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INVESTIGATION THE OPTIMUM CONDITIONS OF GRAIN MILLING

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ABSTRACT

The objective of this work is to study the optimum conditions of grain milling during the milling process, and find out the best values for the design parameters (disc diameter, crossing angle of furrows, disc weight and rotational speed).

INTRODUCTION

A metallic-disc mill [1] was choosen for this study. It is composed of two horizontal, parallel and coaxial discs. The discs are made from grey cast iron having 160 H.B, and the distance between them may be adjusted in order to meet the requirements of the grains to be milled. The upper disc is rotary and has an open hole in the centre through which the grains may be passed, while the lower disc is stationary. The grains which fall through the open hole of the upper disc are pulled and moved outward by centrifugal forces.

STRESSES IN THE ROTARY DISC

The particles of a rotary disc are under the action of centrifugal forces which try to tear off the particles from the disc. Thus internal stresses are created in the disc.
Consider an element of the rotary disc. The various stresses acting on it are indicated in the Fig. (1). Solution for these stresses are given as below :
Radial stress σ_r at the radius r of a hollow disc of internal radius r_i and external radius r_o is given by equation :

$$\sigma_r = \left(\frac{3+\nu}{8}\right)\frac{\rho\omega^2}{g}\left(r_i^2 + r_o^2 - r^2 - \frac{r_i^2 r_o^2}{r^2}\right) \qquad (1)$$

and the hoop stress θ is given by :

$$\sigma_\theta = \left(\frac{3+\nu}{8}\right)\frac{\rho\omega^2}{g}\left[r_i^2 + r_o^2 - \frac{1+3}{3+}\, r^2 + \frac{r_o^2 r_i^2}{r^2}\right] \qquad (2)$$

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The maximum radial stress occurs at $r = \sqrt{r_o r_i}$

Thus $$(\sigma_r)_{max} = \frac{\rho \omega^2}{g} r_o^2 \left(\frac{3+\nu}{8}\right)\left(1 - \frac{r_i}{r_o}\right)^2 \qquad (3)$$

and
The maximum hoop stress occurs at $r = r_i$

Thus $$(\sigma_\theta)_{max} = \frac{\rho \omega^2}{g} r_o^2 \frac{(3+\nu)}{4}\left(1 + \frac{1-\nu}{3+\nu}\frac{r_i^2}{r_o^2}\right) \qquad (4)$$

The allowable speed can be calculated based on the distortion energy theory [2] as follows :

$$(\omega)_{max} = \left[\frac{8 g \sigma_a}{\rho(3+\nu) r_o^2}\left\{\frac{1}{2 + \left(\frac{r_i}{r_o}\right)^2\left(1 - \frac{(1+3\nu)}{3+\nu}\right)}\right\}\right]^{\frac{1}{2}} \qquad (5)$$

ACTING FORCES ON THE GRAIN

The acting forces on the grain during the milling process may be divided into the following items :-

Frictional Forces Due to the Rotary Disc

$$F_{f1} = \mu_1 \frac{W_d}{n_g} \qquad (6)$$

Frictional Forces Due to the Stationary Disc

$$F_{f2} = \mu_2 \frac{W_d}{n_g} \qquad (7)$$

Vertical Load

$$F_v = \frac{W_d}{n_g} \qquad (8)$$

where ,

$$n_g = \frac{A_d}{A_g} . K_o$$

Centrifugal Force of Grain

$$F_c = M_g \omega_g^2 q = \frac{M_g \omega^2 q^3}{S_o^2} \qquad (9)$$

where ,

$$\omega_g = \frac{\omega q}{S_o}$$

Shearing Force

$$F_{sh} = \sigma_{sh} \; A_{sh} \tag{10}$$

The grain movement may be described as a multiturn spiral w.r.t the stationary disc, and the absolute velocity may be obtained from the equation of multiturn spiral. The spiral equation can be written as follows :

$$q = K\theta \; [3] \tag{11}$$

where

$$K = a / 2\pi$$

The above equation is plotted in Fig. (2) . The acting resultant force on the grain F_g during the milling process can be obtained as follows :

$$F_g = \sqrt{(F_{sh} \sin\alpha - F_q)^2 + (F_\theta + F_v + F_{sh} \cos\alpha)^2} \tag{12}$$

where ,

$$F_q = M_g \left(\frac{\omega}{S_o}\right)^2 q^3 ,$$

$$F_\theta = 2 M_g \left(\frac{\omega}{S_o}\right)^2 q^3 K \text{ and}$$

$$F_v = \frac{W_d}{n_g}$$

Substituting the values of F_q , F_θ and F_v in eq. (12), yields ;

$$F_g = \sqrt{(F_{sh} \sin\alpha - M_g \left(\frac{\omega}{S_o}\right)^2 + (2 M_g \left(\frac{\omega}{S_o}\right)^2 q^2 K + \frac{W_d}{n_g} + F_{sh} \cos\alpha)^2} \tag{13}$$

From eq. (13), it is clear that the acting resultant force on the grain during the milling process depends on the crossing angle (α), rotational speed (ω) of the rotary disc, variable radial vector (q) and the the weight of the rotary disc (W_d) .
The value of the optimum rotational speed of the rotary disc must not exceed 22 rad/sec [4] to avoid the increase in flour temperature which in turn leads to unfavorite change its colour.
Let,
ω = 20 rad/sec, K = 0.016 m, , $W_g = 0.05 \times 10^{-3}$ kg, $A_g = 0.12 \times 10^{-4}$ m^2,

$\sigma_{sh} = 2.1$ [4] kg/mm^2 , $K_o = 0.06$, a = 0.1 m , $A_{sh} = 0.011 \times 10^{-4}$ m^2,

$S_o = 2 \times 10^{-3}$ m.

Substituting from equations (8-11) into equation (13) and using the above values yields ;

$$F_g = \sqrt{(2.373 \sin\alpha - 505 q^3)^2 + (16.31 q^2 + 8.98 \times 10^{-7} W_d)^2} \tag{14}$$

RESULTS AND DISCUSSION

Figure (3) shows the effect of the crossing angle (α) on the resultant force. It can be seen that the force (F_g), that acts on the grain, decreases very slightly with an increase in the crossing angle.
Small crossing angles cause high reduction rate of the semi-product which consequently consumes high power. This will lead to choose the crossing angle in the range from 30 to 50 degrees.
Figure (4) represents the relation between the weight of the rotary disc and the resultant force acting on the grain. It can be noticed that the relation is almost a horizontal straight line which means that the resultant force can be considered to be constant with the weight of the disc. The effect of the variable radial vector (q) on the resultant force is shown in Fig. (5). It is clear that the resultant force increases with an increase in the variable radial vector, which is thought to be logical. The best value of (q) lies in the range from 0.45 to 0.5 m. Above this range, the increase in (q) will cause more power consumption.

CONCLUSIONS

The following conclusions may be drawn from this study :

1- The best value of crossing angle of furrows lies between ($30 - 50^{o}$).

2- The best value of the disc diameter lies between (0.9 - 1.2) meter, and the ratio between the inner and outer radius of the rotary disc must be not less than 0.3.

3- The weight of the rotary disc has a very small effect on the acting resultant force on the grain.

4- The frictional forces between the grain and the disc surfaces have a significant effect on the milling quality.

5- The best value of the rotational speed is 22 rad/sec to avoid an increase of flour temperature and bad colour of flour.

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NOMENCLATURE

α: Crossing angle of furrows in degrees

ν: Poisson ratio — dimensionless

μ: Coefficient of friction between the grain and the disc surface

ρ	: Density of the material of the disc	kg/cm^3
θ	: Grain rotating angle from the initial position	degrees
ω	: Angular velocity of the rotary disc	rad/sec
ω_g	: Grain angular velocity	rad/sec
σ_a	: The allowable or design stress	kg/cm^2
σ_{sh}	: Grain shear stress	kg/mm^2
a	: The lead of the spiral	m
A_g	: Grain Cross-Section area	m^2
A_{sh}	: Shearing area of the grain	m^2
D_d	: Disc diameter	m
F_c	: Centrifugal force	kg
F_g	: Resultant force	kg
F_q	: Radial force component	kg
F_θ	: Normal force component	kg
F_{sh}	: Shearing force	kg
K	: The Parameter of the spiral	m
K_o	: Contact factor between the grain and the disc surface	
M_g	: Mass of grain	kg
n_g	: The number of grains that are milled in the same time	grain
F_v	: Vertical load	kg
q	: Variable radial vector	m
r_1	: Internal radius of the disc	m
r_o	: External radius	m
S_o	: Grain thickness	m.m
W_d	: Disc weight	kg

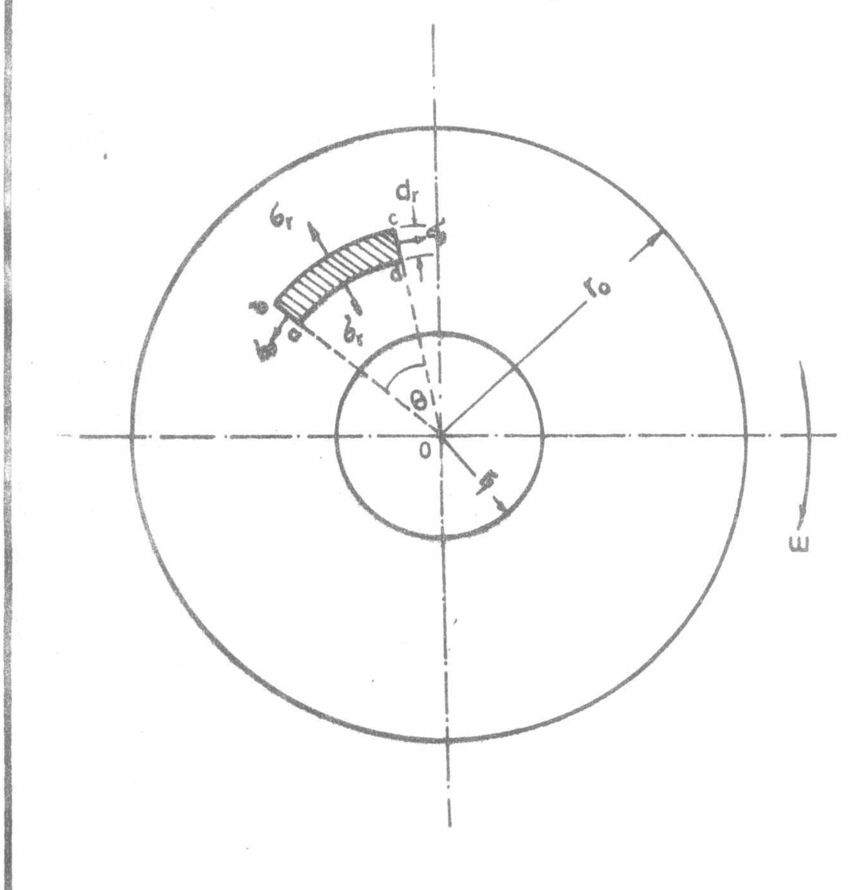

Fig. (1) : Stresses in the Rotating Disc.

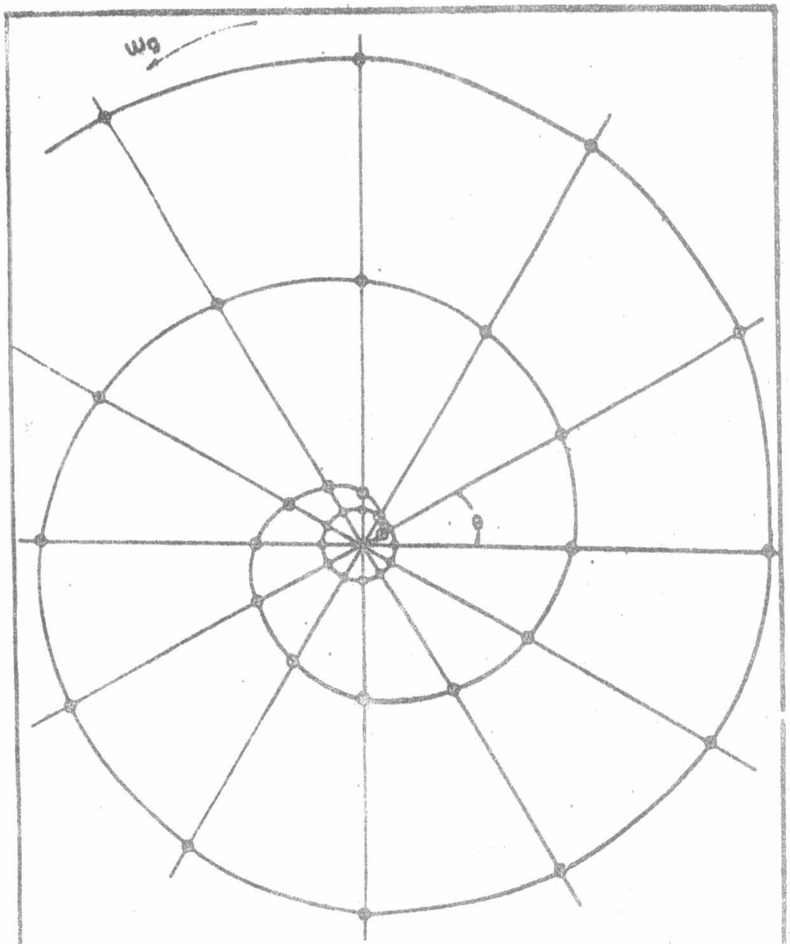

Fig. (2) Plotted the Equation q = K θ.

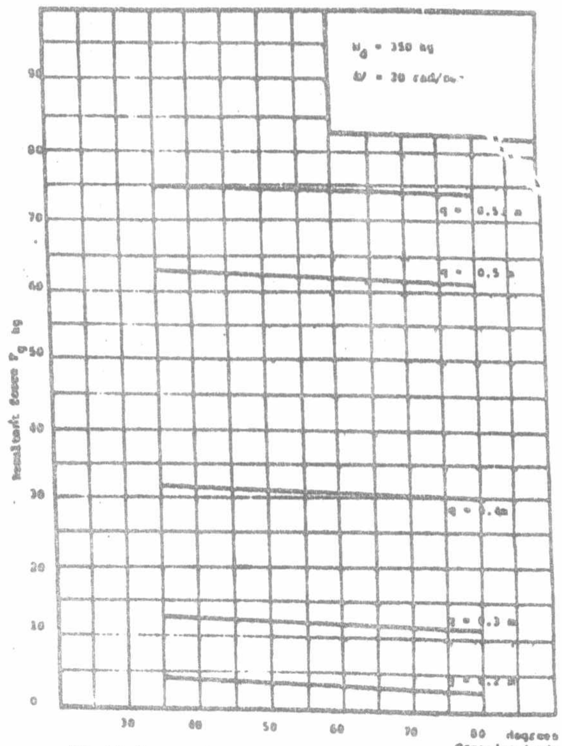

Fig. (3) The relation between the resultant force and the crossing ∝

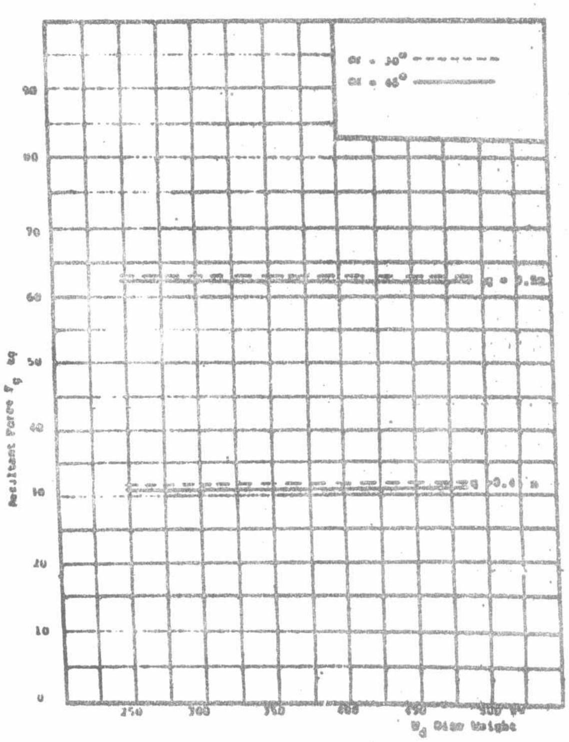

Fig. (4) The relation between the resultant force and the disc weight

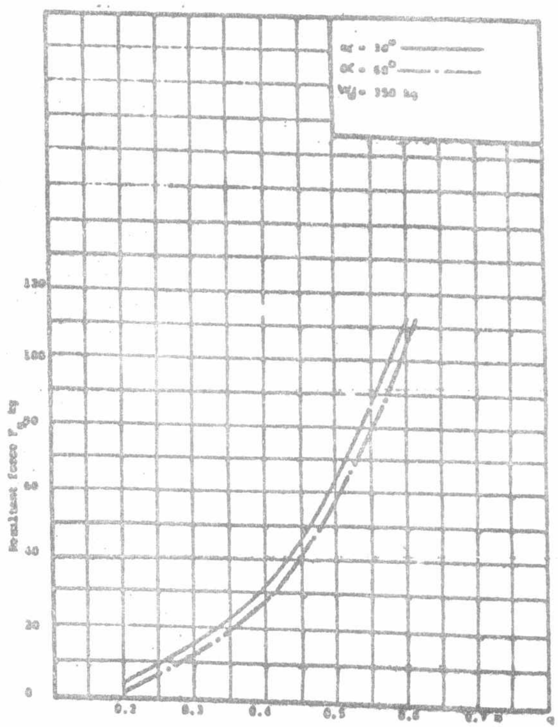

Fig. (5) The relation between the resultant force and the variable radial vector q.