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POSTER SUMMARY

FORCE ANALYSIS IN HANDLING WHOLE STICK CANE

LOUBSER RC[1] and REEVES J[2]

[1]*Sugar Milling Research Institute, c/o University of KwaZulu-Natal, Durban, 4041, South Africa*
[2]*Mechanical Engineering, University of KwaZulu-Natal, Durban, 4041, South Africa*
rloubser@smri.org *204506411@ukzn.ac.za*

Abstract

To determine the size that a machine needs to be to perform its function requires an understanding of the forces involved to manipulate the product to satisfy the process requirements. The determination of the forces involved in the feeding of whole stick cane is one such application. To save on capital expenditure, it is necessary to size the mechanical equipment correctly for the application.

The stiffness characteristics of a bundle of whole stick cane were determined using a static compression test by measuring the compressive force for given compression displacements. This information was used as input into a model to determine the compression forces and motor power required for compressing whole stick cane on a conveyor from a free height to a selected compressed height. In addition to this the change in density could be determined.

Keywords: sugarcane, handling, whole stick, stiffness, forces, power, model

Introduction

When a piece of equipment is designed, a judgement needs to be made as to how big is 'big enough'. Without sufficient information regarding the forces involved in a machine, the tendency is to make the machine bigger so that it will not break. However, in any environment where the cost of the asset has become an important consideration, it is no longer acceptable to simply increase the size of the component.

As part of a research project it was necessary to design a device to feed whole stick cane in a uniform dense mat. A design using levellers and a roller was chosen. It was necessary to determine the stiffness properties of a layer of matted sugarcane so that the rollers and motors could be designed appropriately.

Once the stiffness properties are known, a mathematical model can be constructed to determine the design forces for the equipment.

Determination of the stiffness of a cane bundle

A metal frame was constructed to contain a sample of cane stalks. A lid was placed on top of the stalks. Hydraulic loading was used to compress the stalks while force and displacement were measured. The results of the compression test are shown in Figure 1. The force per unit area or pressure, σ (stress), was plotted as the dependent variable, and the fractional deflection, ε (strain), as the independent variable. The slope of the line was considered analogous to the 'Elastic' or 'Young's' modulus for the cane, although the compression mechanism is decidedly plastic in nature.

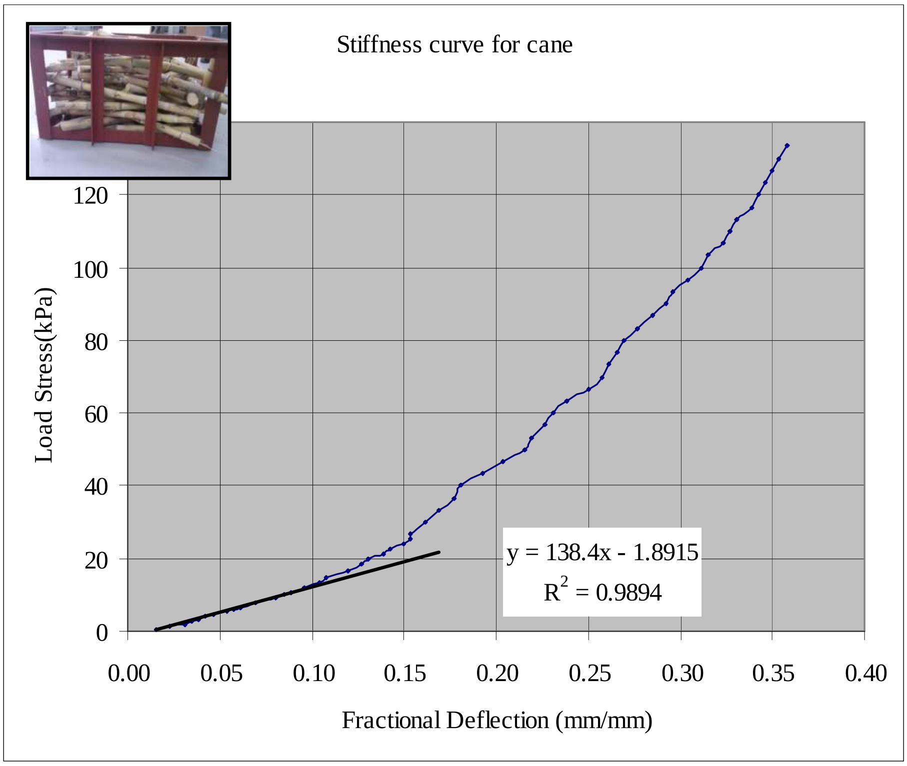

Figure 1. Compression test.

From Figure 1 it can be seen that, for a compression of 10% (0.1 mm/mm), the relationship is essentially linear. Thereafter the voids between the cane stalks become small and other effects such as crushing, with associated expression of juice, and snapping of the stalks dominate. In the linear part of the curve, the Elastic modulus, E, for the cane used was 138.4 kPa. This is applicable in the direction that the force was applied.

Application to a pinch roller

If a cane bed is compressed using a roller, the fractional change in the height of the cane varies to the equation:

$$\varepsilon_y = \frac{h}{h_0} = 1 + \frac{R}{h_0}(\cos\theta_0 - \cos\theta)$$

where

h	is the height of the cane on a point on the roller
h_0	is the original height of the cane
R	is the radius of the roller
θ_0	is the angle from the vertical at which the cane first makes contact with the roller
θ	is the angle from the vertical to the point of interest
y	refers to the vertical direction.

The vertical stress is given by:

$$\sigma_y = E\varepsilon_y$$

The vertical force on the roller can then be calculated from:

$$F_y = EWR\int_0^{\theta_0}[1 + {}^{R}\!/_{h_0}(\cos\theta_0 - \cos\theta)]\cos\theta d\theta$$

where

W is the width of the roller.

This can be manipulated and integrated analytically to give:

$$\begin{aligned} F_y &= EWR\Big[\,(1+{}^{R}\!/_{h_0}\cos\theta_0)\sin\theta - {}^{R}\!/_{2h_0}\,\theta - {}^{R}\!/_{4h_0}\sin 2\theta\,\Big]_{\theta=0}^{\theta_0} \\ &= EWR[(1+{}^{R}\!/_{h_0}\cos\theta_0)\sin\theta_0 - {}^{R}\!/_{2h_0}\,\theta_0 - {}^{R}\!/_{4h_0}\sin 2\theta_0] \end{aligned}$$

where θ is measured in radians.

This formula gives the vertical force on the roller given the height of the cane bed, the width and radius of the roller, the contact angle and the stiffness of the cane. This force can be used as a starting point for the calculation of shaft and bearing sizes.

The vertical force on each element of the roller can be divided into two components, namely the radial and tangential components. By multiplying the tangential component by the radius, the torque on the roller may be determined, giving rise to the equation:

$$T = EWR^2\int_0^{\theta_0}[1+{}^{R}\!/_{h_0}(\cos\theta_0-\cos\theta)]\cos\theta\sin\theta\,d\theta$$

which gives:

$$T = EWR^2\Big[\,({}^{1}\!/_{2}+{}^{R}\!/_{2h_0}\cos\theta_0)\sin^2\theta + {}^{R}\!/_{3h_0}\cos^3\theta\,\Big]_{\theta=0}^{\theta_0}$$

This assumes that there is no slip between the roller and the cane.

This torque may be used to calculate the size of the motor.

The cane was permanently deformed after the load was removed from the lid. If the cane is compressed further by additional rollers, it will be necessary to take any previous permanent deformation of the cane into account. The model for initially randomly packed cane will not be applicable to further compression processes. This is analogous to pre-stressing of a material to extend its elastic range.

Conclusion

The ‘stress’-‘strain’ curve of a bundle of cane was determined experimentally. From this curve, an estimate of the stiffness analogous to Young’s modulus was determined. A simple model was used to derive formulae from which the vertical force and torque on a pinch roller could be determined. This data may be used by an equipment designer to determine the minimum size of a pinch roller shaft and bearings more accurately. The model used was static and allowances would have to be made for dynamic effects such as shear rate.

In certain project evaluations, the cost of excessive reserve factors can result in unnecessary rejection of proposals, whereas correct sizing of components could allow substantial cost savings.