>
<td>0.900</td>
<td>1.346</td>
</tr>
<tr>
<td>10</td>
<td>3.926</td>
<td>3.926</td>
<td>7.067</td>
<td>405.000</td>
<td>-4.280</td>
<td>-0.353</td>
<td>0.364</td>
<td>0.637</td>
<td>0.734</td>
</tr>
<tr>
<td>11</td>
<td>4.363</td>
<td>4.363</td>
<td>7.853</td>
<td>450.000</td>
<td>-4.363</td>
<td>-0.500</td>
<td>0.100</td>
<td>0.001</td>
<td>0.100</td>
</tr>
<tr>
<td>12</td>
<td>4.799</td>
<td>4.799</td>
<td>8.638</td>
<td>495.000</td>
<td>-4.446</td>
<td>-0.354</td>
<td>0.363</td>
<td>-0.635</td>
<td>0.732</td>
</tr>
<tr>
<td>13</td>
<td>5.235</td>
<td>5.235</td>
<td>9.423</td>
<td>540.000</td>
<td>-4.735</td>
<td>-0.001</td>
<td>0.998</td>
<td>-0.900</td>
<td>1.344</td>
</tr>
<tr>
<td>14</td>
<td>5.671</td>
<td>5.671</td>
<td>10.208</td>
<td>585.000</td>
<td>-5.317</td>
<td>0.353</td>
<td>1.635</td>
<td>-0.638</td>
<td>1.755</td>
</tr>
<tr>
<td>15</td>
<td>6.108</td>
<td>6.108</td>
<td>10.994</td>
<td>630.000</td>
<td>-6.106</td>
<td>0.500</td>
<td>1.900</td>
<td>-0.002</td>
<td>1.900</td>
</tr>
<tr>
<td>16</td>
<td>6.544</td>
<td>6.544</td>
<td>11.779</td>
<td>675.000</td>
<td>-6.897</td>
<td>0.354</td>
<td>1.638</td>
<td>0.635</td>
<td>1.757</td>
</tr>
<tr>
<td>17</td>
<td>6.980</td>
<td>6.980</td>
<td>12.564</td>
<td>720.000</td>
<td>-7.480</td>
<td>0.001</td>
<td>1.002</td>
<td>0.900</td>
<td>1.347</td>
</tr>
<tr>
<td>18</td>
<td>7.416</td>
<td>7.416</td>
<td>13.349</td>
<td>765.000</td>
<td>-7.771</td>
<td>-0.353</td>
<td>0.365</td>
<td>0.638</td>
<td>0.735</td>
</tr>
<tr>
<td>19</td>
<td>7.853</td>
<td>7.853</td>
<td>14.135</td>
<td>810.000</td>
<td>-7.854</td>
<td>-0.500</td>
<td>0.100</td>
<td>0.002</td>
<td>0.100</td>
</tr>
<tr>
<td>20</td>
<td>8.289</td>
<td>8.289</td>
<td>14.920</td>
<td>855.000</td>
<td>-7.936</td>
<td>-0.355</td>
<td>0.362</td>
<td>-0.635</td>
<td>0.730</td>
</tr>
<tr>
<td>21</td>
<td>8.725</td>
<td>8.725</td>
<td>15.705</td>
<td>900.000</td>
<td>-8.225</td>
<td>-0.001</td>
<td>0.997</td>
<td>-0.900</td>
<td>1.343</td>
</tr>
<tr>
<td>22</td>
<td>9.161</td>
<td>9.161</td>
<td>16.490</td>
<td>945.000</td>
<td>-8.807</td>
<td>0.352</td>
<td>1.634</td>
<td>-0.638</td>
<td>1.755</td>
</tr>
<tr>
<td>23</td>
<td>9.598</td>
<td>9.598</td>
<td>17.276</td>
<td>990.000</td>
<td>-9.596</td>
<td>0.500</td>
<td>1.900</td>
<td>-0.003</td>
<td>1.900</td>
</tr>
<tr>
<td>24</td>
<td>10.034</td>
<td>10.034</td>
<td>18.061</td>
<td>1035.000</td>
<td>-10.386</td>
<td>0.355</td>
<td>1.639</td>
<td>0.634</td>
<td>1.757</td>
</tr>
<tr>
<td>25</td>
<td>10.470</td>
<td>10.470</td>
<td>18.846</td>
<td>1080.000</td>
<td>-10.970</td>
<td>0.002</td>
<td>1.003</td>
<td>0.900</td>
<td>1.348</td>
</tr>
<tr>
<td>26</td>
<td>10.906</td>
<td>10.906</td>
<td>19.631</td>
<td>1125.000</td>
<td>-11.261</td>
<td>-0.352</td>
<td>0.366</td>
<td>0.639</td>
<td>0.736</td>
</tr>
<tr>
<td>27</td>
<td>11.343</td>
<td>11.343</td>
<td>20.417</td>
<td>1170.000</td>
<td>-11.344</td>
<td>-0.500</td>
<td>0.100</td>
<td>0.003</td>
<td>0.100</td>
</tr>
</tbody>
</table>
Cycloid For $\lambda > 1$

<table>
<thead>
<tr>
<th>S.No</th>
<th>$t$</th>
<th>$X = V \cdot t$</th>
<th>$\omega \cdot t$</th>
<th>$\phi$</th>
<th>$-x_a$</th>
<th>$-y_a$</th>
<th>$U_x$</th>
<th>$U_y$</th>
<th>$V_{abs}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>-0.500</td>
<td>0.000</td>
<td>1.000</td>
<td>1.250</td>
<td>1.601</td>
</tr>
<tr>
<td>2</td>
<td>0.314</td>
<td>0.314</td>
<td>0.785</td>
<td>45.000</td>
<td>-0.668</td>
<td>-0.354</td>
<td>0.116</td>
<td>0.884</td>
<td>0.892</td>
</tr>
<tr>
<td>3</td>
<td>0.628</td>
<td>0.628</td>
<td>1.571</td>
<td>90.000</td>
<td>-0.628</td>
<td>-0.500</td>
<td>-0.250</td>
<td>0.000</td>
<td>0.250</td>
</tr>
<tr>
<td>4</td>
<td>0.942</td>
<td>0.942</td>
<td>2.356</td>
<td>135.000</td>
<td>-0.589</td>
<td>-0.354</td>
<td>0.116</td>
<td>-0.884</td>
<td>0.891</td>
</tr>
<tr>
<td>5</td>
<td>1.257</td>
<td>1.257</td>
<td>3.141</td>
<td>180.000</td>
<td>-0.757</td>
<td>0.000</td>
<td>1.000</td>
<td>-1.250</td>
<td>1.601</td>
</tr>
<tr>
<td>6</td>
<td>1.571</td>
<td>1.571</td>
<td>3.927</td>
<td>225.000</td>
<td>-1.217</td>
<td>0.353</td>
<td>1.884</td>
<td>-0.884</td>
<td>2.081</td>
</tr>
<tr>
<td>7</td>
<td>1.885</td>
<td>1.885</td>
<td>4.712</td>
<td>270.000</td>
<td>-1.884</td>
<td>0.500</td>
<td>2.250</td>
<td>-0.001</td>
<td>2.250</td>
</tr>
<tr>
<td>8</td>
<td>2.199</td>
<td>2.199</td>
<td>5.497</td>
<td>315.000</td>
<td>-2.552</td>
<td>0.354</td>
<td>1.884</td>
<td>0.883</td>
<td>2.081</td>
</tr>
<tr>
<td>9</td>
<td>2.513</td>
<td>2.513</td>
<td>6.283</td>
<td>360.000</td>
<td>-3.013</td>
<td>0.000</td>
<td>1.001</td>
<td>1.250</td>
<td>1.601</td>
</tr>
<tr>
<td>10</td>
<td>2.827</td>
<td>2.827</td>
<td>7.068</td>
<td>405.000</td>
<td>-3.181</td>
<td>-0.353</td>
<td>0.117</td>
<td>0.885</td>
<td>0.892</td>
</tr>
<tr>
<td>11</td>
<td>3.141</td>
<td>3.141</td>
<td>7.853</td>
<td>450.000</td>
<td>-3.142</td>
<td>-0.500</td>
<td>-0.250</td>
<td>0.000</td>
<td>0.250</td>
</tr>
<tr>
<td>12</td>
<td>3.455</td>
<td>3.455</td>
<td>8.638</td>
<td>495.000</td>
<td>-3.102</td>
<td>-0.354</td>
<td>0.115</td>
<td>-0.883</td>
<td>0.891</td>
</tr>
<tr>
<td>13</td>
<td>3.770</td>
<td>3.770</td>
<td>9.424</td>
<td>540.000</td>
<td>-3.270</td>
<td>-0.001</td>
<td>0.999</td>
<td>-1.250</td>
<td>1.600</td>
</tr>
<tr>
<td>14</td>
<td>4.084</td>
<td>4.084</td>
<td>10.209</td>
<td>585.000</td>
<td>-3.730</td>
<td>0.353</td>
<td>1.883</td>
<td>-0.885</td>
<td>2.080</td>
</tr>
<tr>
<td>15</td>
<td>4.398</td>
<td>4.398</td>
<td>10.994</td>
<td>630.000</td>
<td>-4.397</td>
<td>0.500</td>
<td>2.250</td>
<td>-0.001</td>
<td>2.250</td>
</tr>
<tr>
<td>16</td>
<td>4.712</td>
<td>4.712</td>
<td>11.780</td>
<td>675.000</td>
<td>-5.065</td>
<td>0.354</td>
<td>1.885</td>
<td>0.883</td>
<td>2.081</td>
</tr>
<tr>
<td>17</td>
<td>5.026</td>
<td>5.026</td>
<td>12.565</td>
<td>720.000</td>
<td>-5.526</td>
<td>0.001</td>
<td>1.002</td>
<td>1.250</td>
<td>1.602</td>
</tr>
<tr>
<td>18</td>
<td>5.340</td>
<td>5.340</td>
<td>13.350</td>
<td>765.000</td>
<td>-5.694</td>
<td>-0.353</td>
<td>0.117</td>
<td>0.885</td>
<td>0.893</td>
</tr>
<tr>
<td>19</td>
<td>5.654</td>
<td>5.654</td>
<td>14.136</td>
<td>810.000</td>
<td>-5.655</td>
<td>-0.500</td>
<td>-0.250</td>
<td>0.002</td>
<td>0.250</td>
</tr>
<tr>
<td>20</td>
<td>5.968</td>
<td>5.968</td>
<td>14.921</td>
<td>855.000</td>
<td>-5.615</td>
<td>-0.354</td>
<td>0.115</td>
<td>-0.882</td>
<td>0.890</td>
</tr>
<tr>
<td>21</td>
<td>6.283</td>
<td>6.283</td>
<td>15.706</td>
<td>900.000</td>
<td>-5.783</td>
<td>-0.001</td>
<td>0.998</td>
<td>-1.250</td>
<td>1.599</td>
</tr>
<tr>
<td>22</td>
<td>6.597</td>
<td>6.597</td>
<td>16.492</td>
<td>945.000</td>
<td>-6.242</td>
<td>0.353</td>
<td>1.882</td>
<td>-0.885</td>
<td>2.080</td>
</tr>
<tr>
<td>23</td>
<td>6.911</td>
<td>6.911</td>
<td>17.277</td>
<td>990.000</td>
<td>-6.910</td>
<td>0.500</td>
<td>2.250</td>
<td>-0.002</td>
<td>2.250</td>
</tr>
<tr>
<td>24</td>
<td>7.225</td>
<td>7.225</td>
<td>18.062</td>
<td>1035.000</td>
<td>-7.578</td>
<td>0.354</td>
<td>1.886</td>
<td>0.882</td>
<td>2.082</td>
</tr>
<tr>
<td>25</td>
<td>7.539</td>
<td>7.539</td>
<td>18.848</td>
<td>1080.000</td>
<td>-8.039</td>
<td>0.001</td>
<td>1.003</td>
<td>1.250</td>
<td>1.602</td>
</tr>
<tr>
<td>26</td>
<td>7.853</td>
<td>7.853</td>
<td>19.633</td>
<td>1125.000</td>
<td>-8.207</td>
<td>-0.353</td>
<td>0.118</td>
<td>0.886</td>
<td>0.894</td>
</tr>
<tr>
<td>27</td>
<td>8.167</td>
<td>8.167</td>
<td>20.418</td>
<td>1170.000</td>
<td>-8.168</td>
<td>-0.500</td>
<td>-0.250</td>
<td>0.003</td>
<td>0.250</td>
</tr>
</tbody>
</table>

Prof. Dr. Muhammad Iqbal, Department of Farm Machinery & Power, University of Agriculture, Faisalabad
Pitch of reel

• The distance between identical points on adjacent cycloids is called the pitch of reel (Sz).
• Let, \( Sm = \) distance traversed by machine during one reel revolution, \( m \) (\( Sm=V.t \))
• \( t=\) the time period, \( s \)
• \( Z=\) number of bats on reel
Therefore, 
\[ S_z = \frac{S_m}{Z} = \frac{V \cdot t}{Z} \]

because, \[ \phi = 2\pi = \omega \cdot t \text{ or } t = \frac{2\pi}{\omega} \]

and, \[ S_m = V \cdot t = V \left[ \frac{2\pi}{\omega} \right] \]

therefore, \[ S_z = \frac{V \left[ \frac{2\pi}{\omega} \right]}{Z} \]

insert, \[ \omega = \frac{U}{R} \]

then, \[ S_z = \frac{V \left[ \frac{2\pi}{U} \right] R}{Z} = \left[ \frac{2\pi}{Z} \right] \frac{R}{\lambda} \]
• This equation indicates that,
• Pitch “Sz” is directly proportional to reel radius “R”
• The increase in ‘λ’ and ‘Z’ decreases Sz
The number of strikes ‘k’ made by reel bat on stalks per meter sweep of machine depends on the pitch ‘Sz’ that is

\[ k = \frac{1}{Sz} = \frac{Z\lambda}{2\pi R} \]

More the number of bats ‘Z’ more will be the strikes on stalks ‘k’.

Prof. Dr. Muhammad Iqbal, Department of Farm Machinery & Power, University of Agriculture, Faisalabad
Platform auger
The helical line represents the path developed by a point ‘A’ moving along a circle of a given radius ‘R’ in the plane ‘Z’ and simultaneously travelling along axis ‘OY’.

In the moment of time considered when point ‘A’ has taken position ‘A₁’ and simultaneously travelled over the path ‘A₁B’, its coordinates in the plane ‘XZ’ are as following:

\[ X = R \cdot \cos \phi \quad Z = R \cdot \sin \phi \quad Y = A₁B = \theta_1 \theta = V_y t \]

\[ Y = V_y t = \left[ \frac{\text{distance, helix pitch}}{\text{time period for full point rev}} \right] t = \left[ \frac{S}{T} \right] t \]

Where, \( V_y \) = speed of travelling of the point coordinate along the ‘OY’

\[ Y = \left[ \frac{S}{2\pi} \cdot \frac{1}{\omega} \right] t = \frac{S}{2\pi \omega} t \]

This is the value of Y-coordinate during time ‘t’
Knife section

Cutter bar

Knife guard/fingers

Combine cutting table
Lecture 4

Cutter bar
# Cutter bar

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Mower/reaper/combine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material of ledger plate</td>
<td>U9 steel</td>
</tr>
<tr>
<td>Material of knife</td>
<td>HCS</td>
</tr>
<tr>
<td>Hold down clamp</td>
<td>Wrought iron</td>
</tr>
<tr>
<td>Knife serration pitch</td>
<td>2-3 times smaller than stalk diameter</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Cereals</td>
<td></td>
</tr>
<tr>
<td>Stalk dia: 2-4 mm</td>
<td>Pitch: 1-1.2 mm</td>
</tr>
<tr>
<td>Grass</td>
<td></td>
</tr>
<tr>
<td>Stalk dia: 0.4 mm</td>
<td>Pitch: 0.2 mm</td>
</tr>
<tr>
<td>Cutting pair clearance:</td>
<td>0.3 mm</td>
</tr>
<tr>
<td>(Knife ledger plate clearance)</td>
<td></td>
</tr>
<tr>
<td>Stroke length</td>
<td>76.2 mm</td>
</tr>
<tr>
<td>Number of strokes per minute</td>
<td>Combine: 1000-1200;</td>
</tr>
<tr>
<td></td>
<td>Reaper/mower: 1700-2000</td>
</tr>
<tr>
<td>Field speed</td>
<td>1.3 – 3 m/s</td>
</tr>
</tbody>
</table>
## Crop cutting machines

<table>
<thead>
<tr>
<th>Machine</th>
<th>Width, m</th>
<th>Cutting height, mm</th>
<th>Peripheral / linear Speed, m/s</th>
<th>Remarks</th>
<th>Field speed m/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotary cutters</td>
<td>1.0 - 2.1</td>
<td>25 – 50</td>
<td>Ph: 51 – 76</td>
<td>2-4 cutters</td>
<td>1.3 – 3</td>
</tr>
<tr>
<td>Flail shredder</td>
<td>1.2 – 6.1</td>
<td>25 – 50</td>
<td>Ph: 46 – 56</td>
<td>3-4 rows swinging knives</td>
<td>1.3 – 3</td>
</tr>
<tr>
<td>Flail conditional mowers</td>
<td>1.8 – 3.0</td>
<td>25 – 50</td>
<td>Ph: 43</td>
<td></td>
<td>1.3 – 3</td>
</tr>
<tr>
<td>Mower cutters/reaper</td>
<td>1.3 – 1.5</td>
<td>50 - 100</td>
<td>Lin: 2.1 – 2.5</td>
<td></td>
<td>1.3 – 3</td>
</tr>
</tbody>
</table>
## Power requirements for mowing heavy mixed hay with 2.13 m wide mower

<table>
<thead>
<tr>
<th>Item</th>
<th>Average PTO power, hp</th>
<th>Average peak PTO power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inertial and friction load (no cutting)</td>
<td>1.7</td>
<td>6.18</td>
</tr>
<tr>
<td>Mowing at 7.9 km/h</td>
<td>2.55</td>
<td>7.0</td>
</tr>
<tr>
<td>Increase due to cutting</td>
<td>0.8</td>
<td>0.82</td>
</tr>
</tbody>
</table>

Note: At crank speed of 942 RPM and maximum crop load, peak power is 1-hp/ft
Effect of grass moisture content on friction angle (ph1+ph2) of mower cutter bar

(ph1+ph2) = 0.49 MC + 19.9, $R^2 = 0.9$
Lecture 5

Grain threshing mechanism
Threshing mechanism

- Rasp bar cylinder and concave – wheat grain threshing by impact and rubbing action (90% grain separation)
- Spike tooth cylinder and concave – paddy kernels threshing by tearing and shredding action
- Angle bar cylinder and concave – oil seed crop threshed by rubber coated angle irons both at cylinder and concave
Pakistan is basically an agricultural and a developing country of South Asia. The Pakistan like many other developing countries of the world is facing the problem of low agricultural productivity. Many countries are faced with the challenge to producing more food and fiber, while there is a little room for expansion in the cultivated area and yield per unit area of various crops (Alam and Naqvi, 2003).
• With the proper application of biological inputs, hydrological input, chemical inputs and mechanical inputs, food security issues of Pakistan can be solved. A wheat thresher is a tractor driven machine and is used to thresh and separate grains to reduce post harvest wheat losses. There are many manufacturers developing and fabricating wheat threshers in the country, most of which are located in Punjab Province. Population of threshers had been tremendously increased, over the years, in the country (Table T1)
Population of threshers in Pakistan

<table>
<thead>
<tr>
<th>Year</th>
<th>No. of Threshers</th>
</tr>
</thead>
<tbody>
<tr>
<td>1975</td>
<td>5635</td>
</tr>
<tr>
<td>1984</td>
<td>78377</td>
</tr>
<tr>
<td>1994</td>
<td>112707</td>
</tr>
<tr>
<td>2010</td>
<td>124000</td>
</tr>
</tbody>
</table>
Thresher human injuries (16%)

Case No. 1.

ANWAR MAJPUTS
S/O
NEMAT KHAN
Left arm completely damaged (while irrigating the crops)

Case No. 2.

RIAZ AHMAD
S/O
NEMAT ALI
(Right hand completely affected)
CASE NO. 5.

MUHAMMAD SHARIF  
S/O  
GHULAM MUHAMMAD

CASE NO. 12.

MUHAMMAD SHARIF  
S/O  
GHULAM MUHAMMAD

(Tube-well Engine accident)
CASE NO. 13

ABUUL MAJEED
S/O
MUHAMMAD HUSSAIN
(Toka accident)

CASE NO. 15

MAHWT ALI
S/O
MIAN SANEER BHATI
(Tips of the fingers of the right hand)
Units of King Wheat Thresher

- Feeding unit
- Threshing unit
- Separating unit
- Cleaning unit
Figure 4. Cylinder design from three different types of combines: (a) spiketooth, (b) raspbar, and (c) anglebar
Concave
ROTOR RASP BARS

For Case/IH, Gleaner & New Holland combines. Helical, Flat and Specialty Rotor Rasp Bars are available in Standard, Hardened or Hard Chrome.

All bars are carefully checked and sets are matched for equal weight distribution on the rotor, prior to shipment. Grade 8 hardware is included for most models.
A rasp bar
Threshing cylinder specifications:

• Diameter: 38 – 56 cm
• Speed: 150 – 1500 RPM
• Conventional cylinder speed: 700 – 800 RPM (30 – 35 m/s tip velocity)
Performance of threshing mechanism is measured by:

\[
\text{Threshing efficiency} = \frac{\text{threshed grains, kg}}{\text{total grains entering, kg}} \times 100
\]

\[
\text{Separation efficiency} = \frac{\text{grains separated at concave, kg}}{\text{total grain entering in threshing mechanism, kg}} \times 100
\]

\[
\text{Grain damage} = \frac{\text{mechanically damaged grain, kg}}{\text{total grains, kg}} \times 100
\]
# Factors affecting threshing performance parameters

<table>
<thead>
<tr>
<th>Design factors</th>
<th>Operating parameters</th>
<th>Crop conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cylinder diameter</td>
<td>Cylinder speed</td>
<td>Crop moisture content</td>
</tr>
<tr>
<td>Concave length</td>
<td>Cylinder-concave clearance</td>
<td>Crop maturity</td>
</tr>
<tr>
<td>Number of rasp bars</td>
<td>Material feed rate</td>
<td>Crop type</td>
</tr>
</tbody>
</table>
Cylinder-concave specifications

• Cylinder diameter: 480 – 600 mm (average 559 mm)
• Cylinder width: 685 – 1525 mm
• Cylinder tip velocity:
  Spike tooth/rasp bar type: 18-33 m/s
  Flail type: 1.3 – 1.5 m/s
• Cylinder-concave clearance: 6 – 13 mm
Lecture 6

Grain separation
# Separation mechanisms

<table>
<thead>
<tr>
<th>Thresher</th>
<th>Combine</th>
</tr>
</thead>
<tbody>
<tr>
<td>All threshed material at cylinder-concave passes to sieves where grains are separated by tossing action of sieves and blowing air of fans</td>
<td>70-90% grains separated at cylinder –concave of combine</td>
</tr>
<tr>
<td>Radial fan sucks chopped straw upward and throws horizontally out of thresher</td>
<td>Remaining 30-10% separated at straw walker</td>
</tr>
<tr>
<td></td>
<td>Un-chopped straw is thrown out on rear side of combine</td>
</tr>
</tbody>
</table>
Straw walkers

• Straw walker consists of several long sections mounted on two crankshafts (front and rear).
• Rotation of crank shafts causes the straw walkers to follow an elliptical/circular path.
• The straw and grain bounces on top of channels and moves to the rear of combine.
• During mixture bouncing action, grains pass down through the straw walker slots and straw fall on the rear of combine.
<table>
<thead>
<tr>
<th>Straw walker Parameters</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of straw walker sections</td>
<td>3-8</td>
</tr>
<tr>
<td>Section width</td>
<td>20-30 cm</td>
</tr>
<tr>
<td>Crank throw</td>
<td>5 cm</td>
</tr>
<tr>
<td>Crank speed</td>
<td>200 RPM</td>
</tr>
</tbody>
</table>
Grain separation theory:

Grain moves through the mat of straw like Fick’s Law of diffusion process:

\[ F = -D \frac{dC}{dX} \]

Where,
F= material flow rate, kg.m^{-2}. Min^{-1};
C= material concentration, kg/m^{3};
X=distance, m;
D=diffusion coefficient, m^{2}/min
In a combine harvester:

\[ Q_g = -D \frac{A}{L_d} [C_2 - C_1] \]

Where,
- \( Q_g \) = volumetric grain flow rate, \( m^3/min \);
- \( A \) = x-sectional area, \( m^2 \);
- \( D \) = diffusion coefficient, \( m^2/min \);
- \( C_2 \) = concentration of grain in straw walker, \text{grain (m}^3)/ \text{MOG (m}^3\text{)}
- \( C_1 \) = concentration of grain outside of straw walker, \text{grain (m}^3)/ \text{MOG (m}^3\text{)}
- \( L_d \) = length through which diffusion is occurring, \( m \)

{-ve sign indicates movement towards decreasing concentration}
The grain flow rate with time can be written as:

\[ Q_g = \frac{dV_g}{dt} = -D \frac{A}{L_d} [C_2 - C_1] \quad 3a \]

\[ Q_g = \frac{dV_g}{dt} = -D \frac{W \cdot L}{L_d} [C_2 - C_1] \quad 3b \]

Where \( V_g = \) volume of grain in straw walker, m³

(For straw walker, it is the change in grain volume with time)

\( t = \) time, min
\( A = \) area = straw walker width*Length = W.L
\( C_1 = \) concentration of grain out of straw walker = 0
\( C_2 = \) concentration of grain on straw walker

(volume of grain/ total volume of material)

(Since the grain is contained in the volume of MOG, the total volume is the volume of MOG)
Since \( C_1 = 0 \) out of straw walker,

\[
Q_g = \frac{dV_g}{dt} = -D \frac{W \cdot L}{L_d} [C_2]
\]

\[
Q_g = \frac{dV_g}{dt} = -D \frac{W \cdot L}{L_d} \left[ \frac{V_g}{V_{MOG}} \right]
\]

Separating variables and integrating with limits;

\[
\int_{V_{gi}}^{V_{gf}} \frac{dV_g}{V_g} = \int_{t_0}^{t} -D \frac{W \cdot L}{L_d \cdot V_{MOG}} dt
\]

or \[ \log \left( \frac{V_{gf}}{V_{gi}} \right) = -D \frac{W \cdot L}{L_d \cdot V_{MOG}} (t - t_0) \]

or \[ \log \left( \frac{V_{gf}}{V_{gi}} \right) = -D \frac{W \cdot L}{L_d \cdot V_{MOG}} (t - 0) \]

or \[ \log \left( \frac{V_{gf}}{V_{gi}} \right) = -D \frac{W \cdot L}{L_d \cdot V_{MOG}} (t) \]
Taking antilog:

\[
\frac{V_{gf}}{V_{gi}} = e^{-\left[\frac{D.W.L}{L_d \cdot V_{MOG}}\right]t}
\]

or,

\[
\frac{G_f}{G_i} = e^{-\left[\frac{D.W.L}{L_d \cdot V_{MOG}}\right]t}
\]

Where, \(G_f\) and \(G_i\) are final and initial grain weight (g) respectively.

because, \(G_{grain} = V_{grain} \cdot \rho_{grain}\)

and, \(\frac{V_{MOG}}{t} = \frac{MOG \text{ feed rate (kg/min)}}{\rho_{MOG}} = \frac{m}{\rho_{MOG}}\)

or, \(\frac{t}{V_{MOG}} = \frac{\rho_{MOG}}{m}\)
Therefore equation 7a becomes,

$$\frac{G_f}{G_i} = e^{-\left[ \frac{D.W.}{L_dV_{MOG}} \right] t} = e^{-\left[ \frac{D.W. \rho_{MOG}}{L_d m^0} \right] L} \quad \text{--- 8}$$

$$\frac{G_f}{G_i} = e^{-K_L L} \quad \text{--- 9}$$

where, \( k_1 = e^{-\left[ \frac{D.W. \rho_{MOG}}{L_d m^0} \right]} \)

Equation 9 indicates a decaying function of straw walker length
Read et al., (1974) model for straw walker grain separation:

\[ GL = \frac{G_f}{G_i} = e^{-bL} - 10 \]

Where, \( b = \text{constant} = K_L \) and \( L = \text{walker length of equation 9} \)
The walker length corresponding to 50% efficiency is determined as following:

\[ \text{separation efficiency} = 1 - GL \]

From the data of experiments, following equation was developed:

\[ GL = 0.5 = e^{-b \cdot L_{1/2}} \]

or, \[ 0.5 = e^{-b \cdot L_{1/2}} \]

or, \[ \ln(0.5) = -b \cdot L_{1/2} \]

or, \[ b = \frac{-\ln(0.5)}{L_{1/2}} = \frac{0.693}{L_{1/2}} \]

From the data of experiments, following equation was developed:

\[ b = 684.4 \cdot m^{0.396} \cdot \left[ \frac{MOG}{\text{Grain}} \right]^{-0.662} \]
Example

Given:
- Length of straw walker, \( L = 2.4 \) m
- Grain separated at cylinder-concave = 70%
- Grain to be separate at straw walker = 30%
- Existing Grain loss: 15% of the 30% separation share of walker = 4.5%

Desired: For Grain loss 5% of 30% separation share of walker (1.5%),
Determine the straw walker length, \( L \)?

Solution:

\[
GL = \frac{G_f}{G_i} = e^{-bL} \quad \quad \quad \ln(GL) = -bL
\]

\[
b = \frac{-\ln(GL)}{L} = \frac{-\ln(0.15)}{2.4} = 0.791
\]

Therefore, for \( GL = 5\% (0.05) \),
\[
L = \frac{-\ln(0.05)}{b = 0.791} = 3.79 \text{ m}
\]
Lecture 7

Grain cleaning
The separation and cleaning occurs due to differences in the terminal velocities of grain and chaff material.

<table>
<thead>
<tr>
<th>Material/crop</th>
<th>Terminal velocity, m/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat, oat, barley grain</td>
<td>5-10</td>
</tr>
<tr>
<td>Short pieces of straw</td>
<td>2-5</td>
</tr>
<tr>
<td>Short pieces of chaff</td>
<td>1.5-2.5</td>
</tr>
</tbody>
</table>
Grain cleaning theory

• The mixture of grain, chaff, and small pieces of straw falls from the oscillating grain pan onto the front part of the chaffer sieve.
• As the mixture falls, a blast of air is directed at $45^0$ angle towards the rear of the combine.
• The air velocity is adjusted such that it carries most of the chaff with it while some of the chaff falls along with grain onto the chaffer sieve.
• The remaining mixture of crop material is subjected to the air movement as well as mechanical oscillations.
• The mat of the of the crop material moves towards the rear of the combine on the chaffer sieve due to the oscillations.
• The air moving through the mat causes the mat to lose the chaff as it is carried by the air stream while the grains sift down through the mat of chaff and small pieces due to gravity and pass through the openings in the chaffer.
• The grain and a small fraction of chaff fall on the shoe sieve where the process is repeated.

Therefore, the theoretical principles applicable to the cleaning process are:
Theoretical principles of grain cleaning process

1. Aerodynamic separation based on terminal velocities
2. Movement of the crop material on to the chaffer sieve
3. Movement of grain through the chaff straw mat
4. Escape of grain through chaffer openings
Assumptions for aerodynamic model of grain separation

1. The drag coefficient is independent of air velocity.
2. The particles are accelerated as free bodies.
3. The air velocity through the upper screen is constant.
4. Air flow above the upper screen is streamlined parallel to the orientations of the chaffer lips.
Sum of forces on particles in vertical direction

\[ F_g - F_d = m \cdot a = m \cdot g \]  

Where,

- \( F_g \) = gravitational force on particle, N
- \( F_d \) = aerodynamic drag force acting on particle, N
- \( a \) = particle acceleration, m/s\(^2\)
- \( m \) = particle mass, kg
The aerodynamic drag force is given by:

\[ F_d = C_d \cdot V_y^2 \]  

or,

\[ C_d = \frac{F_d}{V_y^2} \]

Where,

- \( C_d \) = drag coefficient,
- \( V_y \) = relative velocity between the particles and air in the vertical direction, m/s

Since at terminal velocity: the drag force = particle weight

\[ F_d - F_g = m \cdot a = m \cdot g = 0 \]

Therefore,

\[ F_d = F_g = m \cdot g = C_d \cdot V_t^2 \]

or,

\[ C_d = \frac{m \cdot g}{V_t^2} \]
Where, \( V_t \) = particle terminal velocity, m/s

Comparing equation-3 & 6

\[
\text{or, } C_d = \frac{F_d}{V_t^2} = \frac{m \cdot g}{V_t^2} \\
F_d = m \cdot g \cdot \frac{V_y^2}{V_t^2}
\]

Insert this equation-8 into equation-1

\[
m \cdot a = F_g - F_d \\
\frac{d^2}{d_t^2} = g - g \cdot \frac{V_y^2}{V_t^2}
\]

This is the acceleration in vertical direction

If \( V_y = V_t \), then,

\[
\frac{d^2}{d_t^2} = g - g \cdot \frac{V_y^2}{V_t^2} = 0
\]
Acceleration in the horizontal direction:

\[
\frac{d_x^2}{d_t^2} = g \frac{V_x^2}{V_t^2}
\]

Where, \( V_x \) is the particle velocity relative to the air in the x-direction. Note that:

\[
V_x = \frac{d_x}{d_t} - V_{ax} \quad \text{and} \quad V_y = \frac{d_y}{d_t} - V_{ay}
\]

\( V_x \) and \( V_y \) are the particles relative velocities relative to the air in horizontal and vertical direction respectively.

\( V_{ax} \) and \( V_{ay} \) are the horizontal and vertical components of the air velocity respectively.

\( V_a \) = vector sum of \( V_{ax} \) and \( V_{ay} \) horizontal and vertical components of air velocities
The above last two equations of $V_x$ and $V_y$ (velocity of particle relative to the air in ‘X’ and ‘Y’ direction) are non-linear and require numerical solution. The equations can be solved using an analog computer. The solution can be obtained in two parts:

1. First part is related to the free fall of particles from the grain pan.
2. Second part consists of particles motion on the chaffer and shoe sieves.

The vertical motion comes to stop as the particles reach the chaffer sieve. It has been seen practically that as the particles fall 17.78 cm (7 in), the second condition applies. It was considered, based on the experimental studies that excessive loss would occur if the grain travels 7.62 cm (3 in) toward the rear of the combine without landing on the chaffer.
Lecture 8

Threshing Cylinder Design Equations
To determine the forces imposed on the threshing cylinder tube, an estimation of wheat feeding rate is needed. The highest mean yield in Punjab province has been found to be 3-t/ha. The feed rate can be calculated as follows (Behroozi, 2001):

\[ Q = \frac{Y \cdot V \cdot W \cdot e}{36} \]  

---

**Where:**

- \( Q \) = feeding rate, kg/s,
- \( Y \) = yield, tons/ha,
- \( V \) = forward speed of combine, km/h,
- \( W \) = width of cut of combine, m
- \( e \) = field efficiency,
• Forward speed seldom exceeds 4.5 km h\(^{-1}\) but yet it will be considered 6 km h\(^{-1}\) to account for exceptionally higher yields than 4 tons h\(^{-1}\). The working width of the combine is 3.75 m and the expected field efficiency is 85%. Taking the 4.304 ton ha\(^{-1}\) yield (Popov et al., 1986) and replacing these figures in the equation 1:

\[ Q \approx 2 \text{ kg/s} \]

(2)
• To thresh this rate of crop a force ‘F’ is needed, which is a function of cylinder linear speed as well as the friction coefficients between the crop- crop and crop-metal (Popovet al., 1986).

Thus,

\[ F = F_c + F_r \] 

(3)

Where:

\[ F = \text{the force needed for threshing crop, N} \]
\[ F_c = \text{impact force of the cylinder, N} \]
\[ F_r = \text{friction force, N} \]

The impact force \( F_c \) may be calculated from eq. 4 below;

\[ F_c = Q.(V_2 - V_1) \] 

(4)
Where: \( V_2 \) = speed of the threshed crop as it exits the cylinder, m/s
\( V_1 \) = speed of the crop as it enters the cylinder, m/s
\( V_2 \) is proportional to the linear speed of the cylinder (V);
\[
V_2 = a \cdot V
\]  
\( R \) = threshing cylinder radius, \( \omega \) = cylinder rotary speed, rad/s, 
\( N \) = cylinder RPM; \( a \) = coefficient, an empirical figure depended upon cylinder length, straw humidity, shape of rasp bar, feed rate and physical properties of the threshing unit. For a thresher of 0.8 m in length, humidity of 15 - 25%, feed rate of 3.5 kg/s, the coefficient \( a \), has been determined equal to 0.70 - 0.85 (Hall et al., 1981).
• The linear speed of the cylinder ‘V’ has also been determined equal to 15 - 37 m/s (Behroozi, 2004). Inserting equation (5) in equation (4):

\[ F_c = Q \cdot (a \cdot V - V_1) \]

(6)

• \( F_c \) is dependent upon many factors such as the friction coefficient, type of breakage of the straw, the intense of threshing and etc. It is however proportional to the total force necessary to thresh the crop, \( F \). Now \( F_r \) is given as:
Fr = f \cdot F \quad \text{---------------------------------------- (7)}

- The coefficient $f$, for rasp bar type cylinders is equal to $0.65 - 0.75$ and for finger type equal to $0.7 - 0.8$. Inserting equations 6 and 7 in equation 3;

$$
F = Q (aV - V_1) + f F \quad \text{---------------------------------------- (8)}
$$

Or,

$$
F (1 - f) = Q (aV - V_1)
$$

and therefore,

$$
F = \left[ \frac{Q (aV - V_1)}{1 - f} \right] \quad \text{---------------------------------------- (9)}.
$$

Required power for threshing, $P_1$ in watts, may be obtained by multiplying both sides of equation (9) by $V$;

$$
P_1 = FV = \left[ \frac{q (aV - V1)}{1 - f} \right] V \quad \text{------------------------- (10)}
$$
The total power for the threshing is more than what is shown in equation (10). Power is also needed to overcome the air resistance against the rotation of the cylinder and the friction force in bearings. This power is calculated from equation 11, below:

\[ P_2 = A \cdot V + B \cdot V^3 \]  

(11)

The first term after the equal sign \((A \cdot V)\) is due to friction and the second term \((B \cdot V^3)\) is for air resistance. A and B are two coefficients. Coefficient A is determined as 0.85 - 0.90 N per 100 kg mass of rasp bar type thresher cylinder and 5 - 5.5 N per 100 kg mass of finger types. Coefficient B for cylinder diameters of 550 mm is equal to 0.065 N.s^2/m^2 per m of cylinder length of rasp bar type and 0.045 N.s^2/m^2 for finger type.
• The total required power is then:

\[ P = P_1 + P_2 = \frac{Q(a.V - V_1)}{(1 - f)} V + A.V + B.V^3 \ -----(12) \]

Substituting the least value for \( V_1 \) but the maximum for other components yields; \( P = 11.75 \text{ kW} \) and for a design coefficient of 1.5 the total power requirement is:

\[ P = 11.75 \times 1.5 = 17.6 \text{ kW} \ -----(13) \]

• Tube outer diameter can be calculated from the following classic equation (Hall et al., 1981).

\[ d_o = \frac{16}{\pi.S_s(1-k^4)} \sqrt{\left[C_m.M + \frac{a.F.d_o(1+K^2)}{8}\right]^2 + (C_t.T)^2} \ -----(14) \]

Prof. Dr. Muhammad Iqbal, Department of Farm Machinery & Power, University of Agriculture, Faisalabad
• Where,
• \(do = \) tube outside diameter, mm
• \(K = \frac{do}{di}\)
• \(Di = \) tube inside diameter, mm
• \(M = \) bending moment, N.mm
• \(S_s = \) permissible shear stress, N/mm\(^2\)
• \(T = \) torsion moment, N.mm
• \(C_m, C_t = \) coefficients (Hall et al., 1981).
• The second term inside the radical sign is due to tension, which does not exist in this case and thus is set to zero.
To calculate the moments, the imposed forces must first be determined as follows:

1. Horizontal forces, which are reaction to the threshing force and friction may be calculated from the total power requirement.

2. Vertical forces due to the weight of the components such as: rasp bars, plates, star flanges, tube flanges, tube, power transmission pulley, shaft flanges, short and long shafts.
• The weight of the should be known. Power is transmitted to the cylinder by V-belt pulleys at an angle of 30° angle with respect to the horizontal. The tight and slack side tensions can be calculated from the following equation (Behroozi, 2000);

\[
P = \frac{(T_1 - T_2) \cdot V}{1000} = \frac{T \cdot N}{9549} \quad \text{(15)}
\]

Where,

- \( P \) = total design power = 17.6 kW
- \( T_1, T_2 \) = tensions on the tight side and slack side of the V-belt, N,
- \( V \) = linear speed of the belt, m/s
- \( T \) = Torque, N.m,
- \( N \) = rotational speed, rpm
Lecture 9

Machine capacity
• The capacity of a machine is the number of units which it can process or cover in a specific time.

• Capacity may be expressed as the acreage covered per hour, in bushels harvested per day, bales handled per hour, etc.

• The effective field capacity is the measure of a machine's ability to do a job under actual field conditions.

• To estimate effective field capacity, calculate the theoretical field capacity and multiply by the field efficiency.

• To estimate the effective field capacity of a machine, compute the theoretical field capacity from the following formula.

\[
TFC \text{ (Acres per Hour)} = \frac{\text{Speed (mph)} \times \text{Machine Width (ft)}}{8.25}
\]
The machine cannot operate at its theoretical capacity at all times while it is in the field due to the following factors:

- Turning and idle travel
- Operating at less than full width
- Handling seed, fertilizer, chemicals, water or harvested materials
- Cleaning clogged equipment
- Machine adjustment
- Lubrication and refueling during the day
- Waiting for other machines
- Waiting for repairs to be made
- Consequently, the field efficiency is always less than 100-percent.
Field Efficiency

• Field efficiency is defined as the percentage of time the machine operates at its full rated speed and width while in the field. Using the field efficiency compute the actual, or effective, field capacity as follows:

\[
\text{Effective Field Capacity} = \text{Theoretical Capacity} \times \text{Field efficiency}
\]

– Typical values of field efficiency and speed for various machines are given in Table M1.1.
– Selecting the exact values to use for a particular operation requires judgment and experience.
– Instead of calculating the effective field capacity from the above formulas, Figures M1.1 and M1.2 can be used.
• For example, a four-row planter (42" rows) will be used to plant a hilly field with short rows. The short rows will cause the turning time to be high and the field efficiency low.

• Due to the terrain, the operating speed would have to be low. Hence we choose from Table M1.1: *Field efficiency - 60% and Speed - 4.0 mph*
• From Figure M1.1 find 14 feet on the horizontal axis, move vertically to the intersection of the 4 miles per hour line, then horizontally to find the theoretical field capacity of 6.8 acres per hour on the vertical axis.

• From Figure M1.2 find the 6.8 acres per hour on the horizontal axis, move vertically to the intersection of the 60-percent field efficiency line, then horizontally to find an effective field efficiency of 4.1 acres per hour.
Figure M1.1: Determining Theoretical Field Capacity From Swath Width and Operation Speed.
Figure M1.2: Determining Effective Field Capacity.
<table>
<thead>
<tr>
<th>Implement/Equipment</th>
<th>Field speed, MPH</th>
<th>Field efficiency (fraction)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tillage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cultivator - field</td>
<td>3 - 8</td>
<td>.70 - .90</td>
</tr>
<tr>
<td>Cultivator - row crop Disk harrow</td>
<td>1.5 - 5</td>
<td>.70 - .90</td>
</tr>
<tr>
<td>Disk plow</td>
<td>3 - 6</td>
<td>.70 - .90</td>
</tr>
<tr>
<td>Moldboard plow</td>
<td>3.5 - 6</td>
<td>.70 - .90</td>
</tr>
<tr>
<td>Spike tooth harrow</td>
<td>3.5 - 6</td>
<td>.70 - .90</td>
</tr>
<tr>
<td>Spring tooth harrow</td>
<td>3 - 6</td>
<td>.70 - .90</td>
</tr>
<tr>
<td>Rotary hoe</td>
<td>3 – 6</td>
<td>.70 - .90</td>
</tr>
<tr>
<td>Chisel Plow</td>
<td>5 - 10</td>
<td>.70 - .85</td>
</tr>
<tr>
<td>Planting</td>
<td>3.5 - 6</td>
<td>.70 - .90</td>
</tr>
<tr>
<td>Endgate seeder 3 - 6 .70 - .90</td>
<td>3 - 6</td>
<td>.70 - .90</td>
</tr>
<tr>
<td>Grain drill</td>
<td>2.5 - 6</td>
<td>.65 - .85</td>
</tr>
<tr>
<td>Row-crop planter</td>
<td>3 - 8</td>
<td>.50 - .85</td>
</tr>
<tr>
<td>Transplanter</td>
<td>1.5 – 4</td>
<td>.50 - .75</td>
</tr>
<tr>
<td>Harvesting</td>
<td>2 - 4</td>
<td>.65 - .80</td>
</tr>
<tr>
<td>self-propelled</td>
<td>2 - 4</td>
<td>.65 - .80</td>
</tr>
<tr>
<td>Corn picker 2 - 4 .65 - .80</td>
<td>1.5 - 4 (5-10 tons/hr.)</td>
<td>.50 - .70</td>
</tr>
<tr>
<td>Forage harvester</td>
<td>5 - 7</td>
<td>.75 - .85</td>
</tr>
<tr>
<td>Mower Hay conditioner</td>
<td>3 - 5 tons/hr.</td>
<td>.60 - .85</td>
</tr>
<tr>
<td>Hay baler (Conventional)</td>
<td>3 – 8</td>
<td>.50 - .80</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>3 - 5</td>
<td>.60 - .75</td>
</tr>
<tr>
<td>Sprayer, (conventional, hydraulic)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fertilizer distributor</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Prof. Dr. Muhammad Iqbal, Department of Farm Machinery & Power, University of Agriculture, Faisalabad
EXAMPLE

• Determining Effective Field Capacity
• A soybean producer has 500 acres of soybeans on 36-inch rows to harvest and he wants your advice on what size combine to buy.
• One can use section M1 to estimate the time required to cut the 500 acres.
• From Table M1.1, page M1.5, select 3.0 miles per hour. (The recommended speed.)
• From Figure M1.1, page M1.3, find the swath width of 12-feet, move vertically to the 3 mph line and horizontally to read a theoretical field capacity of 4.5 acres per hour.
• From Table M1.1. select a field efficiency of .65 - .80, depending on field size, terrain, travel distance necessary to dump beans, etc.
• If you select a field efficiency of .70, from Table M1.2, find 4.5 acres per hour, move up to the 70-percent line and across to the effective capacity of 3.2 acres per hour. Because of dew and weather conditions 8 hours per day is a good average or 25 acres per day. At this rate 20 good harvesting days would be required.
Unit-10

Critical velocity determination
The behavior of particles in an air stream is governed by their aerodynamic properties. Let particles behavior considered in vertical stream.

Parameters are:

1. \( V_{cr} \) = critical velocity, m/s
2. \( k \) = coefficient of resistance of air (\( k \) depends upon shape of body, its surface, state and species of medium in which its located and on the velocity of air stream and decreases with an increase in air velocity)
3. \( k_d \) = drift coefficient
4. \( G \) = gravitational force=weight of body (grain), N
5. \( R \) = upward force due to air stream= resistance of air stream, N
6. \( \rho_a \) = density of air, kg/m\(^3\)
7. \( A \) = projected area of body on a plane perpendicular to air stream direction, m\(^2\)
8. \( V_a \) = velocity of air stream in vertical direction, m/s
9. \( U \) = velocity of the body (grain), m/s

Using Newton’s law;

\[
R = k \rho_a A (V_a - U)^2 N_a
\]
During the air flow in vertical direction, forces G and R act in opposite direction:

• If \( G > R \) the particle moves downward

• If \( R > G \) the particle moves upward

• If \( G = R \), that is \( U = 0 \), then \( V_a = V_{cr} = \) critical velocity, m/s, the particle is suspended in air
At $G = R$,  
\[ V_{cr} = \sqrt{\frac{G}{k \cdot \rho_a \cdot A}} \]  

or,  
\[ G = k \cdot \rho_a \cdot A \cdot V_{cr}^2 \]  

The drift coefficient,  
\[ k_d = \frac{9.8 \cdot k \cdot \rho_a \cdot A}{G} \]  

insert equ3 into equ 4,  
\[ k_d = \frac{9.8 \cdot k \cdot \rho_a \cdot A}{k \cdot \rho_a \cdot A \cdot V_{cr}^2} = \frac{9.8}{V_{cr}^2} \]
• Coefficients $k$ and $k_d$ are difficult to determine and therefore determined experimentally.

• The $V_{cr}$ is determined by using critical velocity determination apparatus with transparent vertical tube. The $V_{cr}$ is sometimes determined from the dynamic head ($N/m^2$) of the air stream. Since the dynamic head of air ($N/m^2$) stream equals to the kinetic energy of a unit volume of air i.e.
Where

\( m = \rho_a \), mass of 1-m\(^3\) of air

Assume, at temperature of 20 °C and 10.3x10\(^4\) N/m\(^2\) atmospheric pressure, the air density \( \rho_a = 1.2 \text{ kg/m}^3 \), then

\[
h_d = \frac{m \cdot V^2}{2} = \frac{\rho_a V^2}{2}, \quad \frac{N}{m^2}
\]

or,

\[
V_a = \sqrt{\frac{2}{\rho_a}} h_d
\]

\[
\text{where}
\]

\[
m = \rho_a, \text{ mass of } 1\text{-m}^3 \text{ of air}
\]

The dynamic head of air is determined by pitot tube. Knowing the \( V_{cr} \), the coefficients \( k \) and \( k_d \) can be determined easily from equations 2 and 4 respectively.
Table 1. Aerodynamic properties of various crops

<table>
<thead>
<tr>
<th>Crop</th>
<th>$V_{cr}$</th>
<th>$k_d$</th>
<th>$k$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Grains</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wheat</td>
<td>8.9-11.5</td>
<td>0.075-0.12</td>
<td>0.184-0.265</td>
</tr>
<tr>
<td>Rye</td>
<td>8.36-9.89</td>
<td>0.1-0.14</td>
<td>0.16-0.22</td>
</tr>
<tr>
<td>Oats</td>
<td>8.08-9.11</td>
<td>0.169-0.3</td>
<td>0.118-0.15</td>
</tr>
<tr>
<td>Corn</td>
<td>12.48-14</td>
<td>0.05-0.06</td>
<td>0.16-0.28</td>
</tr>
<tr>
<td><strong>Chaff</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wheat</td>
<td>0.75-5.25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oat</td>
<td>0.74-3.86</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 1. The Experimental set-up for determination of terminal velocity of grain.
1. The experimental apparatus used to determine the terminal velocity is shown in Fig. 1.

2. It consists of a fan, electronic revolution regulator, electric motor, plenum chamber, airflow straightener, vertical transparent tube with diameter 110 mm and an observation window on the tube.

3. The different values of air speed can be obtained by changing the revolution of electric motor with an electronic revolution regulator.

4. A 0.35 KW centrifugal blowing fan is used for developing air flow through the tube.

5. A hot wire anemometer having a least count of 0.1 m/s is used for the measurement of air velocity in tube. The dimensions of each seed, namely length, width and thickness, are measured in three directions by using digital vernier caliper with 0.001 mm accuracy.

6. The seeds to be measured are taken randomly as 100 samples. The dimensions of cereal seed are measured as length and thickness because the thickness and width of lentil seeds are nearly same.

7. Equation (9) can be used for determining the geometric mean diameter of seeds (Mohsenin, 1980; Song and Litchfield, 1991)

---

Prof. Dr. Muhammad Iqbal, Department of Farm Machinery & Power, University of Agriculture, Faisalabad
\[ d_g = (abc)^{1/3} \]  

Where, 
\( D_g \) = geometric mean diameter in mm;  
\( a \) = length of seed in mm;  
\( b \) = width of seed in mm;  
\( c \) = thickness of seed in mm

The diameter of equivalent sphere is determined by using Eq. (10) (Gorial and O’Callaghan, 1990).

\[ d_e = \left[ \left( \frac{W_t}{\gamma_t} \right) \left( \frac{6}{\pi} \right) \right]^{1/3} \]  

Where 
\( d_e \) = is the diameter of equivalent sphere in mm;  
\( W_t \) = is weight of seed in kg;  
\( \gamma_t \) = is true density of seed in kg/m\(^3\).
Sphericity used for determining the similarity of seed to sphere is calculated by Eq. (11) as suggested by Mohsenin (1980).

\[
\phi = \text{geometric mean diameter} / \text{major diameter}, \text{ i.e.}
\]

\[
\phi = \frac{(abc)^{1/3}}{a}
\]

Where \( \phi \) = sphericity

The mass of seeds is measured by using digital electronic balance with an accuracy of 0.0001 g.

The moisture content of each grain variety is determined according to ASAE S352.1 (ASAE, 1984).

The bulk density of seeds based on the volume occupied by the bulk sample is measured by using the standard hectometer method (Çarman, 1996; Konak et al., 2002; Tabil et al., 1999).

The true density is defined as the ratio of the mass of a sample to its solid volume and is determined by using the liquid displacement method. For this purpose, pycnometer and toluene is used.

The projected area of a seed in three different positions is determined by using the image processing method.
Where:

\( V_{\text{kt}} \) = The theoretical terminal velocity in m/s
\( g \) = Gravitational acceleration in m/s²
\( \gamma_a \) = True density of air in kg/m³
\( \frac{\text{weight of sample}}{\text{volume of displaced fluid}} \)
\( Z \) = Shape factor

The general form for the shape factor of any shape is:

\[
K_s = \frac{(D_e A)}{V}
\]

where

\( K_s \) : Shape Factor
\( D_e \) : Equivalent Diameter of a sphere with a volume equal to the volume of the non-spherical particle
\( A \) : Area of the shape
\( V \) : Volume of the shape
A vertical air tunnel with a plexiglass tube is used to determine experimental terminal velocity. Ten seeds from each grain variety are randomly selected for measurement of terminal velocity. The seed sample are placed on a mesh screen in vertical tube. The air velocity is adjusted by increasing the speed of motor until the seed began to float. The air velocity near where the seed become suspended is measured with a hot wire anemometer having a least count of 0.1 m/s. Equation (14) is used to calculate the drag coefficient of grain varieties.

\[
C = \frac{2m_t g}{\gamma_a V_{\text{krd}}^2 A_t}
\]

Where;

- \(C\) = The drag coefficient
- \(m_t\) = Mass of seed in kg
- \(V_{\text{krd}}\) = Terminal velocity experimentally measured in m/s
- \(A_t\) = Projected area of seed in m²
• Intel (R) Celeron (TM) CPU 1100 MH2, 600x1200 DPI Scanner and the IT version 2.0 of the Uthscsa Image Processing Program are used for processing the images of the files formatted as TIF from scanner to computer.

• The 100 seeds from each variety are positioned on a white sheet in three different positions. These positions are named as A1, A2, and A3. In A1 position, the hilum axis of grain are parallel to horizontal plane and seed was placed on hilum axis. In A2 position, the hilum axis of grain is parallel to horizontal plane and seed is placed on its side. In A3 position, the hilum axis of grain is vertical to horizontal plane (Figure 2).

• The samples, which are scanned with 600x1200 DPI Scanner and translated to computer as TIF file format, are processed by image processing program. Equation (12) as suggested by Gorial and O’Callaghan (1990) is used for theoretical calculation of terminal velocity. For this purpose, the diameter of equivalent sphere and shape factor calculated by Eq. (13) can be used.
Unit-11  Figure. Correcting Wheat Harvest Losses

Separator Loss Over .5%? Yes → Engine & Separator Speed OK? Yes → Header Too Low? No → Ground Speed Too Fast? No → Unthreshed Kernels? Yes → Increase Thresher Speed or Decrease Clearance

Loose Kernels?

Pulverized Straw Behind Combine or Damaged Wheat in Tank? Yes → Decrease Thresher Speed or Increase Clearance

Chaffer Opening Too Narrow? Yes → Adjust Chaffer

Air/Fan Supply? Too Strong → Adjust Air Vanes or Reduce Fan Speed

Too Weak → Increase Fan Speed

Reel Speed Too Fast?

Shattered Kernels?

Poor Knife Condition?

Ground Speed Too Fast?

Header Loss Over .5%?

Cutterbar Too High?

Whole Heads?

Reel Speed Too Slow?

Reel Height Incorrect?
References


Lecture-12

Potato harvesting

Prof. Dr. Muhammad Iqbal, Department of Farm Machinery & Power, University of Agriculture, Faisalabad
INTRODUCTION

• Potato has become an important crop for both farmers and consumers in Pakistan.
• Potato is the fourth most important crop by volume of production
• Potato is high yielding, having a high nutritive value and gives high returns to farmers.
• At the time of independence, the area under production increased to around 112,000 ha during 2004-2005.

Prof. Dr. Muhammad Iqbal, Department of Farm Machinery & Power, University of Agriculture, Faisalabad
<table>
<thead>
<tr>
<th>CROP</th>
<th>PLANTING</th>
<th>HARVESTING</th>
<th>PRODUCTION SHARE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring</td>
<td>Jan-Feb</td>
<td>April-May</td>
<td>07.10 %</td>
</tr>
<tr>
<td>Summer</td>
<td>March-May</td>
<td>August-Oct</td>
<td>15-20 %</td>
</tr>
<tr>
<td>Autumn</td>
<td>Sept-Oct</td>
<td>Jan-Feb</td>
<td>70-75 %</td>
</tr>
</tbody>
</table>

Prof. Dr. Muhammad Iqbal, Department of Farm Machinery & Power, University of Agriculture, Faisalabad
Important Potato Production Districts in Pakistan


Khyber Pakhtoon Khah: Nowshera, Dir, Swat, Balakot, Gilgit, Sakardu and Mansehra

Balochistan: Pishin, Killa Saifulla and Kalat
Area and production of potatoes in Pakistan:

<table>
<thead>
<tr>
<th>YEAR</th>
<th>AREA.  (000 HA)</th>
<th>PRODUCTION.(000) TONNES</th>
<th>YIELD. TONNES/ HA.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1947-48</td>
<td>3.0</td>
<td>30.0</td>
<td>10.0</td>
</tr>
<tr>
<td>1999-2000</td>
<td>112.8</td>
<td>1871.0</td>
<td>17.3</td>
</tr>
<tr>
<td>2000-2001</td>
<td>101.5</td>
<td>1665.7</td>
<td>16.4</td>
</tr>
<tr>
<td>2001-2002</td>
<td>105.2</td>
<td>1730.7</td>
<td>16.4</td>
</tr>
<tr>
<td>2002-2003</td>
<td>115.8</td>
<td>1946.3</td>
<td>16.8</td>
</tr>
<tr>
<td>2003-2004</td>
<td>109.7</td>
<td>1938.1</td>
<td>17.7</td>
</tr>
<tr>
<td>2004-2005</td>
<td>112.0</td>
<td>2024.9</td>
<td>18.1</td>
</tr>
</tbody>
</table>
Potato Planting Tips

1. Purchase and plant certified seed tubers.

2. Warm the seed at room temperature for about one week, or until eyes just begin to sprout before cutting.

3. Cut seed, sterilizing the cutting knife and other tools between tubers. Use 10 percent household bleach or a "tamed" iodine disinfectant (available at dairy supply stores).

4. Bleach is very corrosive to metal tools, so wash and oil them after use.

5. Allow the cut seed to heal for three days in a warm moist area, then plant in warm (at least 50F) moist soil.

6. Plant potato seed pieces 3-4 inches deep and mound soil around the potatoes "hilling" as they grow for best tuber growth.

7. There should be 2-3 feet between potato rows and 12 inches between plants in the row. Ideally, the seed piece and the soil should be the same temperature to reduce the chances of soft rot.
Potato growth phases

First phase: sprouts emerge and root growth begins.

Second phase: Photosynthesis begins as the plant develops leaves and branches.

Third phase: New tubers develop, which is often (but not always) associated with flowering. Tuber formation halts when soil temperatures reach 80 °F (26.7 °C); hence potatoes are considered a cool-season crop.

Fourth phase: Tuber bulking occurs when the plant begins investing the majority of its resources in its newly formed tubers. At this stage, factors critical to yield are; optimal soil moisture and temperature, soil nutrient availability and balance, and resistance to pest attacks.

Fifth phase-maturation phase: The plant canopy dies back, the tuber skins harden, and their sugars convert to starches.
General Tips For Healthy Potatoes

1. Don't overwater. Keep the soil moist but not soggy.

2. Don't plant potatoes and tomatoes near each other -- they are affected by the same diseases.

3. Remove infected or diseased plants from the garden.

4. Remove potato debris from the garden after harvest.
Potato harvesting tips

1. At harvest time, gardeners usually dig up potatoes with a long-handled, three-prong a **spading fork** is similar to the graip but with tines at a 90 degree angle to the handle. In larger plots, the plow is the fastest implement for unearthing potatoes.

2. Commercial harvesting is typically done with large potato harvesters, which scoop up the plant and surrounding earth. This is transported up an apron chain consisting of steel links several feet wide, which separates some of the dirt.

3. The run past workers continue to sort out plant material, stones, and rotten potatoes before the potatoes are continuously delivered to a wagon or truck. Further inspection and separation occurs when the potatoes are unloaded from the field vehicles and put into storage.

4. Immature potatoes may be sold as "new potatoes" and are particularly valued for taste. Farmers pull out the young tubers by hand while leaving the plant in place.

5. Potatoes are usually cured after harvest to improve skin-set. Skin-set is the process by which the skin of the potato becomes resistant to skinning damage. Curing allows the skin to fully set and any wounds to heal. Curing is normally done at relatively warm temperatures 50 °C (122 °F) to 60 °C (140 °F) with high humidity and good gas-exchange if at all possible.
6. Potatoes can be harvested any time for eating. As the plants begin to mature at the end of the growing season, the vines will begin to yellow and die.

7. If the potatoes are going to be stored instead of consumed immediately, then the tubers be allowed to "harden" in the soil before digging. Hardening allows the skin to thicken, preventing storage diseases and shrinkage due to water loss.

8. Vines should be killed or removed two weeks before digging the potatoes. A longer period of hardening will increase the amount of black scurf that may develop on the tubers and should be avoided.

9. Vines can be killed by normal maturity, frost, pulling, or simply cutting the vines off at the soil line. Avoid bruises and injury during harvest, as these provide entry sites for storage diseases.

10. After harvest, store potatoes for the first two weeks at about 65F to allow injuries to heal. For best results, tubers should then be stored at 35-40F in the dark for the remainder of storage.

11. Two diseases - soft rot and dry rot are common in storage. As the names imply, soft rot is a wet, mushy decay and dry rot is a dry, crumbly decay. Tubers which decay in storage should be removed to prevent the decay from spreading to the other potatoes.
Potato separation problems in heavy soil

Prof. Dr. Muhammad Iqbal, Department of Farm Machinery & Power, University of Agriculture, Faisalabad
An old tractor-drawn potato harvester  
A modern self-propelled potato harvester  
A Ferguson potato digger  
A Horse-drawn Blackstone potato Digger
Row Potato Diggers Description
The digger digs one row of potatoes or other root crop. The digger can be pulled on the centerline of the tractor or offset as when straddling two rows and digging one. The standard diggers return the produce onto the dug soil after shaking the bulk of the soil through the chain. The soil type and produce size dictate what pitch of chain is needed. The hydraulic drive allows better matching of chain speed with digging conditions.

Features
• 540 RPM - PTO Driven Self Contained Hydraulic Drive System
• 25" Wide Hook Chain In Cleaning Bed
• Tail Section Movable To Minimize Drop Height
• Tail Section Can Be Raised To Deliver Produce Onto A Towed Trailer
• Adjustable Blade and Cleaning Bed Angle for Varying Conditions
### Specifications

<table>
<thead>
<tr>
<th></th>
<th>D-10T</th>
<th>D-10M</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tractor Attachment</td>
<td>Drawbar</td>
<td>3-point, Cat I or Cat II</td>
</tr>
<tr>
<td>Overall Length</td>
<td>169&quot;</td>
<td>71&quot;</td>
</tr>
<tr>
<td>Overall Width</td>
<td>53&quot;</td>
<td>40&quot; - Center Hitch</td>
</tr>
<tr>
<td>Overall Height</td>
<td>45&quot;</td>
<td>45&quot;</td>
</tr>
<tr>
<td>Cleaning Bed Length</td>
<td>102&quot;</td>
<td>48&quot;</td>
</tr>
<tr>
<td>Blade Width</td>
<td>26&quot;</td>
<td>26&quot;</td>
</tr>
<tr>
<td>Weight (Basic Machine)</td>
<td>1350 lbs</td>
<td>680 lbs</td>
</tr>
<tr>
<td>Tractor Requirement (Estimate)</td>
<td>20 HP</td>
<td>20 HP Min.</td>
</tr>
</tbody>
</table>

---

Prof. Dr. Muhammad Iqbal, Department of Farm Machinery & Power, University of Agriculture, Faisalabad
Da Lat farmers create potato-digging machine

- Field capacity- 3 hectares / day
- Shakes off the dirt before dropping them on the ground.

ingenious potato-digging machine in Indiana. J.C. Allen & son's potato-harvesting machine being drawn by a crawler-type tractor in Indiana, USA.
Digging Lily Bulbs with Antique Potato Diggers – Gently and Quickly

This is a simple case of mechanics. The designer used an assortment of old-fashioned but quite serviceable iron potato diggers, some of which date back to the early 1900’s – parts of them, anyway – to gently harvest the lily bulbs in fall. The "Modern" embellishments to this model include rubber tires from the 1940's (technology at its finest and gentle on the driveway) plus a converted Model A car transmission to neatly attach to tractor’s PTO (power take off) shaft.
Potato digger

Engine power: 9HP diesel engine
Overall Size: (L*W*H) mm 1770*645*1040
Net Weight: (kg) 120 Gross Weight (kg) 150
Output Shaft Roate Speed: (rpm) 700
Rated Power: [kw(HP)/rpm] 6.3(8.6)/1800
Starting System: Recoil starter
Potato diggers developed in Pakistan

Star wheel diameter, \( d = 1.00 \) m
Gear speed ratio = 1:8
PTO rpm = 540 rpm
Star wheel speed = \( \frac{540}{8} = 67.5 \) rpm
Angular velocity = \( 2 \times 3.141 \times \frac{67.5}{60} \)
= 7.07 rad/s
Wheel tip velocity, \( v = \frac{d}{2} \times 7.07 \)
= 3.52 m/s
(Range 3.52 – 7 m/s)
## Video potato harvester links

<table>
<thead>
<tr>
<th>Video Link</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="http://www.youtube.com/watch?v=vQaRestxEWM&amp;feature=related" alt="Video Link 1" /></td>
</tr>
<tr>
<td><img src="http://www.youtube.com/watch?v=oit-VlfqzYY&amp;feature=related" alt="Video Link 2" /></td>
</tr>
<tr>
<td><img src="http://www.youtube.com/watch?v=HTf8BuZOFiU&amp;feature=related" alt="Video Link 3" /></td>
</tr>
<tr>
<td><img src="http://www.youtube.com/watch?v=FQj99QAn7z8&amp;feature=related" alt="Video Link 4" /></td>
</tr>
<tr>
<td><img src="http://www.youtube.com/watch?v=Lyuo1c3TbV0" alt="Video Link 5" /></td>
</tr>
</tbody>
</table>
Lecture-13
Crop harvest recommendations

Reference: Combines and combining, Agricultural Education Service, Department of Agricultural Education, The Ohio State University, USA, 1970

Prof. Dr. Muhammad Iqbal, Department of Farm Machinery & Power, University of Agriculture, Faisalabad
Wheat Harvest Recommendations

• Wheat matures at 30% moisture content.
• Each day delay in combining after maturity leads to a loss of 12 pounds per acre due to shattering.
Problems for harvesting wheat between 20-30% moisture content:

• Kernels damage by threshing cylinder action
• Damaged grain will not keep well in storage due to attack of insect / pest
• The test weight per bushel is lowered
• The seed germination is lowered
Problems of harvesting wheat below 14%

- More shattering loss (1-bushel/ acre for each 5-days)
- More cutter bar loss
- More green material growth in field which is ultimately taken by combine
- More risk of lodged grain
- Test weight per bushel is reduced (1-bushel / acre each 5-days Figure 64)
  - Grain standing in the field dries and is rewetted with rain or dew it swells and does not re-dry back to its original volume. Therefore, there are less kernels in a bushel and the weight is lower.
Benefits for harvesting wheat within 20-14% moisture content

• High test weight
• Good seed germination
• Undamaged kernels if machine properly adjusted
• Cutter bar loss is less
• Rack and shoe loss are minimum
Effect of date of harvesting on test weight
Effect of date of harvesting on test on grain loss
Soybean Harvest Recommendations

Losses with the combine have commonly been from 10 to 20 percent of the available crop.

• High moisture combining is considered when the kernels are above 12 percent moisture, and the pods are dampened from dew or rain.
a. Adjust the Cylinder and Concave

- For dry beans adjust the cylinder-Concave to minimize cylinder losses.
- In soybeans there will be no tendency to over load the rack and shoe with chaff as it would in wheat. While the cylinder loss for dry soybeans will be low, the gathering loss is usually quite high. Gathering losses can be greatly reduced if the beans that have dried down to 14 percent moisture or below are harvested after the pods and straw have been remoistened by dew or rain.
- Damp harvesting conditions can be achieved by harvesting after a rain or when the early morning or late evening dew is on the plants.
Figure 67 Effect of soybean moisture content on harvesting loss

(Shatter losses and total losses are greatly reduced as the moisture content at harvest increases. Damp harvesting conditions can be achieved by harvesting after a rain or when the early morning or late evening dew is on the plants)

Prof. Dr. Muhammad Iqbal, Department of Farm Machinery & Power, University of Agriculture, Faisalabad
Figure 68 Effect of time of harvesting in a day on shatter loss and kernel moisture content

(Harvesting in the morning under damp pod stalk moisture conditions due to dew at night can greatly reduce shatter losses which then after increases during day hours as the crop dries. However, because damp beans are more difficult to thresh, the cylinder and concave adjustments must be changed (Table 1). Closer clearances are used for damp conditions)
Table 1. Crop and machine adjustment

<table>
<thead>
<tr>
<th>Soybean Crop condition</th>
<th>Cylinder dia / speed</th>
<th>Cyl. Tip speed (ft/min)</th>
<th>Cyl-concave clearance, inch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry</td>
<td>22-inch (400 RPM)</td>
<td>2300</td>
<td>3/8</td>
</tr>
<tr>
<td>Damp</td>
<td>22-inch (782 RPM)</td>
<td>4500</td>
<td>1/4</td>
</tr>
</tbody>
</table>

Prof. Dr. Muhammad Iqbal, Department of Farm Machinery & Power, University of Agriculture, Faisalabad
b. Lower the cutter bar as close to as possible

- Lower cutter-bar adjustment reduces shatter loss due to direct cutting of beans and stubble loss caused by cutting above the pods
Figure 69. Effect of cutting height on soybean shatter loss at different moisture levels
Figure 70 shows the effect of different cylinder speeds on cylinder loss of beans at two different moisture levels. Cylinder adjustment is a compromise between cylinder loss, crackage, and perhaps a germination reduction. Cylinder loss should not be above 0.5 percent with only a few beans found in pods.
c. Adjust the reel

Figure 71.

The faster the reel operates in relation to the ground speed the greater the shattered loss will be. Combine speed 2.6 to 2.9 m.p.h. Bean moisture 10-11%. (Reel index of 1 = reel traveling at ground speed of combine, 2 = reel traveling twice combine ground speed, etc.)
(2) The bat penetrates the grain no more than necessary to hold the beans while being cut and move them onto the platform. (Figure 72) In case of lodged beans the reel will need to be operated at a lower setting.

**Figure 72.**
Shatter losses increase as the reel is adjusted downward. Dry beans shatter more than moist beans.

MOISTURE

<table>
<thead>
<tr>
<th></th>
<th>BEANS</th>
<th>PODS</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.6%</td>
<td></td>
<td>9.6%</td>
</tr>
<tr>
<td>12.0%</td>
<td></td>
<td>13.4%</td>
</tr>
</tbody>
</table>

(3) The axis of the reel is adjusted so that it is 6 to 12 inches ahead of the knife. Except for stalk carryover this adjustment has little effect upon losses.
d. Keep machine forward speed reasonable. At lower reel index, stalk slippage along the cutter bar increases due to increased speed of forward travel.

Figure 73.

FORWARD SPEED AFFECTS STALK SLIP-PAGE ON KNIFE.
Figure 74.
THE EFFECT OF COMBINE GROUND SPEED ON HARVESTING LOSS.
Favorable working days for a field operation of soybean harvesting

• A farmer needs to know how many favorable working days he can expect to have available for a given operation. This will help him in determining the number of acres of a crop that he can take care of and the size of machinery he needs to do the required jobs.

• The Department of Agricultural Economics at The Ohio State University has conducted a study to determine the days available for combining soybeans. The days available for both early and late harvest of soybeans for two moisture levels are given in Fig. 75.
<table>
<thead>
<tr>
<th>Period and Level of Moisture</th>
<th>November 7 - December 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>14% moisture</td>
<td>5 1/2 day worst year</td>
</tr>
<tr>
<td></td>
<td>10 1/2 day average</td>
</tr>
<tr>
<td></td>
<td>18 1/2 day best year</td>
</tr>
<tr>
<td>16% moisture</td>
<td>10 1/2 day worst year</td>
</tr>
<tr>
<td></td>
<td>16 1/2 day average</td>
</tr>
<tr>
<td></td>
<td>20 1/2 day best year</td>
</tr>
</tbody>
</table>
Corn Harvest Recommendation Conditions

• The corn head snaps the ears from the stalks and feeds them into the cylinder for shelling.
Figure 76. CORN HEAD ATTACHMENT USING A CONVEYOR TO FEED MATERIAL INTO THE CYLINDER.

Figure 77. CORN HEAD ATTACHMENT USING AUGERS TO FEED MATERIAL INTO THE CYLINDER.
Figure 78. SNAPPING BARS SHOULD BE ADJUSTED JUST CLOSE ENOUGH TOGETHER TO PREVENT PASSAGE OF EARS.

Figure 79. THE EARS ARE FED INTO THE THRESHING UNIT WHERE THEY ARE SHELLED BY THE RUBBING ACTION OF THE ROTATING CYLINDER AGAINST THE CONCAVE. (Courtesy of International Harvester Company.)
1. **Pre-harvest loss (PHL)**: Longer corn dries in the field the greater the PHL.

Figure 80. **PRE-HARVEST CORN LOSSES INCREASE AS CORN DRIES DOWN BEFORE HARVESTING.** (W. H. Johnson, "Corn Harvesting Data," OARDC, 1964.)
1. **Highest machine yields:** Highest combine and picker yields had been observed between 20 and 30% moisture content. At high moisture content of 35% the combine yield being lower than picker was due to invisible losses (kernel tips remain in the cob and un-measureable small chips of kernels/fines).

![Graph showing yields of dry shelled corn per acre harvested at different moisture levels with a combine and a picker.](image)
Figure 84. HOW TO TELL WHEN CORN WILL MATURE

(USDA Agr. Research Sept. 1955)

When planted at the ordinary time corn dries about as follows:

- 88% moisture at planting.
- 75% moisture after 2% per day drying for 6 days.
- 50% moisture after 1.2% per day drying for 21 days.
- 35% moisture after .75% per day drying for 33 days.
- 20% moisture after 25% per day drying for 25 days.
- 20% moisture after 20% per day drying for 10 days.

Fairly Constant Rate of Drying

Prof. Dr. Muhammad Iqbal, Department of Farm Machinery & Power, University of Agriculture, Faisalabad

Drying may take 7 - 26 days
3. **Ears dropped** The amount of lodging greatly influence the number of ears lost (Figure 85, 86). As corn weathers in the field, some ears drop before harvest.

**Figure 85.**
INFLUENCE OF LODGED STALKS ON LOST EARS OF 15,000 PLANTS PER ACRE.

**Figure 86.**
LATE SEASON HARVESTING RESULTS IN INCREASED LOSS OF EARS.
(Wooster)
Figure 87.

EARLY SEASON HARVESTING RESULTED IN LESS LOSS OF EARS. (Columbus)
Paddy Harvesting
Content

• Introduction
• What is harvesting
• Harvesting systems
• When to harvest
• How to harvest (technology options)
• Harvest losses
• Recommendations
Introduction

Harvesting is the process of collecting the mature rice crop from the field.

- **Cutting**: cutting the panicles and straw.
- **Hauling**: moving the cut crop to the threshing location.
- **Threshing**: separating the paddy grain from the rest of the cut crop.
- **Cleaning**: removing immature, unfilled and non-grain materials.
- **Field drying**: (optional) leaving the cut crop in the field and exposing it to the sun for drying.
- **Stacking / Piling**: (optional) temporarily storing the harvested crop in stacks or piles.
Good harvesting practices

At harvest the quality of rice is best. From then on it can deteriorate quickly:

- Heat build up from mold and insect development
- Discoloration/Yellowing from heat build-up
- Cracking from re-wetting of dried grains
- Loss of vigor
- Reduced head rice yield
- Shattering losses

Goals of good harvesting:
- maximize grain yield (minimize losses)
- minimize grain damage
- Minimize quality deterioration
Paddy Harvesting systems

1. Manual system

• Manual operation sometimes using tools
• Labor requirement: 48 person days / ha

Prof. Dr. Muhammad Iqbal, Department of Farm Machinery & Power, University of Agriculture, Faisalabad
Harvesting systems
2. Manual cutting / machine threshing

Labor requirement: 28 person days/ha  Optional: Winnowing or cleaning
Harvesting systems

3. Machine cutting / machine threshing

Optional: Winnowing or cleaning
Harvesting systems
4. Combine harvesting

- Cutting, hauling, threshing, cleaning in one combined operation
- Capacity: > 0.5 ha/h
- Labor requirement: 1 - Operator
When to harvest paddy

Harvest rice when:
• 20-25% grain moisture
• 80-85% straw colored and
• the grains in the lower part of the panicle are in the hard doe stage
• 30 days after flowering

Prof. Dr. Muhammad Iqbal, Department of Farm Machinery & Power, University of Agriculture, Faisalabad
Manual cutting and hauling

- **Capacity:** 0.07 ha/person day
- **Advantages**
  - effective in lodged crop
  - less weather dependent
- **Problems**
  - high labor cost
  - labor dependent, competes with other operations in peak season
  - winnowing/cleaning necessary

Prof. Dr. Muhammad Iqbal, Department of Farm Machinery & Power, University of Agriculture, Faisalabad
Mechanical reaping

- **Capacity**: 2-4 ha/d
- **Advantages**
  - Fast cutting
- **Problems**
  - Places crop in windrow back in the field
  - Problem with lodged crop
  - Complex cutter bar and conveying mechanism
Manual threshing

• Capacity: approximately 15 person days/ha
• Threshing by impact
• High shattering losses
• Pre-drying might be needed
Pedal thresher

• Principle
  • Wire loop threshing drum
  • Mainly combing the grains off the straw, some threshing by impact

• Advantages
  – Maintains the straw

• Disadvantage
  – Needs winnowing after threshing

Prof. Dr. Muhammad Iqbal, Department of Farm Machinery & Power, University of Agriculture, Faisalabad
Axial-flow thresher

- **Capacity:** 0.3-3 t/h
- Threshing through impact
- With or without cleaner
- **Advantages**
  - Can thresh wet crop
  - Compact

Produced in 9 different countries used by several 100,000’s of rice farmers across Asia.

- Peg tooth threshing drum
- Axial flow principle
Winnowing

- **Principle:** lighter materials are blown away by air
- Removes chaff, straw and empty grains
- Hand or mechanical winnowing
- Does not work for materials heavier than grain (dirt, stones)
Cleaning

- Combination of fan and oscillating sieves
- Air delivered by fan removes lighter materials
- Top sieves with large holes remove larger straw particles
- Bottom sieves with smaller holes remove small seeds (e.g. weed seeds)
Combine harvesting

• **Features**
  – capacity: 4-8 ha/day
  – combines cutting, threshing, cleaning and hauling
  – tracks for mobility in wet fields

• **Advantages**
  – high capacity
  – low total harvest losses

• **Disadvantages**
  – Requires relatively large field sizes
  – Problem in terraced fields

Prof. Dr. Muhammad Iqbal, Department of Farm Machinery & Power, University of Agriculture, Faisalabad
Stripper harvesting

• **Capacity:** 1 ha/day
• **Advantages**
  – strips and collects grains only
  – less material to handle
• **Problems**
  – problems in wet soils and lodged crop
  – straw treatment
  – does not work well with long straw
  – complex machine
  – skills required

Despite strong promotion in SE-Asia the stripper harvester has not gained wide popularity because of its problems in less favorable harvesting conditions.
Losses during cutting

• **Shattering loss:** premature shedding of mature grains from the panicle caused by birds, wind, rats, and handling operations. Certain rice varieties shatter more easily than others.

• **Lodging loss:** plants with mature grains in the panicles fall on the ground making the grains difficult to recover.

• **Standing crop loss:** standing plants with mature grains are left standing in the field after harvesting operations as a result of oversight, carelessness or haste.
Losses during threshing

- **Separation loss** or “blower loss”: mature grains that are mixed with straw or chaff during the cleaning operation.
- **Scatter loss**: mature grains that are scattered on the ground during the threshing and cleaning operation.
- **Threshing loss**: mature grains that remain attached to the panicle in the straw after completion of the threshing operation. High threshing efficiency will lead to low threshing loss, and vice versa.
Recommendations for optimizing quality

- Harvest at the right time and moisture content
- Avoid stacking the cut crop in the field
- Avoid delays in threshing after harvesting
- Use the proper machine settings when using a threshing machine
- Clean the grain properly after threshing
- Avoid delay in drying after threshing
Tips for manual threshing

• Thresh as soon as possible after cutting
• Hand thresh at lower moisture
• Place a large canvas under the threshing frame to minimize shatter loss
Tips for machine threshing

• Thresh as soon as possible after cutting
• Level the thresher
• Set machine correctly
  – drum speeds in thresher (600rpm)
  – air flow in the cleaner
  – angle in the cleaner sieves
Setting threshing drum speed

Always adjust the thresher correctly

- For peg-tooth drums the drum tip speed should be about 12-16 m/sec (see Table for correct RPM).
- Higher speeds result in higher grain damage and de-hulled grains.
- Lower speeds increase the amount of non-threshed grain and result in grain loss. Lower speeds also decrease the throughput of the thresher.

<table>
<thead>
<tr>
<th>RPM</th>
<th>Tip speed (m/s) for drum diameters of</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>30 cm</td>
</tr>
<tr>
<td>400</td>
<td>6.3</td>
</tr>
<tr>
<td>450</td>
<td>7.07</td>
</tr>
<tr>
<td>500</td>
<td>7.85</td>
</tr>
<tr>
<td>550</td>
<td>8.64</td>
</tr>
<tr>
<td>600</td>
<td>9.42</td>
</tr>
<tr>
<td>650</td>
<td>10.21</td>
</tr>
<tr>
<td>700</td>
<td>11</td>
</tr>
<tr>
<td>750</td>
<td>11.8</td>
</tr>
<tr>
<td>800</td>
<td>12.6</td>
</tr>
<tr>
<td>850</td>
<td>13.4</td>
</tr>
<tr>
<td>900</td>
<td>14.14</td>
</tr>
</tbody>
</table>

Prof. Dr. Muhammad Iqbal, Department of Farm Machinery & Power, University of Agriculture, Faisalabad
Setting concave clearance

Concave clearance

• For most threshers clearances between peg-teeth and concave should be about 25mm.
• Smaller clearance increases grain damage and might lead to clogging of straw.
• Larger concave clearances reduce threshing efficiency.
Axial flow thresher
Combine harvester

- Grain tank
- Straw walker
- Return chute
- Grain
- Straw/Chaff
- Crop
- Auger
- Sieve
- Reel
- Conveyor
- Threshing cylinder
- Cutterbar
- Concave
- Blower
Tips for good winnowing

- Place grain on a winnowing tray
- Place a net or mat on the ground
- Tilt the tray against the wind
- Pour grain slowly at a height of about 1m
- Wind will separate light from heavy grains
- Recover only the heavier grains
- Repeat the procedure, if needed
- Use a fan or blower if there is insufficient wind.
(I) The principle of cleaning

2. Screen type cleaning mechanism:

   The use of a mixture of various components of the differences in size characteristics of the separation and sorting.

Specific ways:

   According to grain size, shape, design an appropriate sieve, so as to achieve the purpose of screening.

3. Airflow combined screen type cleaning mechanism:

   The use of a mixture of the size of the various components of the aerodynamic properties and characteristics of the screen and fan cleaning with separation.

Effective cleaning, in the majority of thresher and combine harvester adopts the form of such support.
cleaning mechanism of combine harvester
cleaning mechanism of combine harvester

I  Introduction

II  Principles of grain cleaning and cleaning mechanism
I、Introduction
II、 Cleaning mechanism and theoretical analysis

(I) The principle of cleaning
(II) Power consumption of cleaning mechanism
(III) The motion analysis of ejection on screen surface
(I) The principle of cleaning

The short ejection which take off by the threshing device and separate by the separation device with a mixture of broken stem, chaff and dust, such as small inclusions. Cleaning mechanism of function is a mixture of grain separated from the other mixed objects outside, in order to obtain clean seeds.

The principle of cleaning:
Cleaning objects using the various components of the mechanical properties between the physical differences separated them.

The type of cleaning mechanism:
Airflow type, screen type, airflow combined screen type.
( I ) The principle of cleaning

1. Airflow type cleaning mechanism:

In accordance with the various components of a mixture of grains of different aerodynamic characteristics for sorting. General floating rate of materials to be used to show that $V_p$.

The speed of the floating material $V_p$:

The objects placed inside the vertical upward flow, when the air force on the object equal to the $P$-gravity objects $mg$ of the object at a relatively static state of suspension by the rate of airflow (sometimes also known as the critical velocity).
( I ) The principle of cleaning

\[ P = k \rho F V^2 \]

Where: \( k \) – drag coefficient, and object shape and surface characteristics,

Wheat: 0.184 ~ 0.265;
\( \rho \) – air density, g/m3;
F – objects of the wind area, m2;
V – gas velocity, m / s, wheat \( V_p = 8.09 \sim 11.5 \) m / s.

The mechanical use the principle of cleaning are Airflow type thresher, the use of air currents generated by the separation of grains and other election. Jan Field throw high-speed belt drive will be seen hurling the mixture of air, floating speed of objects being thrown from the larger grain distance, while the floating rate of the smaller objects will be on the light from a place close to grain thrower.
Working Principle of airflow type thresher

Prof. Dr. Muhammad Iqbal, Department of Farm Machinery & Power, University of Agriculture, Faisalabad
2. Screen type cleaning mechanism:

The use of a mixture of various components of the differences in size characteristics of the separation and sorting.

Specific ways:

According to grain size, shape, design an appropriate sieve, so as to achieve the purpose of screening.

3. Airflow combined screen type cleaning mechanism:

The use of a mixture of the size of the various components of the aerodynamic properties and characteristics of the screen and fan cleaning with separation.

Effective cleaning, in the majority of thresher and combine harvester adopts the form of such support.
( I ) The principle of cleaning
( I ) The principle of cleaning

the cleaning mechanism which fan with the screen
( I ) The principle of cleaning

Body diagram of cleaning mechanism

1. 阶梯抖动板  2. 风扇  3. 筛子  
4. 谷物螺旋推运器  5. 杂余螺旋推运器
The principle of cleaning
The type of screen:
(1) Woven screen: made of metal wire woven to create a simple, small flow resistance and effective area, high productivity, in the multi-screen configuration should be made on the screen. However, small-plane strength, easy deformation.
(2) Punching screen: In the thin metal plate on the red system with a specific shape of the screen. To create simple, not easy to deformation, but the effective area of small, low productivity, under the screen normally used.
(I) The principle of cleaning

(3) Fish-eye screen: In the thin sheet metal protruding out of the red system of fish-eye-shaped sieve. Mixture in the sieve surface cleaning can only be one-way, the ability to push back is better, simple structure, low productivity, they are advised to make the next screen.
( I ) The principle of cleaning
(1) The principle of cleaning

(4) Louver sieve: formed by stamping and louver sieve piece combination louver sieve hole. Orifice size adjustable, easy to plug, high productivity, adaptability. However, the complex structure of the joint application of more Harvester.
( I ) The principle of cleaning
（I）The principle of cleaning

Type of fan:
Working principle of centrifugal fan:

High-speed rotating impeller of the centrifugal force generated when the fluid so that access to energy, that is fluid through the impeller, the pressure energy and kinetic energy have been improved, and thus can be transported to a height or distance.

Structural characteristics:
Simple structure, easy to configure, control plane domain, but non-uniform air distribution. General through the allocation of a number of fans to flow evenly.

1-进气室；2-进气口；3-叶轮；4-蜗壳；5-主轴；6-出气口；7-扩散器

图7-1-3 离心风机结构简图

Prof. Dr. Muhammad Iqbal, Department of Farm Machinery & Power, University of Agriculture, Faisalabad
( I ) The principle of cleaning

The relationship between the agricultural centrifugal fan and cleaning the screen with

Prof. Dr. Muhammad Iqbal, Department of Farm Machinery & Power, University of Agriculture, Faisalabad
(I) The principle of cleaning
( I ) The principle of cleaning

Working principle of axial flow fan:

Rotating blades force the air by the impact, so that was a certain air speed and wind pressure by the guide vane and the cylinder part of the spread of kinetic energy into static pressure, so that export has a certain fan speed and air pressure.

Characteristics:

Airflow distribution, structure size small, but the control surfaces is small.
(Ⅰ) The principle of cleaning

the role of wind collector is to reduce the resistance loss of the entrance

The role of the impeller, the impeller blades rotate when the impact of air, air to obtain a certain degree of speed and wind pressure

Reverse the role of guide vane rotary outflow from the impeller flow, so that deflection of airflow kinetic energy into static pressure energy, at the same time reduce air resistance caused by loss of rotation

The role of the proliferation of tube is part of the axial flow kinetic energy can be transformed into static pressure.
( I ) The principle of cleaning

Working Principle:

The use of cross-flow fan impeller when rotating the eccentric vortex impeller along the entire width of suction and exhaust, the intake and exhaust the direction of the direction in a plane and vertical with the impeller, the fan width along the row direction of the gas distribution (that is, fans width restriction).

Cross-flow fan features:

Also known as run-off fans, air flow from radial to axial inhalation, the airflow in the horizontal distribution, power consumption of small, structurally complex, high manufacturing costs.
( I ) The principle of cleaning
(II) Power consumption of cleaning mechanism

\[ N_s = \frac{1}{\eta} Q_s N_p, \ (kW) \]

Where: 
- \( Q_s \) - unit time into the ejection of the cleaning mechanism quality (kg / s); 
- \( N_p \) - flat screen cleaning ejection quality power required (kW / kg / s) 
- On screen: 0.4 ~ 0.5, the next screen: 0.25 ~ 0.3; 
- \( \eta \) - coefficient of sorting capacity, 0.8 ~ 0.9.
(III) The motion analysis of ejection on screen surface

Short ejection into the cleaning mechanism which sieve and fan the composition of, the use of fans to do with the surface of the screen back and forth before and after the campaign to get more opportunities through the sieve. In general sieve screen surface by, the composition of the quadrilateral boom and crank linkage composition, in order to identify the effects of extrusion material movement along the screen surface of the main factors in nature, we have assumed sieve into a parallelogram similar institutions.
(III) The motion analysis of ejection on screen surface

As the length of boom and crank is far greater than rod radius, can be approximated that the sieve is the amplitude of the movement for the $A = 2\alpha$ (\(\alpha\) is the crank radius) of the linear reciprocating motion.
( III ) The motion analysis of ejection on screen surface

Set up: the rotating crank center and screen frame o-link connection point o / the extended line connection oo / direction to the direction of vibration sieve, crank on the left with the oo / coincidence of the location of the initial movement for the crank position of the sieve displacement, velocity, acceleration and time for:

\[ x = -r \cos \omega t \]
\[ V_x = r \omega \sin \omega t \]
\[ a = r \omega^2 \cos \omega t \]
Assumption screen surface has the that a quality is $m$ particle ejection and the sieve with movement, in $\omega t = 0 \sim \pi / 2$ and $3\pi / 2 \sim 2\pi$ interval (1,4 range), the acceleration $a$ is positive, negative inertia force $u$ direction along the $x$-axis to the left, ejection there before sliding along the screen-oriented trend.

\[ a = r\omega^2 \cos \omega t \]
At $\omega t = \pi / 2 \sim 3\pi / 2$ interval (2,3 range), the acceleration of a negative inertia force $u$ is positive, the direction along the $x$-axis to the right, off screen objects are oriented along the sliding trend after.

$$a = r\omega^2 \cos \omega t$$
(Ⅲ) The motion analysis of ejection on screen surface

The assumption that there is a quality is m on screen surface with the ejection of particles and sieve movement, when the ejection slide along the screen surface, the role of the ejection force, inertial force in addition to u, there are gravity mg, screen surface to the reaction of the law N and frictional force F.

\[ \omega t = 0 \sim \pi /2 \]  and  \[ 3\pi /2 \sim 2\pi \]

\[ \omega t = \pi /2 \sim 3\pi /2 \]
(III) The motion analysis of ejection on screen surface

1. Screening for pre-ejection along the limits of the conditions of sliding

When the acceleration is positive, ejection in the role of inertial force before sliding under the trend shown by all external forces to a projection screen surface:

\[ u = m r \omega^2 \cos \omega t \]
\[ F = N \tan \phi \]

\[ \phi \] - friction angle of ejection and the screen surface, wheat: 25 ~ 36 °; Rice: 23 ~ 32 °.

By
\[ \sum x = 0 \]
\[ \sum y = 0 \]
so
\[ u \cos (\varepsilon - \alpha) + mg \sin \alpha = F \]
\[ N = u \sin (\varepsilon - \alpha) + mg \cos \alpha \]
( III ) The motion analysis of ejection on screen surface

Take $u$ and $F$ in. And organize:

$$u \cos(\varepsilon - \alpha) + mg \sin \alpha = \left[ u \sin(\varepsilon - \alpha) + mg \cos \alpha \right] \tan \varphi$$

Transpose and organize:

$$u \left[ \cos(\varepsilon - \alpha) - \sin(\varepsilon - \alpha) \tan \varphi \right] = mg \left( \cos \alpha \tan \varphi - \sin \alpha \right)$$

On both sides of the same equation was multiplied by $\cos \phi$:

$$u \left[ \cos(\varepsilon - \alpha) \cos \varphi - \sin(\varepsilon - \alpha) \sin \varphi \right] = mg \left( \cos \alpha \sin \varphi - \sin \alpha \cos \varphi \right)$$

Use:

$$\sin(\alpha \pm \varphi) = \sin \alpha \cos \varphi \pm \cos \alpha \sin \varphi$$

$$\cos(\alpha \pm \varphi) = \cos \alpha \cos \varphi \mp \sin \alpha \sin \varphi$$
( III ) The motion analysis of ejection on screen surface

Organize:

\[ mr\omega^2 \cos \omega t \cos (\varepsilon - \alpha + \phi) = mg \sin (\phi - \alpha) \]

\[ \frac{r\omega^2}{g} \cos \omega t = \frac{\sin (\phi - \alpha)}{\cos (\varepsilon - \alpha + \phi)} \]

for the sieve so that the acceleration of movement than because \( \cos \omega t \leq 1 \), to save before the ejection slide along the sieve, sieve movement must meet the following conditions:

\[ \frac{r\omega^2}{g} > \frac{\sin (\phi - \alpha)}{\cos (\varepsilon - \alpha + \phi)} \]
(Ⅲ) The motion analysis of ejection on screen surface

Order: \[
\frac{\sin(\varphi - \alpha)}{\cos(\varepsilon - \alpha + \varphi)} = K_1
\]

K1 for ejection slide along the screen in front of the characteristics of the conditions, when \( K > K_1 \), the ejection in front of sliding along the screen.
(III) The motion analysis of ejection on screen surface

2. The ejection of sliding after along the screen for the extreme conditions

When the acceleration is negative, the extrusion material in the role of inertial force after sliding under the trend shown by all external forces to a projection screen surface:

\[ u \cos(\varepsilon - \alpha) = F + mg \sin \alpha \]

\[ N = mg \cos \alpha - u \sin(\varepsilon - \alpha) \]

by

\[ \begin{align*}
\sum x &= 0 \\
\sum y &= 0 
\end{align*} \quad \text{so} \]

Prof. Dr. Muhammad Iqbal, Department of Farm Machinery & Power, University of Agriculture, Faisalabad
(III) The motion analysis of ejection on screen surface

Organize:

\[ \frac{r\omega^2}{g} \sin(\alpha + \varphi) > \frac{\sin(\alpha + \varphi)}{\cos(\varepsilon - \alpha - \varphi)} \]

Order:

\[ \frac{\sin(\alpha + \varphi)}{\cos(\varepsilon - \alpha - \varphi)} = K^2 \]

K2 for ejection after along the screen in front of the characteristics of the conditions, , when K\(>\) K2, , ejection will be slippery after along the screen surface.

Prof. Dr. Muhammad Iqbal, Department of Farm Machinery & Power, University of Agriculture, Faisalabad
( III ) The motion analysis of ejection on screen surface

3. the ejection behind that of screen surface limit conditions
When the ejection in the screen surface movement on the left to meet the characteristics of the conditions, ejection would leave us far behind screen surface. Under what conditions may be far better than ejection screen surface?

As already introduced, ejection by force of inertia of the movement, when the inertial force along the X-axis positive \( u \), along with the increase \( r\omega^2 \), the power to the anti-\( N \) decreased, ejection there is a deviation from the trend of screen surface. ejection marks a deviation from the screen surface is \( N = 0 \).
(III) The motion analysis of ejection on screen surface

由 $\sum y = 0$ 有：$N = mg \cos \alpha - u \sin(\varepsilon - \alpha)$

Order: $N = 0$

$$mg \cos \alpha - mr \omega^2 \cos \omega t \sin(\varepsilon - \alpha) = 0$$
The motion analysis of ejection on screen surface

Organize:

\[ \frac{r \omega^2}{g} > \frac{\cos \alpha}{\sin(\varepsilon - \alpha)} \]

Order:

\[ \frac{\cos \alpha}{\sin(\varepsilon - \alpha)} = K_3 \]

$K_3$ for characteristics conditions that ejection thrown Screen surface, when $K > K_3$, ejection will be thrown Screen surface.
( III ) The motion analysis of ejection on screen surface

Discussion:

From the above analysis, when the cleaning and installation of structural parameters of sieve parameters determined, without taking into account factors other conditions, ejection of the movement in the sieve surface depends primarily on the results of the Sieve movement acceleration ratio:

\[ K = \frac{r \omega^2}{g} \]

Conclusion:

Reached as long as the K value of K1, K2, K3 value can be pre-slip, slide and leave us far behind after the screen surface. We hope that the results of the sieve movement is: ejection along the screen surface both before and after Waterloo Waterloo, and after the slide before the slide is greater than the volume of traffic, but not allowed to have out-stripped the screen surface of the phenomenon.

Prof. Dr. Muhammad Iqbal, Department of Farm Machinery & Power, University of Agriculture, Faisalabad
(Ⅲ) The motion analysis of ejection on screen surface

Cleaning Screen normal working conditions:

\[ K_3 > K > K_1 > K_2 \]

At present, the main parameters of cleaning mechanism:

- \( K = 2.2 \sim 3 \)
- \( r = 23 \sim 30 \text{mm} \)
- \( \epsilon = 12 \sim 25^\circ \)
- \( \alpha = 1 \sim 3^\circ , (\text{few } 7 \sim 8^\circ) \)
- \( n = 200 \sim 350 \text{r/min} \).
(Ⅲ) The motion analysis of ejection on screen surface
1. What is the function of cleaning mechanism and the principle of cleaning?

2. What is the characteristics of The three types of common cleaning mechanism?

3. What is floating rate?

4. How to derivate the limited conditions that ejection After sliding along the screen surface and toss?
Lecture#17

Energy Requirement Model for a Combine Harvester
1. Introduction

- Energy is an important input of production agriculture.
- The timeliness of operation depends on energy availability.
- Energy input for harvesting and threshing of grain crops constitutes a major part of the total energy input.
- The combine harvester is a widely used harvesting machine for grain crops.
- The components of combine harvester need to be modeled for power and energy requirements by using a number of processes and knowledge of physics, mechanics and mathematics.
• These models will incorporate the crop, machine and soil parameters.
• The modulus of elasticity, moment of inertia of the transverse section, height and linear density of the crop stem, and crop throughput are some of the crop parameters should be identified for the models.
• Forward travel speed of the machine, total weight of the machine, peripheral speed of the respective components and several design parameters are the machine parameters need to be incorporated in the models.
• The models are expected to be a useful tool for optimization of energy use for harvesting operation by combine harvester.
2. Methods of model development

• A combine harvester machine consists of several sub units or functional components
• During the working of the machine, the components interact with each other, crop and/or terrain to achieve the main goal of harvesting and/or threshing.
• Energy expenditure takes place because of such interaction.
• The power is supplied from the prime mover using power transmission devices to meet energy demand of these components.
• Some energy is lost in the transmission device and other parts to overcome bearing friction of the respective components.
Components of a combine harvester:
- reel
- cutter bar
- platform auger
- feeder conveyor
- threshing cylinder
- straw walker
- cleaning sieve
- Fan blower
- grain conveyor unit
- tailings feeding unit
- traction device
2.1 Reel

• The reel in a combine harvester machine delivers the stalks to the cutting mechanism, holds them upright during cutting and pushes the cut crop towards the platform conveyor.

• The power input into the shaft of the reel is spent in pushing the crop stem and in overcoming air friction.

• These two processes (Process 1 & 2) are modeled as given below.
2.1.1 Power required by reel for deflecting the crop

• In an ideal condition, the top of the crop stem experiences a deflection $\delta$ in m (stem mass) due to action of the reel bat as shown in Fig. 1.

• The stem resists the deflection by generating a resisting force $F_r$.

• The following classical formula for the deflection of cantilever beam is used to estimate $F_r$ in kN (stem resistance):
\[ F_r = \frac{3nEI\delta}{h^3} \]

Eqn. 1

where:

\( F_r \) = stem resistance force to deflection, kN

\( E \) = the modulus of elasticity of the crop stem in kPa;

\( I \) = the geometrical moment of inertia of the transverse section of the crop stem in \( m^4 \);

\( h \) = the height of the crop stem in m;

\( n \) = the number of crop stems deflected by a reel bat.

Fig. 1. Action of a reel bat on crop stem; \( h \), stem height; \( \delta \), stem deflection and \( F_r \), resisting force against deflection of crop stem.
• The reel bat undergoes a complex cycloid motion resulting from translatory motion of the harvesting machine and a rotary motion of the reel with respect to the machine.

• The number of crop stems deflected by a reel bat is governed by:
  
  – crop stand density,
  – travel speed of the machine,
  – angular speed of the reel and
  – Geometry of the reel.

• From the operational geometry of the reel, n can be expressed as given below:

\[ n = \frac{5\pi C_d w v_f}{9 \omega_r Z} \]  

----------  Eqn. 2
• where:
  
  $Cd$ is the crop stand density in number/m$^2$;
  $w$ is the cutting width of the machine in m;
  $v_f$ is the forward velocity of the machine in km/h; or
  is the angular velocity of the reel in rad/s and
  $Z$ is the number of reel bats.

• The deflection of the stalks varies depending on their positions.

• As the resistance of stalks against bending is linearly proportional to deflection, the mean value of the deflection is considered as estimated in Eqn 3.
  (where $p_z$ is the pitch of the reel bat in m)

  \[ \delta = \frac{0 + p_z}{2} = \frac{p_z}{2} \]  

  -------------- Eqn. 3
• The pitch of the reel bat, which is function of the travel speed of the machine, angular speed of the reel and number of reel bat, is expressed as given below:

\[ p_z = \frac{5\pi v_f}{9\omega_r Z} \]  

\[ \text{Eqn. 4} \]

• The tangential force \( F_{tr} \) in kN experienced by the reel bat due to crop stem deflection can be expressed as given below:

\[ F_{tr} = \frac{F_r}{\sin \theta} \]  

\[ \text{Eqn. 5} \]

• The angle \( \Theta \) is the angle made by a reel bat with a horizontal plane passing through the reel centre.
• Similar to the variation of the deflection $\delta$, angle $\Theta$ also varies.

• However, from geometry it can be shown that, the angle $\Theta$ corresponding to the assumed average deflection is function of the position of the reel centre with respect to the ground surface and cutter bar, radius of the reel, crop height ($h$) and reel speed index ($l$).

• Using the geometry of the reel, functional relationship can be obtained for angle $\Theta$ relating the above parameters.

• Now, the power requirement by the reel for bending crop stems is obtained by multiplying $F_{tr}$ with reel peripheral velocity $u_r$

• Thus, combining Eqns (1)–(5) and simplifying power requirement by the reel for bending crop stems is obtained as given below:

$$P_r^b = \frac{5\pi^2 EI r^2 w C_d v_f}{3h^2 2l} \frac{1}{\sin \theta} \quad \text{-------------- Eqn. 6}$$
where:

- $P^b_r$ is power requirement by the reel for bending crop stems in kW;
- $r$ is the radius of the reel bat in m;
- $Z$ is the number of reel bats;
- $\lambda$ is the reel speed index;
- $\Theta$ is an angle made by the reel bat with respect to horizontal plane in radian \((\text{angle } \Theta \text{ is function of reel geometry and crop height, } h)\)

- The reel speed index $\lambda$ is the ratio of peripheral speed of reel to the forward travel speed of the combine harvester and is given by

\[ \lambda = \frac{18r\omega_r}{5vf} \]  

------------------------  Eqn. 6a
The crop feed rate $F$ or throughput can be expressed in terms of:

- crop stand density, $\rho$
- cutting width of the machine, $w$
- travel speed of the machine, $v_f$ and
- other crop and operational parameters as given below:

\[
F = wc_d v_f \rho (h - h_c) \times 10^{-3}
\]

\[
= m \cdot (1/m^2) \cdot (Km/h) \cdot (g/m) \cdot m \cdot (1000 m/km) \cdot (Mg/1000000 g) = 10^{-3}Mg/h
\]

where:

- $F$ is the crop feed rate in Mg/h
- $C_d$ is the crop stand density in number/m$^2$;
- $w$ is the cutting width of the machine in m;
- $v_f$ is the forward velocity of the machine in km/h
- $h_c$ is the height of cut in m;
- $h$ is the crop height, m
- $\rho$ is the linear density of the crop stem in g/m; and
• Finally, incorporating Eqn (7) into Eqn (6), the power requirements by the reel for bending crop stems is expressed as below:

\[
P^b_r = \left( \frac{5 \times 10^3 \pi^2 EI r^2}{3 \rho(h - h_c)h^3Z^2 \lambda \sin \theta} - \frac{1}{F} \right) \text{ Eqn. 8}
\]
2.1.2 Power required by reel to overcome air resistance

• In addition to bending the crop stem, power is also spent while overcoming the air resistance. It has been found that windage loss is proportional to the cube of the peripheral speed. The following relationship is used to estimate the power required to overcome air resistance using a proportionate coefficient (Eqn. 9):

\[ P^w_r = k^w_r (u_r)^3 \]  

--- Eqn. 9

• where:
  
  • \( P^w_r \) is the power loss due to windage in kW;
  • \( u_r \) is the peripheral speed of the reel in m/s;
  • \( K^w_r \) is the coefficient used to estimate the power requirement due to air resistance.
2.1.3 Total power requirement for working of the reel

- The total power requirement for the operation of reel Pr in kW is the sum total of the power required for overcoming resistance against stem bending and air resistance as given below:

\[ Pr = Eqn.\ 8 + Eqn.\ 9 = P^w_r + P^b_r \]

\[ Pr = k_r^w (u_r)^3 + k_r^b F \]  \hspace{1cm} Eqn. 10

- Where

\[ k_r^b = \left(\frac{5 \times 10^3 \pi^2 EI r^2}{3\rho(h - h_c) h^3 Z^2 \lambda \sin \theta}\right) \]  \hspace{1cm} Eqn. 10a
2.2 Cutter bar

• Crop stems are first deflected and then sheared off in cutter bar. Apart from the energy expenditure for deflecting and shearing the crop stem, energy is also required to overcome friction at sliding surfaces of the reciprocating knife. The power expenditure for all three processes are discussed below.
2.2.1 Power required for stalk deflection

- The component of the stalk deflection along the path of reciprocation of the knife is considered for modeling the power requirement for this phenomenon. The deflection of an individual crop stem due to knife movement is schematically shown in Fig. 2.

- Considering a crop stem as a simply supported beam where bottom end is supported by ground surface and the top end is by a reel bat, the resistance force against bending $F_{kd}$ in kN is estimated using the following classical formula (Gaylord & Gaylord, 1968) by
where:

- $F_{kd}$ the resistance force against bending in kN
- $d_i$ is the deflection of the plant stem in m. The magnitude of deflection depends on the location of the stem within the stroke length of the cutter bar.
- Half of the stroke length is considered as an approximate estimate of deflection.

$$F_{kd} = \frac{12EIh^3d_i}{(4h-h_c)(h-h_c)^2h_c^3}$$

\[\text{Eqn. 11}\]
• If a stem offers resistance for an average distance of half of stroke length, then the energy expended to bend a single stem $e_b$ in kJ can be estimated by

$$e_b = \frac{3EIh^3s^2}{(4h - h_c)(h - h_c)^2h_c^3} \quad \text{--------- Eqn. 12}$$

where $s$ is the stroke length in m.

• The average power required by knife section for stalk deflection is the product of $e_b$ and the number $n_s$ of stalk deflected per second.

• The number of stalks deflected per second $n_s$ is estimated by

$$n_s = \frac{5}{18} wC_d v_f \quad \text{--------- Eqn. 13}$$
Therefore, the average power required for stalk deflection is obtained from Eqns (12), (13) and finally by the substitution of Eqn (7) as given below:

\[
P_{cb}^d = \frac{5 \times 10^3 EI h^3 s^2}{6 \rho (4h-h_c)(h-h_c)^3 h_c^3} F \quad \text{Eqn. 14}
\]

\[
P_{cb}^d = k_{cb}^d F \quad \text{Eqn. 15}
\]

Where \( P_{cb}^d \) is the power expended for stalk deflection in kW and \( k_{cb}^d \) is the deflection energy coefficient for the cutter bar given by

\[
k_{cb}^d = \frac{5 \times 10^3 EI h^3 s^2}{6 \rho (4h-h_c)(h-h_c)^3 h_c^3} \quad \text{Eqn. 15a}
\]
2.2.2 Power required for shearing of stem

- Power required for shearing of stem is estimated from the average shearing force during the stroke.
- Considering that the stems are sheared off at a linearly increasing rate from the beginning of the stroke to the end of the stroke, the average shearing resistance per unit length of stroke is expressed by the following relationship:

\[ F_s = \frac{\tau_s A_c w C_d f}{s} \]  

--------- Eqn. 16

where:

- \( F_s \) is the average shearing resistance per unit length of stroke in kN/m;
- \( \tau_s \) is the shear strength of the crop stem in kN/m²;
- \( A_c \) is the cross-sectional area of crop stem in m² and
- \( f \) is the forward movement of the machine per stroke of the knife in m.
• Now, the average power per unit stroke length of the knife to overcome the shear resistance can be obtained by multiplying $F_s$ with knife velocity, $v_k$.

• The knife velocity $v_k$ in m/s for a reciprocating cutter bar can be expressed with the help of the following expression:

\[ v_k = u_{cb} \sin \varphi \]  
\[ \text{--------- Eqn. 17} \]

• where, $u_{cb}$ is the peripheral velocity of the knife driving pulley in m/s and $\varphi$ is the angle made by the crank in radian.
Substituting the expression for knife velocity and then integrating the average power so obtained over the stroke length and finally simplifying the results of integration, the total power $P_{cb}^s$ in kW required by the knife for shearing the stems are obtained as given below:

$$P_{cb}^s = \frac{5\pi \times 10^3}{36\rho(h-h_c)} \tau_s A_c r_c F$$

---------- Eqn. 18

or

$$P_{cb}^s = k_{cb}^s F$$

---------- Eqn. 19

where, $k_{cb}^s$ is the shear energy coefficient for the cutter bar, given by

$$k_{cb}^s = \frac{5\pi \times 10^3}{36\rho(h-h_c)} \tau_s A_c r_c$$

--- Eqn. 19a

and $r_c$ is the radius of the knife driving crank in m.
2.2.3 Power required for overcoming friction at sliding surfaces

• The knife sections slide over two surfaces during its reciprocating motion. Power is spent due to friction at these surfaces. The instantaneous power required to overcome friction is estimated using the following relationship (Eqn. 20):

\[ P_{cb}^f = (F_h + F_v) \times |v_k| \]  

------- Eqn. 20

• where: \( P_{cb}^f \) is the instantaneous power required to overcome friction at the sliding bearing surfaces in kW;
• \( F_h \) and \( F_v \) are the frictional resistances over horizontal and vertical bearing surfaces, respectively, in kN and
• \( v_k \) is the knife velocity in m/s (Figs. 3 and 4).
Using the law of friction, $F_h$ and $F_v$ can be obtained from the normal reaction and the dynamic coefficient of friction between the knife and the sliding bearing surfaces.

The normal reaction at the horizontal sliding surface arises due to self-weight of the knife and weight of the crop mass supported by the reciprocating knife.
• If $A_r$ in m$^2$ is the projected area of the reciprocated portion of the knife and $A_t$ in m$^2$ is the total projected area of the cutter bar over which crop mass flows, then the crop mass supported by the reciprocating knife can be expressed as given below (Eqn. 21):

$$m_{cb}^r = \frac{10^{-3} A_r l_k}{v_f A_t} F \quad \text{--------- Eqn. 21}$$

• where: $m_{cb}^r$ is the mass of the crop mass supported by the reciprocating portion of the cutter bar in kg and

• $l_k$ is the length of the cutter bar section in m.
Now, if \( m_k \) is the mass of the reciprocating knife in kg, then \( F_h \) can be expressed as below (Eqn. 22):

\[
F_h = \mu^d_h g \left[ m_k + \frac{10^{-3} A_r l_k}{v_f A_t} F \right]
\]

\text{--------- Eqn. 22}

where:

\( F_h \) resistance over horizontal bearing surface
\( g \) is the gravitational acceleration in m\(^2\)/s; and
\( \mu^d_h \) is the dynamic coefficient of friction between knife and horizontal bearing surface
\( m_k \) mass of reciprocating knife
Similarly, the frictional resistance $F_v$ over the vertical bearing surface is the product of dynamic coefficient of friction and the normal reaction to the vertical bearing surface. The normal reaction to the vertical sliding surface for a combine harvester is estimated from the crop pressure exerted by the reel. Combining Eqns (1)–(4), (6a) and (7) the pressure exerted by reel is used to estimate the normal reaction $R_v$ in kN to vertical sliding surface as given below (Eqn. 23):

$$R_v = \left(\frac{5 \times 10^3 \pi^2 EI r^2}{3\rho(h - h_c)h^3 Z^2 \lambda}\right) \frac{F}{u_r}$$  \text{------------------- Eqn. 23}

The frictional resistance on the vertical bearing surface is obtained as given below (Eqn. 24):

$$F_v = \mu_v^d R_v = \frac{5 \times 10^3 \mu_v^d \pi^2 EI r^2}{3\rho(h - h_c)h^3 Z^2 \lambda} \frac{F}{u_r}$$  \text{------------------- Eqn. 24}

where, $\mu_v^d$ is the dynamic coefficient of friction between the knife and the vertical bearing surface.
Incorporating the $Fh$, $Fv$ and $vk$ into Eqn (20) and then integrating in the interval of $\left(0 \leq \vartheta \leq \pi/2\right)$; the average power required to overcome frictional resistance can be obtained as given below

\[
P_{cb}^f = \frac{2}{\pi} \mu_h^d m_k g u_{cb} + \frac{2 \times 10^{-3} \mu_h^d A_r l_k g}{\pi A_t} \frac{u_{cb} F}{v_f} + \frac{10^4}{3} \frac{\pi EI r^2 \mu_v^d}{h^3(h - h_c)Z^2 \rho \lambda} \frac{u_{cb}}{u_r} F
\]

\[
P_{cb}^f = k_{cb}^{f1} u_{cb} + k_{cb}^{f2} \frac{u_{cb} F}{v_f} + k_{cb}^{f3} F
\]

where the three coefficients for the energy components $k_{cb}^{f1}$, $k_{cb}^{f2}$ and $k_{cb}^{f3}$ are given by

\[
k_{cb}^{f1} = \frac{2}{\pi} \mu_h^d m_k g
\]

\[
k_{cb}^{f2} = \frac{2 \times 10^{-3} \mu_h^d A_r l_k g}{\pi A_t}
\]

\[
k_{cb}^{f3} = \frac{10^4}{3} \frac{\mu_v^d \pi EI r^2}{h^3(h - h_c)Z^2 \rho \lambda} \frac{u_{cb}}{u_r}
\]

--------- Eqn. 25

--------- Eqn. 26
2.2.4 Total power requirement for cutter bar

The power requirements of the cutter bar is the sum total of the power requirements of stalk deflection, stalk shearing and sliding friction as given by Eqns (15), (19) and (26), respectively. Therefore, adding the power requirements for these three processes, the power requirements of the cutter bar \( P_{cb} \) in kW can be written as given below:

\[
P_{cb} = (k_{cb}^d + k_{cb}^s + k_{cb}^{f3})F + k_{cb}^{f2} \frac{u_{cb}F}{v_f} + k_{cb}^{f1}u_{cb} \]

------------------- Eqn. 27

Prof. Dr. Muhammad Iqbal, Department of Farm Machinery & Power, University of Agriculture, Faisalabad
2.3 Platform conveyor

• On a grain combine harvester, the platform conveyor gathers the crop mass from the sides to the centre of the platform. The platform conveyor consists of left and right augers with open flight and central sections with spikes. Power is needed to convey the crop mass from both sides of the platform to the centre and also to lift the crop mass by the central spikes.
2.3.1. Power required for conveying crop mass to the centre of the auger

- Ignoring the curvature of the auger, the movement of crop mass within a pitch length can be visualized as the movement over a sliding surface (Fig. 5). During half of its pitch length the crop mass undergoes upward movement while in the other half it undergoes downward movement. The total resistance against the movement of crop mass in the auger $F_{pc}$ in kN can be obtained using the law of mechanics and physics as given below.
Fig. 5. Platform auger conveyor: (a) three sections of a platform conveyor; $l_a$, length of auger section; $l_p$, pitch length of auger; (b) movement of crop mass within a pitch length and forces acting on it; $W$, vertical load due to crop mass within a pitch length; $\mu_s$, coefficient of sliding friction between the crop mass and the auger surface; $\psi$, angle made by an imaginary plane oriented in the path of material movement which passes through the bottom and top of the platform conveyor.
\[ F_{pc} = \frac{l_a}{l_p} \left( \mu^s W \cos \psi \right) \]

Eqn. 28

Where

- \( F_{pc} \) is the total resistance against the movement of crop mass in the auger in kN;
- \( W \) is the load due to crop mass flowing within a pitch length in kN;
- \( \psi \) is the angle made by an imaginary plane oriented in the path of material movement which passes through the bottom and top of the platform auger in radian \( 0 < \psi < \pi/2 \);
- \( l_a \) is the length of the auger section in m;
- \( l_p \) is the length of the auger pitch in m; and
- \( \mu^s \) is the coefficient of sliding friction between the crop mass and the auger surface.

The pitch of the auger governs the value of the angle \( \psi \) where \( \cos \psi \) is always positive and less than one \( 0 < \cos \psi < 1 \).
• The load on the platform conveyor is due to the crop mass entering into the machine. Further, the load at any point is proportional to distance from the outer end where the load is zero. The expression for \( W \) in kN can be obtained from the average value of loading rate as given below:

\[
W = \frac{gl_a}{7200wn_p} F
\]

------------------ Eqn. 29

• Where,
  – \( W \) is average crop mass load on auger, kN
  – \( w \) is the cutting width of machine, m
  – \( g \) is the acceleration due to gravity, m/s\(^2\)
  – \( n_p \) is the rotational speed of the conveyor (RPS)
  – \( L_a \) is the length of auger section, m

Prof. Dr. Muhammad Iqbal, Department of Farm Machinery & Power, University of Agriculture, Faisalabad
• Now substituting $W$ from Eqn (29) into Eqn (28)

\[ F_{pc} = \frac{l_a}{l_p} (\mu^s W \cos \psi) \]

-------- Eqn. (28)

\[ W = \frac{g l_a}{7200 w n_p} F \]

-------- Eqn. (29)

\[ F_{pc} = \frac{g l_a^2 \mu^s}{7200 w l_p n_p} \cos \phi F \]

let $l_p n_p = v_p$

\[ F_{pc} = \frac{g l_a^2 \mu^s}{7200 w v_p} \cos \phi F \]

------ Eqn (29b)
Multiplying the resistance \( F_{pc} \) by the velocity of the crop mass (assume \( n_p x l_p = v_p = v_f \)) and finally simplifying, the power \( P_{pc}^c \) in kW required for material conveying is obtained as given below:

\[
\begin{align*}
\text{\( P_{pc}^c = F_{pc} \times \text{velocity of crop mass} \)} \\
\text{\( P_{pc}^c = (\frac{g(l_a)^2 \mu^s}{7200w} \cos \psi) F \)} & \text{ \quad Eqn. 30} \\
\text{\( P_{pc}^c = k_{pc}^c F \)} & \text{ \quad Eqn. 31}
\end{align*}
\]

where the crop conveying energy component coefficient \( k_{pc}^c \) is given by

\[
k_{pc}^c = (\frac{g(l_a)^2 \mu^s}{7200w} \cos \psi) \text{ \quad Eqn. 31 a}
\]
2.3.2 Power required for lifting the material through the central spike section

• The central spiked portion of the platform conveyor lifts the crop mass from the platform to the feeder conveyor. If the effective height of lift is $h_{al}$ in m and $F$ is the crop throughput in Mg/h, then power required to lift the material by the spike section $P_{pc}^{l}$ in kW is given by the following expression:

• **Material lift power,**
\[ P_{pc}^{l} = \frac{g h_{al}}{3600} F \]  \[\text{----- Eqn. 32}\]

\[ P_{pc}^{l} = k_{pc}^{l} F \]  \[\text{------------- Eqn. 33}\]

\[ k_{pc}^{l} = \frac{g h_{al}}{3600} \]  \[\text{------------- Eqn. 33a}\]
2.3.3 Total power requirements for operation of platform conveyor

• The total power requirement of the platform conveyor $P_{pc}$ in kW for handling the crop mass is the sum of $P_{pc}^c$ and $P_{pc}^l$ as given below

\[ P_{pc} = (k_{pc}^c + k_{pc}^l)F \]  

----------  Eqn. 34
2.4 Feeder conveyor

- The crop mass delivered by platform conveyor is transferred to threshing cylinder by feeder conveyor. Generally, power is consumed for conveying the crop mass by a slat type of endless chain. A free body diagram of the feeder conveyor is shown in the Fig. 6. The model used to estimate the power required to convey the crop mass $P_{fc}$ in kW is based on potential energy required and is given below:

Power required to convey the crop mass, $P_{fc}$

\[ P_{fc} = \frac{gh_f}{3600} F \]  \hspace{1cm} \text{-------- Eqn. 35}

\[ P_{fc} = k^l_{fc} F \] \hspace{1cm} \text{-------- Eqn. 36}

- Crop lift energy coefficient, \[ k^l_{fc} = \frac{gh_f}{3600} \] \hspace{1cm} \text{-------- Eqn. 36a}
Fig. 6. Crop mass passing through feeder conveyor; $h_f$, height of feeder conveyor.
2.5 Threshing cylinder

The shaft of the rotating cylinder is powered to perform threshing function. The power is expended to thresh the grain and also to overcome air resistance.
2.5.1. Power for threshing the crop

- The flow of crop mass is maintained through the clearance between cylinder and concave.
- The revolving cylinder imparts impact force required to dislodge the grain from non-grain portion.
- The internal resistance amongst the plants of the flowing crop mass and frictional resistance at the concave surface resists the movement of the crop mass.
- The thresher also compresses the crop masses.
- Thus, the cylinder needs to be powered to provide the tangential force at cylinder periphery which comprises the forces of:
  - (i) impact of threshing member on crop mass,
  - (ii) compression of crop mass and
  - (iii) resistance against movement of crop mass.
Estimation of power ($P_{cy}^t$, kW) to overcome tangential force,

- \[ P_{cy}^t = F_{tt}u_{cy} \] \hspace{2cm} \text{Eqn. 37}
- where: $F_{tt}$ is the tangential force in kN; and $u_{cy}$ is the peripheral speed of threshing cylinder in m/s.
- $F_{tt} = \text{sum of cylinder impact force (} f_{t1} \text{) + crop compression force (} f_{t2} \text{) + crop movement resistances force (} f_{t3} \text{).}$

\[ F_{tt} = f_{t1} + f_{t2} + f_{t3} \] \hspace{2cm} \text{Eqn. 38}

1. $f_{t1}$ is determined using the principle of conservation of momentum,

\[ f_{t1} = \frac{5}{18}(u_2 - u_1)F \] \hspace{2cm} \text{Eqn. 39}

Fig. 7. Cylinder-concave arrangement of a cross flow type threshing cylinder; $u_{cy}$, peripheral speed of threshing cylinder; $F_{tt}$, tangential force on threshing cylinder periphery.

Prof. Dr. Muhammad Iqbal, Department of Farm Machinery & Power, University of Agriculture, Faisalabad
• Assumptions:
  – Ignore the change in density of the crop mass due to impact
  – Cylinder impact action maintains the increased speed due to reduction of the thickness of flow-path

\[
f_{t1} = \frac{25}{324 \Delta \rho_{o}} \left( \frac{1}{c_{c}} - \frac{1}{t_{c}} \right) F^2
\]  
-------------------------------- Eqn. 40

• where:
  • \( F \) is the crop feed rate, Mg/h
  • \( c_{c} \) is the cylinder concave clearance in m;
  • \( t_{c} \) is the thickness of the incoming crop stream in m;
  • \( r_{o} \) is the bulk density of the incoming crop stream in kg/m\(^3\);
  • \( w_{c} \) is the width of the threshing cylinder in m.
2. Estimation of resistance due to crop compression ($f_{t2}$):

Consider the crop mass as an elastic body undergoing changes in volume due to compression (Mohsenin, 1980). If $\Delta \rho$ is the increase in density in kg/m$^3$ due to compression of the entrapped crop mass between cylinder and concave, then resistive force experienced by the cylinder at its periphery is, $f_{t2}$:

$$f_{t2} = K c c w c \frac{\Delta \rho}{\rho_i}$$  

\[\text{Eqn. 41}\]

- where: $K$ is the elasticity of the crop mass, kPa
- $w_c$ is the width of the cylinder, m
- $\rho_i$ is the bulk density of the entrapped crop stream, kg/m$^3$
3. Estimation of resistance ($f_{t3}$) against the movement of the crop mass $kN$ is estimated based on the frictional resistance over the concave surface with an area $A_{cc}$ in $m^2$.

The normal reaction to the concave surface is the result of the compression pressure and force of gravity on the crop mass occupying the clearance volume.

$$f_{t3} = \left(\frac{K}{\rho_i} + g\rho_ic_c\right) A_{cc}\mu_c$$

--------------------- Eqn. 42

where:

- $A_{cc}$ is the effective area of concave, $m^2$;
- $\mu_c$ is the coefficient of friction of the crop mass over the concave surface.
- $\rho_i$ mass density of the entrapped crop
- $K$ is the elasticity of the crop mass, kPa
- $c_c$ is the cylinder concave clearance in m;
2.5.2. Power required to overcome air resistance

It depends upon:

– the surface, shape, size and speed of the cylinder
– air properties.

Klenin et al., 1985 found that the cylinder power $P_{cy}^w$ in kW required to overcome air resistance is:

$$P_{cy}^w = k_{cy}^w (u_{cy})^3$$

--- Eqn. 46

• where: $k_{cy}^w$ is a proportionality coefficient to estimate the power requirements to overcome air resistance.
2.5.3. The total power requirement at threshing cylinder

\[ P_{cy} = P_{tcy} + P_{wcy} \]

\[ = F_{tt} U_{cy} + K_{wcy} \left( U_{cy} \right)^3 \]
2.6. Straw walker

- Power given to the straw walker is utilized to agitate the straw mass by throwing it in a rearward and upward direction.
- The throwing of the crop mass is achieved by reciprocating motion of the straw walker racks.
- The average power required at straw walker driving shaft depends upon:
  - the design and operational parameters of the straw walker like length of the racks, crank throw, and speed of operation
  - the load of the crop mass over the straw walker at any time

- Power requirement for operation of straw walker, $P_{sw}$ kW is:

\[
P_{sw} = e_{sw} f_{sw}
\]

Eqn. 48

where: $e_{sw}$ is the energy expended per oscillation and is directly proportional to crop throughput $F$ and lift of oscillation;

- $f_{sw}$ is the frequency of oscillation of straw walker per second (1/s).
Where, the energy expended per oscillation ($e_{sw}$):

$$e_{sw} = \frac{s_f l_{sw} h_{sw} g F}{3600 v_{sw}}$$  \hspace{1cm} \text{-------------------- Eqn. 49}$$

where:

- $s_f$ is the ratio of straw mass in the straw walker to throughput;
- $l_{sw}$ is the length of straw-walker in m;
- $h_{sw}$ is the effective lift of throw of the straw mass in m;
- $v_{sw}$ is the average speed of the straw movement over the straw walker in m/s. Now substituting Eqn (49) into Eqn (48):

$$P_{sw} = \frac{s_f l_{sw} h_{sw} g F}{3600 d_{sw}}$$  \hspace{1cm} \text{-------------------- Eqn. 50}$$

and

$$P_{sw} = k_{sw}^a F$$  \hspace{1cm} \text{-------------------- Eqn. 51}$$
• where $d_{sw}$ is the rearward straw displacement per oscillation over the straw walker expressed by the ratio of $v_{sw}$ to $f_{sw}, m$

• $k^a_{sw}$ is the energy coefficient for straw walker:

$$k^a_{sw} = \frac{sfl_{sw}h_{sw}g}{3600d_{sw}}$$

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

Eqn. 51a
2.7. Blower

Power requirement of the blower $P_b$ in kW depends upon:

- The peripheral speed of the fan
- Fan design parameters.

The following relationship (Baumeister & Marks, 1958) is used to estimate blower power requirements:

$$P_b = k_{wb}^w (u_b)^3$$

Equation 52

- where: $k_{wb}$ is the coefficient of blower power requirement involving design parameters of the blower
- $u_b$ is the peripheral speed of the fan in m/s.
2.8. Sieves

- A set of sieves ensures cleaning of the grains from the non-grain part with the help of mechanical agitation.
- The power requirement for mechanical agitation depends on crop and machine factors.
- The rate of flow of material through the sieve, which depends upon the feed rate of the crop and its condition, effects the power requirements.
- Considering the set of sieves as an equivalent single sieve, a relationship similar to the straw walker is used to estimate power requirements by the sieves $P_s$ in kW as given below.

\[ P_s = k_s^a F \]

--- Eqn. 53

Prof. Dr. Muhammad Iqbal, Department of Farm Machinery & Power, University of Agriculture, Faisalabad
where: $k_s^a$ is the coefficient of power requirements by the cleaning sieves:

$$k_s^a = \frac{c_f l_s h_s g}{3600 d_s}$$  

---------- Eqn. 53a

where:

- $c_f$ is the ratio of mass agitated by sieves to throughput;
- $l_s$ is the equivalent length of sieves in m;
- $h_s$ is the lift of agitation in m; and
- $d_s$ is the rearward displacement of the crop mass over sieve per oscillation in m.
2.9. Grain-conveying unit

This unit consists of:

(i) lower grain conveyor,
(ii) grain elevator
(iii) upper grain conveyor.

The lower and upper grain conveyors are of screw auger type, which deliver the grain to the grain elevator and grain tank, respectively. A chain- and pad-type grain elevator lifts the grain from the lower grain conveyor to the upper grain conveyor.
2.9.1. Power requirements for auger type (lower and upper) grain conveyor

Let

\[ W_{gc} \] is the load carried by the grain conveyor in kN/s

\[ S_g \] is the ratio of non-grain to grain

\[ F \] the feed rate, Mg/h

Then

\[
W_{gc} = \frac{gF}{3600(1 + S_g)}
\]

------------- Eqn. 54
The power requirement model developed for the platform auger is suitably modified for the lower and upper grain conveyors using the loading rate given by Eqn (54) to obtain the power requirement for the grain conveyor auger \( P_{gc}^a \) in kW:

\[
P_{gc}^a = \frac{g l_{gc} \mu_g^s}{3600(1 + S_g)} \cos \psi_1 F
\]  

\[
\text{-------------- Eqn. 55}
\]

Or

\[
P_{gc}^a = k_{gc}^a F
\]  

\[
\text{-------------- Eqn. 56}
\]

where

\[
k_{gc}^a = \frac{g l_{gc} \mu_g^s}{3600(1 + S_g)} \cos \psi_1
\]  

\[
\text{-------------- Eqn. 56a}
\]
Where

\( \mu_s \) is the coefficient of sliding friction between the grain mass and the auger surface;

\( \psi_1 \) is the angle made by an imaginary plane oriented in the path of material movement which passes through the lower and top of the auger conveyor in radian;

\( l_{gc} \) is the length of the auger section in m.
2.9.2. Power requirements of the elevator section

- If $h_{gc}$ is the effective lift height of grain conveyor, m
- then using Eqn (54), the power requirements $P_{gc}^e$ in kW of the elevator section:

So, Power for elevating for $h_{gc}$ height to grain tank:

- $P_{gc}^e = \frac{gh_{gc}}{3600(1 + S_g)} F$  \hspace{1cm} \text{-------------- Eqn. 57}

- Or $P_{gc}^e = k_{gc}^e F$  \hspace{1cm} \text{-------------- Eqn. 58}

- Where, $k_{gc}^e = \frac{gh_{gc}}{3600(1 + S_g)}$  \hspace{1cm} \text{-------------- Eqn. 58b}
2.9.3. Total power requirements of grain conveyor

Using Eqns. 56 & 58, the total power of grain conveyor would be:

\[ P_{gc} = (P_{agc} + P_{egc}), \text{ kW} \]

\[ P_{gc} = (k_{agc} + k_{egc})F \]

--------- Eqn. 59
2.10. Tailings feed unit

- The un-threshed heads passed through the sieves constitute a major portion of the tailings.
- Tailings are lifted up to cylinder for re-threshing using a similar conveying unit as used for grain conveyor.
- The working of the threshing cylinder and condition of the crop affect the loading rate of the tailings conveyor.
- Following model can be employed to give the power requirement $P_{tc}$ in kW for the tailings feed unit:

$$P_{tc} = (k_{tc}^a + k_{tc}^e)F$$

Eqn. 60

- where: $k_{tc}^a$ and $k_{tc}^e$ are the proportionality coefficients
2.11. Traction unit

• The traction unit of a combine harvester consists of two pairs of pneumatic tyres-
  – one pair on the front large driving wheels
  – the other pair on the rear small steered wheels

• The power expenditure model for propulsion or traction is developed on the assumption that the combine harvester is travelling at a uniform velocity on level ground.

• Thus, power is required to overcome motion resistance experienced by the front and rear wheels.
• Since the driven wheels are larger in size than the size of the steered wheels
• therefore, motion resistances for both the wheels have been separately estimated and added together to obtain the total motion resistance of the machine.
• The relationship given in ASAE Data, D4973 (Anonymous, 1996) is used to estimate motion resistance $R_m$ in kN
Motion resistance $R_m$ in kN

\[ R_m = R_{mf} + R_{mr} = \frac{1.2}{C_i b_f d_f} (W_f)^2 + \frac{1.2}{C_i b_r d_r} (W_r)^2 + 0.04(W_f + W_r) \]

---------- Eqn. 60

- where:
- $R_{mr}$ and $R_{mf}$ are the motion resistances to rear and front wheel, respectively, in kN;
- $C_i$ is the soil cone penetration resistance in kPa;
- $b_r$ and $b_f$ are the widths of rear and front tyre section, respectively, in m;
- $d_r$ and $d_f$ are the diameters of the rear and front wheel, respectively, in m;
- $W_r$ and $W_f$ are the vertical loads borne by rear and front wheel, respectively, in kN.
The vertical loads supported by the wheels consist of:

1. self-weight of the machine
2. weight of crop mass passing over the machine
3. weight of the grain in the grain tank.

The distribution of the vertical loads amongst the wheels is expressed in terms of the position of the centre of gravity of the machine and the wheelbase. The weight of the crop mass passing over the machine is expressed in terms of the length of the material flow path $l_{mf}$ in m, the average speed of flow $v_{mf}$ in m/s and the crop feed rate $F$. 
• In a combine harvester, weight of grain in the grain tank varies—increasing from zero to a maximum value given by the capacity of the tank.

• An average value of the weight of the grain in the tank is assumed and added for calculating the vertical wheel load $W_t$ in kN.

• Incorporating these parameters and then simplifying, Eqn (61) is written as given below
Modified motion resistance $R_m$ in kN

\[ R_m = a_{mr}(W_t)^2 + b_{mr}W_tF + \frac{b_{mr}F^2}{2} + 0.04W_t + c_{mr}F \]

where the motion resistance coefficients $a_{mr}$, $b_{mr}$, and $c_{mr}$ are given by:

\[ a_{mr} = \frac{1.2x_{cg}^2}{bb_fd_fC_i} + \frac{1.2(b - x_{cg})^2}{bb_rd_rC_i} \]

\[ c_{mr} = \frac{10^{-4}gl_{mf}}{9v_{mf}} \]

\[ b_{mr} = \frac{5 \times 10^{-3}ga_{mr}l_{mf}}{9v_{mf}} \]

$b$ is the distance between front and rear wheel & $x_{cg}$ is the distance of the centre of gravity of the combine harvester ahead of the rear axle in m.
• The combine harvester also experiences the resistance due to-crop pressure from the front.
• Longitudinal pressure experienced by the cutter bar
• The total resistance against propulsion of combine harvester is the sum total of motion resistance [Eqn (62)] and crop resistance [Eqn (23)].

    • Multiplying the sum of the resistances with the forward travel speed and then simplifying, the power requirement for propulsion Pt in kW is:

\[
P_t = \frac{5}{18} a_{mr} (W_t)^2 v_f + \frac{5}{18} b_{mr} W_t F v_f \\
+ \frac{5}{36} b_{mr} F^2 v_f + \frac{1}{90} W_t v_f \\
+ \frac{5}{18} \left( u_r c_{mr} + \frac{5 \times 10^3 \pi^2 E I r^2}{3 \rho (h - h_c) h^3 Z^2 \lambda} \right) \frac{F v_f}{u_r}
\]

    ------------ Eqn. 63
2.12. Bearing friction

- The power from the prime mover is transmitted to the rotating shafts of the respective components.
- Power expenditure takes place to overcome friction at the shaft bearings.
- Considering a uniform phenomenon of power expenditure at the bearings, the relationship, proposed by Klenin et al. (1985) can safely be employed to estimate this component of power expenditure.

\[ P_{\text{bearing}} = k_i u_i \]

where:

- \( k_i \) bearing is the proportionality coefficient for bearing friction,
- \( u_i \) is the peripheral velocity of the ith component in m/s and
- \( P_{\text{bearing}} \) is the power expenditure due to bearing friction at the ith component, in kW.
Lecture – 14

Pullers for root crop harvesting
1. TYPES OF PULLERS AND THEIR FUNCTIONS

Pullers are used to harvest flax and to pull out sugarbeet and subsequently to transport the harvest to other processing units. The flax pullers may be in the form of straight belt conveyors and rollers (Fig. 159 a), curvilinear belt conveyors and rollers (Fig. 159 b) or belt and disk machines (Fig. 159 c).

Belt and roller pullers (puller rolls) consist of two endless puller belts 2 running over the driving pulleys 1, the driven pulleys 5 and the rollers 3 which keep the two belts pressed together. The dividers feed the stalks to the puller rolls which grip them at the point of contact of the two belts. The stalks are held over the zone $AB$ where the belts are in close contact.
Fig. 159. Schematic arrangement of flax pullers:

a—straight belt conveyor and rollers; b—curvilinear belt conveyor and rollers;
c—belt and disk; 1—driving pulley; 2—puller belts; 3—clamping rollers;
4—springs; 5—driven pulleys; 6—puller disk; 7—guide plates.
The transport rolls of reapers for harvesting hemp and the feeding units of corn harvesters have similar arrangements.

Belt and disk pullers consist of a puller belt 1, puller disks 6, clamping rollers 3 and a guide plate 7. The stalks are pressed between the belt and the disk. Simultaneous with the pulling operation, the stalks are conveyed to the left (in the direction of motion of the machine). Between the disks, the stalks are transported by the pressure exerted on them by the guide plate 7.

a. Belt and Roller puller

2. OPERATION OF THE BELT AND ROLLER PULLER

The working of the belt and roller pullers consists of the following operations: feeding the stalks to the zone where the belts are closely pressed together, gripping of the stalks by the belts, pulling and transporting the plants. The belts of section conveyors of hemp harvesters and feed units of corn harvesters operate on the same principle.

Stalk feed. Let the stalks led to the puller or transport rolls meet the belt (chain) at the point C (Fig. 160). If the speed of the machine is v and the velocity of the belt or chain is u, then the absolute velocity of the point C on the belt would be \( u_{a5} \), equal to the vector sum of the velocities \( u \) and \( v \). The direction of \( u_{a5} \) subtends an angle \( \beta \) to the direction of motion of the machine.
Fig. 160. Delivery of stalks to the feed channel.
Due to the action of the belts (chain), the stalk is deflected in the longitudinal direction (direction of motion). The extent of this deflection depends upon the slip between the stalks and the belts. The greater the slip, the greater is this deflection. If the deflection is to be reduced, the pulling unit must be so positioned that the stalks do not slip over the belts. This condition is governed by the following inequality

\[ \epsilon \leq 0 \]

where \( \epsilon \) is the angle between the normal to the belt and the direction of the absolute velocity at the point \( C \),

\( \phi \) is the friction angle between the stalks and the belts.

Since \( \epsilon = \beta - \omega t \), we have

\[ \beta \leq \omega t + \phi \quad \text{or} \quad \tan \beta \leq \tan (\omega t + \phi) \]

Assuming \( \tan \phi = f \), where \( f \) is the coefficient of friction, we have

\[ \tan \beta \leq \frac{\tan \omega t + f}{1 - f \tan \omega t} \]  \hspace{1cm} (100)

From the triangle \( CBD \) we have

\[ \tan \beta = \frac{u \cos \omega t}{v - u \sin \omega t} \]
Assuming $u/v = \lambda$ and substituting, we have

$$\tan \beta = \frac{\lambda \cos \omega t}{1 - \lambda \sin \omega t}.$$  

Replacing $\tan \beta$ from equation (100) we have

$$\lambda \leq A,$$

where

$$A = f \cos \omega t + \sin \omega t. \quad (101)$$

From this inequality it follows that the feed of stalks to the feed channel, without slipping over the belts or chains, depends upon the angle $\omega t$, the coefficient of friction $f$ and the kinematic index $\lambda$. The greater the magnitude of $\lambda$, the smaller the angle $\omega t$ at which slip may occur between the stalks and the belts.
Figure 161 shows the variation of $A$ as a function of the angle $\omega t$. Computations show that stalk feed would proceed without slip when $\lambda \geq 0.9$ for flax and hemp pulling combines and $\lambda \geq 1$ for corn harvesting combines.

During the operation of machines, sliding of stalks along the belt (chain) can be eliminated by increasing the working speed of the unit as $\lambda$ decreases with increase of working speed.

![Graph showing variation of $A$ as a function of the angle $\omega t$.](image)

**Fig. 161.** Variation of $A$ as a function of the angle $\omega t$:
1—friction coefficient of stalks $f = 0.5$; 2—friction coefficient of stalks $f = 0.25$. 

Prof. Dr. Muhammad Iqbal, Department of Farm Machinery & Power, University of Agriculture, Faisalabad
Capture of stalks. Stalks directed to the zone where the belts are closely pressed together are captured or gripped by the latter. The capture of the stalks depends upon the design and operating parameters of the belts and the size and physical and mechanical properties of the plants.

Let us consider the capture of stalks (Fig. 162) entering the feed channel, for instance, for a corn harvesting combine.

Let a stalk of diameter $d$ be inclined at an angle $\delta$ to the direction of motion.

The stalk is subjected to a normal force $N$ and a friction force $F$.

![Diagram of stalk capture by belts](image)

**Fig. 162.** Capture of a stalk by the belts.

The belts would capture the stalk when

\[ 2F \sin \omega t \geq 2N \cos \omega t. \]

Since $F_{\text{max}} = fN$,

\[ f \sin \omega t \geq \cos \omega t. \]

(102)
Fig. 162. Capture of a stalk by the belts.

The belts would capture the stalk when

\[ 2 F \sin \omega t \geq 2 N \cos \omega t. \]

Since \( F_{\text{max}} = fN \),

\[ f \sin \omega t \geq \cos \omega t. \]
From the triangle $OAC$ we find that

$$\sin \omega t = \frac{OA}{R} \text{ and } OA = R + a/2 - \frac{1}{2} A'B',$$

where $R$ is the radius of the pulleys carrying the belts,

$a$ is the gap between the belts at the entry.

From the figure we have

$$A'B' = \frac{d}{\sin \delta} + \frac{h}{\tan \delta}.$$

Substituting the above in the expression for $\sin \omega t$ we have

$$\sin \omega t = 1 + \frac{a - \frac{d}{\sin \delta} - \frac{h}{\tan \delta}}{2R},$$

where $h$ is the width of the belts or chain links.

Replacing $\sin \omega t$ and $\cos \omega t$ in equation (102) by the above expression and solving it we have

$$\frac{2R + a - \frac{d}{\sin \delta} - \frac{h}{\tan \delta}}{\sqrt{4R^2 - \left(2R + a - \frac{d}{\sin \delta} - \frac{h}{\tan \delta}\right)^2}} \geq \frac{1}{f}.$$  (103)
With increase of diameter $d$ and decrease of gap $a$ and the angle of inclination $\delta$, the ability of the chain or belt to grip the stalks decreases.

For Khersonets-7 combines, the parameters in inequality (103) are: $R = 10.5$ cm, $h = 2$ cm and $a = 2.5$ cm. If $f$ is assumed to be 0.25, then inequality (103) is satisfied for stalks of diameter $d$ not exceeding 2.4 cm (at $\delta = 70^\circ$).

When harvesting plants of diameter $d = 4$ cm, the gap $a$ has to be increased to 4.5 cm.

If the arrangement is disturbed while harvesting thick stemmed corn, the cutting height should be raised since, with increase of cutting height, the stalks are thinner so the diameter $d$ decreases and the angle of inclination $\delta$ increases.

The working process of belt feeders is similar to that described above.
The working process of belt feeders is similar to that described above.

Pulling of stalks lying in the plane of the puller channel. Let the stalk (Fig. 163) inclined to the soil surface at an angle $\theta$ be in the plane of the puller channel (central stalks). The stalk is gripped at some point $A$ which is at a height $h$ from the soil surface.

The absolute velocity $u_{ab}$ of point $A$ consists of the vector sum of the speed of the machine $v$ and the speed of the belts $u$ which subtends an angle $\alpha$ to the horizontal. The position of the stalk gripped by the belts moves in the direction of absolute velocity $u_{ab}$. The angle between the direction of the absolute velocity $u_{ab}$ and the horizontal is $\beta_1$.

Fig. 163. Pulling of stalks lying in the plane of the puller.

From the triangle $ABD$ we have

$$\tan \beta_1 = \frac{u \sin \alpha}{v - u \cos \alpha}.$$ 

Substituting $u/v = \lambda$ as before we have

$$\tan \beta_1 = \frac{\lambda \sin \alpha}{1 - \lambda \cos \alpha}.$$
Fig. 163. Pulling of stalks lying in the plane of the puller.

From the triangle $ABD$ we have

$$\tan \beta_1 = \frac{u \sin \alpha}{v - u \cos \alpha}.$$ 

Substituting $u/v = \lambda$ as before we have

$$\tan \beta_1 = \frac{\lambda \sin \alpha}{1 - \lambda \cos \alpha}. \quad (104)$$
Pulling is completed as the roots are pulled out of the soil. For a stalk length equal to \( l \) from point 0 to point \( A \) and length of roots equal to \( k \), the plucking or pulling operation terminates at point \( C \) which is given by \( OC = l + k \).

At the instant the stalk is just pulled out of the soil, it is inclined to the horizontal at an angle \( \gamma \). This angle, which depends upon the parameters of the uprooting process, may be determined as follows.

From the triangle \( ACO \) we have

\[
\frac{l}{\sin (\beta_1 - \gamma)} = \frac{l + k}{\sin (\beta_1 - \theta)}
\]

or

\[
\sin (\beta_1 - \gamma) = \frac{l}{l + k} \sin (\beta_1 - \theta).
\]

Let us resolve the vector \( AC \) in the directions of the velocities \( u \) and \( v \). The intercept \( AE \) is the length of the belts over which the pulling process occurs,
whereas the intercept $AF$ specifies the path traversed by the machine during which the stalks held by the belts are uprooted. The intercepts $AE$ and $AF$ are obtained as follows:

From the triangle $OCG$ we have

$$CG = (l + k) \sin \gamma$$

$$CG - h = AE \sin \alpha.$$ 

Substituting $CG$ from the former in the latter equation we have

$$AE = S_b = \frac{(l + k) \sin \gamma - h}{\sin \alpha}. \quad (105)$$

Since $l = h/\sin \theta$,

$$S_b = \frac{h(\sin \gamma - \sin \theta)}{\sin \theta \sin \alpha} + \frac{k \sin \gamma}{\sin \alpha}. \quad (106)$$

From the triangle $ACE$, the path $S$ traversed by the machine during the process of uprooting would be equal to

$$AF = CE = S = S_b \cdot \frac{\sin (\beta_1 + \alpha)}{\sin \beta_1}. \quad (107)$$
Pulling off-center stalks. Let us consider the process of plucking or uprooting of stalks whose roots do not lie in the plane of the puller channel (Fig. 164). Consider a plant whose root $O_1$ lies on the axis of symmetry of the divider. This stalk is separated from the plane of the puller channel by a distance $b$. Let the stalk be inclined at an angle $\theta$ to the $Ox$ axis in the direction of motion of the machine. If uprooting begins at point $A$ when $O_1A = l_r$ and the absolute velocity of the puller channel is $u_{ab}$, then the stalk would be uprooted at point $C$, that is, when $O_1C = l_r + k$.

From the above it is evident that

$$CB = \sqrt{(l_r + R)^2 - b^2}.$$  

Since $l_r = \sqrt{(h^2/\sin^2 \theta) + b^2}$, substituting and rearranging we have

$$CB = \sqrt{\frac{h^2}{\sin^2 \theta} + 2k \sqrt{\frac{h^2}{\sin^2 \theta} + b^2 + k^2}}.$$  

Replacing $(l + k)$ by $CB$ in equation (105) we obtain the following relationship for determining the length to the traversed by the belts to uproot the stalks lying off-center:

$$S_{br} = \sqrt{\frac{h^2}{\sin^2 \theta} + 2k \sqrt{\frac{h^2}{\sin^2 \theta} + b^2 + k \sin \gamma - h}} \div \sin \alpha.$$  

(108)

During this time the distance moved by the machine is given by
Equations (108) and (109) show that magnitudes of $S_{br}$ and $S_r$ are governed by such design parameters as the distance $b$ from the axis of symmetry of the divider to the puller plane, the angle $\alpha$ of inclination of the pulling mechanism and the speed $u$ of the puller belts.
When the distance \( b \), from which the stalks are grasped by the puller, is increased, both \( S_{br} \) and \( S_r \) increase. The greatest influence of distance \( b \) on \( S_{br} \) and \( S_r \) occurs when the puller is placed at lower heights above ground level, that is, for \( h = 10 \) to 25 cm.

If the angle \( \alpha \) is increased, then \( S_{br} \) and \( S_r \) decrease. The influence of the angle \( \alpha \) is greatest when the flax is greatly bent, that is, for \( \theta = 25 \) to 35°.

For the LT-7 flax puller when \( \alpha = 36° \), the path \( S_{br} \) and \( S_r \) is much greater than that for the LTV-4 and LKV-4T machines for which \( \alpha \) varies from 60 to 70°. Hence, the type LTV-4 flax puller units work better with fallen stalks than those with small inclination angles such as LK-7.

For a constant machine speed \( v \), the paths traversed, \( S_{br} \) and \( S_r \), are affected by changes in the belt speed \( u \). In existing flax pullers the belt speed goes up to 2.6 to 3.3 m/sec.

3. PULLING STALKS BY BELT AND DISK UNIT

The process of pulling of flax stalks by the belt and disk units is shown in Fig. 165. Consider a stalk \( OA \) deflected through \( b \) to the right of the \( zOx \) plane. During pulling, this stalk would be in the most unfavorable position. Let the puller grip the stalk at point \( A \) located at a height \( h \) from the soil