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GENERAL PURPOSE ANALOG COMPUTATION

EDUCATIONAL*

APPLICATION STUDY: 7.4.6a

CALCULATION OF THE RADIAL VELOCITY OF A ROTARY SPRAY DRIER

INTRODUCTION

This Study describes the simulation of a rotating-disk atomizer (rotary spray drier) with a PACE® TR-10 desk-top-size general purpose analog computer. The operation of such a drier consists, essentially, of the centrifugal acceleration to a high velocity of a liquid drop before discharge of the drop into the atmosphere. Since the size of the drop (*in toto,* the amount of liquid discharged) and, hence, the effectiveness of the drying operation depend on the velocity attained by the drop, it is of interest to simulate such a drier so that the radial velocity can be calculated.

The total velocity is given by

$$\sqrt{v^2 + (\omega r)^2} \tag{1}$$

where ωr is the peripheral velocity which varies directly as the radius, r. Therefore, this simulation will be directed toward a calculation of the radial velocity, v.

PROBLEM STATEMENT

Consider a disk, as shown in Figure 1, having a number of equally-spaced radial vanes which prevent slippage of the liquid drop(s) over the disk surface. The drop(s) then can be considered to be riding on the vanes, perpendicular to the plane of the disk.

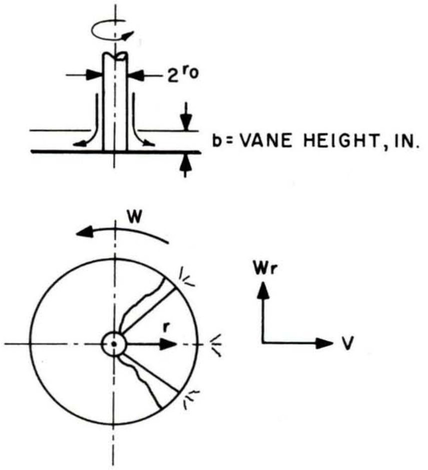

Figure 1: Schematic Diagram of Rotating Disk

If gravitational effects are neglected, and if a viscons resistance depending on liquid depth, viscosity, and average radial velocity and laminar flow are assumed, then the radial motion of the drop(s) can be described (1) by

$$\frac{d^2 r}{dt^2} + \alpha \left(\frac{dr}{dt}\right)^3 - \omega^2 r = 0 \tag{2}$$

where

r = disk radius, in.
t = time, sec.
$\alpha = 3\ \mu b^2/q^2\ \rho_L$, sec./in.^{2}
b = vane height, in.
q = volumetric flow rate of liquid, in.^{3}/sec.
μ = liquid viscosity, poises
ρ_L = liquid density
ω = disk angular velocity, rad./sec.

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For convenience, equation (2) can be rewritten as

$$\frac{dv}{dt} + \alpha v^3 - \omega^2 r = 0 \qquad (3)$$

since $v = dr/dt$.

SCALING AND MECHANIZATION

Suppose that the disk is 10 inches in diameter and is rotating at an angular velocity, ω, of 20800 rad/sec. The peripheral velocity of a drop at the edge of the disk then will be 208000 in./sec. or 17,300 ft/sec.

Since the radial velocity can only approach this value, the maximum value of v can be taken as 20,000 ft/sec. The equation then can be programmed, for convenience, to give v in ft/sec and r in inches as represented by

$$\dot{v} + \alpha v^3 - \omega^2\left(\frac{r}{12}\right) = 0 \qquad (4)$$

or

$$\dot{v} + \alpha v^3 - \left(\frac{\omega^2}{12}\right) r = 0 \qquad (5)$$

and we can assume that the drop is deposited on the disk at a radius, r_o, of 0.5 inches.

The scaled equation is

$$-\left[5 \times 10^{-4}\,\dot{v}\right] = 4 \times 10^{8}\alpha\left[\frac{\left[5 \times 10^{-4} v\right]}{100}\right]^{3} - 41.6\,\omega^2\,(10^{-6})\,[r] \qquad (6)$$

The potentiometer and amplifier assignment sheets are shown in Figures 2 and 3. The scaled computer diagram is shown in Figure 4.

PROBLEM Rotary Spray Drier
DATE ____________

POT NO.	PARAMETER DESCRIPTION	SETTING STATIC CHECK	STATIC CHECK OUTPUT VOLTAGE	SETTING RUN NUMBER 1	NOTES	POT NO.
1	$2000/\beta$	0.200		0.200	$\beta = 10^4$	1
2	$4.16\,\omega^2\,(10^{-6})/\beta$	0.180		0.180	$\omega = 2.08 \times 10^4$ rad/sec	2
3	$4\alpha(10^7)/\beta$	0.664		0.664	$\alpha = 1.66 \times 10^{-4}$ sec/ft^2	3
4	$0.1\,r_o$	0.500		0.050		4
5	$5 \times 10^{-5}\,v_o$	0.900		0	Static Test Only	5
6						6

Figure 2: TR-10 Potentiometer Assignment Sheet

PROBLEM Rotary Spray Drier
DATE ____________

AMP NO.	FB	OUTPUT VARIABLE	STATIC CHECK CALCULATED INTEGRATOR INPUT SUM	STATIC CHECK CALCULATED OUTPUT	STATIC CHECK MEASURED INTEGRATOR INPUT SUM	STATIC CHECK MEASURED OUTPUT	NOTES
1	$\int$	$5 \times 10^{-4}\,v$	-3.94*	+9.00			v in ft/sec
2	$\int$	$-r$	-1.80^{x}	-5.00			r in inches
3	HG	$-2.5\,(10^{-8})\,v^2$		-8.10			
4	Σ	$-5 \times 10^{-4}\,v$		-9.00			
5	Σ	$+2.5\,(10^{-8})\,v^2$		+8.10			
6	HG	$+1.25\,(10^{-12})\,v^3$		+7.29			
7							
8							*C. A. Gain = -0.1
9							^{x}C. A. Gain = -1.0
10							

Figure 3: TR-10 Amplifier Assignment Sheet

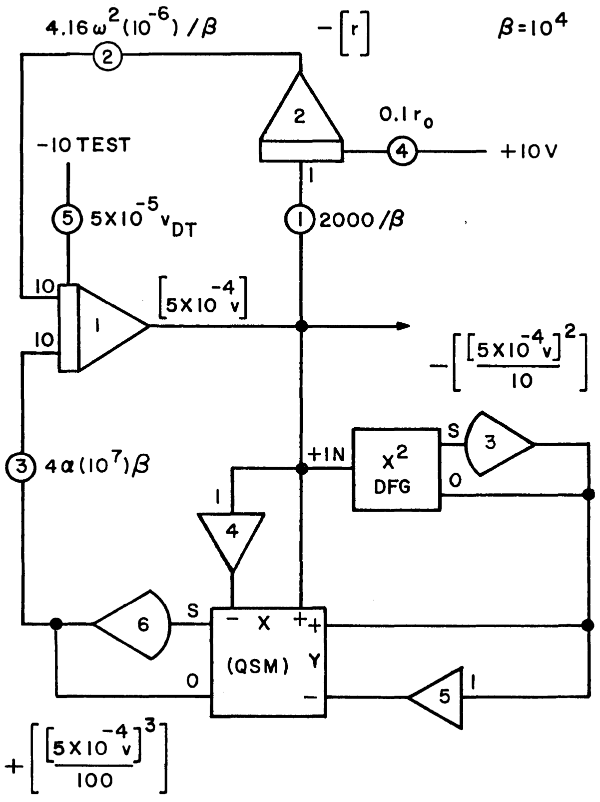

Figure 4: Scaled Computer Diagram

Static Check: For static testing, the values r = 5 in. and v = 18,000 ft/sec were used. Then, the input to amplifier #1 is $-\left[5 \times 10^{4}\,\dot{v}\right]/\beta = 39.38$ volts. Also, the input to amplifier #2 is $\dot{r}/\beta = v/\beta = 1.80$ volts. These values are based on $\alpha = 1.66\,(10^{-4})$ sec/ft^2 and $\omega = 2.08\,(10^4)$ rad/sec.

RESULTS

Figure 5 shows the results of the simulation.

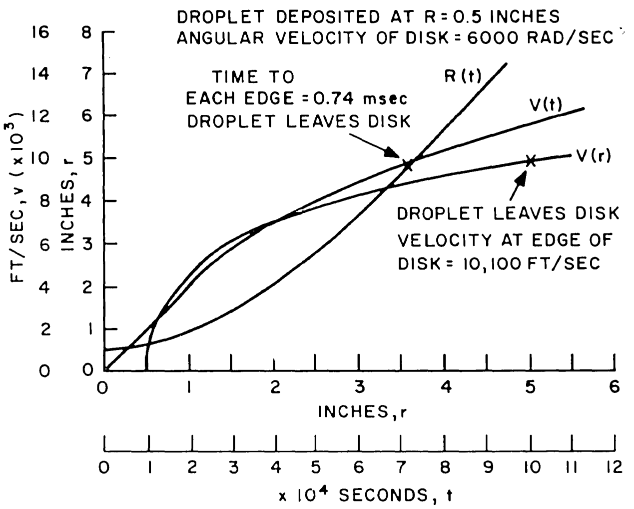

Figure 5. Radial Velocity of Droplet on a Rotary Spray Drier

Curve R (t) shows the variation of the radial position of a drop with respect to time; curve V (r) shows how the radial velocity of the drop varies as a function of drop radial position--its increase in velocity, compared to radial velocity itself, V (t), becomes less as the edge is approached.

It can be seen that, for the given values of α and ω, the drop reaches the edge of the disk in 0.74 milliseconds, having acquired a radial velocity of 10100 ft/sec at that point. At the edge of the disk, ωr = 8670 ft/sec so that the total velocity is 13310 ft/sec.

The values of α and ω can be varied as follows to obtain different curves:

$$0.05 \times 10^{-4} \leq \alpha \leq 2.00 \times 10^{-4} \text{ sec/ft}^2$$

$$0.50 \times 10^{4} \leq \omega \leq 8.00 \times 10^{-4} \text{ rad/sec}$$

COMPLEMENT OF EQUIPMENT

The major pieces of equipment necessary for this simulation include: 6 Operational Amplifiers (2 of which are used as integrators) and 5 potentiometers.

REFERENCES

(1) Marshall, W.R. and E. Seltzer, Principles of Spray Drying, Chemical Engineering Progress, Vol. 46, No. 10, October, 1950, p. 504.

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