MEASURING CUTTING RESISTANCE OF SUGAR CANE STALK WITH PENDULUMS

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ABSTRACT

Since power consumption of cutting sugar cane stalk is high, measuring cutting resistance is necessary for improving cutting efficiency. The pendulum is a simple device for measuring dynamic strength, but for a simple compact design with high capacity of energy storage and impact velocity requirement, a pair of pendulums with one torsional spring was used. The preliminary investigation revealed that the cutting resistance was greatly affected by the cutter geometries, particularly the sharpness of cutter edge. The difference of cutting resistance between a sharpened hand cutter and the less sharpened commercial base cutter of mechanical harvester was three to six times, the power loss for which cannot be overlooked.

The objective of this study is to develop a simple device (the pendulum) to examine the cutting resistance of commercial cutters with different varieties of cane stalks. Cutting cane stalk is a high-power consuming work. A chopped sugar cane harvester is required to chop the cane stalk into pieces (Spargo and Baxter). As such, measuring cutting resistance is necessary for improving the cutter design. Cutting is a dynamic action, the resistance of which is affected by the strength and hardness of cane stalk (Cochran and Baker) and the geometry of the cutter and velocity of cutting (Chang, Mohsenin), hence, cutting resistance should be considered as a composite property. Chang have tried an impact cutting device to measure the cutting resistance. However, it involved a complicated instrumentation which was inconvenient.

The pendulum is a simple device for measuring dynamic strength of biological
materials (Buramistrova\textsuperscript{5}) but its velocity can be limited by the design of arm length. For a base cutter, the common design of cutting velocity is about 10 m/sec. This paper suggests to use a pair of pendulums as shown in Fig. 1, one which is loaded with a torsional spring and tested cutter called acti\textsuperscript{ional} pendulum, from which the energy input to the cutting system and the cutting velocity to be used are pre-determined. The surplus energy right after cutting through the material is measured by a second pendulum called reactional pendulum through an impact action. The actional pendulum is then stopped by a rubber stopper right after taking the impact action with the reactional pendulum at zero position. The advantage of using the torsional spring is that the energy storage capacity and the acting velocity can be increased several times without increasing the physical size of the pendulum.

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{figure1.png}
\caption{The device used for measuring cutting resistance. The actional pendulum with torsional spring on the rotating axle and a stopper with rubber at the center on the bottom of the hammer weight.}
\end{figure}
EXPERIMENTAL PROCEDURES

Theory and equations

The cutting energy absorbed by the cane stalk is determined as follows:

\[ E_c = E_a - E_r \]  (1)

where

- \( E_c \) = Energy absorbed by cane stalk through cutting in kgf-cm
- \( E_a \) = energy delivered by the actional pendulum which is calculable, in kgf-cm
- \( E_r \) = surplus energy after cutting and received by the reactional pendulum, in kgf-cm

The total energy \( E_a \) delivered by the actional pendulum is determined by the formula:

\[ E_a = W \cdot r \left( 1 - \cos \theta_a \right) + \int_0^{\theta_i} \phi \, d\phi + K \phi_i \phi \]  (2)

where

- \( W \) = total weight of the actional pendulum including cutter weight in kgf
- \( r \) = distance of the center of gravity of the actional pendulum with cutter measured from the rotating center in cm.
- \( a \) = angle made by the actional pendulum from center position for the test in degree
- \( i \) = initial angle of the torsional spring made by initial load in degree
- \( \phi \) = angle of torsional spring made by load in degree
- \( K \) = spring constant of the torsional spring in kgf-cm/rad
- \( \text{Rad} \) = angle of radians

The cutting velocity is then determined as follows:

\[ V = \sqrt{\frac{2E_a}{M}} \]  (3)

where

- \( V \) = cutting velocity in m/sec.
- \( M \) = total mass of the actional pendulum in kg.
The average cutting force is determined by the formula:

\[ F = \frac{E_D}{D} \quad (4) \]

where

\[ F = \text{average cutting force in kgf} \]
\[ D = \text{diameter of cane stalk, or distance of cutting through the cane stalk, tangential direction.} \]

The unit cutting resistance is then determined as follows:

\[ R = \frac{F}{A} \]

\[ = \frac{E}{AD} \quad (5) \]

where:

\[ R = \text{cutting resistance in kgf/mc}^2 \]
\[ A = \text{cross-sectional area of cane stalk in cm}^2 \]

**Construction**

The actional pendulum has an arm made of 382 x 25.4 x 6.2 mm of steel plate and hammer made of 150 x 32 x 32 square bar; with a total weight of 1670 g. The reactional pendulum with an arm of 500 x 25.4 x 6.2 mm steel plate and a hammer of 64.5 dia 43 mm of circular plate; total working weight of which is 1110 g. The torsional spring is made of 4 mm steel wire with a coil diameter of 28 mm, spring constant of which is 26.9 kgf-cm/rd. A stopper is constructed at the center under the hammer of the actional pendulum with rubber. Two hammers are under contact at their vertical position at zero degree.

**Calibration**

The calibrations were done from 10° to 80° of the actional pendulum with four different spring conditions. The angle of the actional pendulum versus the corresponding angle of the reactional pendulum of the four spring conditions are shown in Fig. 2. The results showed that the angles between the actional and reactional pendulum are linear. The energy received by the reactional pendulum versus the corresponding reactional angle is shown in Fig. 3. This indicates that the energy — angle relationship is non-linear due to trigonometric function involved.
The energy received by the reactional pendulum is based on the energy delivered by the actional pendulum, therefore, the calibration included the impact loss.

**Test**

Three different commercial new cutters with three different varieties of cane

**TABLE 1. Geometrical and mechanical conditions of the tested cutter blades**

<table>
<thead>
<tr>
<th>Cutter</th>
<th>Edge Angle</th>
<th>Edge Sharpness</th>
<th>Blade thickness</th>
<th>Hardness Rookwell C</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Base cutter)</td>
<td>degree</td>
<td>mm</td>
<td>mm</td>
<td></td>
</tr>
<tr>
<td>Hand cutter</td>
<td>15.6°</td>
<td>0.12</td>
<td>1.2</td>
<td>48-54</td>
</tr>
<tr>
<td>Santal (new)</td>
<td>32°</td>
<td>1.0 flat</td>
<td>3.8</td>
<td>38-46</td>
</tr>
<tr>
<td>Toft (new)</td>
<td>12.4°</td>
<td>0.53</td>
<td>4.6</td>
<td>42-51</td>
</tr>
</tbody>
</table>

**FIGURE 2.** Actional angle of the actional pendulum versus the corresponding reactional pendulum through an impact with four different conditions
TABLE 2. Cutting resistance of first internode with different cutters (preliminary results)

<table>
<thead>
<tr>
<th>Sample</th>
<th>Cutting Resistance in kgf/cm²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hand cutter</td>
</tr>
<tr>
<td>CB·41·14</td>
<td>35.9</td>
</tr>
<tr>
<td>1</td>
<td>17.8</td>
</tr>
<tr>
<td>2</td>
<td>5.0</td>
</tr>
<tr>
<td>3</td>
<td>33.1</td>
</tr>
<tr>
<td>4</td>
<td>28.8</td>
</tr>
<tr>
<td>Ave.</td>
<td></td>
</tr>
<tr>
<td>NAB6·79</td>
<td>21.9</td>
</tr>
<tr>
<td>1</td>
<td>21.1</td>
</tr>
<tr>
<td>2</td>
<td>19.7</td>
</tr>
<tr>
<td>3</td>
<td>20.9</td>
</tr>
<tr>
<td>Ave.</td>
<td></td>
</tr>
</tbody>
</table>

**FIGURE 3.** Energy received by the reactional pendulum (including energy loss of impact) versus the reactional angle.

Stalk were tested. The geometrical and mechanical conditions of the tested cutters are shown in Table 1 and Fig. 4 and 5. Two groups of tests were conducted. The first group was tested by a local hand cutter to cut piece of stalk from the first internode to the top at each middle part of internode with a cutting velocity of
FIGURE 4. Sample cutters used for the tests (a) used by Santal (base cutter new); (b) used by Toft (base cutter new)

FIGURE 5. Cross-sectional construction of the tested cutter, only projected on the edge. Actual size x 9.35
Variety (Variedade)
- NA5679
- CB4114
- AIC58460

FIGURE 6. Distribution of cutting resistance with each number of internode reading taken at each middle part of internode with the hand cutter.

4.2 m/sec. Three different varieties were tested: NA5679, CB4114 and AIC58460. The purpose of this test was to find out the distribution of the cutting resistance along a cane stalk. The second group of tests were conducted with three different commercial cutters: hand cutter, Santal and Toft. Only two of the varieties CB-41-14 and NA56-79 were tested with a cutting velocity of 4.1 to 4.3 m/sec. The purpose of this test was to make a preliminary investigation of the effect of different cutter geometries. Four samples of the first internode for each test were measured at the middle part, the results of which are shown in Table 2.

RESULTS AND DISCUSSION

The cutting resistance along the cane stalk from the bottom to the top cut by hand cutter with three different varieties as shown in Fig. 6 indicates that the cutting resistance distributed in the middle portion is harder than that distributed at the bottom and top internodes. Similar results were obtained by Martin and Cochran for measuring hardness distribution. The results shown in Fig. 6 also indicate that the cane stalk respond to cutting resistance differently with different varieties. For using very sharp hand cutter with an edge sharpness of 0.12 mm,
the NA56-79 gave the highest cutting resistance. However, using unsharpened machine cutters of Santal and Toft as shown in Fig. 4, the results are different. The cutting resistance of CB41-14 is higher than that of NA56-79. This is possibly because the CB41-14 has a higher skin effect which is insensitive to sharp edge blade of hand cutter but very sensitive to the dull edge blade of machine cutters.

Fig. 4 also shows that the dull edge of machine cutters with a sharpness of 0.53 mm of Toft to 1.0 mm of Santal had a cutting resistance three to six times more than that of cutting by the hand cutter which has a sharpness only of 0.12 mm, and blade thickness of 1.2 mm as shown in Fig. 5.

CONCLUSION

This preliminary investigation using the pair of pendulum revealed that the cutting resistance of sugar cane stalk was greatly affected by cutter geometries, especially the edge sharpness. It showed the possibility that the high power consumption of the present cane harvester can be reduced, if proper geometries of cutter can be used for the cane harvester.

REFERENCES


MEDIDAS CON PENDULO DE RESISTENCIA EN CORTE DE TALLOS DE CAÑA DE AZUCAR

Cheu-Sang Chang

RESUMEN

El consumo de fuerza al cortar tallos de caña de azúcar es alto, haciendo necesario medir la resistencia de corte para mejorar la eficiencia de corte. El pendulo es el artefacto más sencillo para medir fuerza dinámica, pero para un diseño simple y compacto con capacidad alta de almacenamiento de energía e impacto de velocidad necesario, se usa un par de pendullos con un muelle de torsión. La investigación preliminar reveló que la resistencia de corte es afectada grandemente por la configuración de la cuchilla de corte, en particular la agudeza del filo de la cuchilla. La diferencia de resistencia de corte entre una cuchilla afilada de corte manual y la cuchilla de base comercial menos aguda de una cosechadora mecánica es de tres a seis veces más - una pérdida de fuerza que no se puede pasar por alto.