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The theory and development of a dyeing machine employing the rotary pendulum

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THE THEORY AND DEVELOPMENT OF A DYEING MACHINE EMPLOYING THE ROTARY PENDULUM

BY

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ABSTRACT

A review of dyeing methods for carpet is made with the objective that the requirements of a new machine could be formulated. The proposal for a new machine is made in the light of the above review using a pendulum as the basic component. A theory is developed for the motion of the pendulum which is mounted on a rotating disc, and the experimental work built on theory is outlined. A prototype machine based on the rotary pendulum mechanism was used to dye impregnate carpet.

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I. INTRODUCTION

The object of the investigation reported here is the development of a rotary pendulum form of impacting device for the application of dye liquor to fabrics, particularly carpeting.

The reasons for undertaking the development of a different design of dyeing machine are centered around the increasing demands of the textile dyeing and finishing industries for more capabilities in industrial equipment. These desired capabilities are the applicability of equipment to non-uniform surfaces and to all fibers, the adaptability of machines to shade changing with minimum down time (less than 10 minutes), the reduction of water consumption per square yard of fabric, an increase in the speed of dyeing (more than 5 running yards per minute), and a reduction of costs per square yard of dyed material.

Currently, the carpet dyeing processes used in the textile industry are stock, skein, package, and piece dyeing. (See Glossary of Textile Terms, page 42, for definitions of these and other terms.) Production flow charts of dyeing processes are shown in Figure 1[1]. Stock dyeing is not shown; however, it is the most lengthy of the processes for the carpet manufacturer.

Piece dyeing has important economies over stock, skein, and package dyeing[2] and also has the following capabilities:

1. Custom dyeing in a complete range of shades from a single greige inventory;
2. Greater flexibility in introducing new shades;
3. More rapid deliveries of carpet to consumers[3].

Thus, the proposed new machine ideally should employ a piece dyeing process. A brief review of the existing piece dyeing processes used on carpets, including their good and bad points, is included to point up the need for a new design. Beck and beam dyeing, two existing piece-dyeing processes, will be reviewed in addition to the roller padding process which is being developed actively in Europe. These processes were studied in order to formulate operating parameters for the proposed new process.

In the beck dyeing process the greige carpet, approximately 150 running yards, is fed into the dye bath over a reel. The ends of the carpet are stitched together to form a continuous length which is immersed repeatedly into the dye liquor[4]. Figure 2 is a diagram of a dyebeck unit.

The primary advantage of the beck dyeing process is the consistency of uniform results from lot to lot, with economic reasons being of secondary importance[5]. The negative features

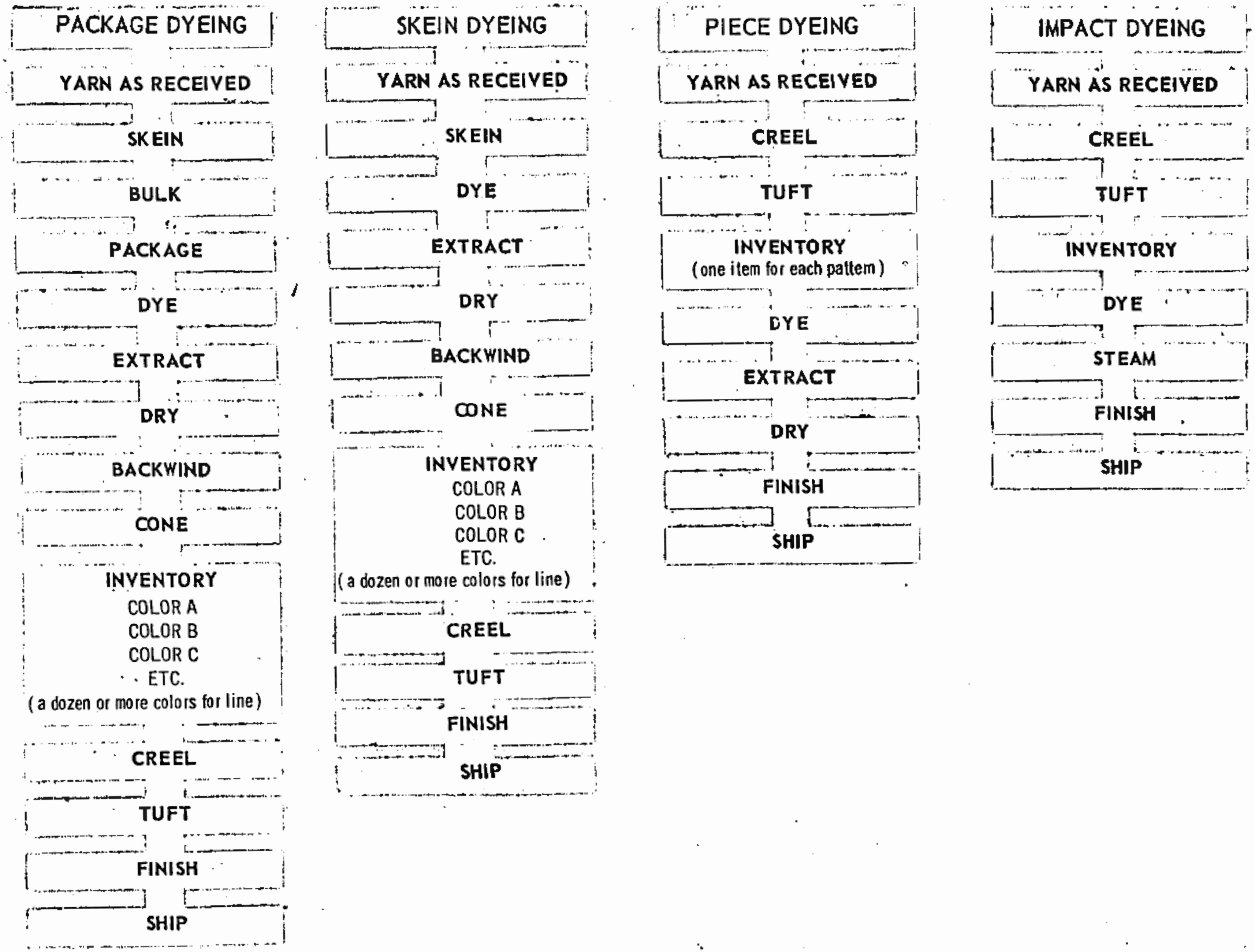
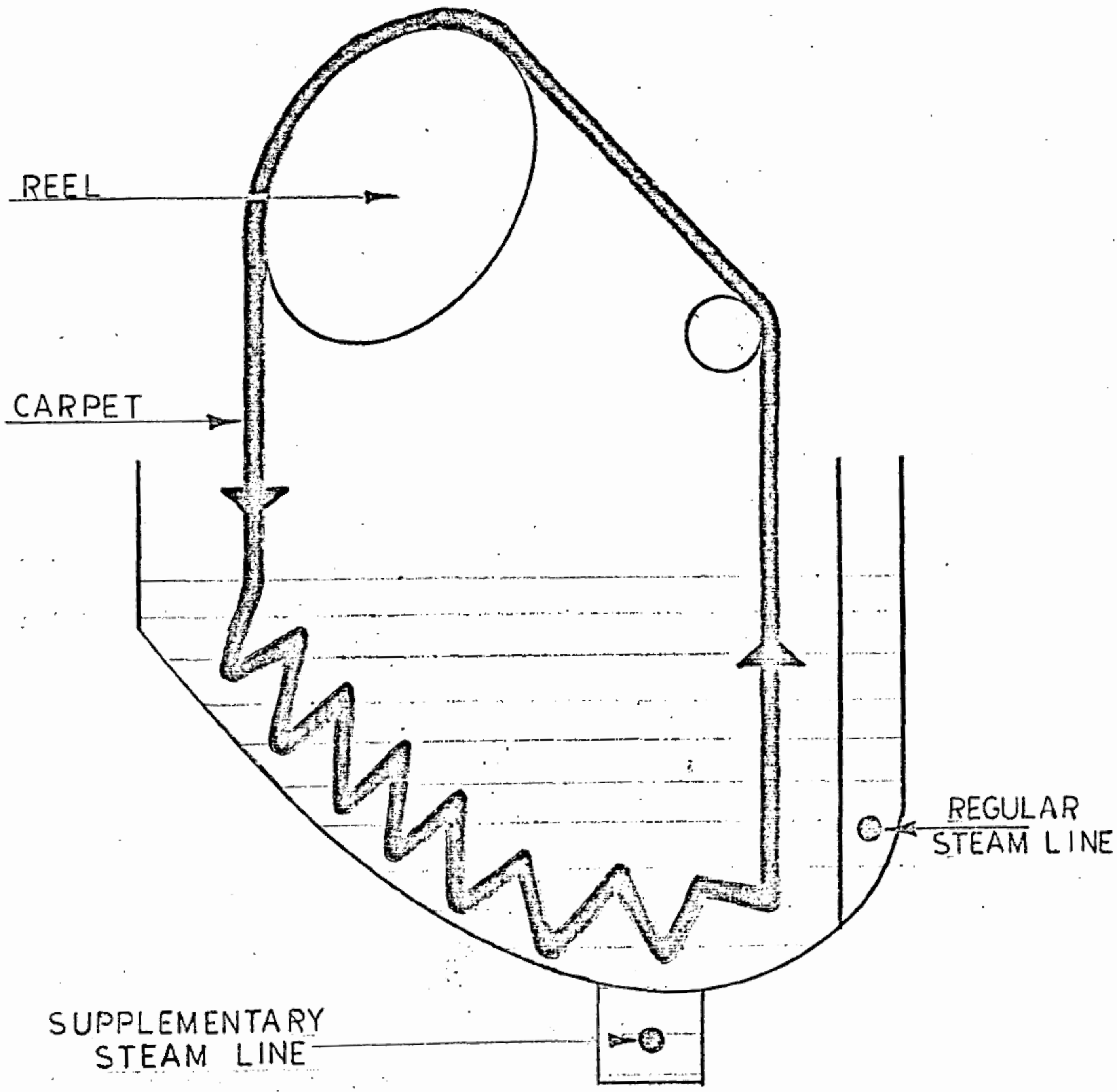

PACKAGE DYEING
YARN AS RECEIVED
SKEIN
BULK
PACKAGE
DYE
EXTRACT
DRY
BACKWIND
CONE
INVENTORY
COLOR A
COLOR B
COLOR C
ETC.
(a dozen or more colors for line)
CREEL
TUFT
FINISH
SHIP
SKEIN DYEING
YARN AS RECEIVED
SKEIN
DYE
EXTRACT
DRY
BACKWIND
CONE
INVENTORY
COLOR A
COLOR B
COLOR C
ETC.
(a dozen or more colors for line)
CREEL
TUFT
FINISH
SHIP
PIECE DYEING
YARN AS RECEIVED
CREEL
TUFT
INVENTORY
(one item for each pattern)
DYE
EXTRACT
DRY
FINISH
SHIP
IMPACT DYEING
YARN AS RECEIVED
CREEL
TUFT
INVENTORY
DYE
STEAM
FINISH
SHIP

FIGURE 1

FIGURE 2



DYEBECK UNIT

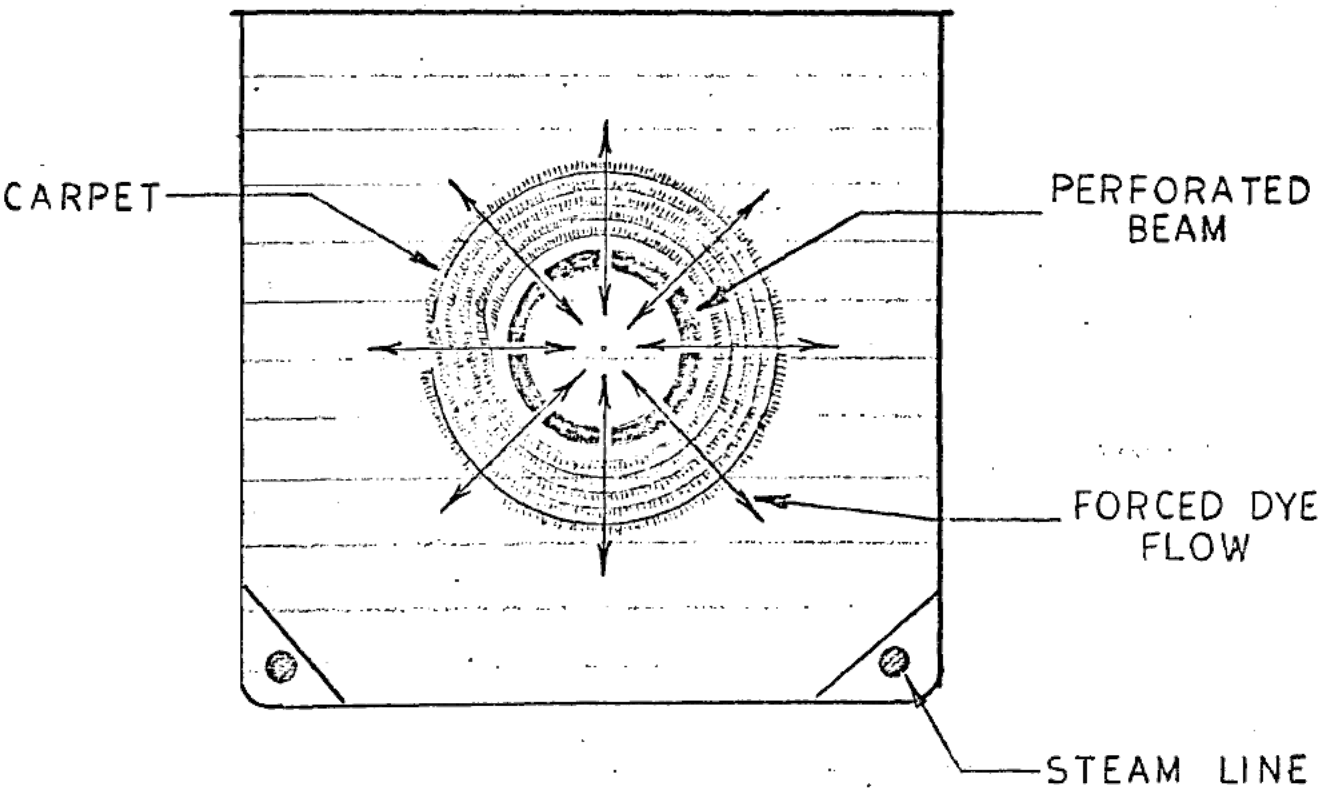
are the slowness of the process (for medium shades an average dyeing time of 4 hours per lot of 250 square yards), large water consumption (approximately 1,500 gallons per lot), and prolonged exposure of fibers to near boiling temperatures which tend to weaken the yarn. Temperature variations of the dye bath (a difference of 3° to 4°F. from point to point) can adversely affect the finish or texture of the carpet by producing pile distortion and variation of shading across the carpet width[6,7].

In beam dyeing, the greige carpet, wound on a special perforated beam, is placed in a dye machine. The dye liquor is pumped through the carpet from the center of the beam outward, and then from the outside carpet surface to the center of the beam (Figure 3)[8]. Beam dyeing is especially useful for particularly textured carpet, such as cut-pile and frieze style, where loss of twist is not as pronounced as in beck dyeing. Positive results obtained when beam dyeing carpets are as follows:

1. Minimum handling of carpet;
2. Less mending involved as carpet is stationary;
3. Virtual elimination of side-to-side shading;
4. Considerable savings in dyestuff, chemicals, water and steam because of a lower dye liquor weight to carpet weight ratio (5:1 compared to 20:1 or 30:1 for beck dyeing)[9].

As in beck dyeing, the disadvantages of the process are

FIGURE 3



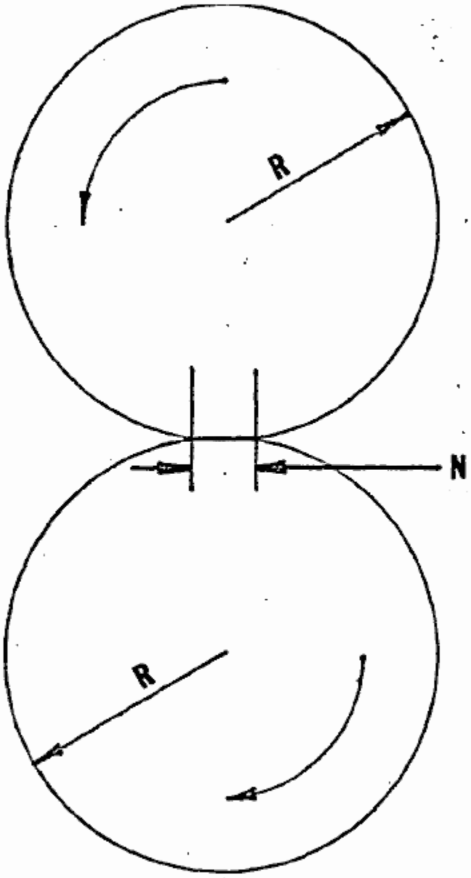
BEAM DYEING UNIT

the slowness of the procedure (which is approximately that of the beck process) and prolonged exposure to elevated temperatures.

In the roller padder process a set of squeeze rollers is used to impregnate the carpet with dye liquor by continuous passage of the carpet through the liquid and then between the rollers. The carpet is then fed into an oven for dye fixation[10]. As the use of the roller padder is currently under development, definite advantages and disadvantages are not yet known.

One major disadvantage of all the above processes is that the dyed carpet must be dried. Present vacuum systems are capable of reducing moisture in the carpeting to only about 125% of the original carpet weight, and the removal of the remaining water must be accomplished through evaporation.

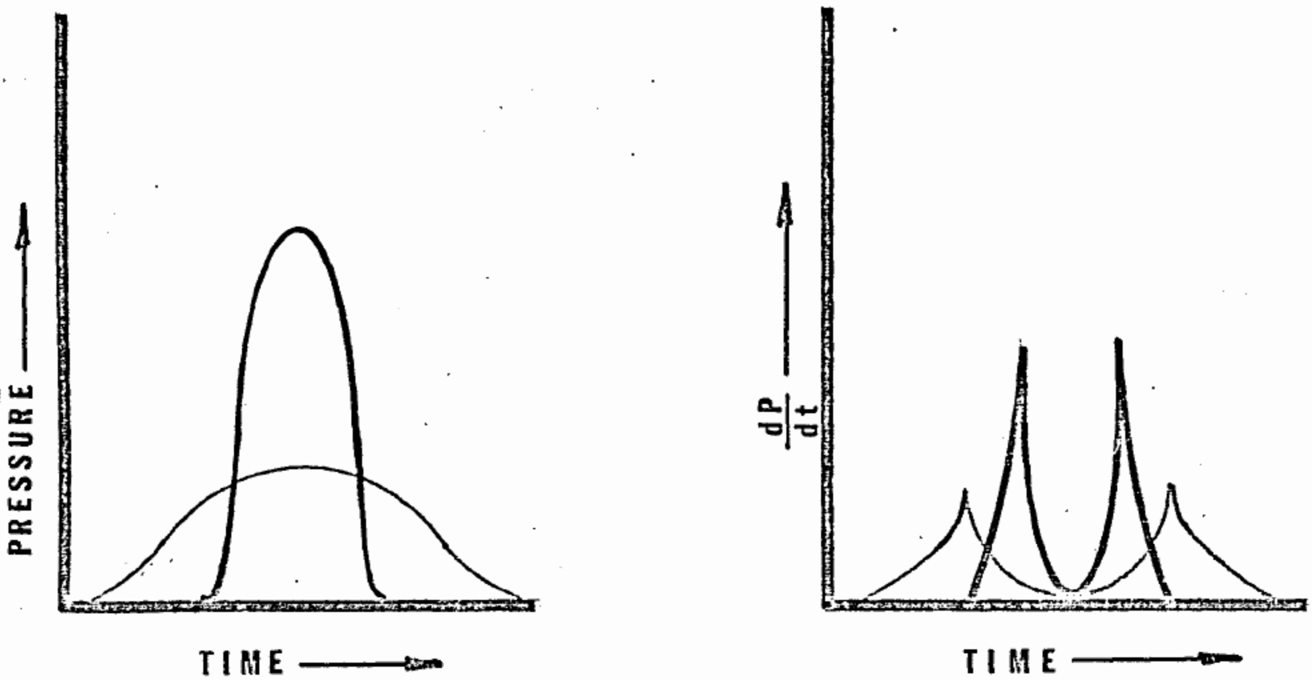
Application of the dye liquor to the carpet in low percentage amounts (less than 100% moisture content) can be accomplished using the roller padder technique. In order to apply dyes in low percentages, the voids in the carpet must be reduced in volume at the time of dye application in order that the liquor is spread over the fiber surfaces rather than into the voids. The dye liquor should not be applied to the carpet until the voids are minimized. This can be done by expressing (injecting) the dye liquor into the carpet at the same time the voids are minimized by the pressure exerted by the rollers. Figures 4 and 5 show conditions for expressing



The nip width N, is proportional to the average radius of curvature R, and the deformability $1/E$, of the rolls and also to their linear loading L.

$$N \propto \frac{LR}{E}$$

Thus, at constant loading, the nip width can be decreased by reducing both the diameter and deformability of the rolls.



Impact conditions are obtained when the rate of rise of pressure in the nip is high. Clearly the nip has to be small and the rolls must turn at a high speed.

FIGURE 4

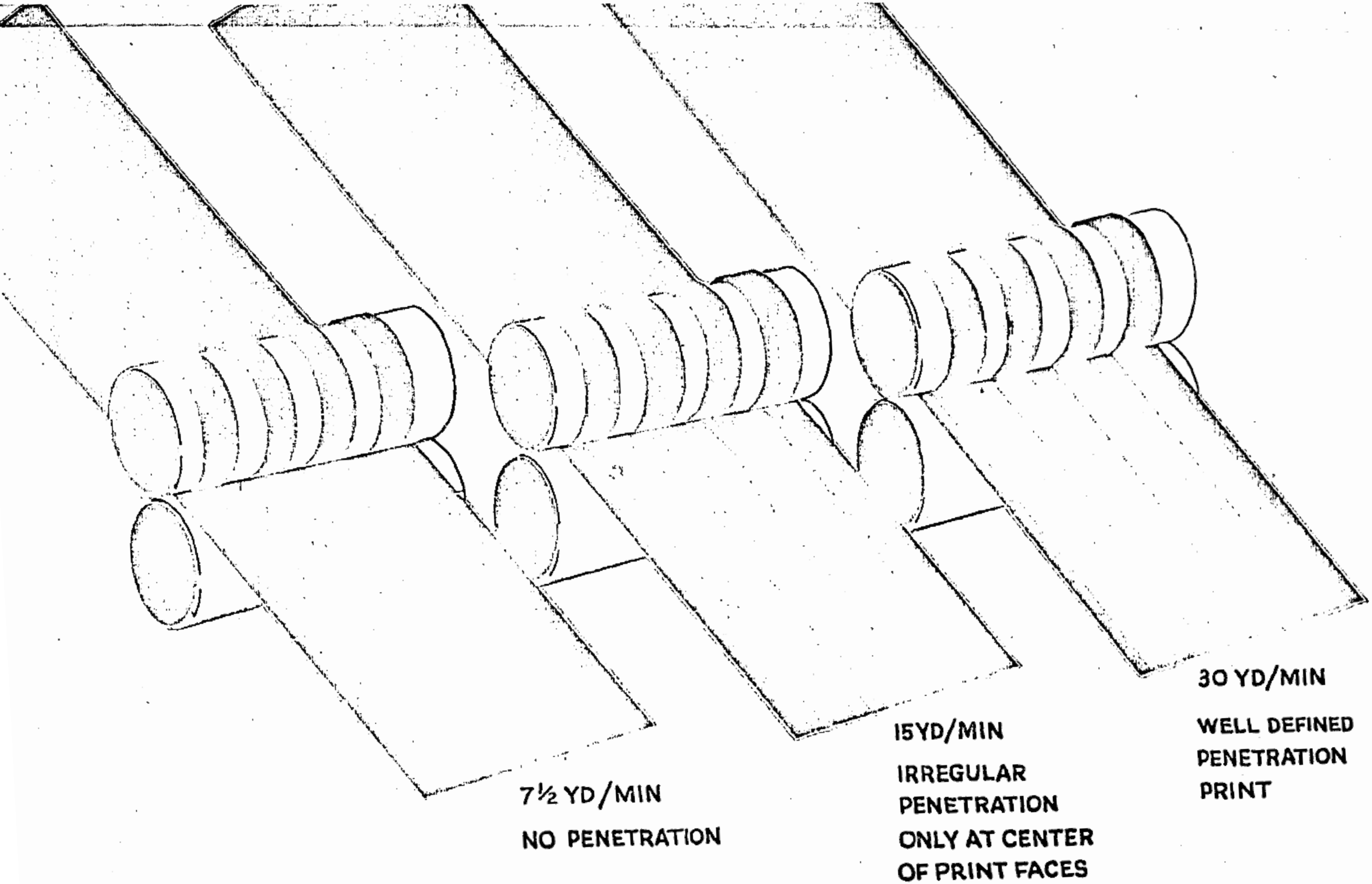

7½ YD/MIN
NO PENETRATION
15YD/MIN
IRREGULAR
PENETRATION
ONLY AT CENTER
OF PRINT FACES
30 YD/MIN
WELL DEFINED
PENETRATION
PRINT

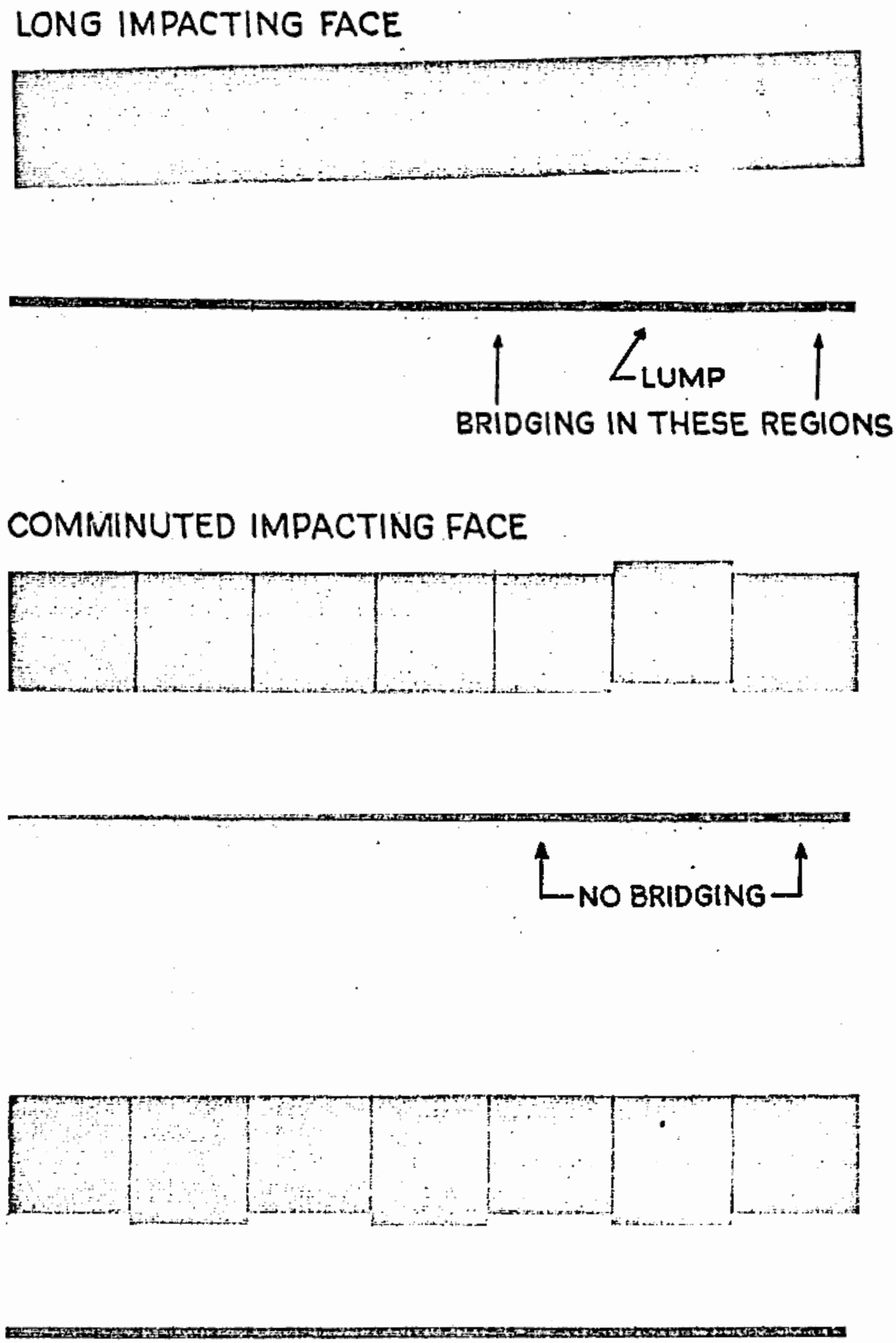
FIGURE 5

dye liquor into a woven fabric by the roller padder method.

This roller application of the dye necessitates running the carpet at speeds in excess of 100 yards per minute[11]. (To provide the reader with a basis for comparison, the general magnitudes of production speeds for various carpet manufacturing machines are: tufter, 33 yards per hour; knitter, 18 yards per hour; loom, 3 yards per hour[12].) The presence of small protuberances (e.g., a knot in yarn) would cause penetration bridging (undyed areas) to occur as high speeds when long rigid faces, such as the two faces forming a nip in the roller padder, are used. As can be seen in Figure 6, the divisions of the rigid roll into smaller units would add flexibility in the dyeing of the various carpet styles that should be processed on the proposed machine.

After reviewing the various dyeing processes, the requirements for a new design were formulated. These requirements are:

1. Applicability to any fiber;
2. Low weight ratio of dye liquor to carpet (less than 50%);
3. Applicability to non-uniform surfaces;
4. Dyeing speed of 10 running yards per minute;
5. Minimum color change-over time (less than 10 minutes);
6. Impact intensity independent of carpet speed;
7. Reduction of time the fibers are exposed to elevated temperatures.



APPLICATION TO HI-LO CARPETING IS A PARTICULAR, ALTHOUGH EXTREME, CASE IN WHICH THIS TECHNIQUE CAN BE APPLIED.

FIGURE 6

These requirements of the proposed dyeing process dictate the establishment of specifications for the machine. A low weight of dye liquor to carpet weight infers impact application methods. This low moisture content reduces the heat required for drying the carpet. Furthermore, impact application of dye liquor in these low percentages allows the use of additives which further shorten the drying time. Applicability to non-uniform surfaces means dividing the impacting face into areas having maximum dimension of 1-1/2 inches instead of a long rigid face. Impact intensity should be independent of carpet speed but the impacting frequency must be related to the carpet speed to achieve complete carpet cover.

To illustrate the complete carpet coverage, assume an impactor face one inch wide. This would require 12 faces per linear foot disposed in a row transverse to the advancing carpet. Assuming a striking length of 3/16 inch in the direction of the advancing carpet, a figure indicated by previous experiments, and an advancing rate of 10 yards per minute, a striking frequency of 32 impacts per second (or 1,920 per minute) would be needed to obtain continuous cover of a strip the width of one impactor face. The form of impactor system proposed for the new dye-application equipment must meet certain criteria, namely:

1. Ability to produce the required impacting frequency;
2. Sufficient impact intensity for dye penetration;

3. Adaptability of impact unit size to a machine frame;
4. Capital cost of machine construction.

Several possible impacting systems were considered, and comparisons were made using the above criteria. From this consideration the system designated as the "rotary pendulum" was selected as one of the prime candidates. The rotary pendulum had been attempted on an early prototype machine for print application but was set aside because of the difficulty in obtaining continuous impacting at the desired position. However, the basic simplicity of the rotary pendulum indicated that a mathematical study of such a system to obtain an understanding of its operation was worthwhile. Thus, control of this system in a repetitive manner for use in the proposed machine might be achieved. From an understanding of the rotary pendulum, impact at the desired position with correct radial positioning of the pendulum, might be achieved if the proper parameters could be determined.

Thus, the object of this research was to develop an equation describing the motion of the rotary pendulum, solve the equation and apply the solution, if feasible, to the construction of a device to achieve dye application to carpet by impact.

II. THEORY

A pictorial drawing of the various components of the rotary pendulum system, indicating how they are arranged relative to one another, is shown in Figure 7. Rotation of the hub moves the pendulum head along the impacting roll-carpet surface until reaching the point at which the pendulum can swing free. The pendulum, swinging freely about the pivot on the hub as it rotates, strikes the carpet and dye reservoir which are passing over the impacting roll simultaneously. The impact expresses the dye, carried in the reservoir, into the carpet.

It was planned to have the pendulum strike the carpet when it was in or near its radial position, then follow the moving carpet surface until it lost contact with it and finally swing freely into the radial position again at the time the hub has completed one revolution from the previous impact. Any tendency to swing past the radial position could cause jamming of the pendulum into the impacting roll.

This plan demanded that there be a certain relationship between the hub radius (a) and the pendulum length (L).

PICTORIAL DRAWING OF ROTARY PENDULUM

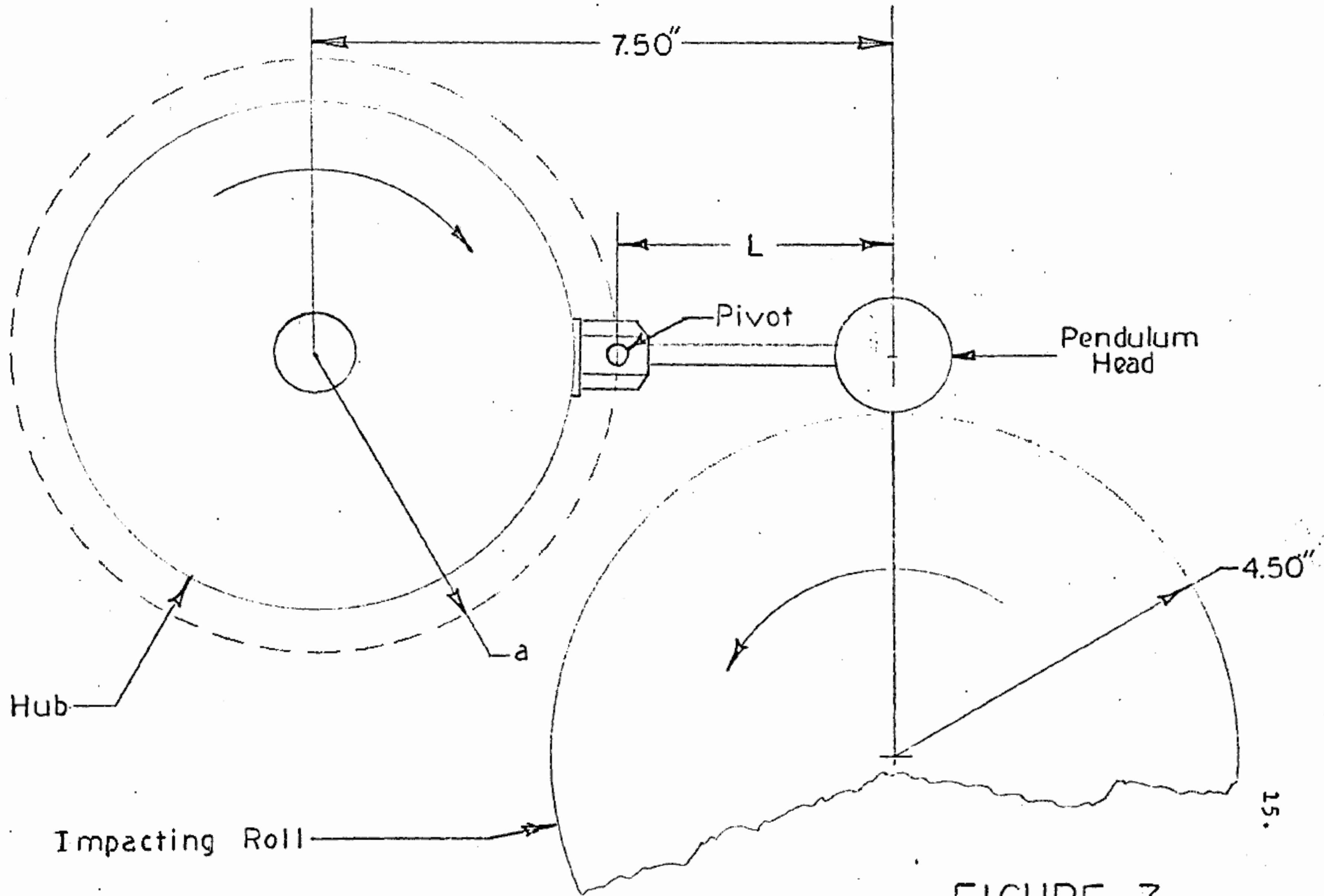


FIGURE 7

Furthermore, believing that the physical quantity required to express the dye from its reservoir into the carpet was the momentum of the pendulum, an experiment was performed with impactors used in an earlier prototype machine and the magnitude of the momentum needed was determined to be 13 kgm-m/sec[14]

In order to facilitate fabrication in the shop the dimensional limits were placed on the sum of the hub radius and pendulum length at 7.50 inches, and the impacting roll diameter at 9.00 inches. This meant that the sum of the hub radius, pendulum head diameter, and impacting roll radius could not be greater than the distance between the centers of the hub and the roll. Otherwise, the pendulum head would not pass between the hub and the roll. Assuming one pendulum per unit width, with the above dimensions, a pendulum head mass of approximately 225 grams would be required to produce the momentum believed necessary at 1,920 revolutions per minute for complete penetration of the heavy carpet (45 oz/square yard of Acrilan®) by the dye liquor. The size of the pendulum head meeting the above mass requirements and dimensions is 1-1/2 inches in diameter by 1 inch in length.

In order to determine the effect of the hub radius (a) and pendulum length (L) on the motion of the pendulum it was necessary to derive and solve the equation of motion for the system and then ascertain if the desired operating conditions could be fulfilled.

These operational conditions are that the impact occur near or at the radial position, that the angle the pendulum makes with the hub radius be decreasing, and that there be no undetermined velocity component upon release from the impacting roll.

Figure 8 is a diagram of the rotary pendulum at some point in its motion showing the forces acting on the pendulum head. To simplify the problem initially, the total mass of the pendulum will be considered located at the center of the pendulum head and gravity was neglected. These assumptions are justified later.

The horizontal and vertical components of the force (F) exerted on the pendulum head produce corresponding accelerations of the mass (m), and the resulting equations of motion are:

$$m\ddot{x} = -F\cos\alpha$$

$$m\ddot{y} = F\sin\alpha$$

Relative to an origin at the center of the disc

$$x = a\sin\theta + L\sin(\theta+\phi) \text{ where } \theta = -wt$$

also

$$y = -a\cos\theta - L\cos(\theta+\phi)$$

Taking the second derivatives of x and y, and putting them into the equations of motion give

$$m[-aw^2\sin(-wt) - L(w+\dot{\phi})^2\sin(-wt+\phi) + L\ddot{\phi}\cos(-wt+\phi)] = -F\cos\alpha$$

$$m[aw^2\cos(-wt) + L(-w+\dot{\phi})^2\cos(-wt+\phi) + L\ddot{\phi}\sin(-wt+\phi)] = F\sin\alpha$$

Multiplying the first equation above by $\sin\alpha$ and the second by $\cos\alpha$, adding and simplifying gives

FORCES ON ROTARY PENDULUM IN FLIGHT

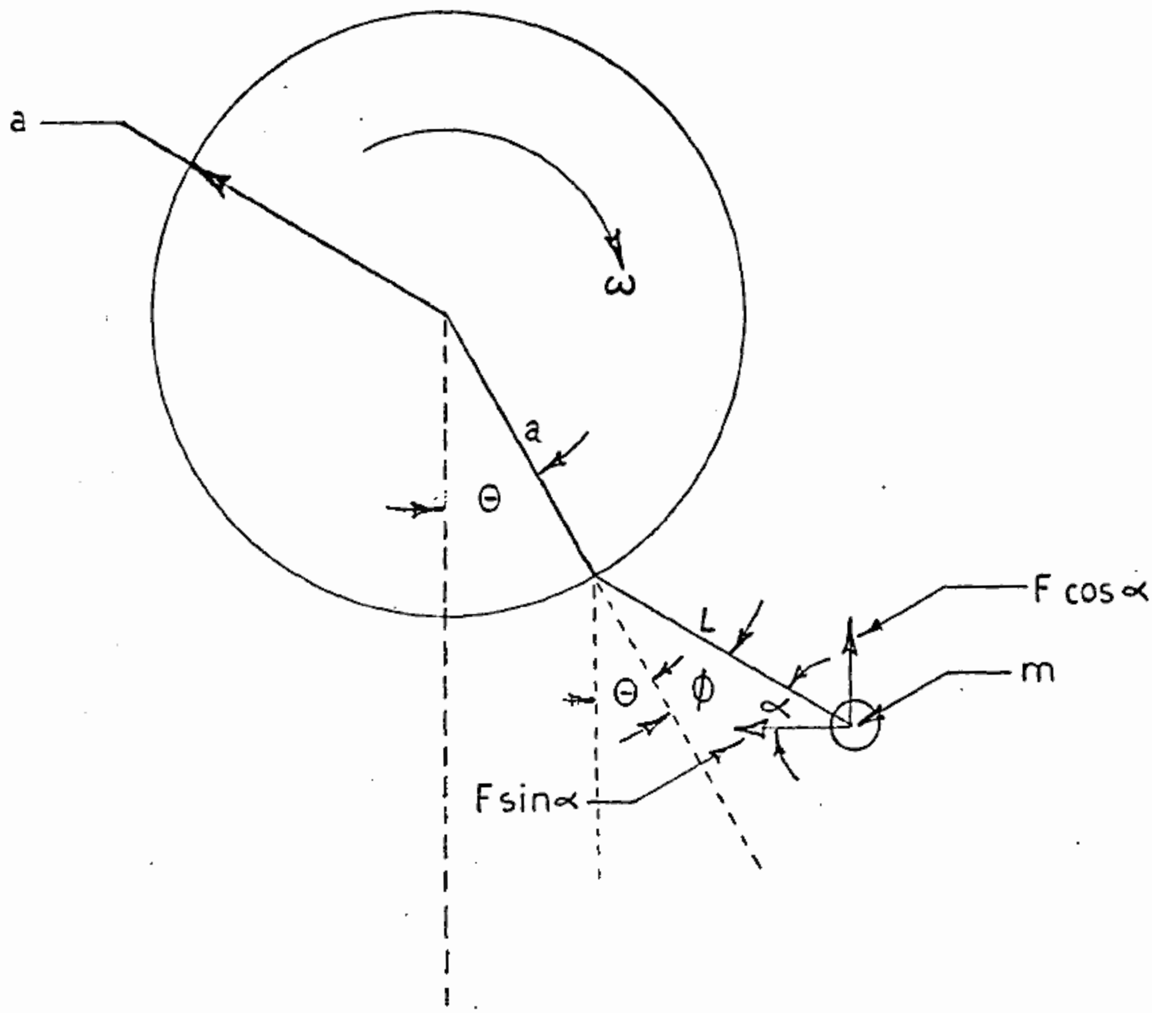


FIGURE 8

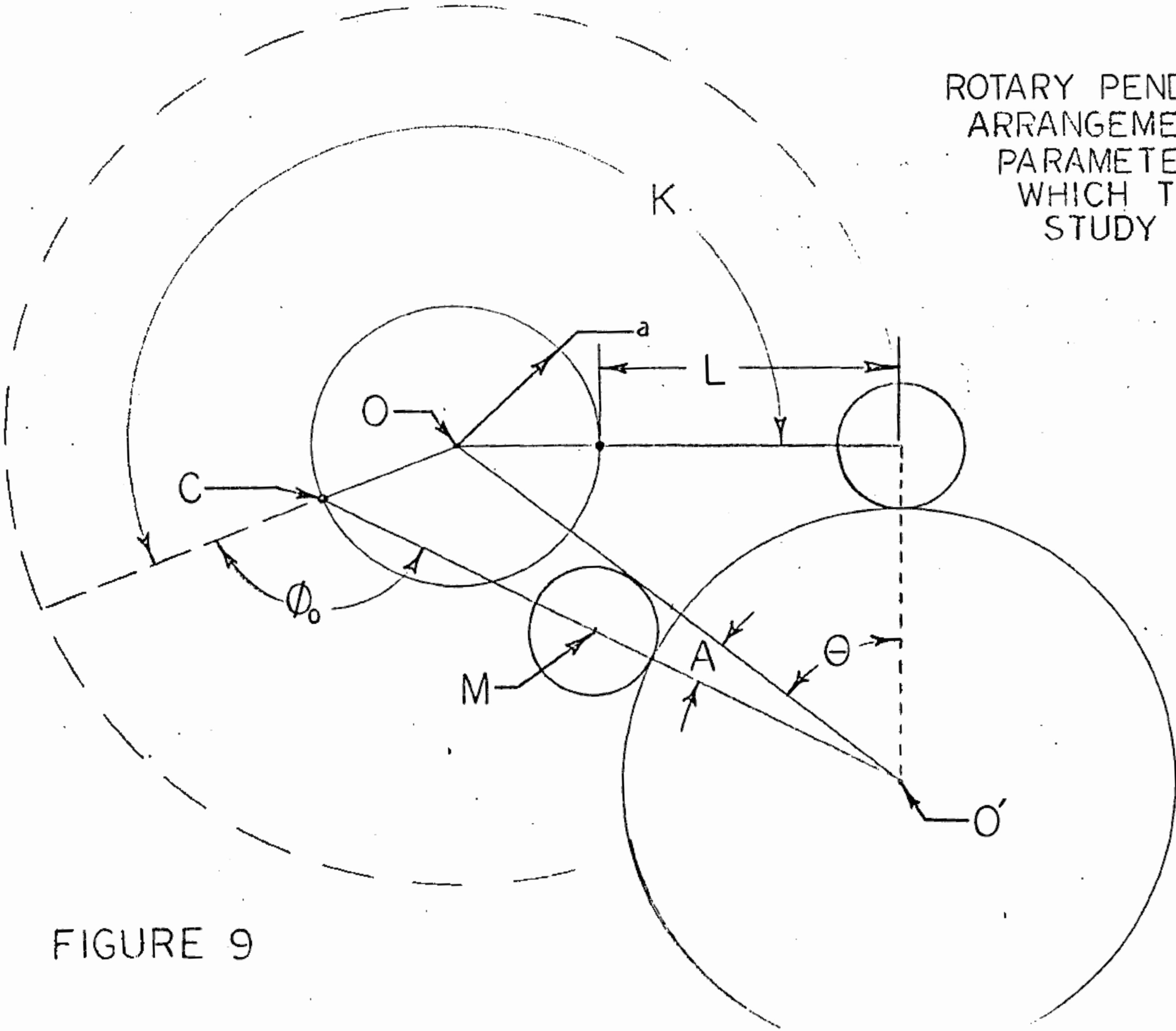
$$\ddot{\phi} = -\frac{w^2 a}{L}\sin\phi$$

which is the equation for a simple pendulum when g is replaced by $\frac{w^2 a}{L}$. The descriptive name of the impact device or rotary pendulum naturally evolved from the fact that its equation of motion is related to that of a simple pendulum.

III. SOLUTION OF EQUATION OF MOTION

This section deals with the method used to obtain the specific solution to the equation of motion of the rotary pendulum which would position the pendulum radially at the moment it strikes the impacting roll subject to the condition that the pendulum started its outward swing upon release from the surface of the impacting roll. The rotary pendulum arrangement on which the computer study is based is shown in Figure 9. The angle K is the arc the pendulum pivot traverses from the moment the pendulum head swings free of the impacting roll until the pendulum, if it were in a radial position, would strike the impacting roll when the pivot was in a horizontal position. The angle $\emptyset_o$ is measured from the extension of the radius passing through the pendulum pivot around to the line from the pivot to the center of the head (CM) at the moment of swing free. A is the angle between the line connecting the centers of the hub and the impacting roll (OO') and the line from the pendulum pivot to the center of the impacting roll (CO') at the moment of pendulum release. The equations and parameters used to determine the initial values at pendulum

ROTARY PENDULUM ARRANGEMENT AND PARAMETERS ON WHICH THE COMPUTER STUDY IS BASED



$OC = a$

$CM = L$

$a + L = 7.50''$

FIGURE 9

release in finding solutions to the equation of motion are shown in Figure 10. The purpose of the series of solutions to the equation is to determine if the specific solution desired can be obtained in the range of possible parameters. Other than the physical parameter possibilities, the series also includes rotational velocity changes in representative steps up to the maximum projected velocity of 209 rad/sec (1920 rpm). Thus, from start-up of the rotary pendulum to the final operational speed of 1920 rpm would involve a transition through lower speeds; any existing condition which might cause difficulties should be anticipated.

The computer group of the company was requested to assist in the study by using the Pace 231R analog computer to plot the curves of the pendulum motion for a series of cases. The computations were based on initial values obtained from the equations and parameters in Figure 10.

Figure 11 is an example of the graphs obtained in the series of case studies. In each study the angle ϕ between the pendulum arm (L) and the extension of the hub radius (a) is shown, along with the sine and cosine of ϕ, and the angular velocity, $d\phi/dt$. The angular velocity of the hub is w radians per second. The inclusion of scale factors (i.e., 1.4×10^{-3} in Figure 11) is the practice of the computer group in making permanent recordings. The horizontal axis of the graph is the time axis, where one machine unit is the time interval measured from the instant the pendulum swings free of the impacting

FIGURE 10

The following equations and parameters were used to determine the initial values to be supplied to the computer group for use in programing the analog computer.

Radius of Circle O is 7.50"
Radius of Circle O' is 4.50"
Pendulum head diameter is 1.50"
a + L = 7.50"
Radius of pendulum head center around Circle O' center is 4.50" + .75" = 5.25"

$\emptyset_o$ is the angle the pendulum relative to the extension of the hub radius at the moment the pendulum is released from the impacting roll surface.

From Figure 9, it can be determined that

$$\emptyset_o = \cos^{-1} \left[\frac{83.81 - a^2 - (12.75 - a)^2}{2a(12.75 - a)} \right]$$

and

$$A = \sin^{-1} \left[\frac{a \sin \emptyset_o}{83.81} \right]$$

K (in degrees) = $360 - (\emptyset_o - A + 35°0')$ or $325° + A - \emptyset_o$

35° is determined from the geometry of the mechanism. K (in radians) is equal to the angular velocity (w) times the time (t) to rotate through the angle K.

Hence, the time can be determined by

$$t = \frac{K \text{ (in radians)}}{w}.$$

roll surface to the time the extension of the hub radius is in the impacting position (horizontal). To find the value of any one of the plotted variables in terms of the original problem, divide the included scale factor into the corresponding value on the vertical axis. The sign of Ø has been chosen positive when L "lags" a, and when L "leads" a, Ø is negative. Figure 11 shows the pendulum (1) lagging the radius extension, (2) passing through the radial position, and (3) leading the radius extension.

Figure 12 shows the percentage of the angle K to obtain radial positioning of the pendulum as a function of hub radius. A plot of the rotational speed of the hub against the percentage of the angle K for radial positioning for various hub radii shows the pendulum response to be insensitive to the speed of rotation (see Figure 13). The case study plots can be divided into two separate groups which are (1) plots to determine if the specific solution desired could be obtained in the range of possible parameters (a = 2.0 to 4.5 inches); and, if so, then (2) plots converging on the specific solution found by reducing the increments of a in the indicated range.

The specific solution desired is where Ø is zero in 1.0 machine time unit. Case 36 (Figure 14) shows Ø has decreased almost to zero and L is lagging slightly. In this case study the hub radius is 2.25 inches and the pendulum length is 5.25 inches. The dimensions used in this case study were used to fabricate the first rotary pendulum.

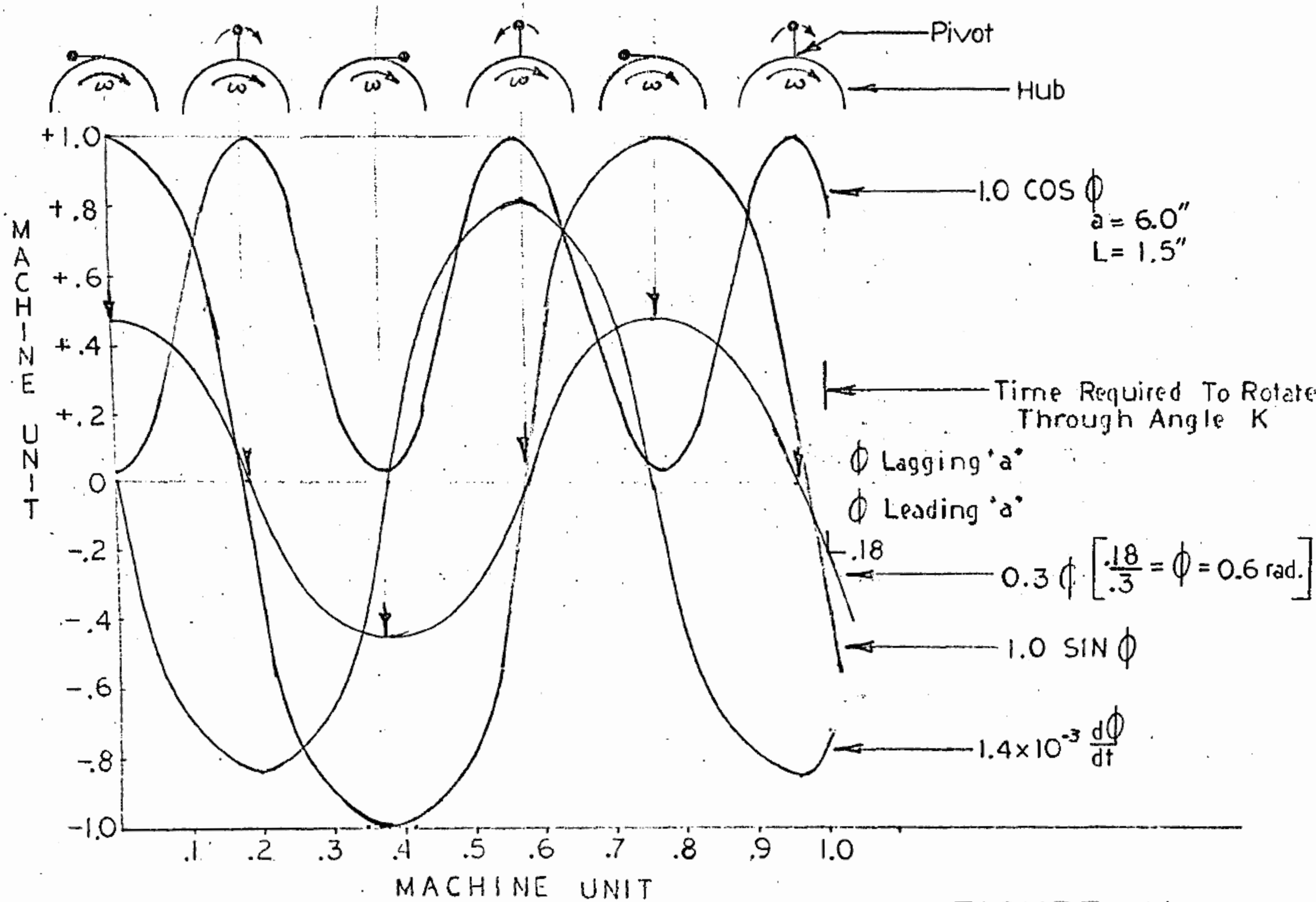
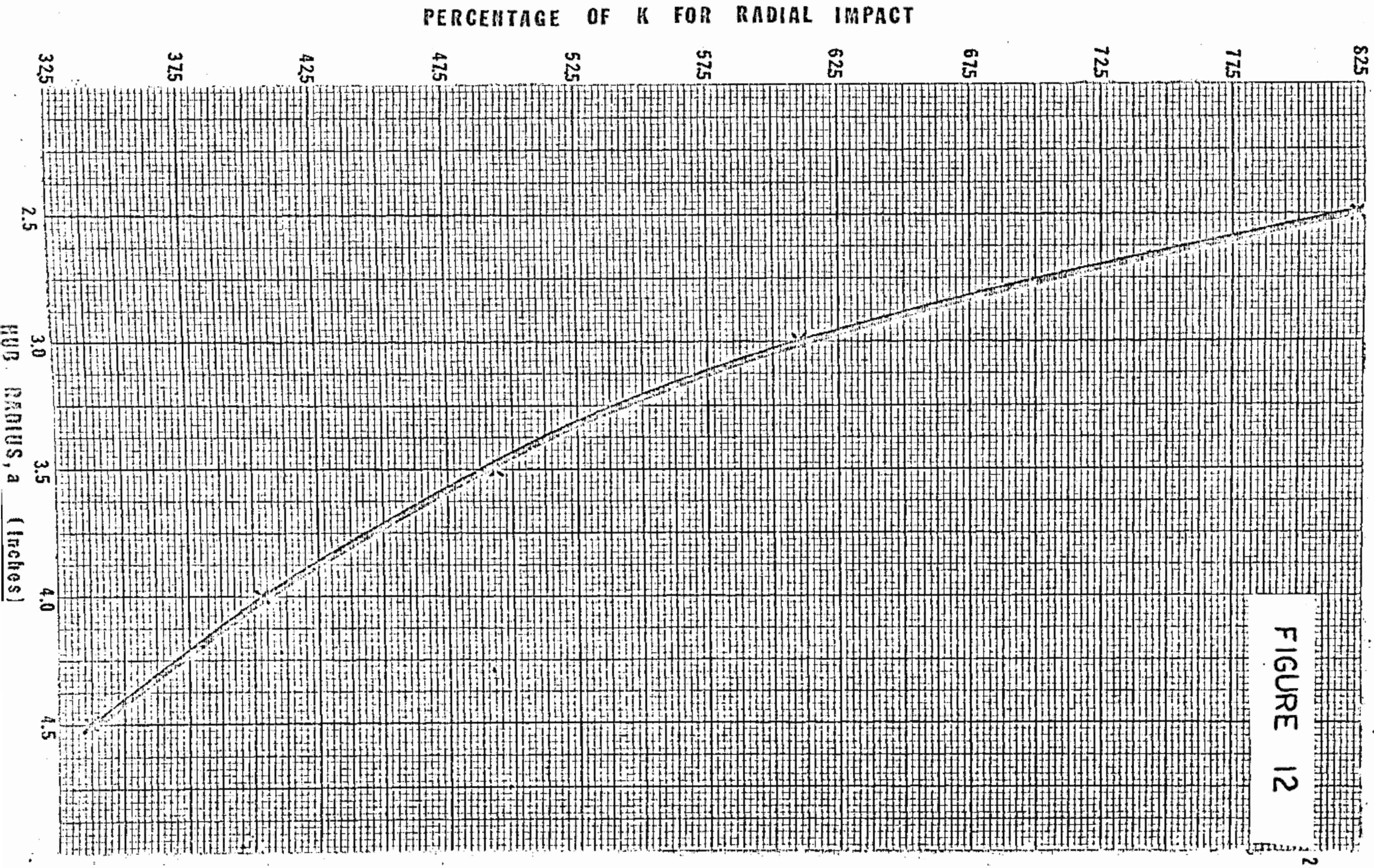

Pivot
Hub
ω
+1.0
+.8
+.6
+.4
+.2
0
-.2
-.4
-.6
-.8
-1.0
MACHINE UNIT
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
MACHINE UNIT
1.0 COS ϕ
a = 6.0"
L = 1.5"
Time Required To Rotate Through Angle K
ϕ Lagging 'a'
ϕ Leading 'a'
.18
0.3 ϕ [.18/.3 = ϕ = 0.6 rad.]
1.0 SIN ϕ
1.4×10^-3 dϕ/dt

FIGURE 11



PERCENTAGE OF K FOR RADIAL IMPACT
32.5
37.5
42.5
47.5
52.5
57.5
62.5
67.5
72.5
77.5
825
2.5
3.0
3.5
4.0
4.5
HUB RADIUS, a (Inches)

FIGURE 12

RESPONCE of the ROTARY PENDULUM to SPEED of ROTATION

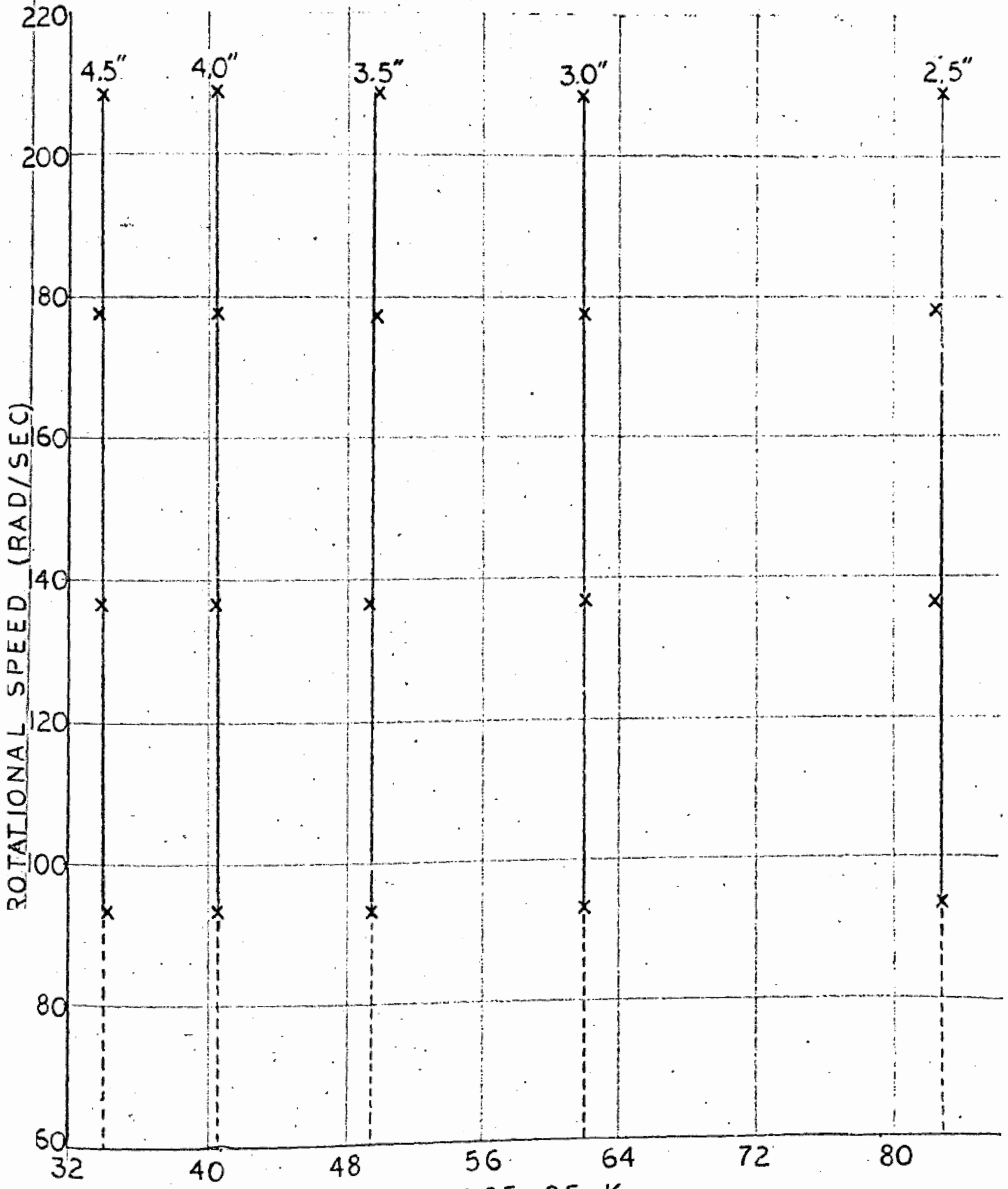


FIGURE 13

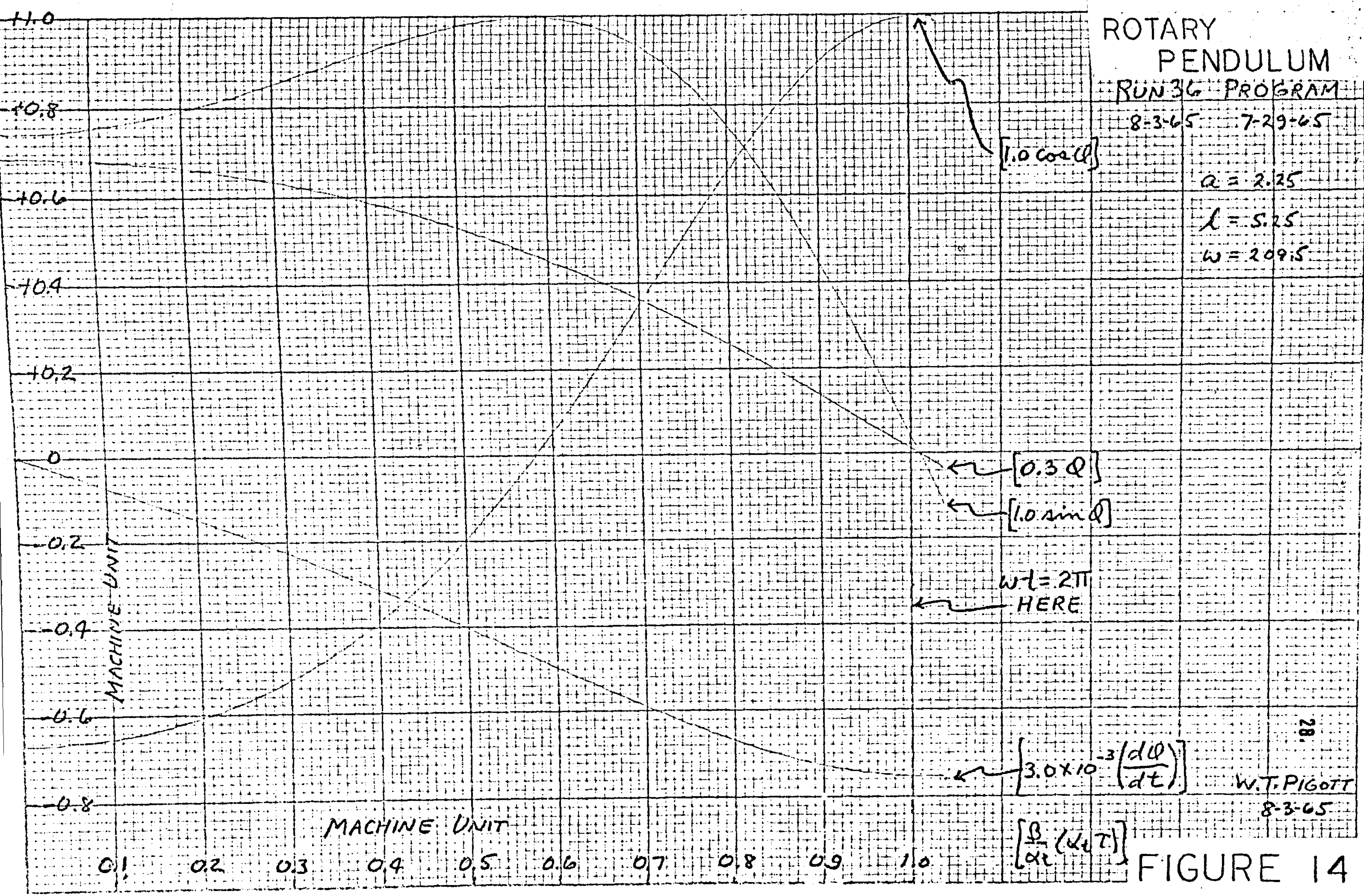

ROTARY
PENDULUM
RUN 36 PROGRAM
8-3-65 7-29-65
a = 2.25
l = 5.25
ω = 209.5
[1.0 cos θ]
[0.3 θ]
[1.0 sin θ]
ωt = 2π
HERE
3.0×10⁻³ (dθ/dt)
W.T. PIGOTT
8-3-65
MACHINE UNIT
MACHINE UNIT
+1.0
+0.8
+0.6
+0.4
+0.2
0
-0.2
-0.4
-0.6
-0.8
0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0

FIGURE 14

IV. MACHINE DESIGN AND TESTING

The first rotary pendulum fabricated was a dimensional model in plexiglas using the values of a and L determined in Run 36. The hub was rotated at speeds up to 100 rpm to determine how nearly the pendulum was responding to the theoretical prediction. By means of a strobe light and a polaroid camera, photographs were made which showed the motion of the pendulum. These photographs indicated that in over two-thirds of the trials the pendulum was lagging the pivot radius by 20° or less at the moment the pivot radius was horizontal. Some interfering factor was causing the pendulum to lead the radius extension sometimes and then lag by over 20° in other instances.

This variation in angles was believed to be due to the low power of the motor as surging of the hub was viewed following the impact of the pendulum on the impacting roll. However, with a favorable percentage of the photographs showing acceptable operation, it was decided to fabricate the pendulum in steel using the relationships of Run 36.

Using this second pendulum, attempts were made to obtain moderate rotational speeds compared to the desired 1920 rpm.

These attempts were failures. Pendulum arms broke and pivot bearing showed damage. In an attempt to reduce these effects the cross-section of the arm was continually increased, but this did not solve the problem of arm breakage or damage to the bearing. Furthermore, the increase in the size of the arm affected the motion of the pendulum. The larger arm in effect was moving the center of mass toward the pivot, which, in turn was changing the ratio of a to L causing the pendulum to lag the pivot radius to a ~~greater~~ LESSER degree.

The damage to the pivot bearing indicated that the impact was not taking place at the center of percussion. Once the pendulum design was modified so that the point of impact and the center of percussion coincided, the rotational speed could be increased without damage. The center of mass of the pendulum was maintained at 4.70 inches from the pivot, but the overall pendulum length was increased significantly to 6.10 inches. This increased length delayed the time of release from the impacting roll and, hence, the result was that the pendulum lagged the pivot radius at impact.

An additional problem evolved as the rotational speed increased. This was the rebounding of the pendulum off of the impacting roll at these higher speeds. Not only did the pendulum rebound off the impacting roll but also off the hub surface. The continual rebounding between the impacting roll and the hub surface meant the pendulum was not being released from the impacting roll surface with zero relative velocity.

Release of the pendulum with some initial relative velocity, whether in the direction of decreasing Ø or not, meant that the pendulum's motion was no longer repetitive. Some means had to be devised to control the point and velocity at which the pendulum was released. A mechanism called an escapement was installed on this second rotary pendulum (see Figure 17). The escapement arrested the successive rebounds between the hub and impacting roll, and provided a definite point of release for the pendulum.

Now, it was found that at rotational speeds in the general range of 700 rpm, the carpet backing was being damaged and the tufts were being pulled out and lower operation speeds were indicated. However, a pendulum with the same mass as required by the 1920 rpm condition would not produce dye impregnation of the carpet at lower speeds if momentum was the physical quantity required. Previous experimentation with dye expression had been carried out at low velocities using large masses. This experience showed that carpet damage did not occur when dye expression was achieved at these low velocities. This led to the consideration of energy as the pertinent physical quantity involved in dye expression and penetration. The magnitude of impactor energy but not the momentum at 300 rpm for the 225 gram pendulum was near that of the machines from which experience had been drawn. Hence it appeared that the physical quantity desired was not momentum as originally believed, and thus lower angular speeds appeared feasible. **In the above analysis it is assumed that the stopping of the hammer in each case was under similar conditions.**

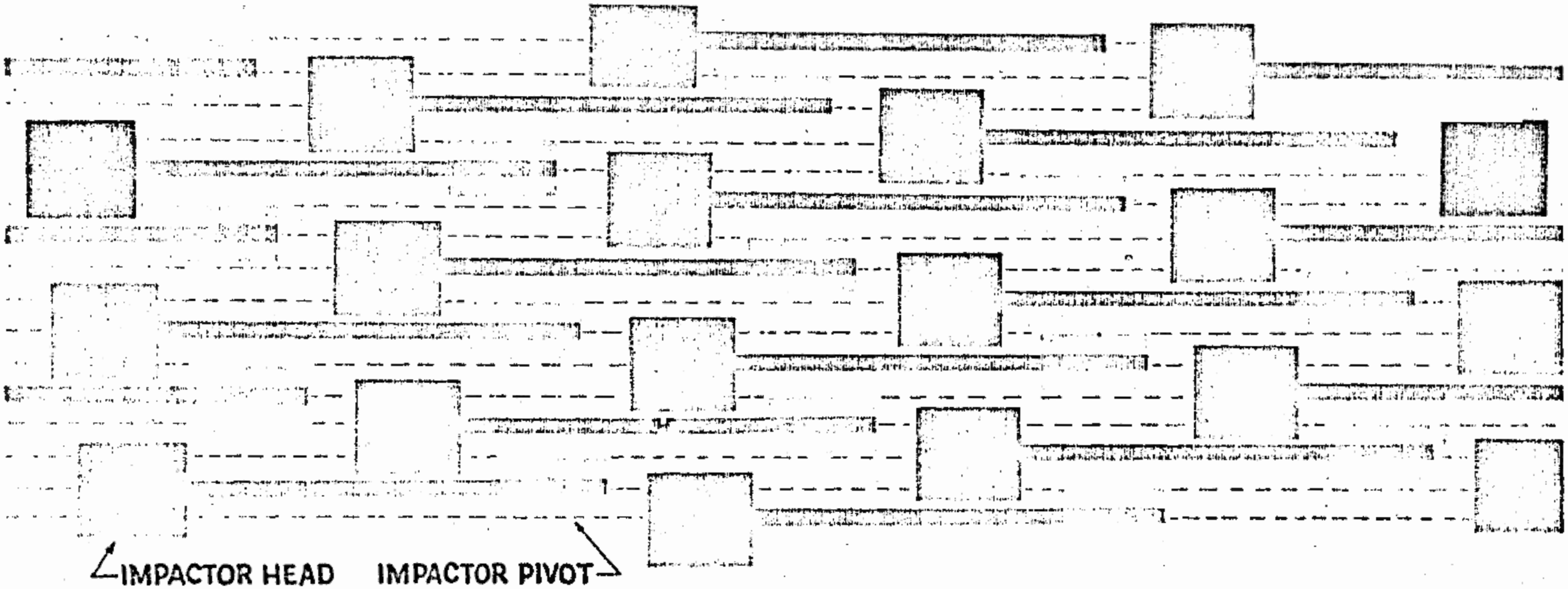
The energy magnitude at approximately 300 rpm suggested the idea of replacing the single pendulum with six pendulums per unit width equally spaced around the hub. This last problem was solved by replacing the single pendulum per transverse position, which called for 1920 rpm, by six pendulums which required the easily obtainable rotational speed of 320 rpm.

To ascertain if the above idea was feasible, a dyeing run was made using the existing one pendulum machine, and a carpet speed of 1/6 of the proposed 10 yards per minute. This run was successful and a continuous strip of dye impregnated carpet the width of the pendulum head was obtained.

When considering the usage of the six pendulums per position in a machine which ultimately would be 180 inches wide, the problem of positioning the pendulums so that they would not interfere with one another arose. A satisfactory tessellation for positioning the pendulums was found using impactor faces 1-1/8 inches wide and is shown in Figure 15. This tessellation had the advantageous built-in feature that provided for overlapping of the impact areas. This overlapping meant that a carpet would be dyed uniformly. The pendulum arrangement and pendulum head width was such that the total area of the carpet would be uniformly impacted with the exception of three-fourths of an inch on each outside edge. However, this portion of the carpet is trimmed during further finishing steps and presents no problem.

180°

TWO IMPACTORS 180° APART
LIE ON EACH 3/8" LONGITUDINAL POSITION



180° EXPANSION OF IMPACTOR DRUM SHOWING IMPACTOR TESSELLATION

THE DRUM IS DIVIDED LONGITUDINALLY INTO 3/8" DIVISIONS AND TWO IMPACTORS 180° APART ARE CENTERED ON EACH 3/8" DIVISION. THE IMPACTOR HEADS ARE 3x3/8" (1 1/8") WIDE SO THAT IN ONE REVOLUTION OF THE DRUM EACH 3/8" LONGITUDINAL POSITION OF THE MATERIAL UNDERGOING IMPACT RECEIVES SIX IMPACTOR BLOWS.

SCALE: FULL SIZE

FIGURE 15

Intermeshing of the impactors without collision among themselves is dependent upon control of the pendulum motion, both before and after impact. Control of a pendulum means that the pendulum must be arrested and released unfailingly from a predetermined position. A mechanism called an escapement was employed to assist in arresting the rebounding pendulums and to provide a definite release point. The escapement is a flexible surface which moves in a circle around the hub axis. A feature of this escapement device is that the pendulum release point can be varied, thus causing the pendulum to strike from the radial position or any other desired position in its flight. This feature of the escapement is used to vary the striking velocity making it possible to regulate the impact energy to the penetration requirement of the particular carpet being dye impregnated.

With the employment of the escapement the requirement that the pendulum be radial in one machine unit of time from the original release position was removed. A ratio of pendulum length to hub radius which produces a more rapid closure rate of ϕ was now needed since an effective escapement would reduce the angle traversed by the pendulum during free flight. Since the equation of motion involves only a ratio of the hub radius and pendulum length, any values of a and L can be used as long as the ratio is within the limits of the original solutions. Information on the motion of the pendulum can be determined for any values of a and L from those already calculated by the computer. Figure 16 is an example of how to obtain this information for any ratio within the above limits. The layout of the rotary pendulum assembly is shown in Figure 17. Figure 18 illustrates the arrangement of six pendulums which would be found in a cross-section of the machine 1-1/8 inches wide.

Figure 19 shows the flight of a rotary pendulum from various escapement openings. From photographs similar to these, the velocity of the pendulum relative to the pivot radius at impact could be determined by knowing the flash frequency of the strobe and measuring the distance between the pendulum head centers. Such measurements of the velocity in the above manner show agreement with the velocities that are predicted by the plots.

FIGURE 16

This figure is an example of how to extract pendulum motion information from the analog plots. A similar exercise was carried out in order to obtain the escapement opening required for radial positioning of the pendulum. Using this opening, the release point relative to the impacting roll could be determined. An adjustible escapement along with a stationary section, could be designed so any position of the pendulum up to radial could be used for impacting the carpet.

For example, using the present parameters of the machine

$$L = 4.45''$$
$$a = \underline{6.31''}$$

$$a + L = 10.76''$$

the escapement opening for radial positioning can be calculated. To convert the present parameters to those of an analog plot, setting up a ratio using a/(a+L).

Present parameters: $\frac{6.31''}{10.76''}$ Plot: $\frac{a}{7.50''}$

Equate the two ratios and solve for the hub radius, a

or $a = 4.40''$.

No analog plot exists for a = 4.40". Using the information in Figure 10, the angle K is 275°. However, the percentage of the hub rotation, K, for radial positioning can be obtained for Figure 13. The percentage of K for radial positioning when a is 4.40" (and L = 3.10") is 34.7. The desired percentage of K = 275° x .347 = 95°.

The escapement must be opened 49° more than the desired percentage of K to release the pendulum when the pivot is at K, in order to allow for the pendulum arm. The escapement opening therefore is 95° + 49° or 144° in order to radially position the pendulum at impact.

LAYOUT OF THE IMPACTOR ASSEMBLY IN THE MACHINE

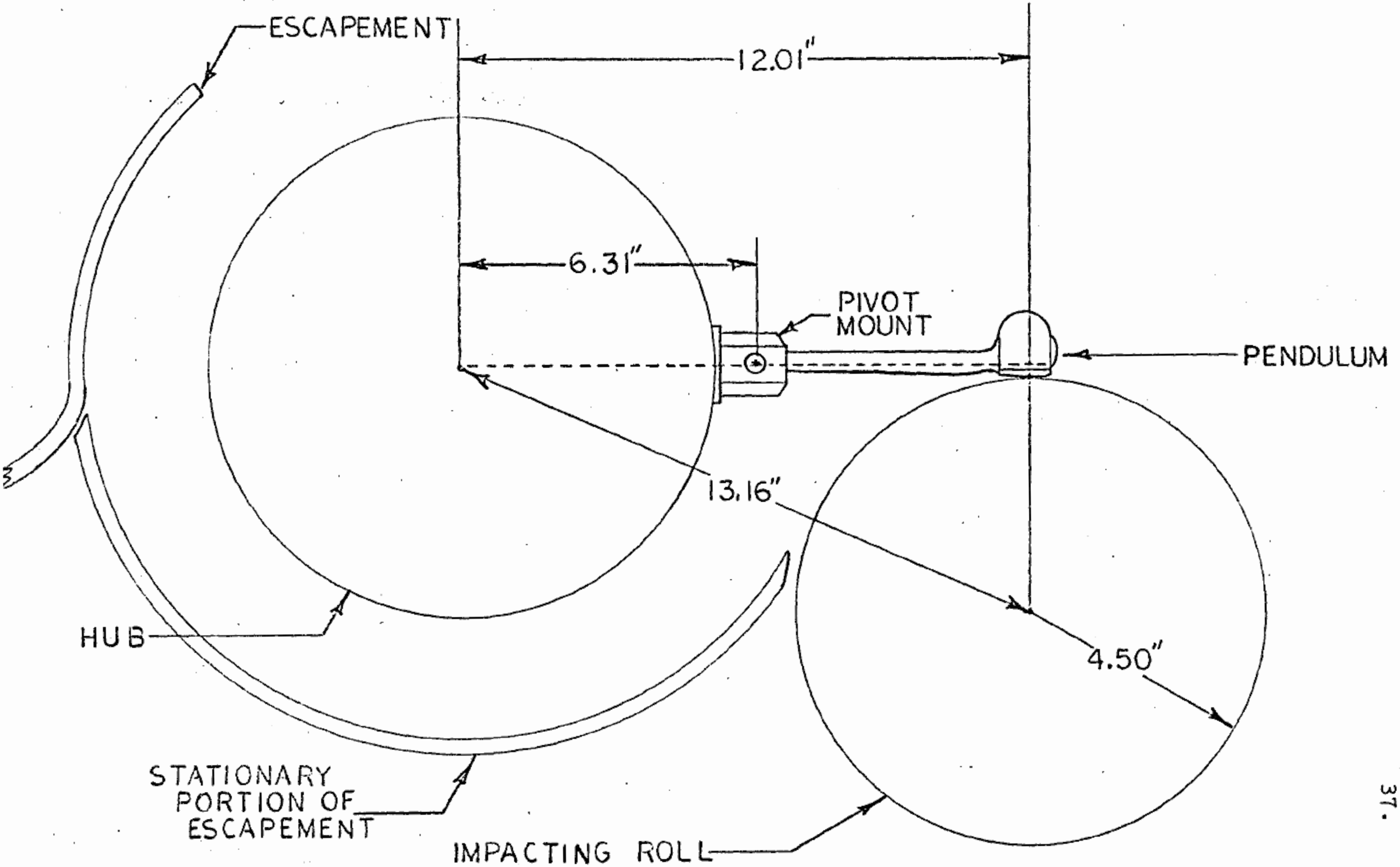


FIGURE 17

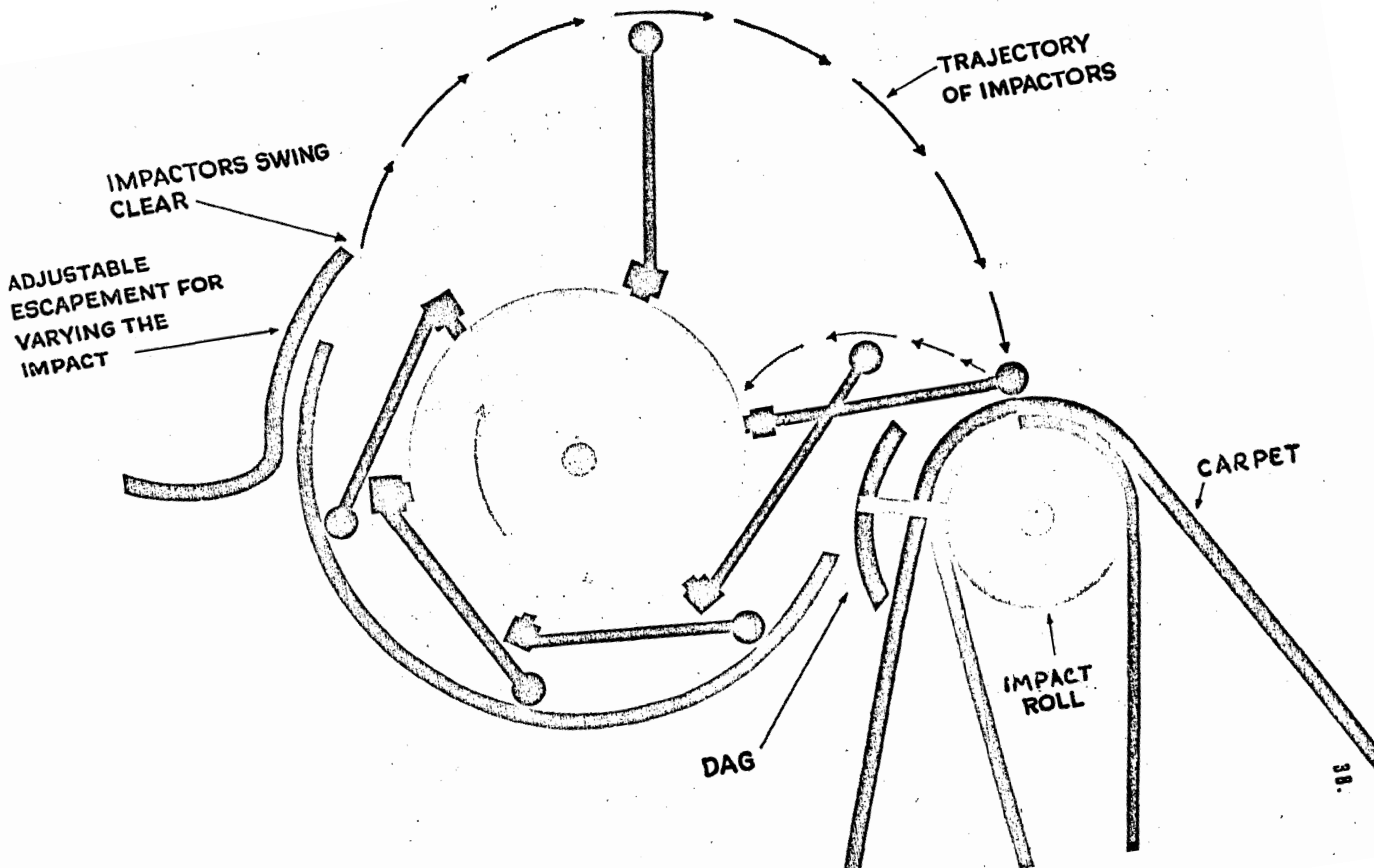
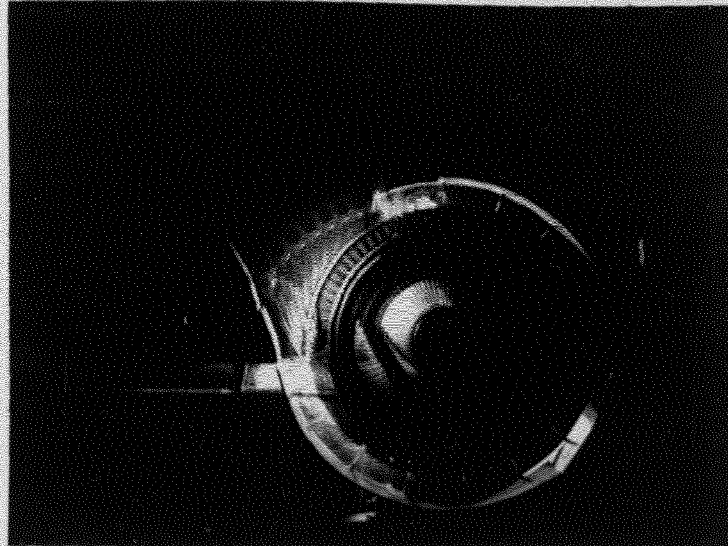
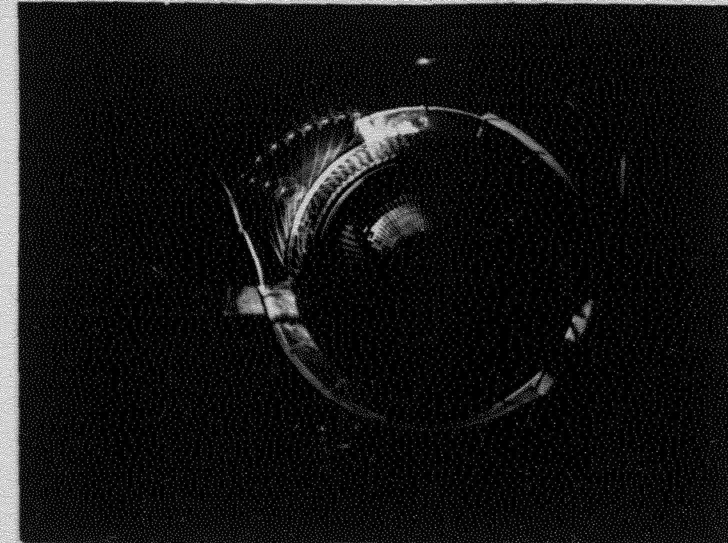

TRAJECTORY
OF IMPACTORS
IMPACTORS SWING
CLEAR
ADJUSTABLE
ESCAPEMENT FOR
VARYING THE
IMPACT
CARPET
IMPACT
ROLL
DAG

FIGURE 18

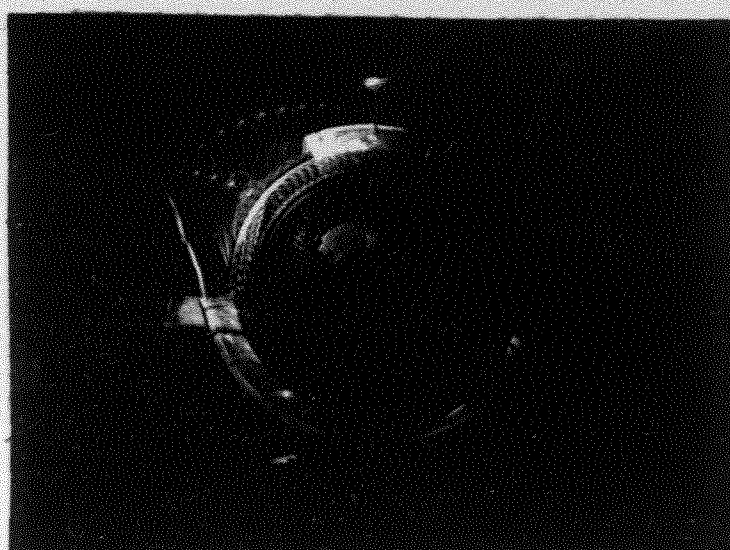
Flight of an Impacter at Various Escapement Openings



65°



80°



100°

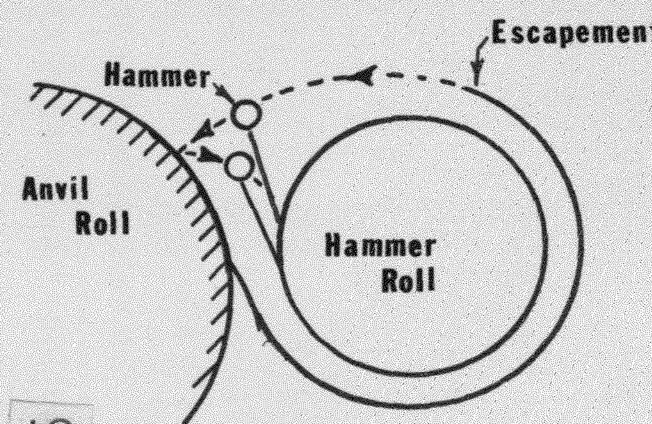


FIGURE 19

V. CONCLUSIONS

A prototype machine as proposed in the introduction to dye carpet was fabricated using the rotary pendulum as the impacting device. The machine would impregnate a carpet strip 4-1/8 inches wide. The six pendulums per position (1-1/8 inches in width) concept of the hub roll was used, with the maximum speed of rotation being 300 rpm. The tessellation shown in Figure 15 was used to locate the pendulum pivots on the hub. The hub had a radius of 6.31 inches, and the individual rotary pendulums (22 in all) had a center of gravity 4.45 inches from the pivot, and a center of percussion 5.70 inches from the pivot. The center of percussion coincided with the striking point.

Carpet was fed through the machine simultaneously with the dye reservoir at 10 yards per minute. The escapement was opened and slowly increased until the rotary pendulums were impacting in a radial position. The carpet was impregnated with dye from the reservoir using the rotary pendulum impacting devices.

Conclusions which can be drawn from the developments leading up to and through the above test are:

1. The rotary pendulum can be controlled and used as a machine component;
2. Carpet can be dye impregnated using the rotary pendulum machine;
3. The theoretically determined values of velocity, position and escapement opening, using the equation of motion for the rotary pendulum and other information obtainable from the analog plots vary no more than 7 percent from the measured values.

GLOSSARY OF TEXTILE TERMS[16]

BEAM DYEING - The greige carpet wound on a special perforated beam is placed in a dye machine. The dye solution is pumped through the carpet from the center of the beam outward and then from the outside carpet surface to the center of the beam.

CUT-PILE CARPETS - These have a surface of brushlike tufts which stand up from the backing, as in corduroy and velveteen fabrics.

DRYER - Various applications of heat to evaporate moisture.

DYE, DYESTUFF - The name given to solutions or materials that color textiles.

DYEING - Process of adding a comparatively permanent color to any fiber or fabric. Dyes may be either natural or synthetic, and differ in effectiveness and methods of application.

FIBER - A basic complete unit in the fabrication of a textile yarn or fabric.

FRIEZE - Heavy, rough, fuzzy, wiry faced material.

GREIGE GOODS (GRAY, GREY, GRIEGE) - Fabrics, irrespective of color, that have not received any wet processing.

LEVEL DYEING - The dyeing of fabric to produce uniformity of color with no streaks or shaded areas.

MOISTURE CONTENT - The moisture present in a textile material expressed as a percentage of the material weight.

PACKAGE DYEING - A method of dyeing yarn. The yarn is wound uniformly on perforated spools or tubes. These packages are then placed in a special dyeing machine in which the liquor is circulated through the yarn alternately from the outside of the package to the center and then from the center to the outside.

PADDER - A set of squeeze rollers used to impregnate any fabric with a liquid by continuous passage of the fabric through the liquid and then between the rollers.

PIECE - A length of fabric.

PIECE DYEING - The fabric is dyed a solid color by complete immersion.

PILE - The cut threads of uncut loops which make the surface of a pile fabric.

RUNNING YARD - One yard of cloth regardless of width in which it is constructed.

SHADED GOODS - A finishing defect in which the fabric shows uneven coloring.

SKEIN DYEING - Dyeing yarn that has been reeled into hanks.

STOCK DYEING - Dyeing loose fibers in bulk form, before any yarn manufacturing operations have begun.

TWIST - The number of turns per unit length of yarn, such as turns per inch.

WET FINISHING - Generally applied to all finishing operations in which the fabric or yarn encounters liquids as any part of the operation.

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VITA

Ashley Paul Smith was born July 24, 1937 in Charleston, West Virginia, to Coleman Ashley Smith and Helen Caldwell Smith. While in elementary school he became a Christian and joined a Baptist church. Paul graduated from Thomas Jefferson High School, Richmond, Virginia in 1955.

Paul entered the University of Richmond, Virginia in September, 1955. He ran cross country and track for the university. In June, 1960 he graduated from the University of Richmond with a bachelor of science degree in Physics. While doing graduate work in Physics at the university he was elected to membership in Sigma Pi Sigma.

During the two years of graduate study from 1960 through 1962, he was a laboratory instructor in Physics at the Medical College of Virginia. In 1961 the instruction of a Physics course at Saint Patrick's High School was added to his experience. In 1961 he married Sharon Anne Slate of Petersburg, Virginia. They have three sons, Steven Paul, Scott Ashley, and David Irby; their ages respectively are 6, 3 and 1.

In 1962 Paul accepted an instructor's position in Physics in the Physical Science Department of Northwestern State College of Louisiana, at Natchitoches, Louisiana. The following year he joined Chemstrand Company (now the Textile Division of Monsanto Company) in Decatur, Alabama, as a textile engineer in the Creative Products Group. In 1968, Paul changed to his present employer and location, Northrop Carolina, Inc., Asheville, North Carolina, as a machinery design engineer in the Textile Machinery Design Group.

He is a member of the Land of the Sky Chapter of American Society of Textile and Manufacturing Engineers.

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