J. Mardon
G. A. Smook

The Present State of Wire Table Drainage

The present state of wire table drainage is reviewed in the light of historical developments. The limitations of the table roll are noted in comparison with more modern drainage elements. Double-wire formers, wet suction boxes aud foils are examined with respect to operating advantages and limitations. The importance of basis weight uniformity and good table alignment are stressed. Finally, the water balance around the wire is considered, and some practical aspects of basic sheet froming principles are illustrated.

Recent papers on wire table drainge should be considerd in relation to all the published literature that is now available on this subject. Perhaps the best starting point is a consideration of the various types of forming equipment developed in recent years. Most of these are divergent from the conventional fourdrinier which has remained essentially unchanged in principle since the original 1807 British patent (BP 2951).

Excluding the various developments of the cylinder machine, stemming from Dickinson's patent, there are:

1. The use of an inner wire, the so-called "power fabric" pioneered by Kitano.[1]
2. Double wire formers:
   (a) Various forms descended from Webster's patents,[2] i.e., the Papriformer, Crescent former, and Periformer;
   (b) true double wrie formers descended from the Inverform, *viz.* the Inver form, (slow speed), Twinverform (high speed variant of the Inverform), Bel Baie former (inertial drainage) and Vertiformer (extrusive drainage or inertial drainage).
3. Wet suction boxes descended from a combination of the ideas of Timmerman[3] and Taylor, *et al.*[4]
4. Foils following the initial development work of Burkhard and Wrist[5]. Note that a foil is essentially a portion of a large stationary table roll.
5. Suction breast roll tissue machines; these, with the headbox covering a large portion of the roll, are essentially pressure forming cylinder machines.

(Based on talk by J. Mardon at N. Y. Empire *Tappi*, Lake Placid, N.Y., June, 1970, and part of the Wire Flow Lecture given at Institute of Paper Technology, Saharanpur, August, 1971).

There have been surprisingly few reviews of these different methods of drainage. One by Mardon and Manson[6] was published (in French) in 1961. A second by De Montigny[7] appeared in 1966, and a third by Mrs. Schmidt[8] in 1968. It thus appears appropriate to review the situation again at this time.

First of all, what was the matter with table rolls? Why was a change necessary? This point has been explored by many authors during the past fifteen years, and it was fully covered in the 1961 paper.[6] Table rolls work by creating a suction as the two surfaces, wire and roll, diverge. Timmerman told us in 1929[3] that "there is a film of water hanging to the underside of the wire, which, when coming back in contact with the table rolls, will be forced back through the wire lifting the partially formed sheet along with it, and as the sheet passes the table rolls, the water is again pulled back through wire by suction due to the action of the rolls turning away from the wire. This happens at each table roll and tends to open the fibre weakening the sheet.............." An additional point is that at higher speed the downward acceleration, as the wire follows the roll, causes "spouting" or "stock jump." The disturbance at the rolls is also directly related to the stability of flow from the headbox. It can be noted from wire flow photographs that unstable headbox flow amplifies the spouting and stock jump actions to the detriment of the forming process.

Table roll operation demands very

effective baffle grinding, roll setting and roll maintenance. Keeping down the distance from crown of roll to the following deflector minimizes the dip of the wire and, thus, the degree of spouting at constant tension. Even when all the proper papermaking discipline is observed with regard to setting of the wire table[9,10,11], formation gets worse with speed.

Figure 1 illustrates the worsening of formation with speed. The remedy for this (about 1957) was to groove the early table rolls. This allows introduction of air into the outgoing nip, which reduces the suction. Figure 2 shows the area over the first grooved table rolls at 2500 fpm with no spouting. Figure 3 shows the disturbance over the second solid roll (following six grooved rolls) at 2400 fpm, and figure 4 illustrates how much worse it was at 2600 fpm. Fig. 5 is effectively a combination of Figures 2 and 4, illustrating the smooth flow over the grooved rolls, and a major disturbance, starting at the second solid roll.

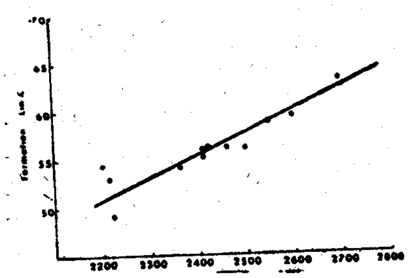

Fig. 1. Formation vs Speed

The major disturbance to formation is caused when the heads of the spouts land again on the wire, as shown in Figure 6. This behavior has been described as "window-like formation".

Reconsidering the division of forming and drainage devices made previously.

1. **Kitano's power fabric** is described in the literature and has considerable merit, since it enables a high tension to be held in the wire, whilst maintaining a fine forming medium. It has not, however, caught on, although at some later date it will, without doubt, come into its own.

2. **Double wire formers** have also been fairly extensively described in the literature, though up to the prssent time the descriptions have been purely qualitative (see Reference 12). Quantitative and detailed papermaking descriptions are badly needed. There are, nevertheless, some points of great importance that can be made at this time.

(a) By enclosing the sheet, whilst fluid, between two wires, there is free surface; however, this means that disturbances from a headbox will be fixed in the sheet and some kinds will form serious sheet defects. Thus, effective double wire drainage is only, possible with improved headboxes; for example, but not exclusively, the Converflow[13] and Bunched Tube[14] headboxes.

(b) The real curved wire formers, such as the periformer, or the various crescent formers, will only work on sheets with a low drainage resistance. If the path of the stock and the pressure gradient are not compatible, backflow will result, and produce sheet defects.

(c) There are two ways to drain on a two wire former: *extrusion drainage* and *inertial drainage*. The former is more difficult, but retains the fines and has substantial advantages. The latter loses the fines, and whilst a well-formed sheet is possible, constant vigilance may be required to avoid a sheet containing undesirable local fiber aggregations—a characteristic floc associated with inertial drainage operation.

(d) The structure of a two-wire sheet is different. Generally, it has lower z-direction tensile strength than a single wire sheet and can be split with little difficulty:

3. *Wet suction boxes* have considerable merit, and the advantages are enhanced in combination with the high speed dandy. They are already well accepted in Europe, but are not common in North America. The principal problem lies in the headbox. As with the double wire machines, a perfect flow is needed. (This point is also valid for foils).

The need for a first-class flow from the headbox must be emphasized. If the headbox flow contains defects, then a free flow area prior to the wet suction boxes must be allowed. The slice must be clean, the box tops must be kept in first-class condition, and the edges must be free of pitch.

To obtain the benefits of wet suction boxes, i.e., improved forma-

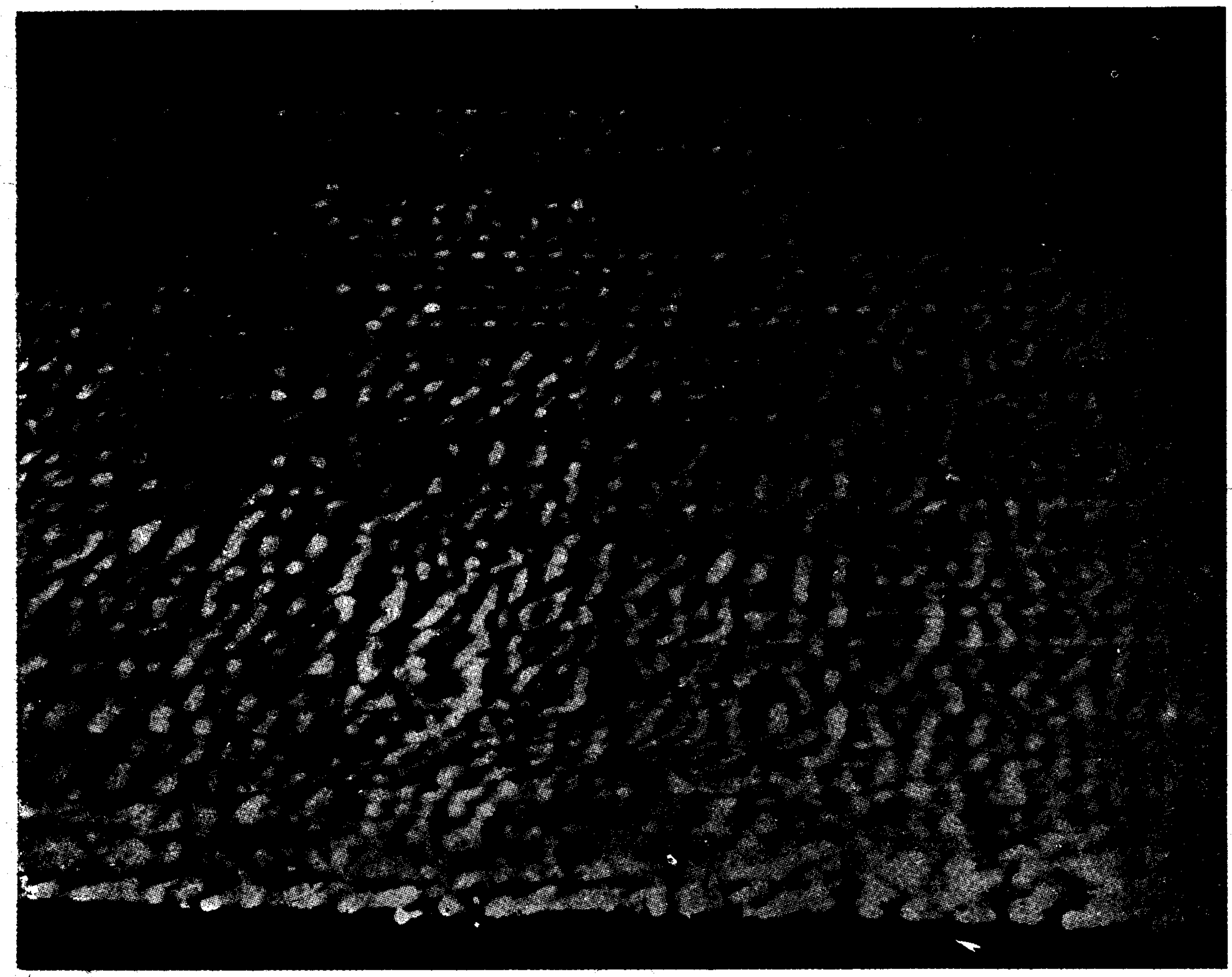

Fig. 2. Area over first grooved table rolls at 2500 fpm with no spouting

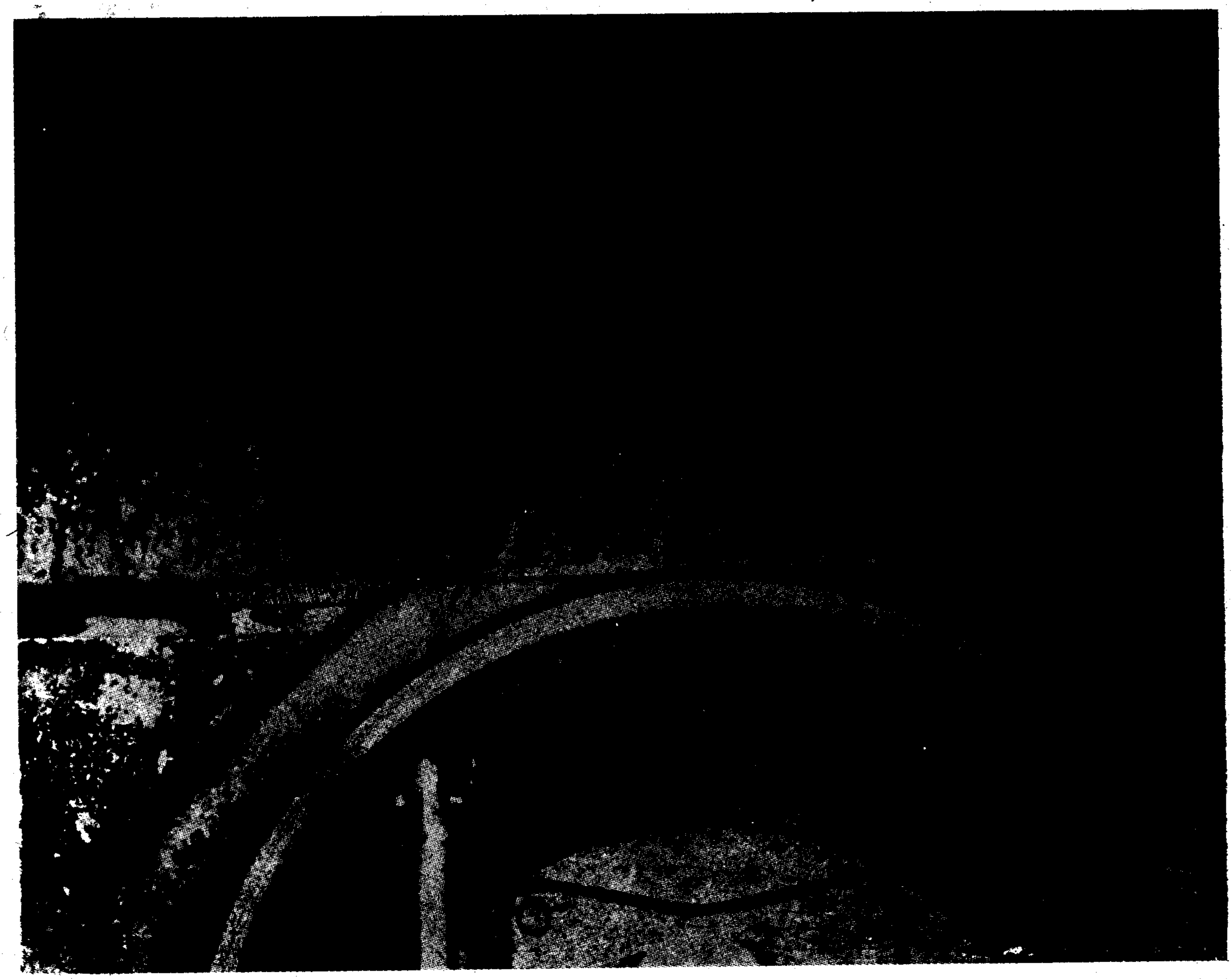

Fig. 3. Disturbance over second solid table roll (following six grooved rolls) at 2400 fpm

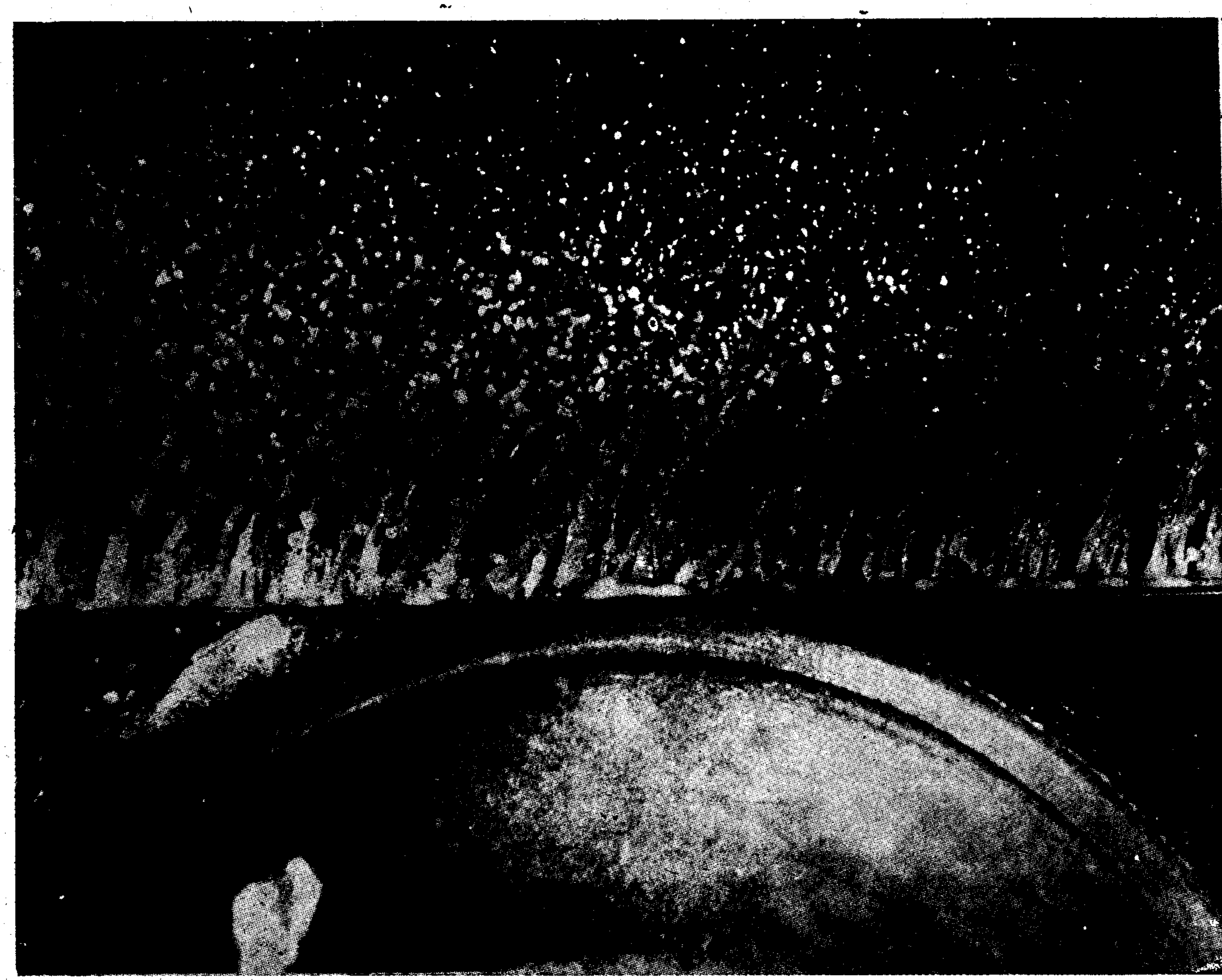

Fig. 4. Disturbance over second solid roll (following six grooved rolls) at 2600 fpm.

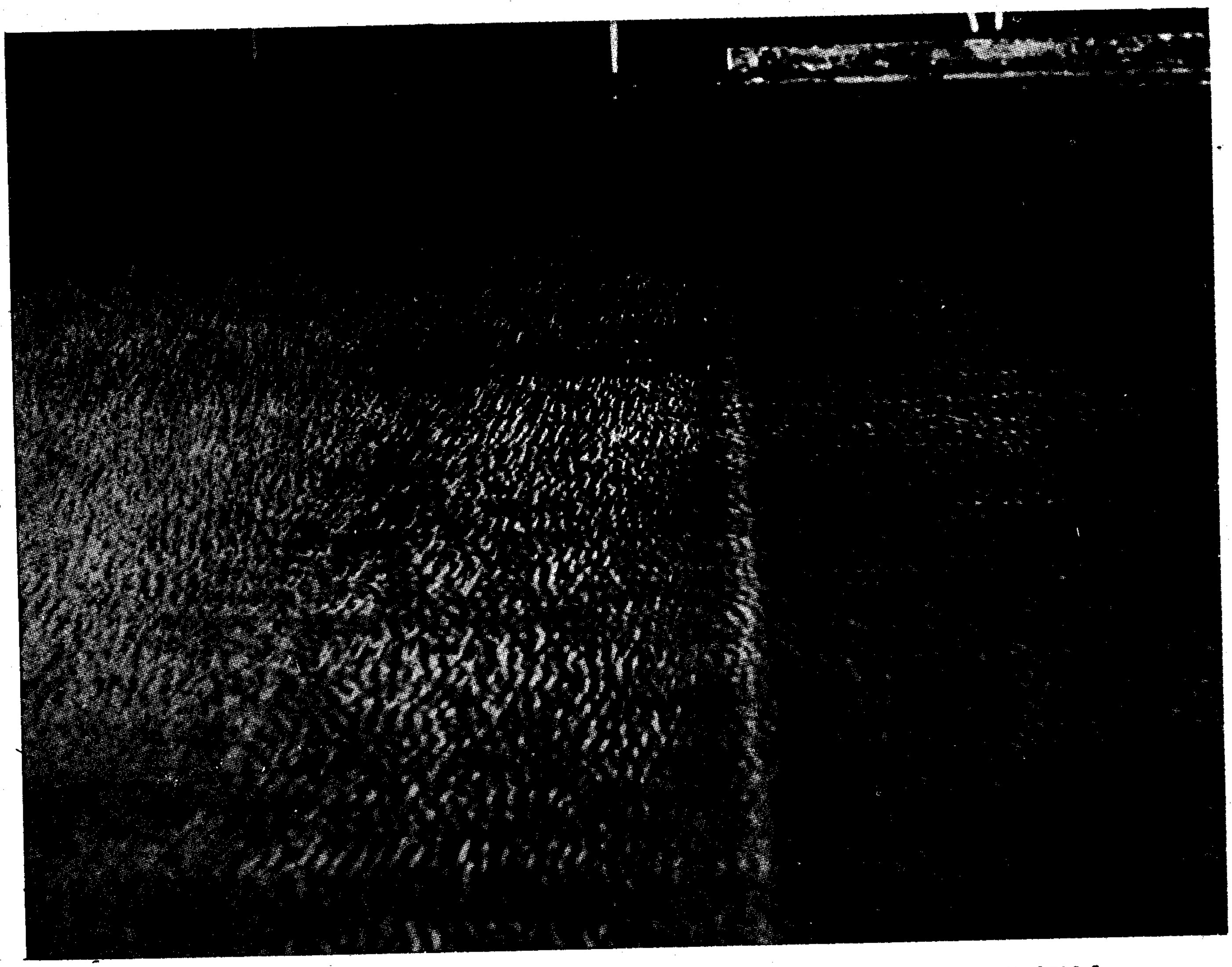

Fig. 5. Smooth flow over grooved rolls and major disturbance at second solid roll, 2500 fpm

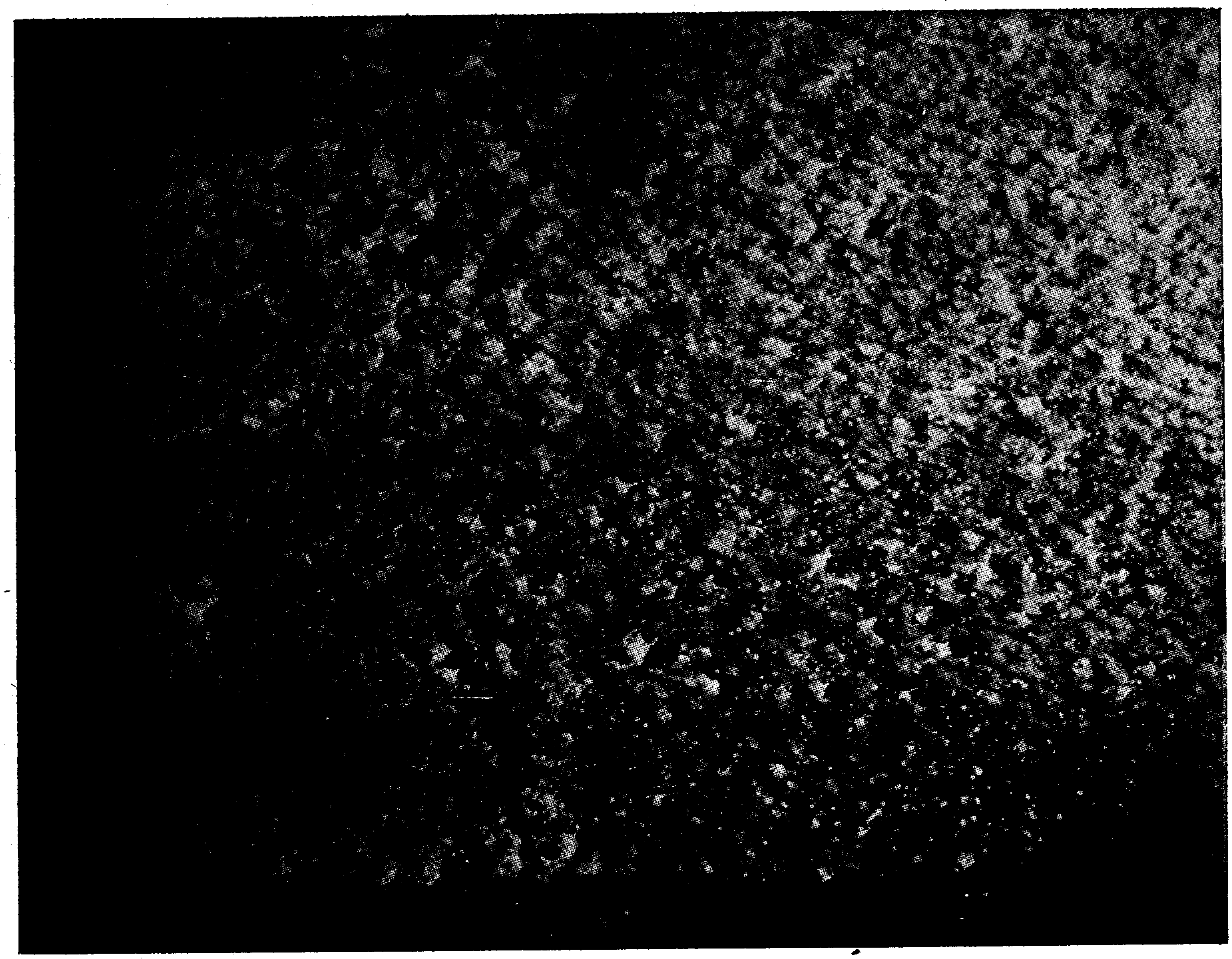

Fig. 6. Heads of spouts landing on wire

tion and lower wire mark, a lower headbox consistency is required. A higher headbox freeness can be expected, due to the reduced quantity of recirculating fines. Figure 7 shows a comparison of wire length requirements or headbox consistency at various machine speeds for suction boxes, as compared to foils and table rolls. Figure 8 shows retention levels for an original wire table equipped with table rolls and the same table after conversion to wet boxes.

Figure 9 shows the difficulties that result when mixing drainage elements of different properties. Three wet suction boxes were installed between the forming board and the table rolls. The wet boxes worked as in Figure 8, but the succeeding table rolls "washed out" the filler and fines to produce a more open and porous sheet. Obviously, the advantage of better retention was lost. Incidentally, the consistencies at the first few table rolls indicate a dense sheet coming from the wet boxes. The top value of drainage consistency is not reached until the fifth table roll.

The homogeneous nature of the sheet made with wet suction boxes is illustrated in Figure 10. This shows a comparison of filler distribution between sheets formed on wire tables using table rolls and wet suction boxes, respectively. It has been reported that sheet splitting is virtually impossible when formed on wet suction boxes.

For slow-draining stocks, it appears that solid rolls are needed at intervals between boxes to maintain the sheet as a fluid bed and to allow drainage to proceed without excessive vacuum. The same point can also be made with regard to foils.

It should also be noted that adequate adjustment is needed on the end seals for wet suction boxes.

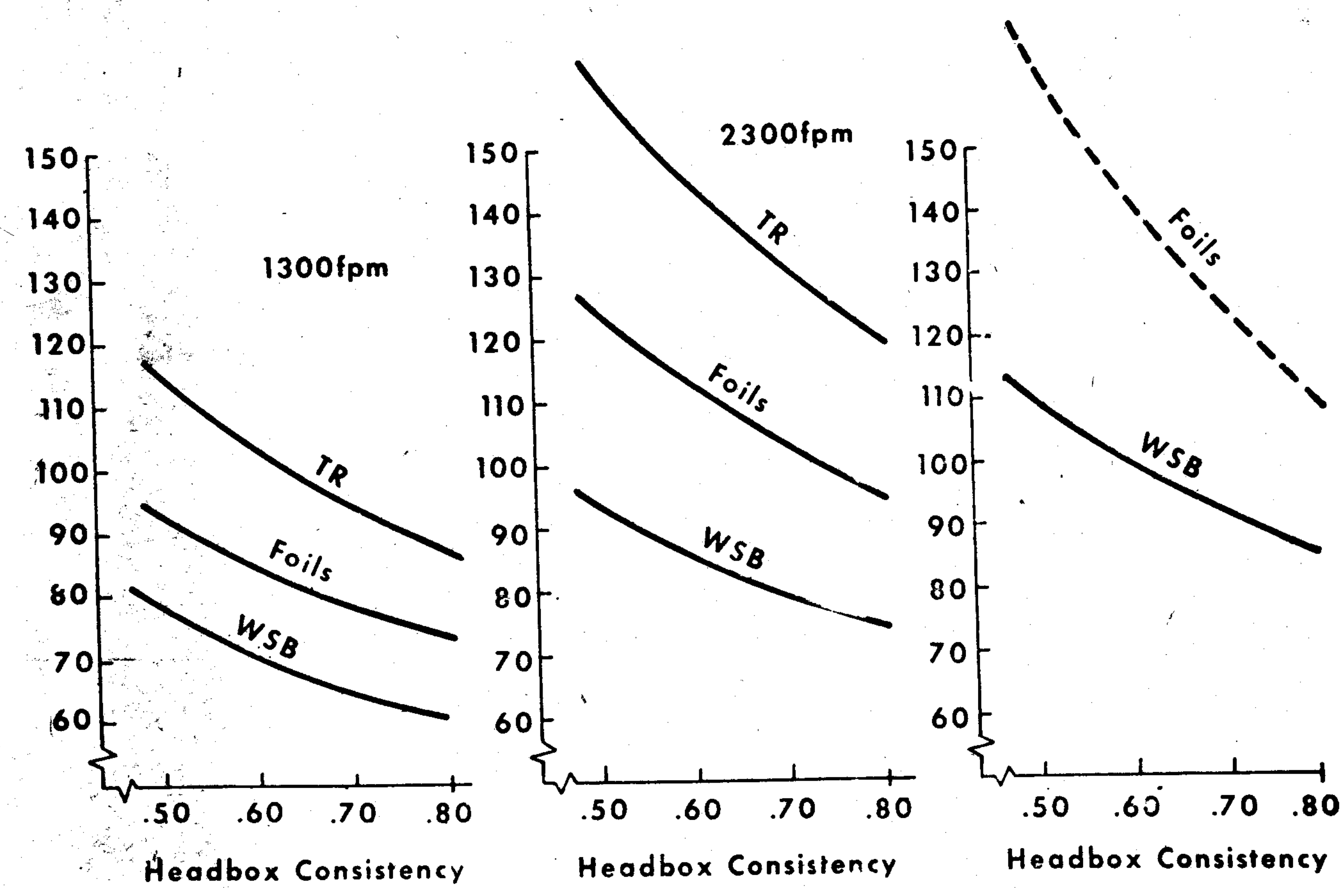

Fig. 7. Wire length requirements vs. headbox consistency for different elements and machine speeds

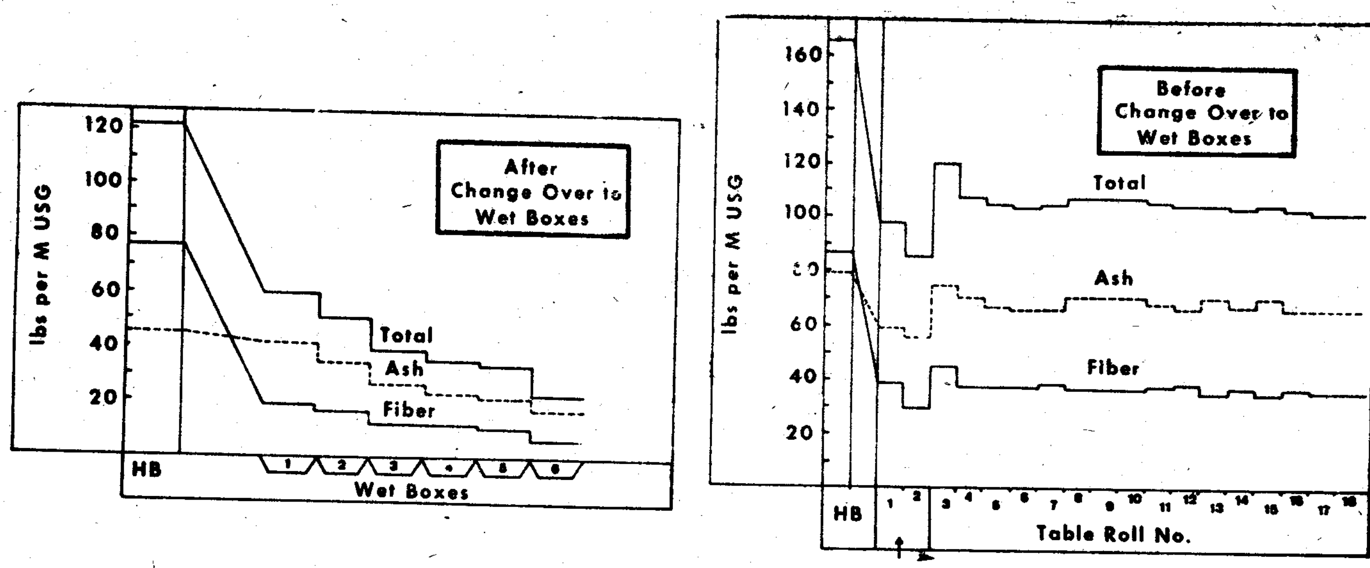

Fig. 8. Table drainage consistencies–comparing the same wire table with different elements

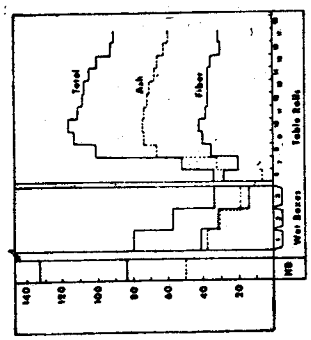

Fig. 9. Table drainage consistencies–illustrating problem of mixing drainage elements with different properties

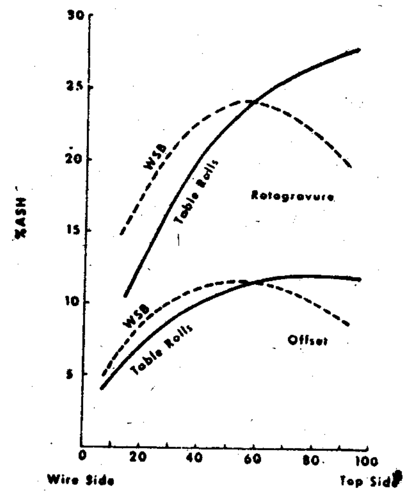

Fig. 10. Transverse distribution of filler in sheets formed with table rolls and wet suction boxes

4. **Foils**

As noted previously, a good headbox delivery is more important on a table equipped with foils than on one equipped with table rolls. But, delivery is not as critical as for wet suction boxes since some "activity" can be maintained. However, both the degree of disturbance and white water consistency are lower with foils than with table rolls due to a sharp and large suction working over a very short time being replaced by a lesser suction over a longer period.

Several authors have listed the potential benefits obtainable from foils. Among these ars improved drainage, better formation, more uniform transverse distribution, lower wire marking, and improved retention. It must be emphasized that formation improvement is largely due to more water just as is the case for wet suction boxes. However, like table rolls, and unlike wet suction boxes, the suction developed by foils is speed dependent. At low speeds and with heavier weights, the drainage capacity of foils may be inadequate. It should also be noted, that foils wear. The wear may not be even, causing irregular drainage and streaking. All foils must be ground at the same time so that they are level in the table.

Reduced pinholing is another paper quality ascribed to foils. This is because a foil, especially an "arc foil" corresponds to a large stationary table roll. The suction developed is more gradual and the spouting is thus reduced. The upthrust of water on the ingoing side is eliminated.

Figure 11 illustrates the flow on the wire above a first set of four foils. (The first and second blades are just noticeable at the right of the photo). The disturbance at 2400 fpm is moderate to severe, but there is no spouting.

figure 12 illustrates the same area at 2600 fpm, with a correspondingly greater disturbance degree.

Figure 13 shows the stability at the second solid table roll at 2400 fpm with prior foils; it is no better than was the earlier case with all grooved rolls prior to the solid rolls. Figure 14 demonstrates that the foil did produce increased stability at the second solid roll as speed increased.

Any new drainage method, including foils, must be considered with regard to formation. A number of investigators have found improved formation with foils, though in some cases it may be due partly to the fabric used in conjunction with the foils.

Figure 15 illustrates that formation became more irregular across the machine as speed increased. Figure 16 documents the reduction of wire mark caused by using foils between the grooved rolls and the solid rolls.

A typical consistency profile along the wire with only table rolls shows the drained white water consistency rising sharply from the grooved rolls to the solid rolls and then gradually falling off. Figure 17 is a comparison of drainage profiles before and after foil installation. Over the foils, the consistency drops sharply, but is virtually the same over the succeeding table rolls as for an all table roll table. Figure 18 illustrates that on the same machine the foils made the formation more even but not better. Sometimes the average formation level may be made worse. *It depends on the level that existed with table roll operation.* An important point is that the foil wire table, being adjustable, is less of a compromise arrangement.

Bas's Weight Uniformity

The most important papermaking variable remains, basis weight. Uniformity of basis weight is critical to all other paper properties, and it is intimately associated with headbox capability and the subsequent wire table arrangement.

Figure 19 is a typical set of basis weight profiles from a first-class standard headbox. The upper line shows basis weight and caliper. The two lower lines indicate the stability. The bottom line is a plot of the residual variation obtained from the upper pair. For a good headbox, this line should be low and horizontal.

Figure 20 illustrates a similar plot from another machine with a different and slightly better headbox. Figure 21 is presented to show the greatly increased stability characteristic of all double wire machines.

Table Alignment

No discussion of the wire table would be complete without considering the importance of proper table alignment. As machine speeds increase and as table rolls are replaced with foils and wet suction boxes, the requirements of table alignment have become more critical. To achieve good alignment and maintain it, requires good measuring equipment, set procedure and discipline.

For a modern high speed machine, the goal should be to know as a matter of continuing record, the position of every roll, deflector and box in the table to within 0.025 inch vertically, and 1/16 inch horizontally.

Along with alignment, there are two other maintenance keeping functions of related importance. One is the planing of deflectors and covers where they are not of the ceramic or steel type. Close attention must be paid to the knife edge on deflectors. The other function is the balancing of rolls. Satisfactory wire table performance is incumbent on following set procedures and schedules.

The Water Balance

The amount of water that must be removed from the wire naturally relates to the amount of water deposited from the headbox. The requirements are:

1) achieve good formation in the forming process; and
2) concentrate the fiber to at least 18% after the couch

For sheets such as newsprint, kraft paper and fine papers, the amount of water removed is on the order of 200 lbs. per lb. of paper made. All factors being equal, a greater ratio of water removal should contribute toward better formation. As already noted, this is the mechanism whereby foils and

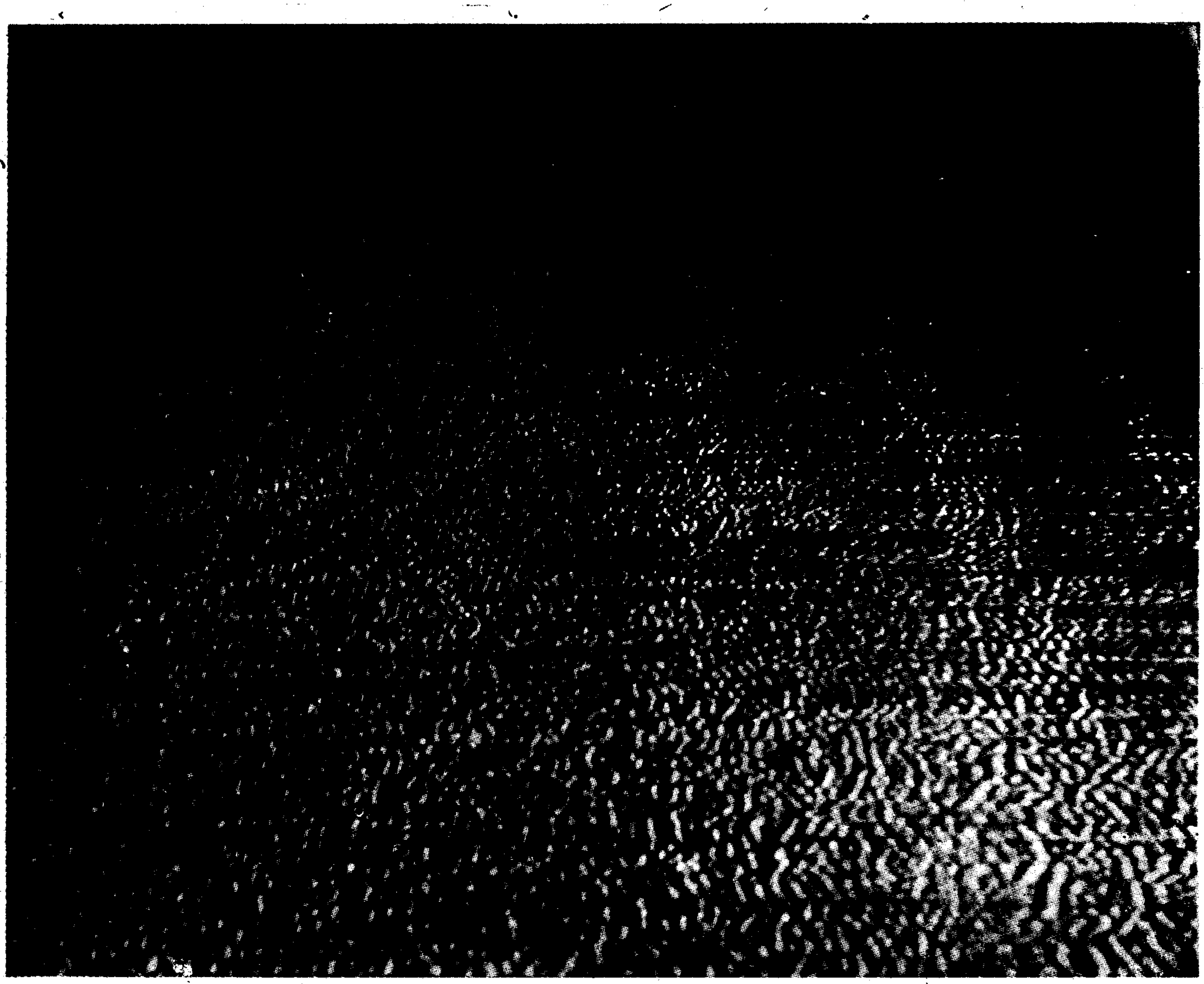

Fig. 11. Flow on wire above first set of foils at 2400 fpm

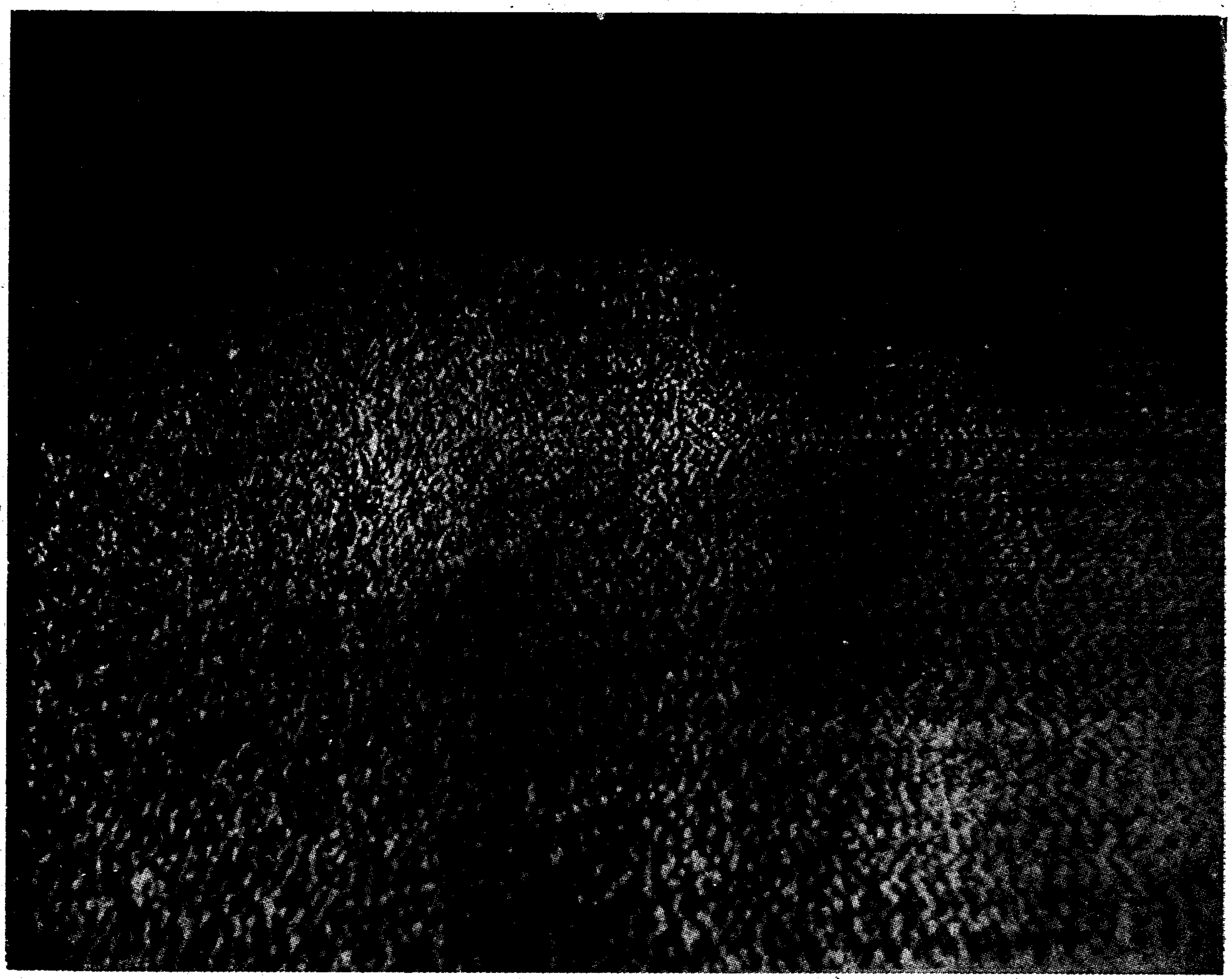

Fig. 12. Flow on wire above first set of foils at 2600 fpm

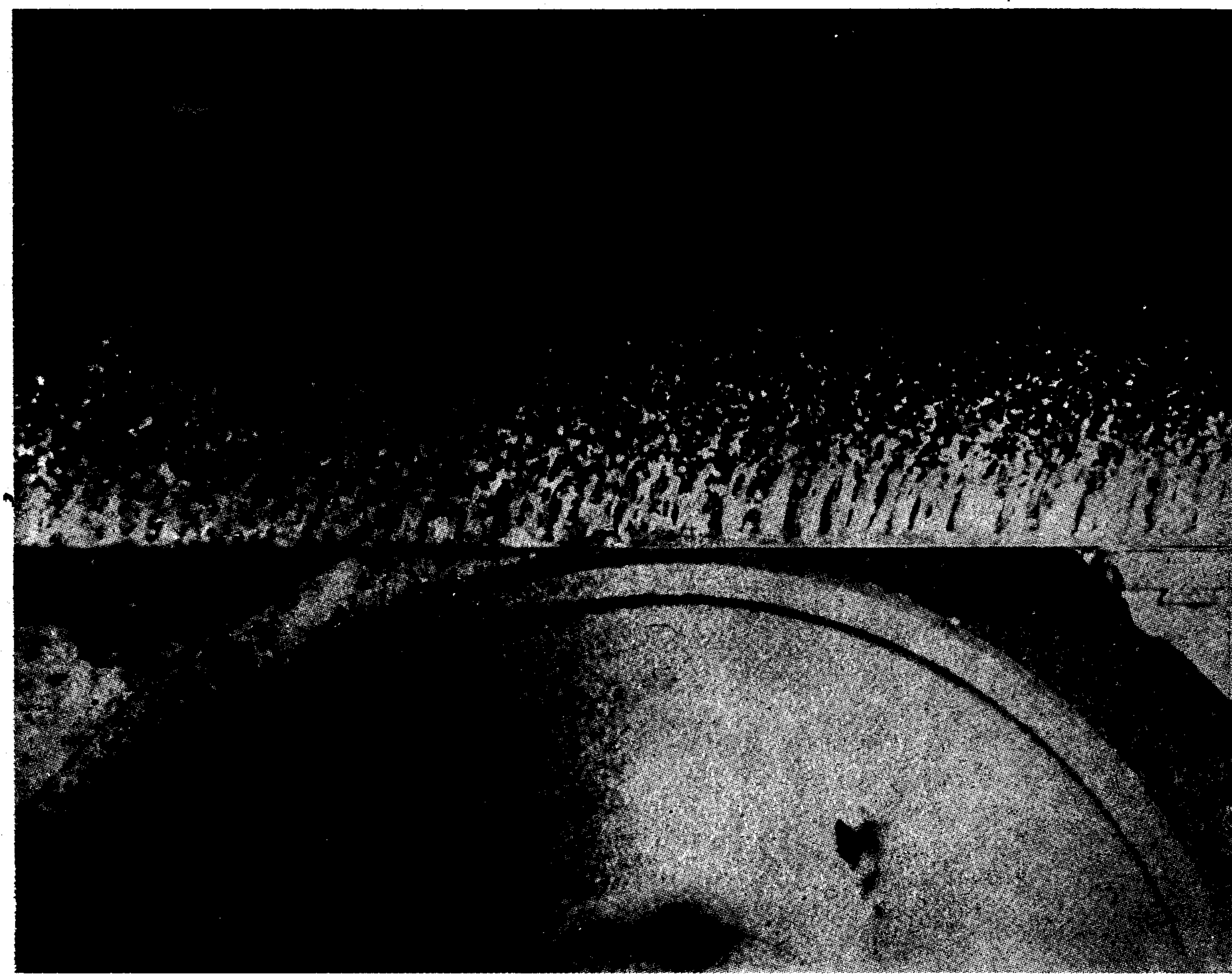

Fig. 13. Flow at second solid table roll after foils at 2400 fpm

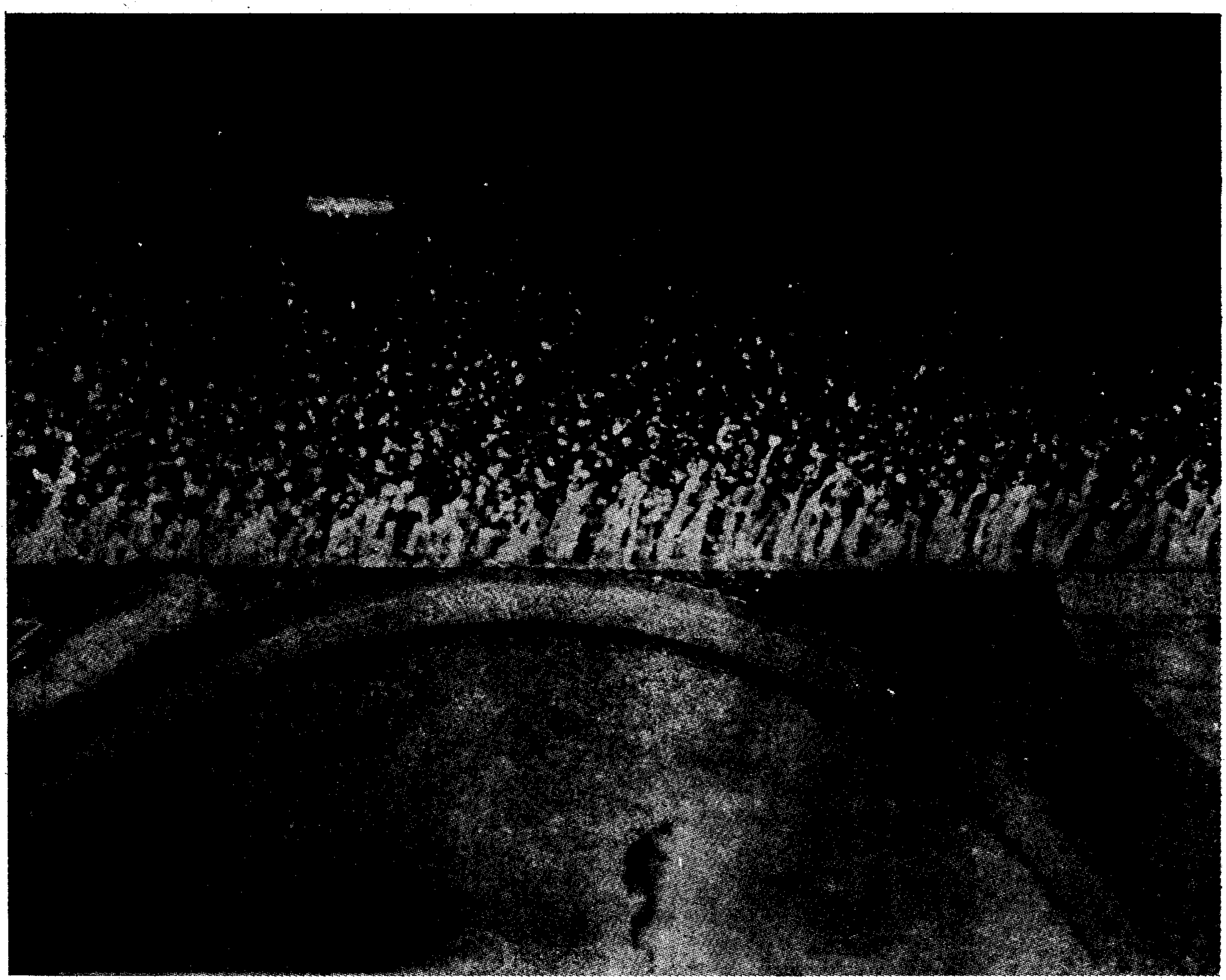

Fig. 14. Flow at second solid table roll after foils at 2600 fpm

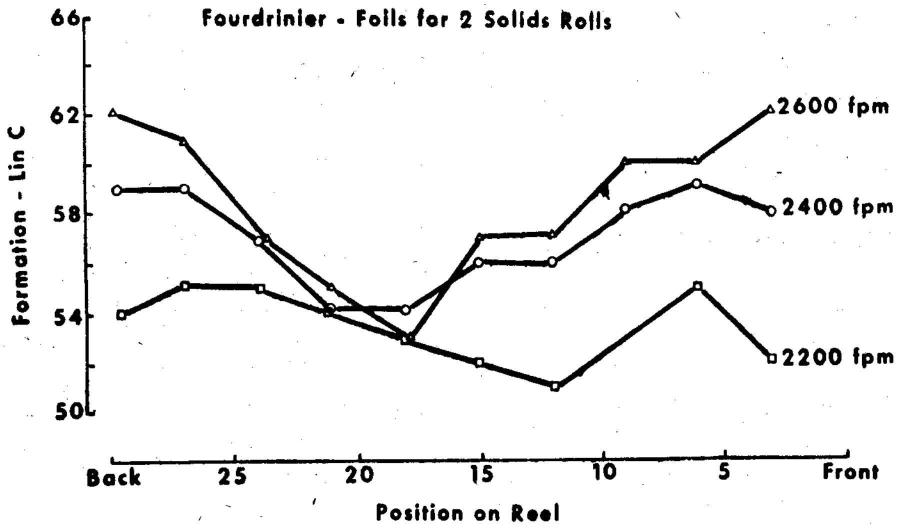

Fig. 15. Effect of machine speed on formation profile

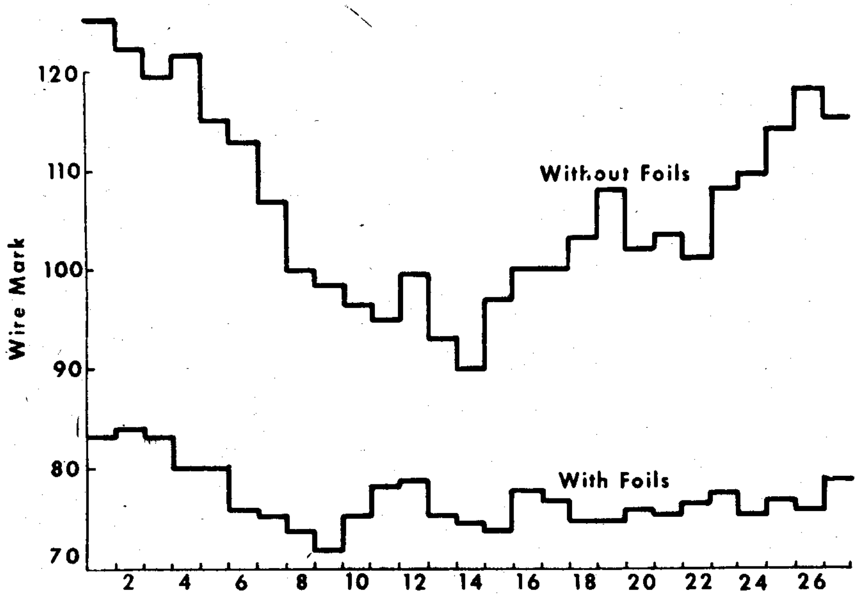

Fig. 16. Effect of foils on wire marking across the machine

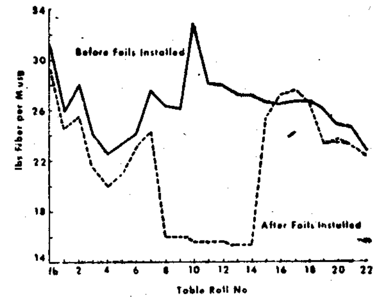

Fig. 17. Drainage table consistencies before and after the installation of foils

wet suction boxes achieve improved formation.

For comparisons at constant machine speed, headbox consistency is sometimes used as a measure of relative water removal. This type of comparison can be misleading where a change of drainage elements has also effected improved retention of fines in the sheet. Figure 22 shows the interrelationship between headbox consistency, wire pit consistency and headbox flow. Take for example, a machine equipped with table rolls, operating at a 0.70% headbox consistency and 0.32% wire pit consistency. If after conversion to foils, the wire pit consistency drops to 0.24%, it will now be necessary to operate with a headbox consistency of 0.63% *in order to maintain the same headbox flow.*

In order to get the most efficient operation from a wire table, it is necessary to know where water is removed (or not removed) along the entire length. This information can be gathered, either by doing consistency and flow measurements at each element, or by blowing samples off the wire and doing a consistency profile. Figure 23 shows a typical wire table profile for a newsprint machnie.

Practical Aspects of Sheet Forming Principles

As pointed out by Parker[16] there are three basic dispersion methods for obtaining good formation while draining water from the fiber suspension: dilution, turbulence and shear. Each of these mechanisms when used intensively or excessively may have a detrimental effect on other sheet properties. In practice, formation is usually obtained through a combination of these factors, although some types of forming equipment may rely more heavily on one factor than another. Excluding cylinder machines, current forming devices can be considered as either Fourdriniers with a free surface, tissue type pressure formers, or double wire formers, both these latter without a free surface.

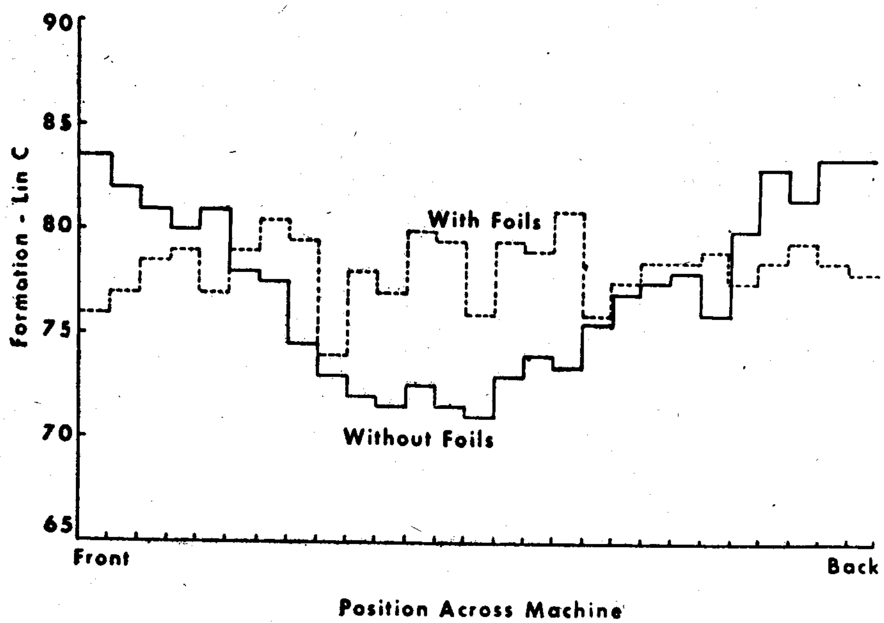

Fig. 18. Effect of foils on formation profile

For the Fourdrinier, the hydrodynamic effects of drainage, oriented shear and turbulence generated along the table are generally the controlling factors in the forming process. The headbox is also important, but usually on a scale that is larger than the structural elements of the paper web, the fiber flocs.

Tissue type roll formers using pressure formation depend primarily on very high turbulence in the initial forming zone for good formation[16]. Parker points out that the MD-oriented shear generated in the flow under the roof by the

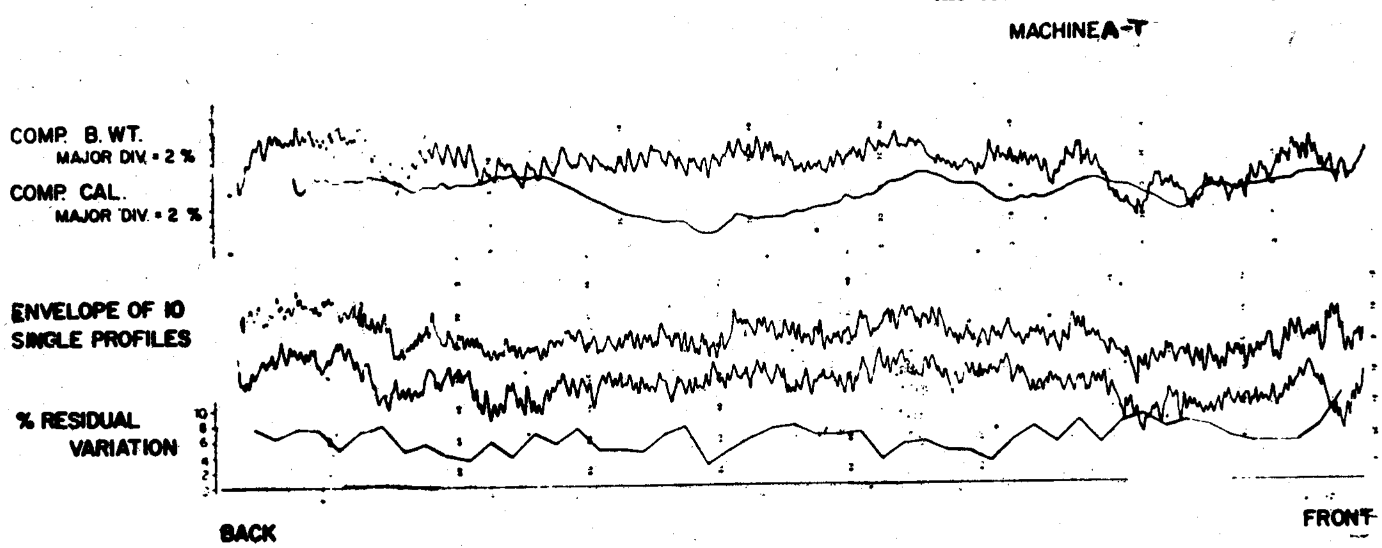

Fig. 19. Basis weight profile–typical of good headbox

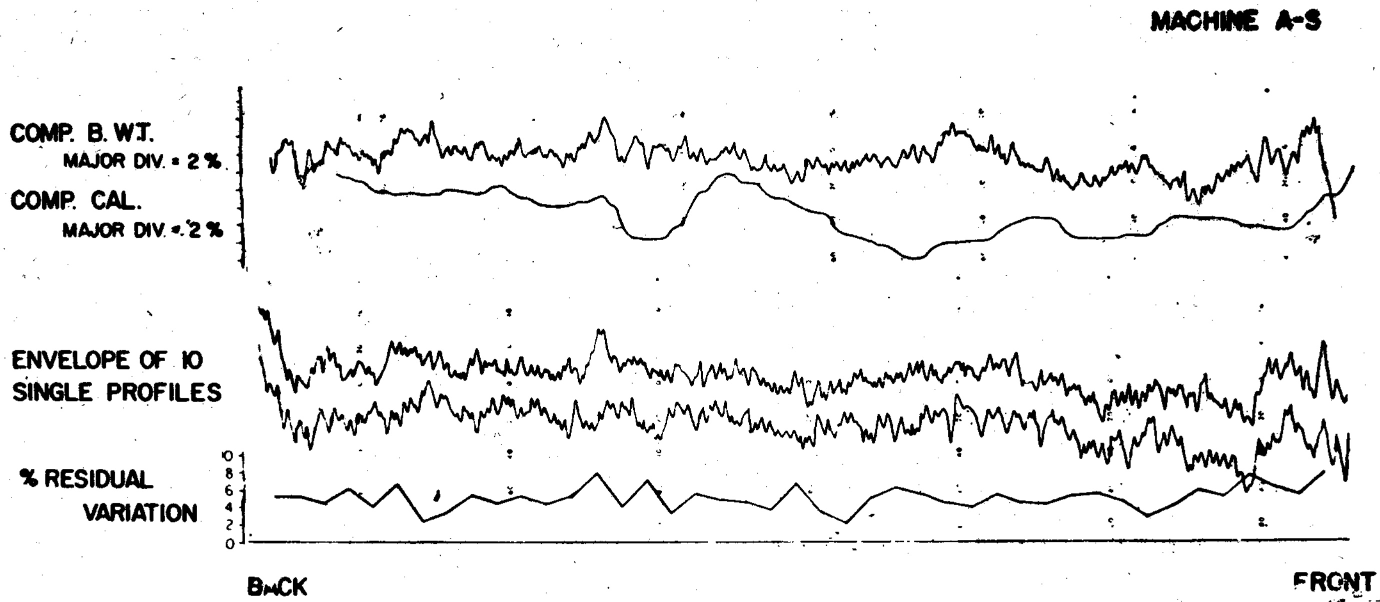

Fig. 20. Basis weight profile—representative of improved headbox

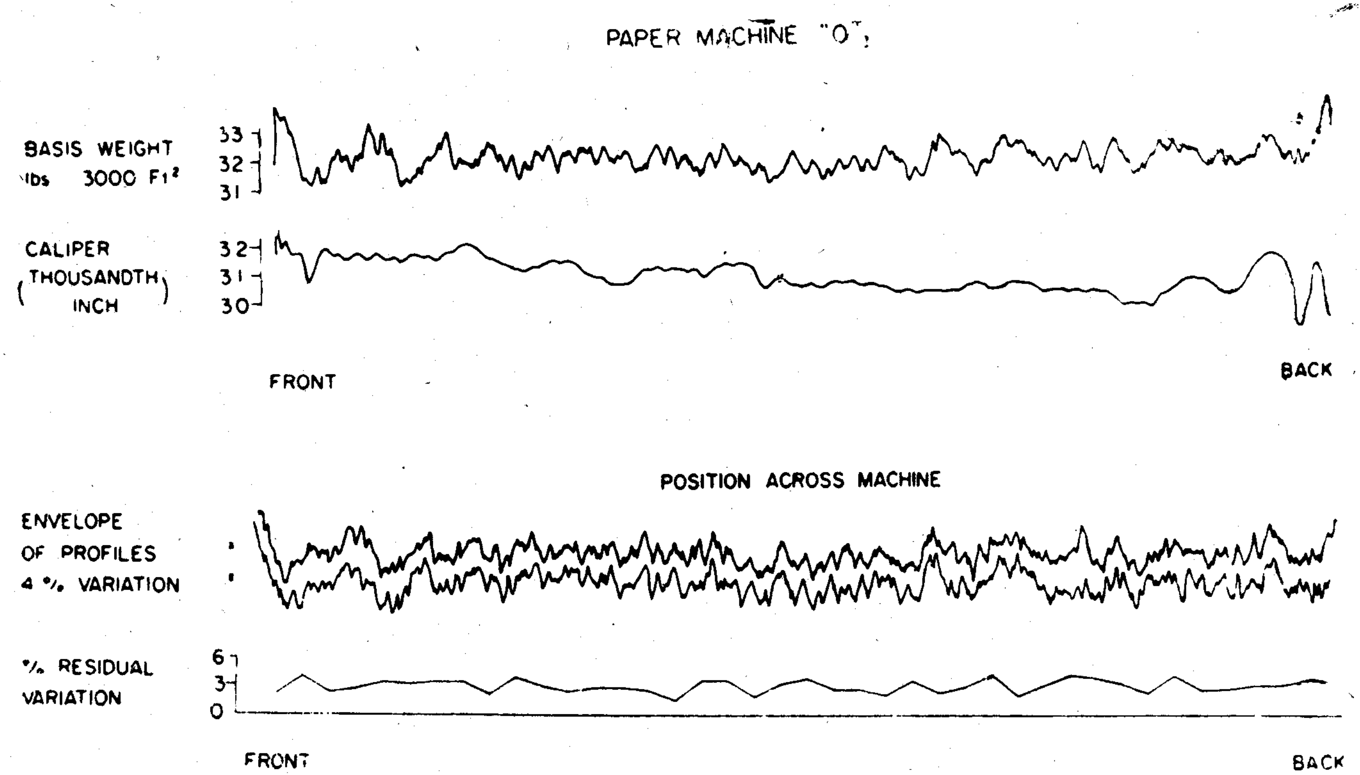

Fig. 21. Basis weight profile--twin wire former

difference in speed between the roll surface and the stationary roof is actually a detrimental effect and can disrupt the mat formed with the initial drainage.

As with roll formers, the elimination of the free surface in twin wire formers allows very high levels of turbulence to be used in the immediate forming zone and precludes free surface erruptions. This feature is exploited in twin wire devices by using headboxes which produce relatively highly turbulent discharges for better initial dispersion. Because the drainage is so rapid, the suspension does not have time

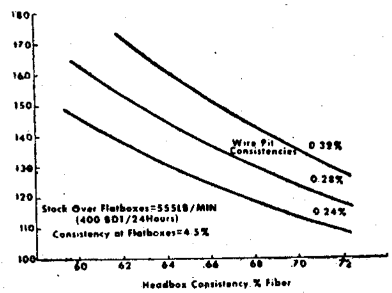

Fig. 22. Total headbox flow as determined from headbox and wire pit consistencies

to reflocculate. Thus headboxes play a more direct role in the forming process for 2-wire machines than for the fourdrinier.

Concluding Remarks

In evaluating the above discussion with respect to practical realities the follwing points must be kept in mind.

— One needs to understand principles to make the right choices and decisions regarding wire table drainage. Do not get carried away by overenthusiastic salesmen.

For example, with foils a number of factors must be considered. Alignment and grinding are critical; any defect in a foil will show up as a streak in the sheet. Frequently, plastic wires are used in combination wlth foils; the plastic wires themselves can introduce complications. Plastic wires usually flex more easily than do bronze wires, thus causing greater disturbances at the same tension. Plastic wires tend to remove more fiber at separation from the sheet; they require a higher pressure water spray for cleaning. The economics of plastic wires must be carefully looked into; machine shutdowns are normally taken on a regular basis anyway, so increased wire life may not necessarily mean increased production at the same time. Finally, couch load increases with both foils and plastic wires.

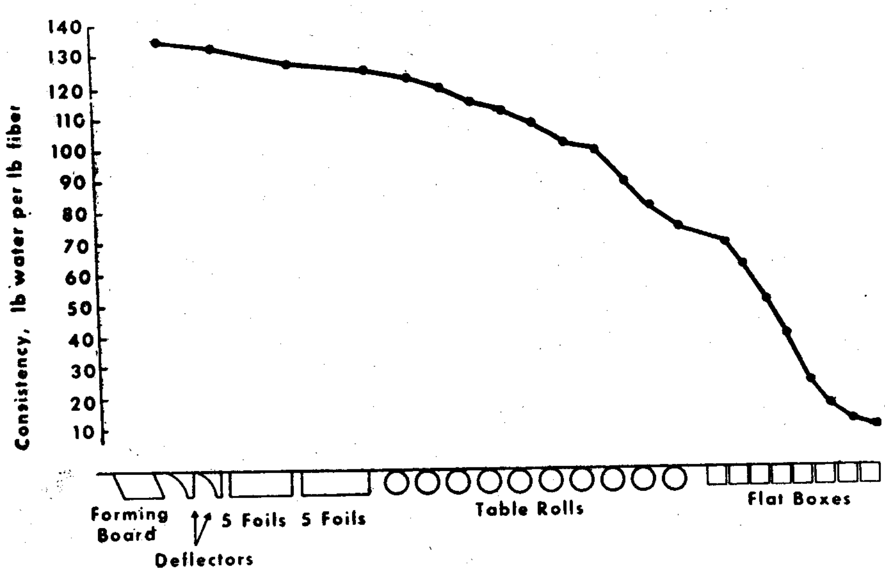

Fig. 23. Table consistency profile.

References

(1) Kitano, A. *Double Wire* Paper Trade Journal (Dec 19, 1960)

(2) Webster, USP 3,201,205, Can P 614–901

(3) Timmerman, USP 1,880,686 (1929) USP 1,926,319 (1933)

(4) Taylor, G.I., *et al.* USP 3,079, 990 Can P 630,219 Fr. Pat 1,236,808 "*A New Method of Paper Formation–The Balanced Loop*" P & P Mag. Can. 67 : 10 : T436–44 (October. 1966)

(5) Burkhard, G. and Wrist, P.E. "*Investigation of High Speed Paper Machine Drainage Phenomena*" P&P Mag. Can. 57:4: 100-118 (March 1956)

(6) Mardon, J., and Manson, D. W. The Formation of Paper Without Table Rolls (In French) La Papeterie 83:10:752–66; 11:852–57

(7) De Montigny, R. A. Discussion of New Sheet Formers : Pulp and Paper Magazine of Canada; T449–T455 (October 1966)

(8) Schmidt, Sylvia Quality High speed Formation Pulp and Paper International; pp. 14–17 (September 2, 1968)

(9 Chatwin, M. A. & Bertram, E. H. *Practical Aspects of Fourdrinier Operation* P & P Mag Can 68:5:T221-26 (May 1967)

(10) Mardon, J. *The Effect of Slice Flow and Flow on the Wire on Newsprint Paper Formation and Properties* Paperi Ja Puu 43 : 5 : 327--342 (May, 1961) 43 : 6 : 384—396 (June 1961) 43 : 7 : 419—434 (July 1961)

11) Mardon, J. & Truman, A.B. *The Wake Effect, Ridge Formation and Spout Development on the Wire of the Fourdrinier Machine* Paperi Ja Puu 41:9:391-399 (Sept. 1959) 41:10:457-466, 474 (Oct. 1959)

(12) Kankaanpaa, M. & Aaltonen, P. *New Forming Methods* Norsk Skogindustri (Swedish) (September 1971) English translation available from Nordiskofilt

(13) Parker, J.& Hergett, D. *Simultaneous Convergence, A New Concept of Headbox Design* TAPPI 51:10:425-32 (October, 1968)

(14) Bennett, R.A. *Bunched Tube Headbox* ..... -- Pulp & Paper 42:35:20-23 (August 26, 1968)

(15) Berkevall, O., Larsson, K. O., & Wahlstrom, B. *Use of Wet Suction Boxes on Printing Grades TAPPI* Engineering Conference, 1967 (Unpubl.)

(16) Parker J.D. *The sheet-Forming process* Special Technical Association Publication No.9 (Copyright 1972 by TAPPI)