Non-uniformity of Moisture Profile Across Paper Sheet in High Speed Paper Machines.

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Summary :

Non-uniform moisture distribution across the paper sheet leads to difficulties like improper runnability during printing, coating and super-calendering. The non-uniformity of moisture is mainly due to uneven heating in the drier section of the paper machine. Improper location of condensate removing equipments and unequal distribution of surrounding air velocity as well as its temperature and humidity are responsible for non-uniform moisture profile. Trials carried out to correct the moisture profile of the paper sheet in a high speed paper machine are described.

INTRODUCTION

Uniformity of paper quality is desirable and sometimes necessary. The paper maker strives to produce paper of constant thickness, basis weight and other important physical and technological properties. The variations from the "should be value" are kept as small as possible.

Unequal distribution of moisture content of paper sheet across the machine direction is not a less seldom feature especially in a high speed machine. Non-uniformity in moisture content of paper causes curl, uneven flatness and dimensional instability. During printing especially in offset printing dimensional instability of paper causes distorted and shabby impression of prints and images. Improper positioning of paper, mis-registering, and fanning or buckling during printing are the results of non-uniform moisture profile.

The paper, as it comes out of the machine, has a moisture content, which is lower than that corresponding to equilibrium moisture of paper under press room conditions. The paper is pre-conditioned by storage at a higher relative humidity than that of press room. As the paper increases its moisture by absorption from the surrounding air, uneven initial moisture distribution across the sheet causes unequal fibre swelling, which results in curl, uneven flatness and distortion of paper sheet. In extreme cases the printers return the paper bales with such defects. In one paper mill in the continent, where the author once worked, about 20 tons of paper from both ends of the sheet had to be rejected daily from a machine of 250 tons per day capacity.

Similar difficulties are encounted during the operation of coating and sizing machines. Performance in super calenders is also adversely affected by non-uniform moisture distribution in paper sheet.

Before going into the details of the measures taken to currect the non-uniformity of the moisture profile, it is desirable to present a few particulars of the machine.

Paper machine particulars :

Speed	630 m/min.
Working width	4.65 m
Number of presses	3
Number of wet felts	3
Number of drying cylinders	55
Each drying cylinder of	
Diameter	1.5 m
Width	5.0 m

Dryers are arranged into four groups as follows :—

1 group	1—14	cylinders
II group	15—28	"
III group	29—42	"
IV group	43—55	"
Cooling cylinders	2	

EXPERIMENTAL

Measurement of moisture contents across the paper sheet showed that the percentage of moisture of paper in the middle was higher than at the two ends by about 4 to 5%. Further the drive side had a lower value of moisture % in paper than the tending side. Fig. 1 shows the moisture profile of a sheet of paper.

1. Trials with water spraying nozzles.

One obvious and relatively simple means of equalising the moisture profile of the sheet of paper would be to spray water in the form of fine particles by means of a pressure-nozzles-aggregate in the region of low moisture content of the sheet. The first trial was to spray water in the region between the last dryer cylinder (55) and the cooling cylinders (Fig. 2A & B). Spraying on the paper sheet directly created uneven flatness. In order to avoid this difficulty it was thought necessary to spary water onto cooling cylinder instead of spraying directly on the paper sheet. However, it was soon found that droplets of water fell from the cylinder on the already dried sheet and caused wrinkles while rewinding in cutters.

The next step was to locate the nozzles between cylinders 1 and 2 as shown in Fig. 3C, water is sprayed directly on the sheet of paper. By spraying this way the moisture content at the ends could be increased by about 1%.

Another step was to spray water on the paper sheet at cylinder no. 27 and 29 (Fig. 3D) wetting only the wire side of paper.

In taking adjustment as to the location of nozzles, the moisture contents of the sheet at various regions of drying section are considered. During drying of a wet sheet of paper, water is removed initially by a constant rate evaporation; after removal of surface free water, water from inside the sheet flows to the surface and the rate of evaporation hence decreases. Next capillarry water is removed. The rate of evaporation drops further due to lower vapour pressure of capillary water. At the last stage bound water is removed. Fig. 4 shows the different phases of water removal from a wet sheet of paper during drying. The paper near the cylinders 27 and 29 had a moisture content of around 51% corresponding to that of absorbed water region.

Experience with water spraying indicated that higher the initial water content of the paper sheet, greater is the difference in moisture content between the middle and the ends of the dryer cylinder.

2. Trials with condensate removing syphons in dryer cylinders :

If it is assumed that the wet sheet of paper leaves the press section with uniform moisture profile, its non-uniformity at the dry end may reasonably be thought to be due to unequal drying across the width of the dryer cylinders.

In conventional paper drying heat required to dry the paper sheet is supplied by steam, which gives up its heat by condensation. The flow of heat is through a steam film, the shell thickness, an air film and finally the paper sheet. In most cases the dry felt also heat the paper sheet from the other side. Thus heat transfer from steam to paper depends on a great many number of factors.

In general the flow of heat is expressed by the equation $Q=A.\ U.\ \Delta T$

where Q is heat transferred per/hr., A the area of heat transfer, U the overall heat transfer coefficient and ΔT the temperature drop.

In other words, the rate of heat transfer is a product of the area, heat transfer coefficient and the temperature drop.

Heating of a sheet of paper involves heat and mass transfer phenomena simultaneously. The amount of heat required in drying a paper on a heated cylinder can be expressed by the formula

$$Q=W.H=U\,(t_s-t_p)+h_p\,(t_a-t_p)$$

where,

W=Water evaporated, kg/m^2

H=heat of vaporisation, kcal/kg.

t_s =steam temperature in cylinder, °C

t_p =Temperature of paper surface, °C

t_a =temperature of air or felt, °C

U is the overall heat transfer coefficient and is function of all film co-efficients. It is expressed by

$$U=\frac{1}{\frac{1}{h_s}+\frac{l_c}{k_c}+\frac{1}{h_c}+\frac{l_p}{k_p}}$$

where

h_s and h_p are heat transfer co-efficients for steam to cylinder and paper to air or paper to felt respectively, kcal/m^2 hr./°C, l_c and l_p are thickness of cylinder and paper respectively, m, k_c and k_p are thermal conductivity of cylinder shell and paper sheet respectively, Kcal/m/hr./°C.

Values of heat transfer co-efficients under certain working conditions are given below :

h steam to cylinder shell = 2000 – 4000 kcal/ m^2 /hr./ °C (1)
h cylinder shell to paper = 1000 ,,
h paper to air = 20 – 80 ,, (2,3,4)

Values of thermal conductivities are

k_c = 35 kcal m/hr./° C (1)
k_{water} = 0.6 ,,

The values show that maximum resistance to heat transfer is shown by the water layer and the air film.

Formation of condensate pool and ring (Fig.5)

During drying steam condenses and collects in the dryer cylinders. Depending on the peripherial speed of the cylinder shell, the condensate forms a pool at the bottom of or a ring around the cylinder shell. At low speeds (upto 350 m/min.) pools are formed while the ring formation takes place at higher speeds (above 400 m/min.). The speed at which ring formation takes place (called the riming speed) depends on the quantity of condensate and the cylinder diameter and is expressed by the formula

$$V = \left(A - \frac{B}{D}\right) . \sqrt[3]{Q} \quad (5)$$

where V is the rimming speed, Q the condensate volume, D the cylinder diameter and A and B are constants. Thus larger the diameter of the cylinder, higher will be the rimming speed for given amount of condensate. Again ring thickness increases with the machine speed (Fig. 6)

As indicated before, the thermal conductivity of the condesate ring is very low and therefore it offers greater resistance to heat. For every millimeter of ring thickness there is a temperature drop of about 4.5 °C (at about 600 m/min. and 500 kg/hr. of condesate). When the machine speed is slowed down, the ring collapses. Naturally, the collapsing speed is lower than the rimming speed. The pool of condensate, on the other hand, has a relatively lower heat resistance, but it requires a higher driving power to rotate the cylinder at higher speed. It is therefore necessary to find out means of reducnig the ring thickness.

With low speed machines the condensate is removed by scoops or syphons. Syphons are inserted through the Journals and extend to the drive side of the drying cylinders. Condesate is removed from the cylinder by syphon tips by application of pressure differentials. The condensate ring is removed by stationary or rotating syphons only.

At a definite speed and condensate volume, the thickness of condensate ring is dependent on the construction of syphon (the form of tip and the clearance between the cylinder wall and the tip).

In a stationary syphon of the type shown in Fig. 7A the thickness of the condesate is equal to the clearance set by the syphon tip. For example, if the clearance is 4 mm, the ring has also a thickness of 4 mm.

The minimum clearance is determined by the thermal expansion and fatigue resistance of the construction material. Since syphon tips are damaged easily they are to be locked in proper position by the provision of a screw setting. In order to avoid the difficulty of setting a syphon shoe in proper position, rotating syphons are preferred often. These syphons are fastened to cylinder and rotate with it. The tip damage here is absent since there is no relative movement between the tip and the cylinder shell. Its disadvantage is that it necessitates higher differential pressure for removal of condensate at higher speeds since the condensate has to flow against the centrifugal force.

Since the paper sheet in the middle portion of the dryer cylinder showed a maximum of moisture content, a new type of syphon with a modified shoe was tried. This syphon, called the Barnscheidt Syphon and patented by J. M. Voith of Germany, (Fig. 7B) is more efficient in removing the condesate ring. The clearence between the syphon shoe tip and the shell surface can be made as low as 2 mm. Experience showed that there is not much advantage in reducing the clearance further than 2 mm., Another advantage of the new syphon shoe is that the condesate ring thickness can be reduced to a value far less than the magnitude of the clearance set (6).

In order to prove the efficiency of the new syphon tip in the paper machine, it was set in the middle of the cylinder and the temperature profile measured. The temperature of the dryer cylinder was measured by means of a swedish SWEMA appartus of the Svenska Matapparatur FAB, Stockholm. Along the width of the cylinder, 12 different points were marked. The points 0 and 00 lie 20 cm away from the two ends of running paper sheet. The points 1 to 10 are equally distributed between 0 and 00 of the ends. It is shown in Fig. 8A, that as a result of better removal of condensate at the point of shoe tip, the temperature of the surface of dryer cylinder shows a higher value than before. Thus the lower moisture content of the middle of the paper sheet can be improved by placing the syphon tips in the middle of the cylinders. In order to prevent overheating in the middle, the syphon tips were located 250 mm away from the middle to the left and right alternately in the 3rd group dryers (29 to 42).

It might be mentioned that the modified syphon tip reduces the thickness of the condensate ring more at the tip than at other regions of the dryer cylinders. Fig. 8B shows the temperature profile of the cylinder surface with the newly constructed syphon shoes and a system of water-spraying nozzles near the middle and at the both sides respectively.

3. Overheating of the cylinder ends

It is seen from Fig. 8A that the temperatures at the two ends are still relatively higher than at other places. This is due to the fact that the paper sheet does not touch the ends of the cylinder surface and hence the heat transferred from the steam is not dissipated. Due to appreciable temperature drop between the ends and the neighbouring points, heat flows from the cylinder ends to the paper sheet ends and the result is overheating of paper and felt.

It was thought therefore to check this overheating of the ends of the cylinder by insulating the edges with a special type of firebricks. Although this idea is very simple, it has been extremely difficult to fix the bricks into the cylinder without too often loosening them. The experience of a few Canadian mills in this regard has been helpful to many mills which decided to reduce the overheating of ends.

Another method, developed by Beloit Corp., is to insulate the cylinder edges with asbestos backed insulating rings, made in sandwitch form with stainless steel retainers. This type of insulation is reported to possess better retention stability inside the cylinders (7).

4. Humidity, temperature and movement of surrounding air of dryers

A very important factor is the ventilation of air. The heat transfer coefficient between the cylinder surface to the paper surface or between felt and paper is dependent on the thickness of the air film, which is governed by the humidity, temperature and velocity of the air.

Increase of air velocity can affect the drying rate more when the paper sheet is relatively wet (constant rate drying period). Its influence decreases continually during the faling rate period, since the air film is only a part of the total resistance to diffusion and heat flow.

Humidity and temperature of ambient air influence the drying rate throughout the drying period. Higher temperature and lower humidity favour rapid drying. At the beginning of drying, the rate of drying should not be excessive, since it may cause the skinning effect and thereby reduce the drying rate subsequently.

The humidity, temperature and the movement of air were studied for a few dryer cylinders with a view to see their influence on uniform drying. They are represented in Fig. 9.

In modern paper machines hoods are provided to eliminte uncontrolled in-draft of dry or cold air. Uniform distribution of humidity ensures even rate of evaporation throughout and helps improving the moisture profile.

Other methods of improving the moisture profile are by the useof Madeleine felt dryer rolls in place of felt rolls, high velocity air dryers, etc., uniform felt drying methods to reduce humid air pockets between cylinder runs and felt runs (the Grewin system).

CONCLUSIONS :

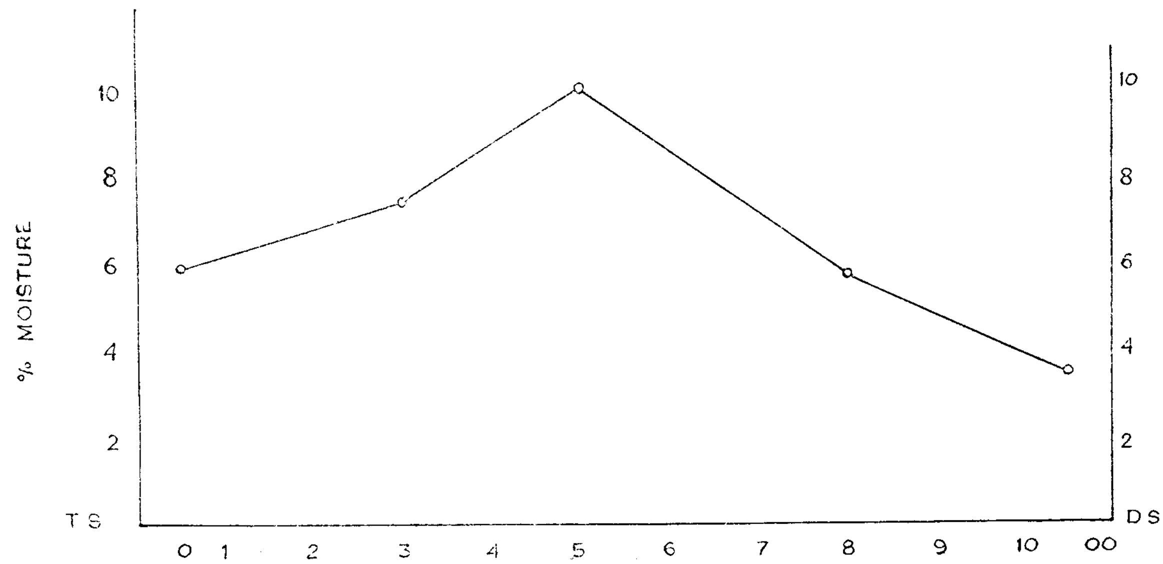
Uniform drying of a paper sheet on a fourdrinier paper machine is a function of mainly two factors : 1) heat distribution inside the dryer cylinder and 2) conditions of ambient air.

Uniform heat distribution can be achieved to a great extent by proper selection and location of syphon tips for uniform removal of condensate inside the dryer cylinders. Overheating of dryer ends can be eliminated by use of bricks as insulators in the edge parmeter of dryers.

Distribution of air, its temperature and humidity can be utilised to correct the moisture profile of the paper sheet.

LITERATURE

1. L. Janson, Sv. Papperstidn. 60 (1957) : 713-19
2. L. Janson—Harminge, Sv. Papperstidn. 63 (1960) :
3. B. Bienkiewicz, and J. Mardon, Paper Maker Annual number (1952) : 32
4. Z. Hilden, unpublished report.
5. G. Gavelin, Paper and paperboard drying (1964).
6. W. Branscheidt and M. Schadler, Das Papier 14,10a (1960) : 600
7. R. B. Hurm, Tappi 46,9 (1963) : 533



MEASURING POINTS ON PAPER SHEET

FIG. 1

Appendix to

Non-uniformity of Moisture Profile Across Paper Sheet in High Speed Paper Machines.

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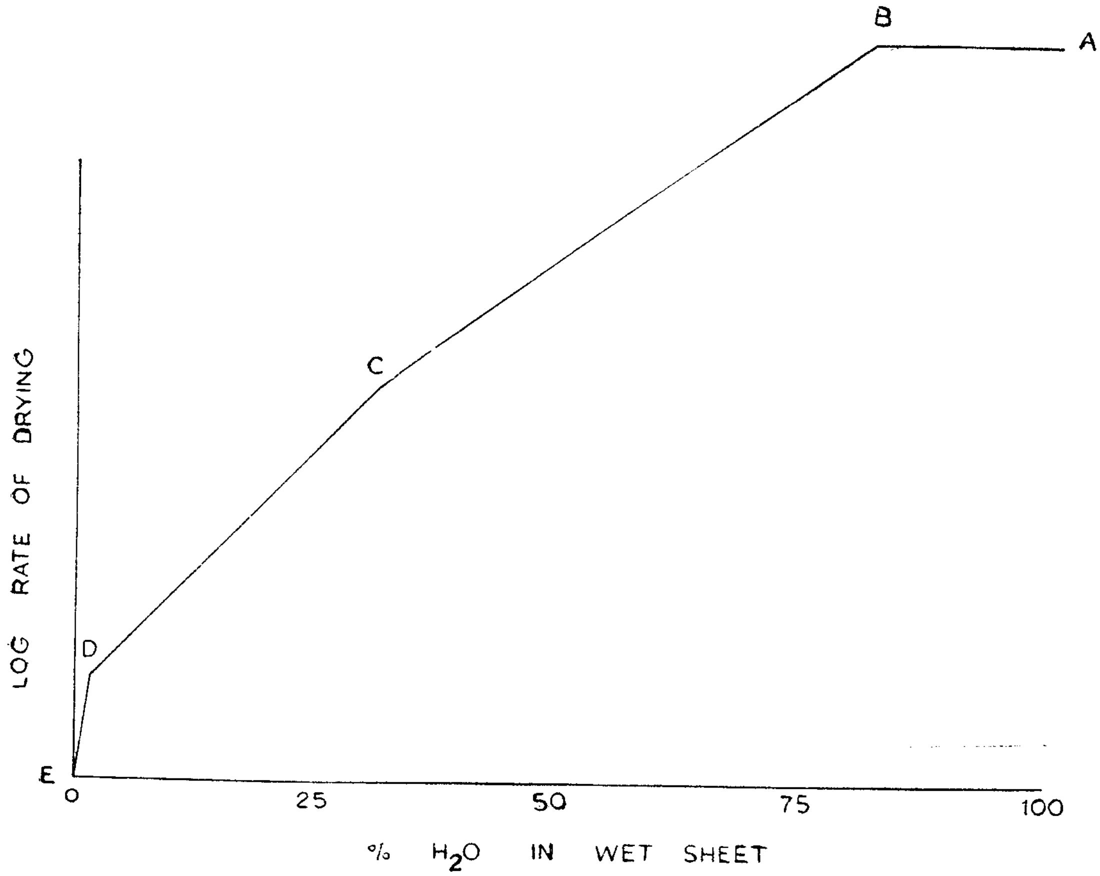

B
A
C
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LOG RATE OF DRYING
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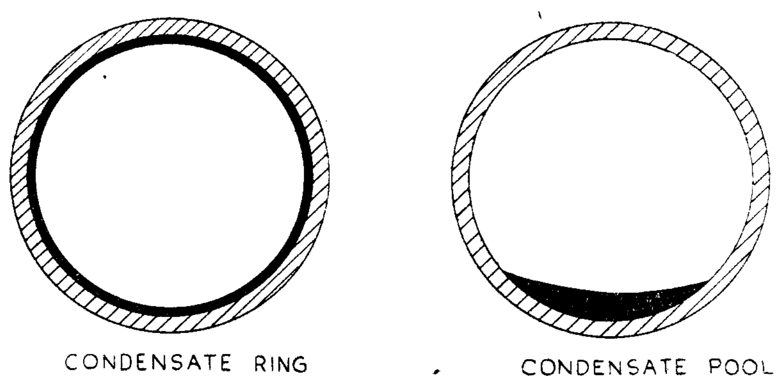
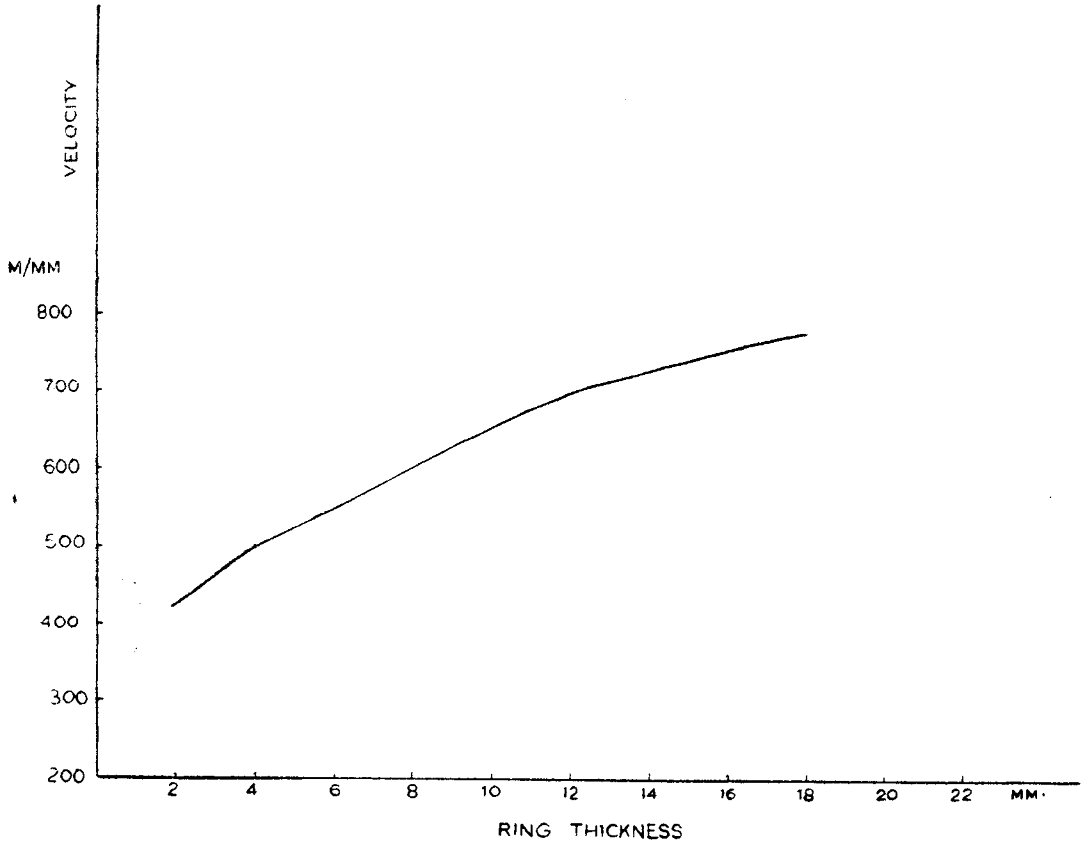
% H_2O IN WET SHEET



CONDENSATE RING
CONDENSATE POOL

FIGURE 5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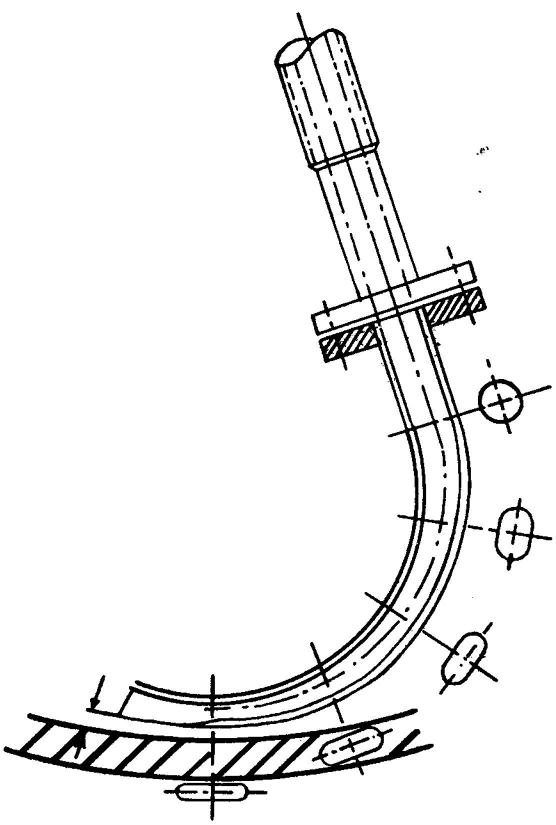

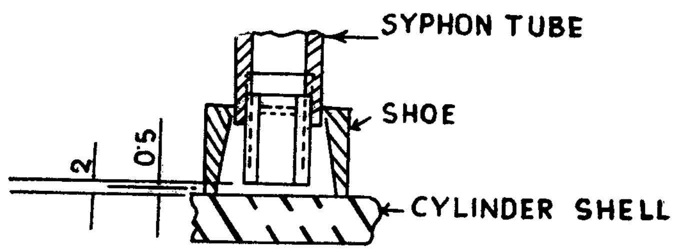
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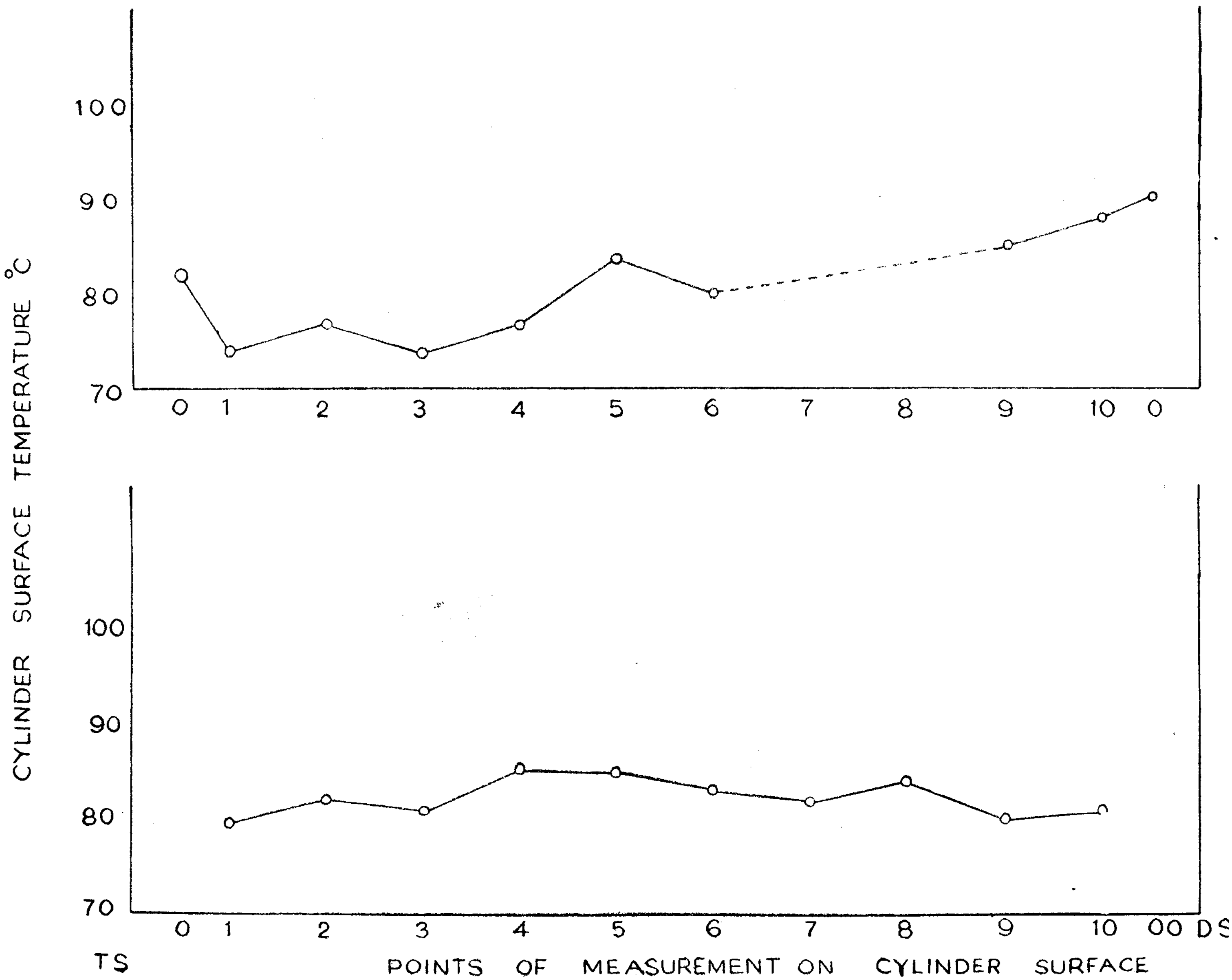

CYLINDER SURFACE TEMPERATURE °C
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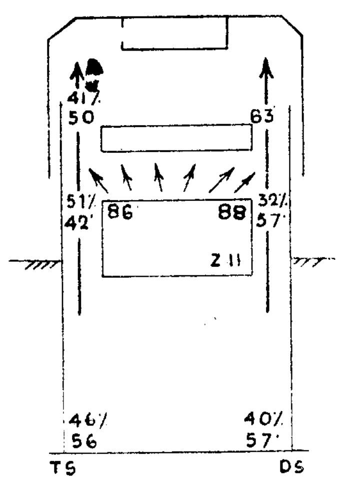
POINTS OF MEASUREMENT ON CYLINDER SURFACE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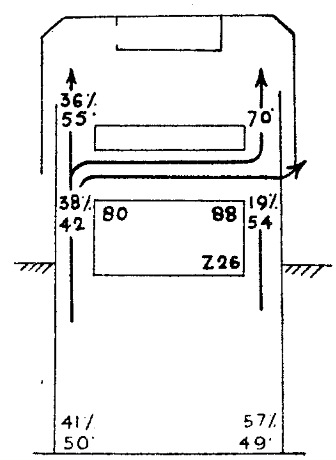
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