Headbox Improvements By Simple Measurements

J. Mardon
R. E. Monahan
E. S. Brown

Five separate headboxes of three basic manifold or distribution system designs are briefly described. The headboxes are of open style and of a construction pattern dating from about 1920-1935. The improvement that can be obtained by the replacement of large pipe manifold type with a taper flow distribution system with a perforated plate and overflow is demonstrated by means of full scale measurements.

Introduction :

It is not the purpose of the present paper to review the headbox literature, but rather to describe a series of relatively simple headbox measurements that enabled a significant improvement to be obtained in the performance level of a group of low speed headboxes. Designs similar to those described are still in use on small production capacity fine paper machines in the less industrially developed nations and the information conveyed is thus still of considerable practical import.

Instead of a comprehensive list of the literature, a small number of references have been selected. The literature prior to 1965 has been reviewed from the aspect of design by the present authors in Reference (1) and from the aspect of operation up to 1968 in Reference (2). There have been several schools of workers active in the field of headbox design whose papers have been cited in the two reviews; amongst these should be mentioned the Dutch school of Van der Meer, the German school of Muller-Rid and Pausch, that centered around C. A. Lee of Kimberly-Clark in the 1950's, the Anglo Paper Products and Oxford Paper groups with which the authors have been associated, and the work of the Beloit group under Parker. Some worthwhile work has been reported by Dahl and Wahlstrom continued his work in this field whilst Research Director at K. M. W.

Amongst these workers a common activity has been the investigation of headboxes through model work. Comparatively little work has, however, been disclosed regarding hydraulic measurement on full scale equipment. In this regard attention should be directed to the paper by Nelson and to those of the authors and their colleagues.

Subsequent to the work quoted in References (1) and (2) Parker has published an important paper (3) describing the work of his school up to approximately 1970 and which cluminated in the converflow headbox (4). The only other development in this field which merits note is the bunched tube headbox (5) (6), the essential design point of which appears to have been anticipated by Showers (7).

Methods of Investigation

A brief note on these is given in Appendix I. They were essentially the same as those described in the paper, "Hydraulic Measurements in Paper Machine design and Operation" (Sevensk Papperstidning 59; 12; 429, June 1956), except that the Ott current meter was used in place of the Neyerpic. The current meter is carried on a support which enables it to be moved so as to point in any direction, the maximum reading being obtained when it is in line with the flow. Slice measurements were made with impact pitot tubes.

Discussion of Results

Hydraulic Measurements

The results of the measurements made over a period of a year on a group of eight headbox fitted to fine paper machines in the 300 fpm to 600 fpm range are described by discussion of a series of figures which show the constructions studied and illustrate the flow condtions obtaining for the initial structures and for the modifications to them which were made.

Figure 1 illustrates a type of manifold common fifteen years ago and still to be founnd feeding an old style headbox with a baffle and knife slices. The disadvantages of such a construction are discussed in the paper, "The Design of Manifold Systems for Paper machine Headboxes, Part I" (Pulp and Paper Magazine of Canada 64;2;T35–49, February 1963) and will show up in the measurements described later.

The authors replaced the old branching type manifold with a tapered header using a perforated plexiglass plate as distinct from the laterals or more lately, tube sheet used by others.* Figure 2 shows such a tapered header fitted to the same type of headbox as that shown in Figure 1.

There have been a considerable number of misleading statements with regard to the shape of the taper. Unless the head loss across the plate or laterals is very high, the actual taper shape is very important. If too high a head loss is designed for, there can be fairly severe and embarrassing effects and accordingly, the authors have designed for a head loss of between 2′ and 4′ depending on the flow rate. Figure 3 shows the theoretical taper, together with the design taper which is not exactly the same for reasons explained later. It is very much easier to obtain a shape for the tapered header that is very close to the theoretical or design shape, if the header is rectangular in cross section rather than constructed of successive conic sections. For this reason the authors have always designed manifolds of rectangular cross section and the majority of those designing headbox distribution headers, have now followed suit.

Figure 4 indicates a refinement in the design that the authors have used where appropriate. The design of the taper must not only allow for the flow into the headbox from the header, but also for the friction. The simplest design equation due to Baines assumes a constant friction factor along the length of the header. If allowance is made for the changing friction factor along the header length, a less sharp taper results. It is also necessary to allow for momentum which opens up the taper still more. The design taper for a header is, therefore, always a less acute taper than the simplest equations suggest.

Following start-up, those designs for which the authors were responsible, were always checked in the field. Figure 5 illustrates the static pressure along the length of the header and the associated drop in longitudinal (cross machine) velocity. Contrary to popular misconception the static pressure should *not* be uniform along the length of the header. but should rise towards the small end as shown to allow for the "port effect" and the effect of momentum.** When any machine makes a wide variation of basis weight, the drainage capacity of the wire part on the heavier weights limits the total flow and, thus, the velocity along the header is less. This effect is shown in Figure 6 for the same headbox on a heavier grade; it can be seen that the static pressure did not rise as much and, thus a poorer distribution was obtained at the overflow end.

This point well illustrates the difficulties with which the designer must cope; for a wide range of flows the design must be a nice balance such that for no one grade is the box unsuitable. Figure 7 illustrates that at a higher flow rate, characteristic of a lighter basis weight, there is a great increase in static pressure for the same machine.

As part of the measurements, made on the full scale when the equipment was started up, the flow velocities were measured, across the full width of the headbox, at successive points from the distribution system to the slice.

Figure 8 illustrates the result of one such series of measurements, when the velocity of flow was measured at the following points:

1. through the holes in the plate
2. above the plate
3. above the first baffle
4. downflow before the second baffle
5. after the second baffle
6. prior to the first slice

These all show not only that the front side, overflow end, has a below normal flow, but that this persists right through to the slice.

The static pressure distribution along the header was measured and found to be approximately correct; accordingly, to find the reasons for the flow irregularity shown in Figure 8, the flow pattern in the two vertical sections was examined. It was found, as indicated in Figure 9, that the jets from the plate were angled at the edge giving the flow pattern shown; this was then traced

* When the tapered header with overflow was invented and first used, we had used the tube sheet (Gavelin, 1955) but changed to the plate as a better engineering solution.

** See "The Design of Manifold Systems for Paper Machine Headboxes, Part II", (TAPPI 46; 3; 172-187, March 1963) and "The Extant State of the Manifold Problem", (Pulp and Paper Magazine of Canada T346-T351, October 1971).

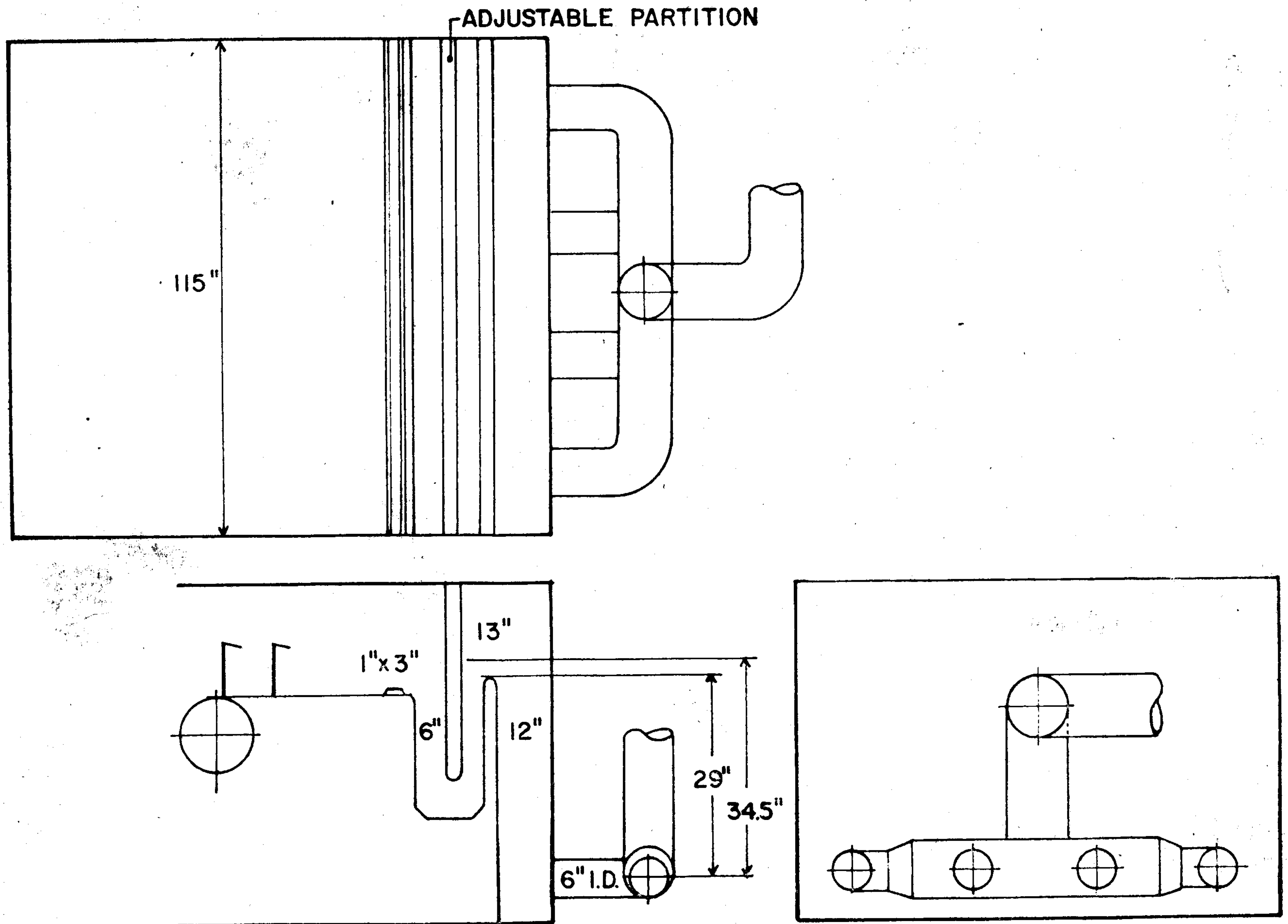


Fig. 1—Machine 1 Mill A

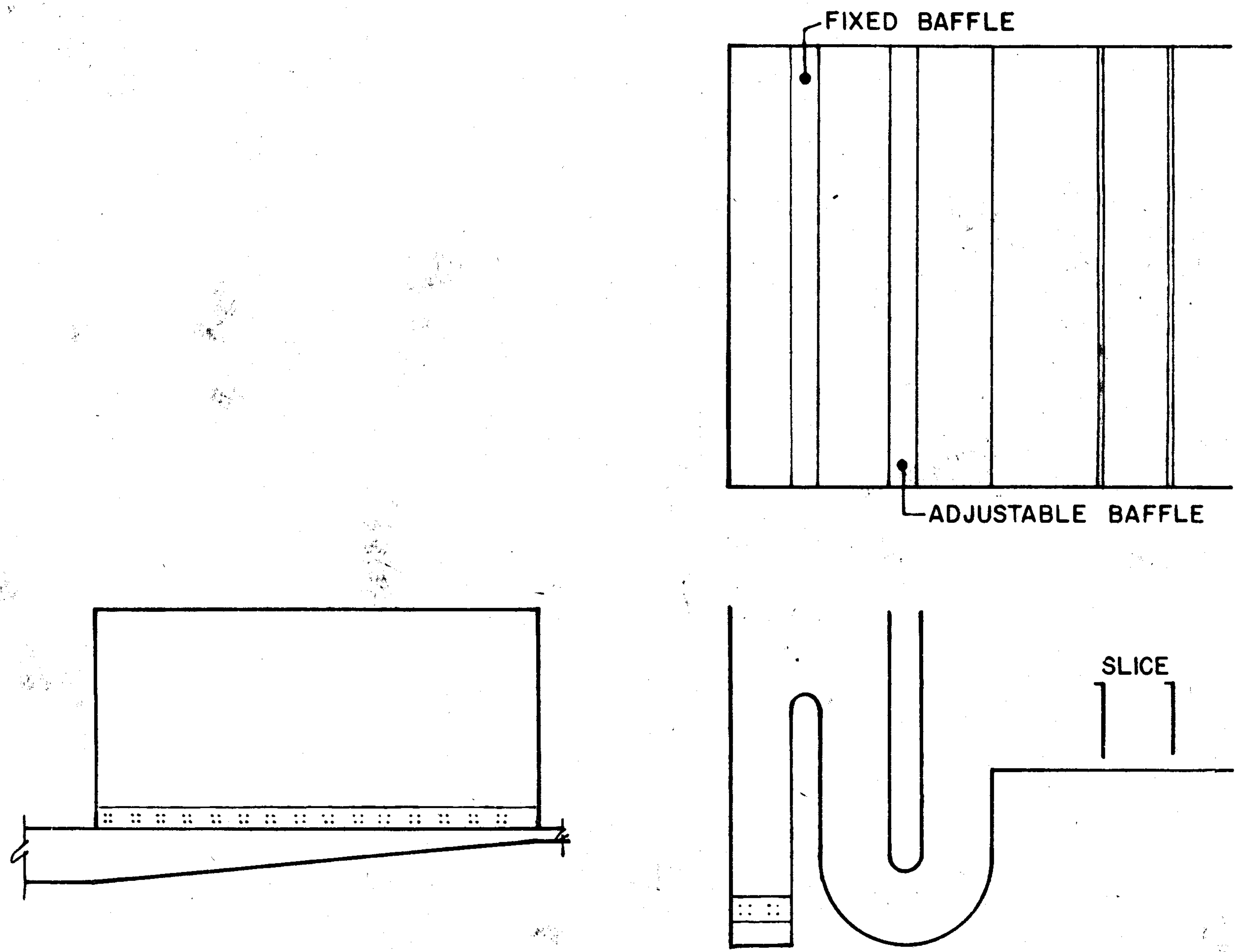


Fig. 2—Machine 2 Mill A

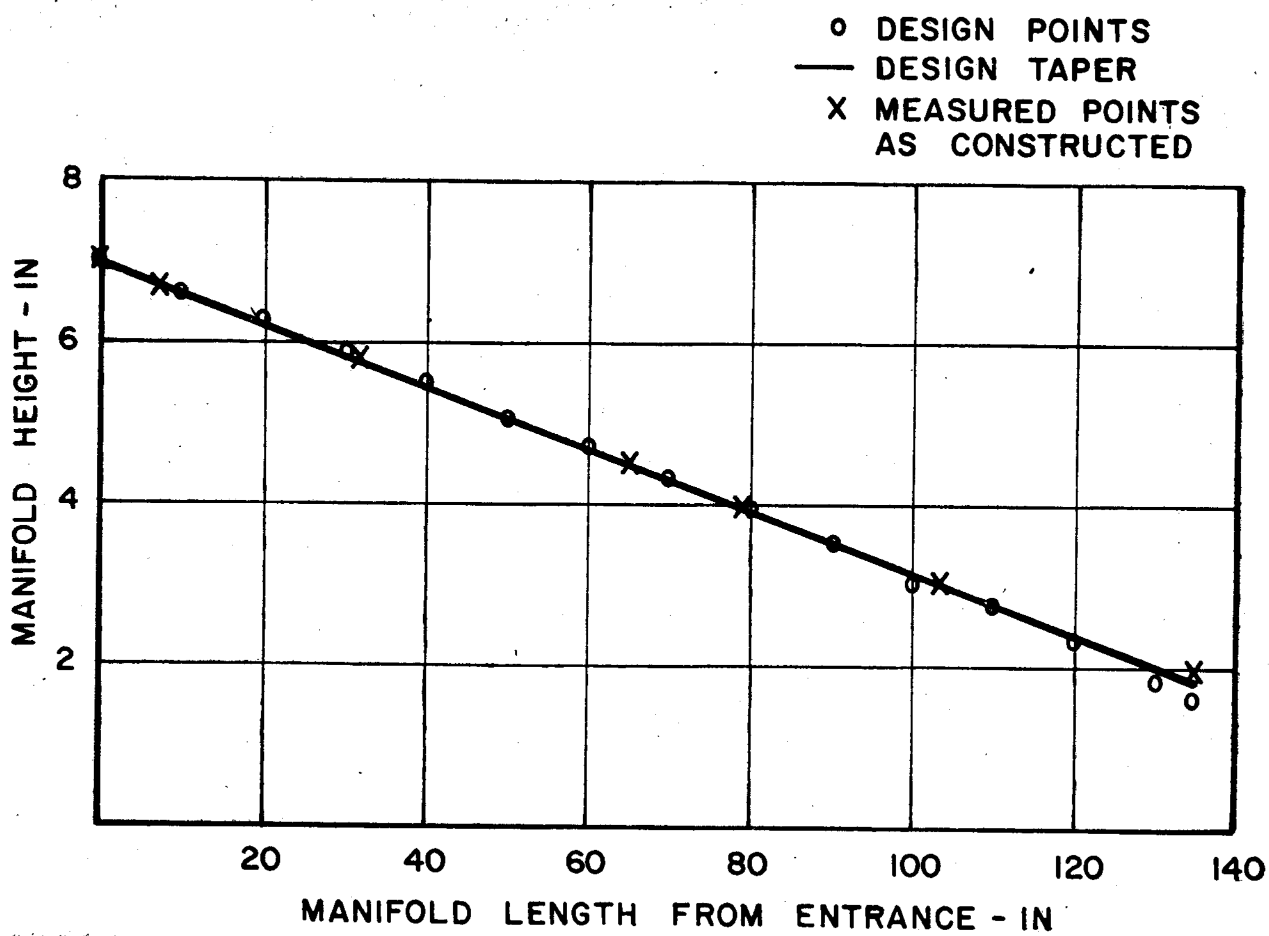


Fig. 3—Design Taper for Number 2 Machine Header

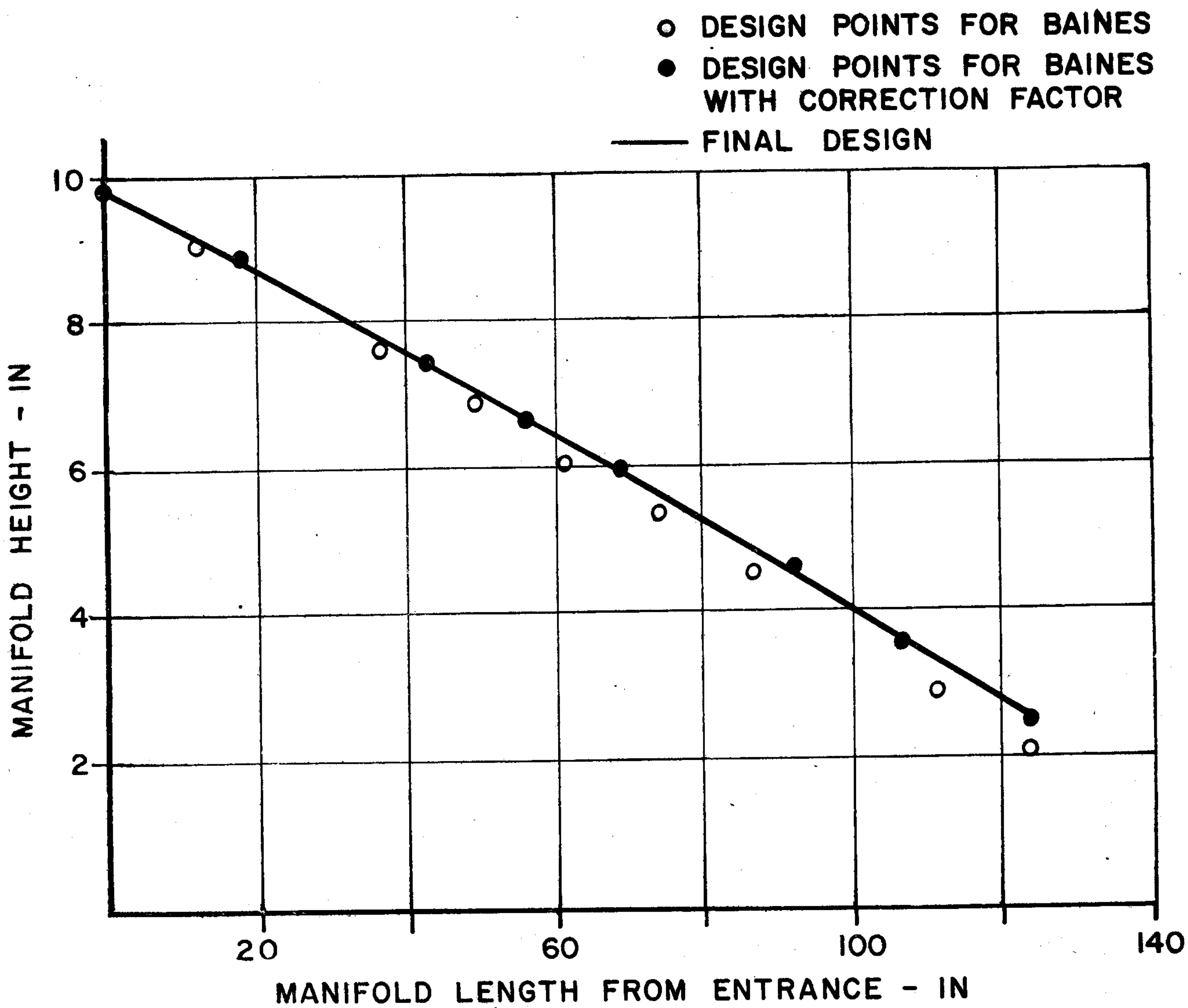


Fig 4—Design Taper for Number 3 Machine Header

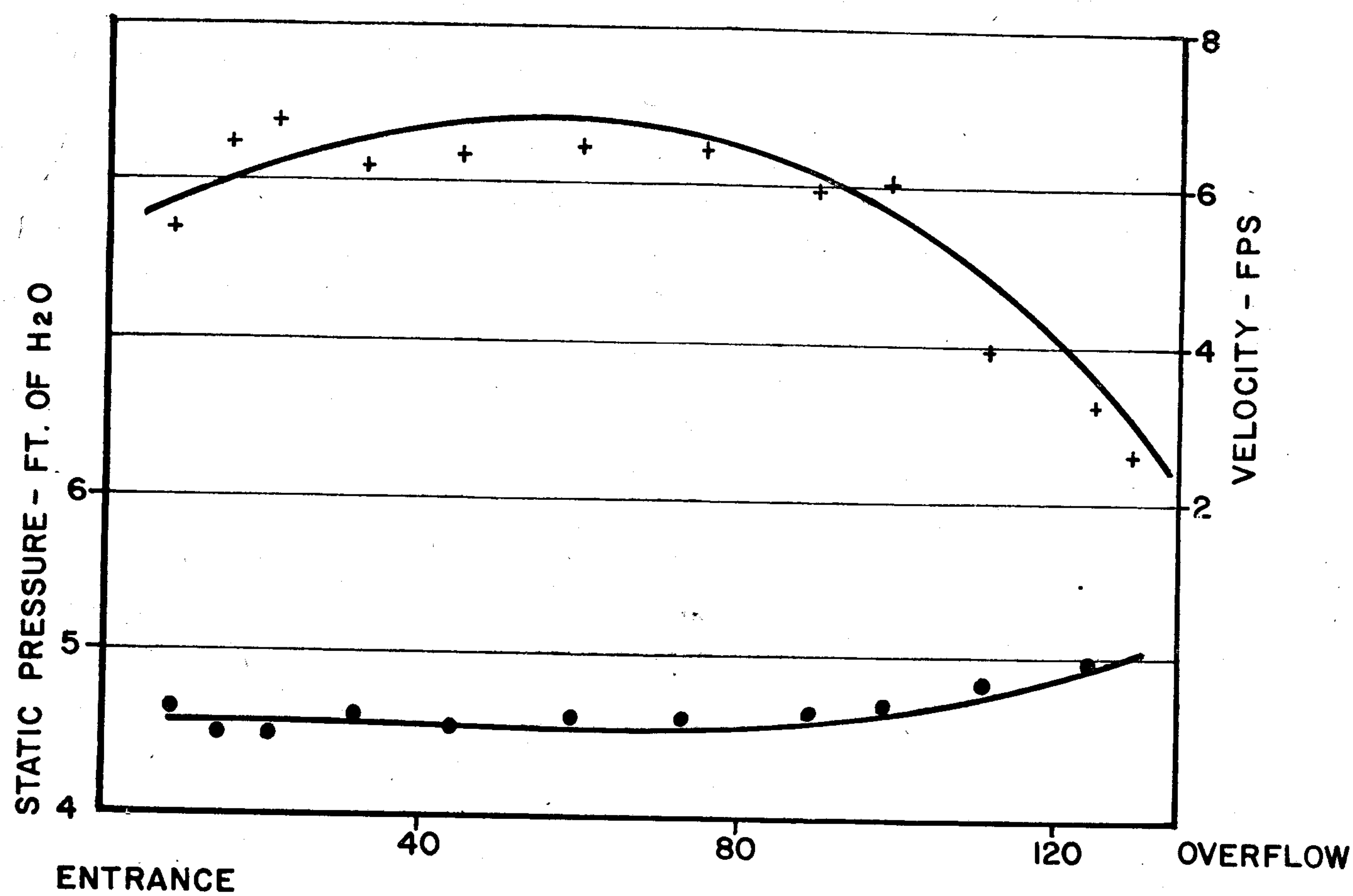


Fig. 5—Static Pressure and Velocity Along Header Number 2 Machine - Light Weight

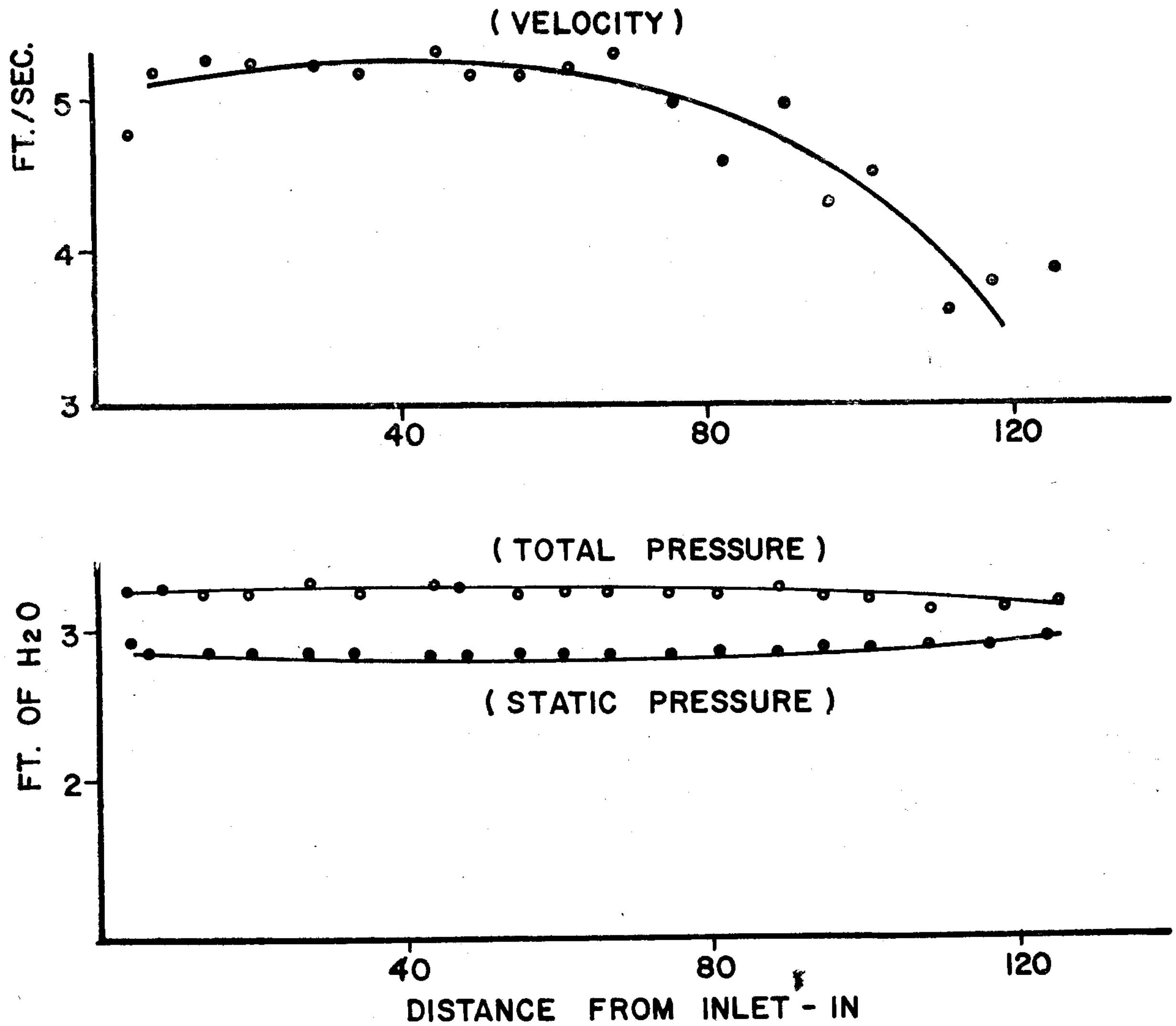


Fig. 6—Number 2 Machine Static Pressure and Velocity Along Header - Heavy Weight

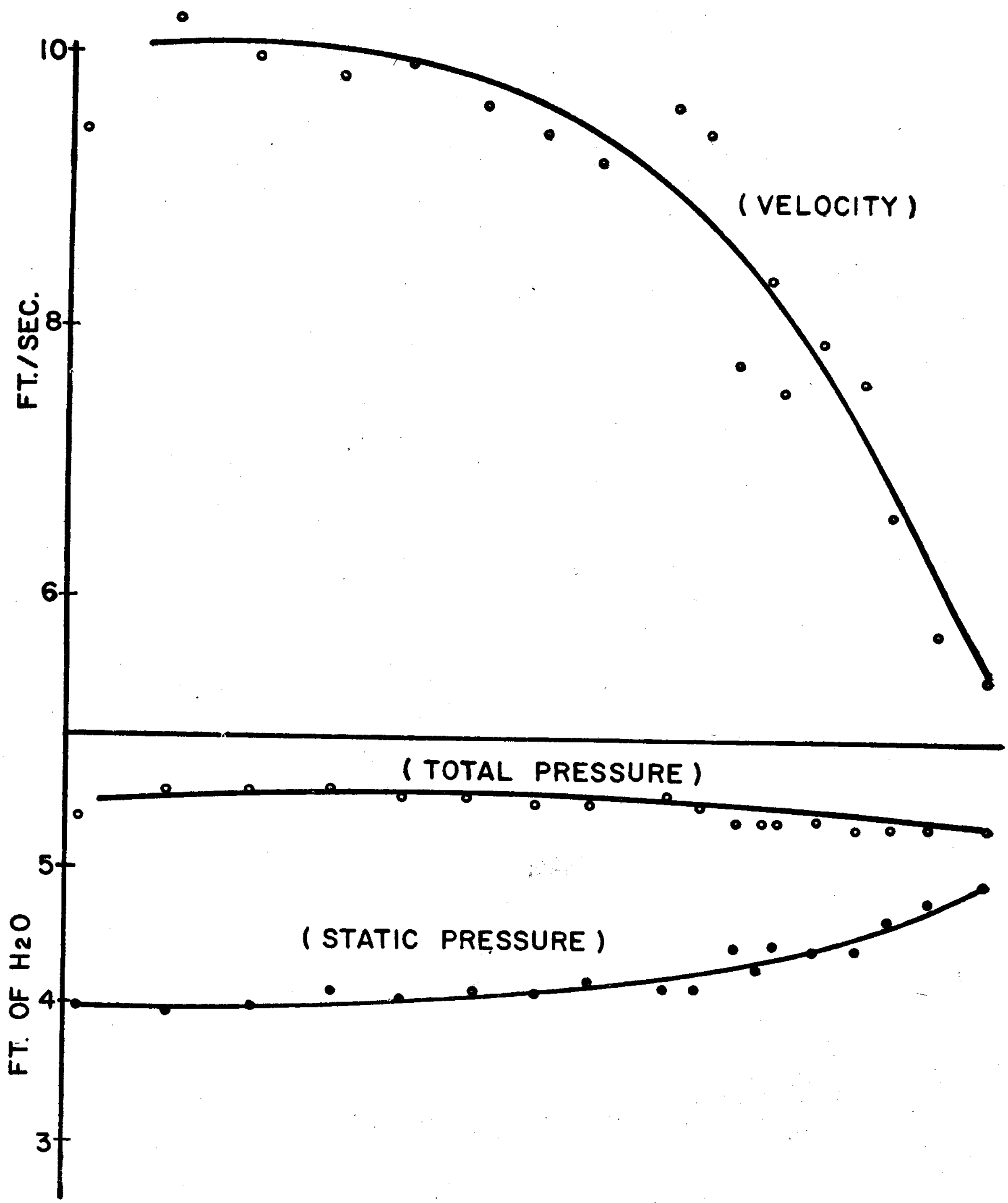


Fig. 7—Number 2 Machine Static Pressure and Velocity Along Header - Light Weight

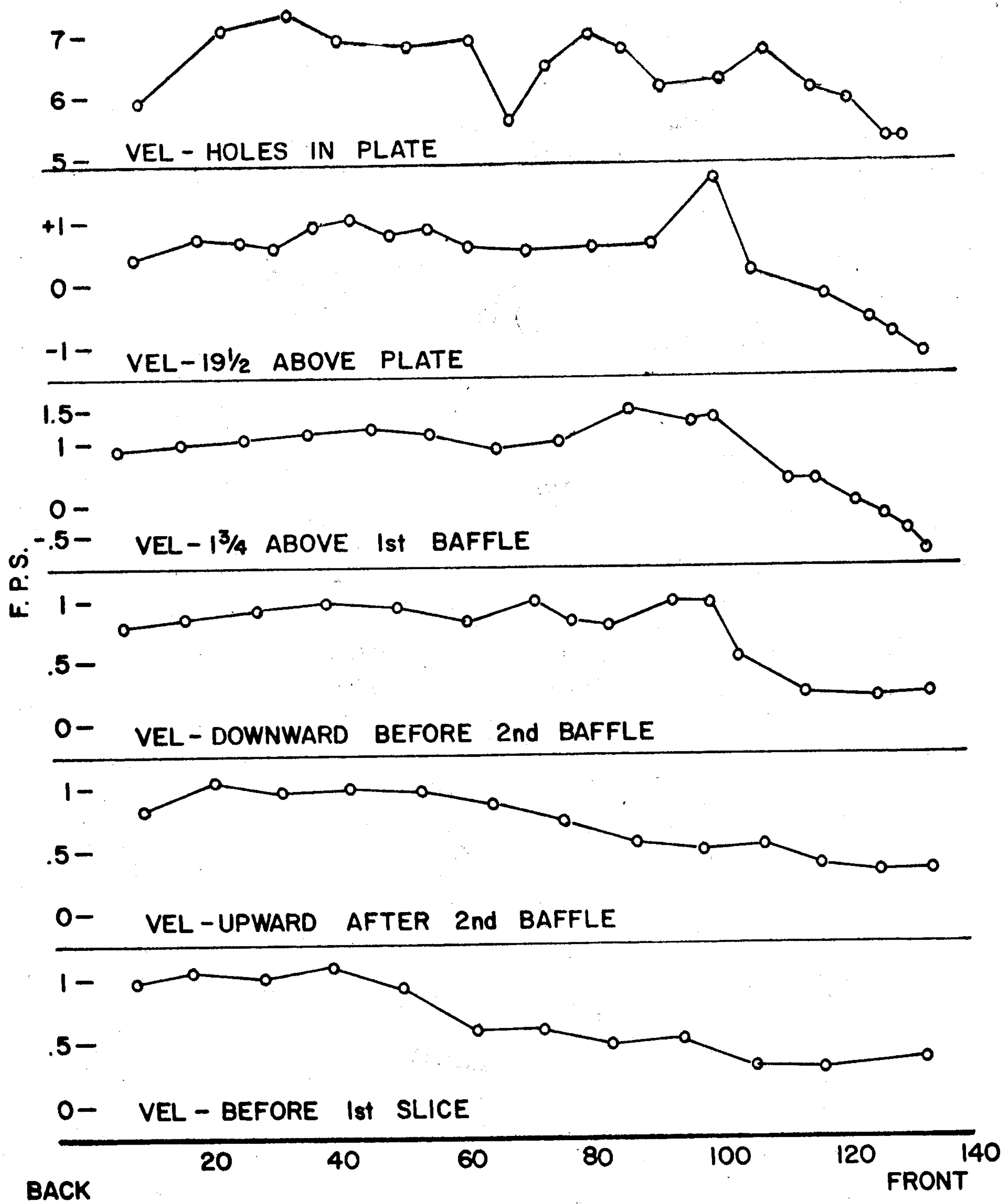


Fig. 8—Flow Pattern Number 2 Machine Headbox Velocity Profiles at Succesive Points in Headbox Faulty Distribution Plate

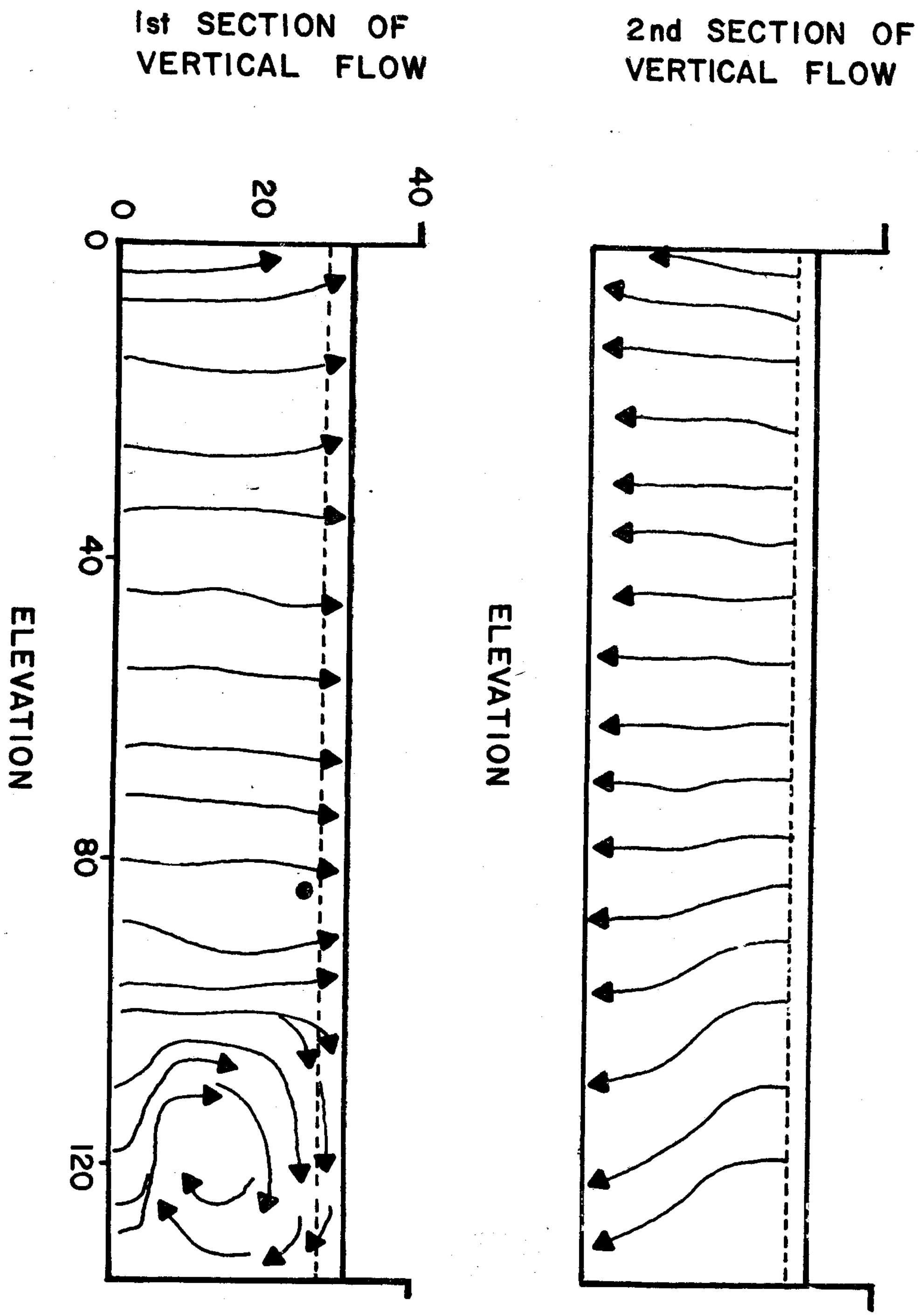


Fig 9—Flow Pattern Number 2 Machine Headbox 1st and 2nd Section Vertical Flow Faulty Distribution Plates

to the plate being too thin (13″)*. Figure 10 illustrates the continuance of this disturbance into the third vertical section and on the surface before and after the baffle.

The plate design was changed back to 2″ thick with half the holes with a 10° included angle for the first inch** and with four additional holes at the overflow end of the plate. Figure 11 shows the resulting flow; the improvement is considerable but the edges were slightly overcorrected. With a better baffle adjustment of the overflow the conditions of Figure 12 were obtained. To see the results described above in perspective, it is necessary to see the flow conditions which were found with the original manifold type, large pipe, inlet to the box. Figure 13 presents the results of a typical set of measurements made on a headbox similar to that shown in Figure 1. There are considerable velocity variations, both with time and across the machine and these are still present at the slice. Figure 14 illustrates the velocity variations in each of the large laterals which give rise to such a condition; the speed of flow varies from 5 fps. down to 1.2 fps. Figure 15, corresponding to Figure 14, again shows the considerable velocity variability across the machine, although the individual manifold pipes cannot be detected in the flow in the headbox.

These results were typical; Figure 16 illustrates a second large pipe manifold type headbox; Figure 17 the velocity variation in the laterals and Figure 18 the flow velocity variations in successive sections of the headbox. The velocties from the manifold inlet pipes varied from 1.83 fps to 3.25 fps; velocity profiles at the first baffle had considerable directionality as depicted by the arrows. By the time the stock reached the adjustable baffle, the directionality had been lost and it was moving generally in the machine direction. It can be seen that there is no relationship between successive profiles; a high point in one profile does not mean that the same high point is fixed in successive profiles. The flow contains such large scale turbulence that the velocity profiles shift from second to second and are completely out of control.

Figures 3 through 13 illustrated the flow conditions obtained with an old box modernized by the replacement of an old large pipe manifold type distribution system by a tapered header with distribution plate and overflow. Figures 14 to 18 illustrated the unstable flow obtained with a system similar to that which had been replaced.

One of the key points with regard to the operation of taper flow inlets is that the static pressure must rise along the header as the velocity falls to obtain the required even distribution; the reasons for this are given in details in References (8) and (9). Figure 19 illustrates the velocity measurements in the header of a second machine with a tapered distribution header with a plate distributor and overflow similar to that shown in Figure 2. The drop in velocity and rise in static pressure just referred to can be noted.

Figure 20 shows the velocity profiles in the headbox of the same machine. The plate had been designed with the edges overcorrected giving high velocities at the edges. A point of major interest is the deterioration of the velocity profiles before the back slice; except for this velocity profile successive profiles were very similar indicating that no matter how good the flow was the profile was disrupted as the back slice was approached. The situation with regard to excessive flow at the edge was corrected by plugging two holes at the backside and one hole at the front side. The resulting velocity profiles were considerably improved as can be seen from Figure 21, but the regularity of the velocity profile is again destroyed just before the back slice.

The final velocity profiles of Figure 21 are not as good as was expected. This was mainly due to the overflow not being adjusted properly; it can be noted in figure 21 that the profiles drop off towards the front of the machine; closing the overflow valve would have brought these up, as is shown in Figure 23.

It was clear that the poor velocity profiles, which, of course, were reflected not only in basis weight distribution, but also in machine operation, and in paper quality, were a function of the baffle position and of the way the flow turned the corner before the back (see Figure 17).

* The 1-3/4″ plate had been put in by error replacing an original 2″ thick plate which was changed for structural reasons.

** To reduce the effect of the originally severe overcorrection at the edge.

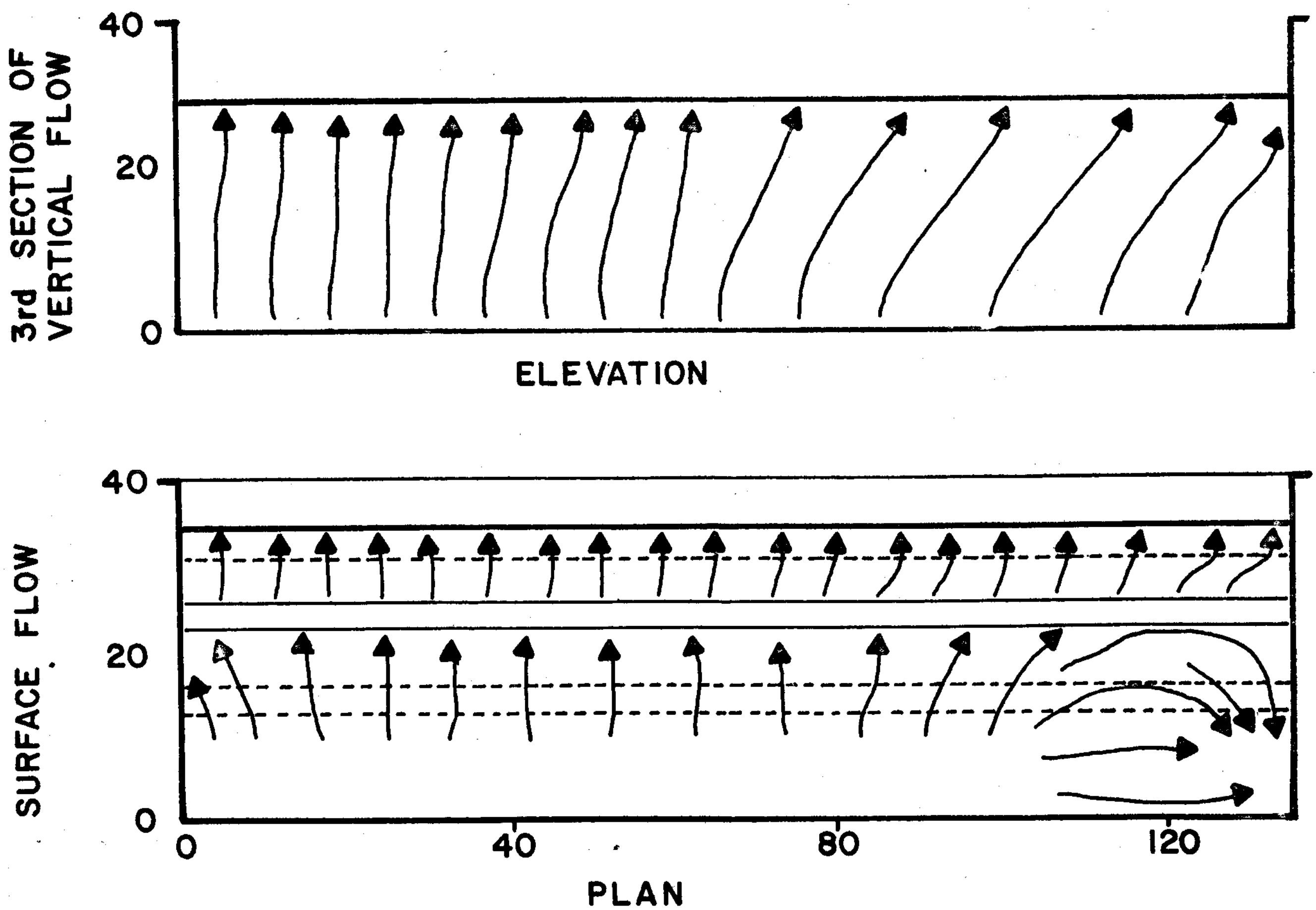


Fig. 10—Flow Pattern Number 2 Machine Headbox 3rd Section Vertical and Surface Flow Faulty Distribution Plate

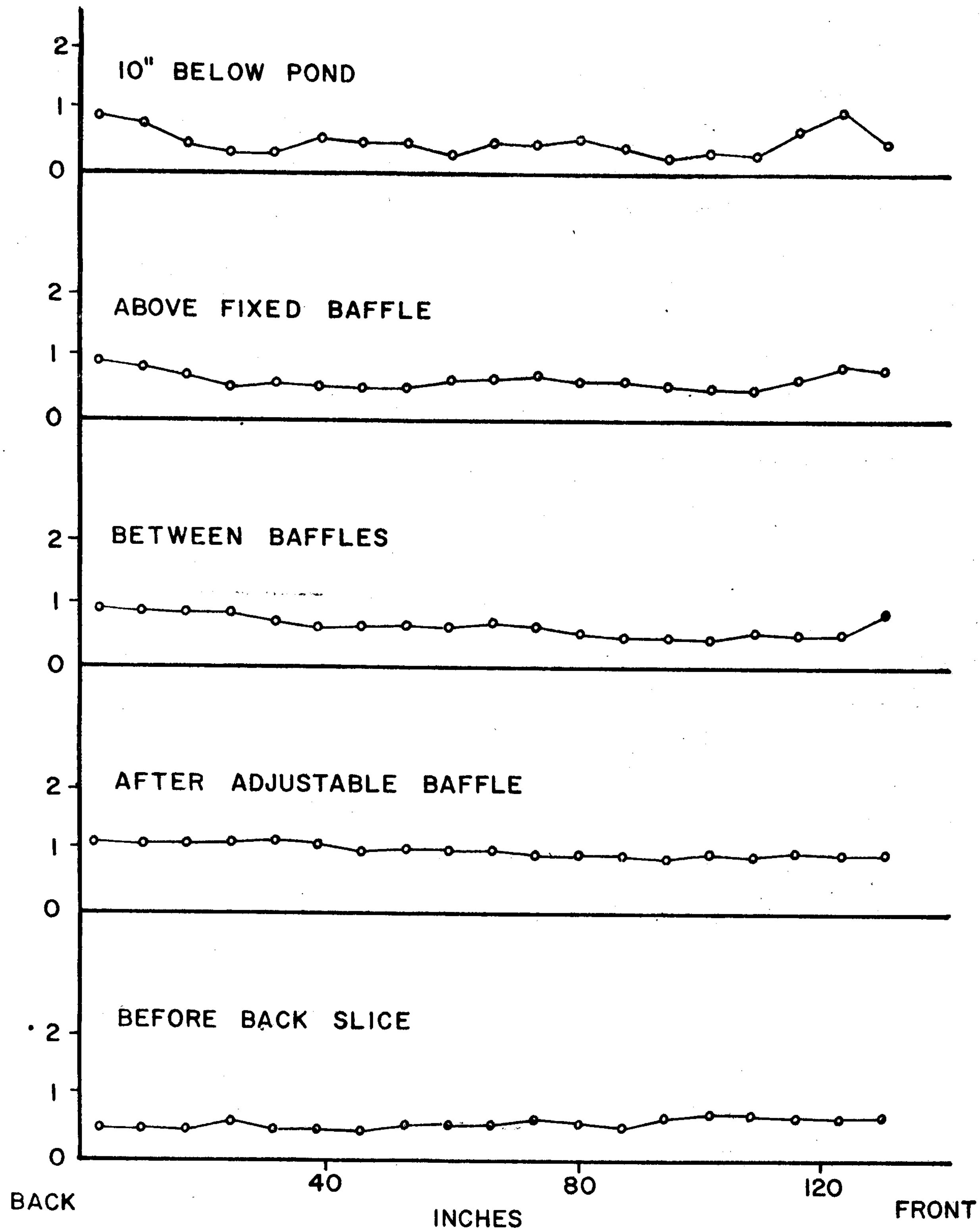


Fig. 11—Number 2 Machine Headbox Velocity Measurements with Changed Distribution Plate

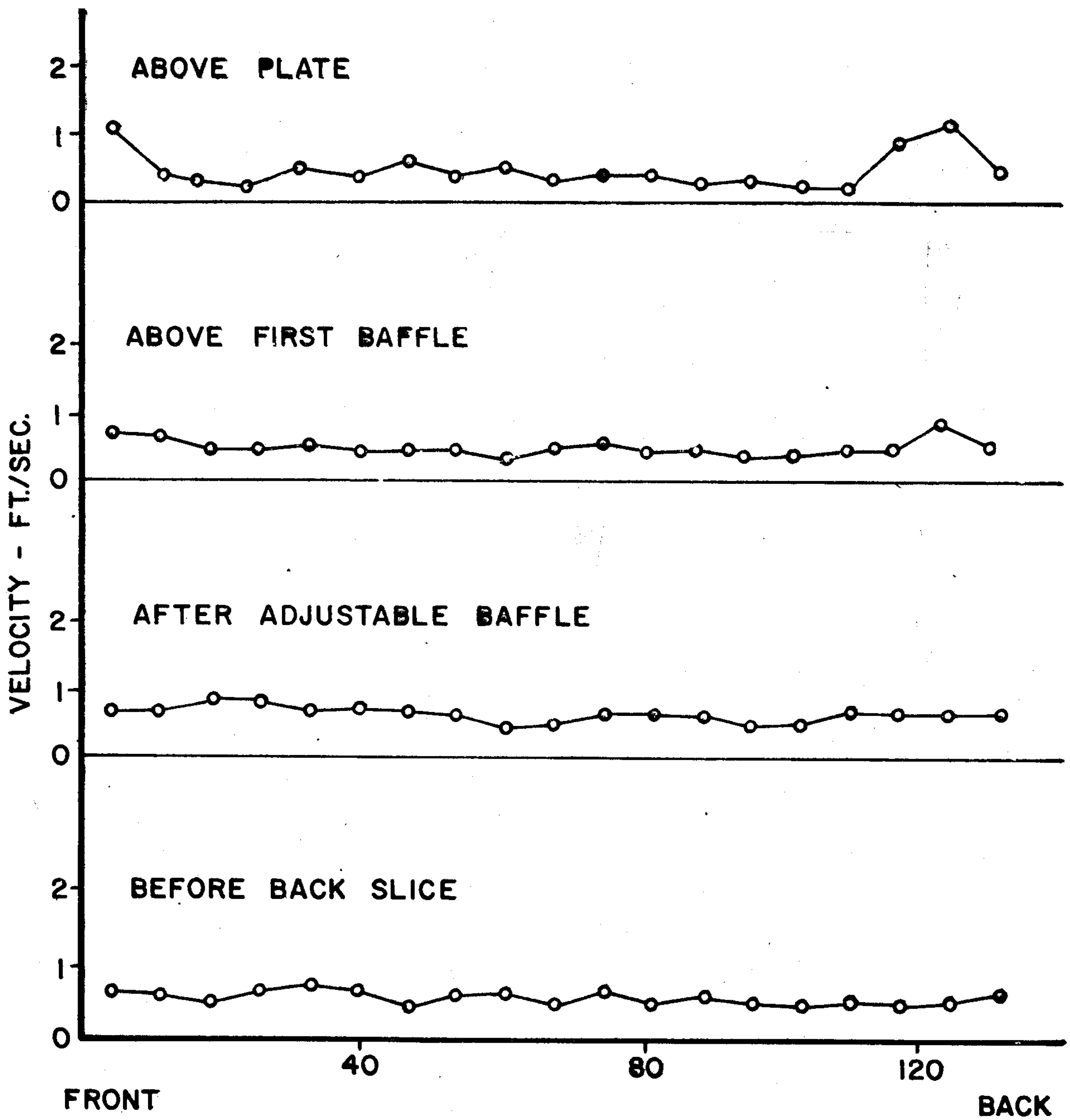


Fig. 12—Number 2 Machine Headbox Velocity Measurements with Changed Distribution Plate and Baffle Adjustment

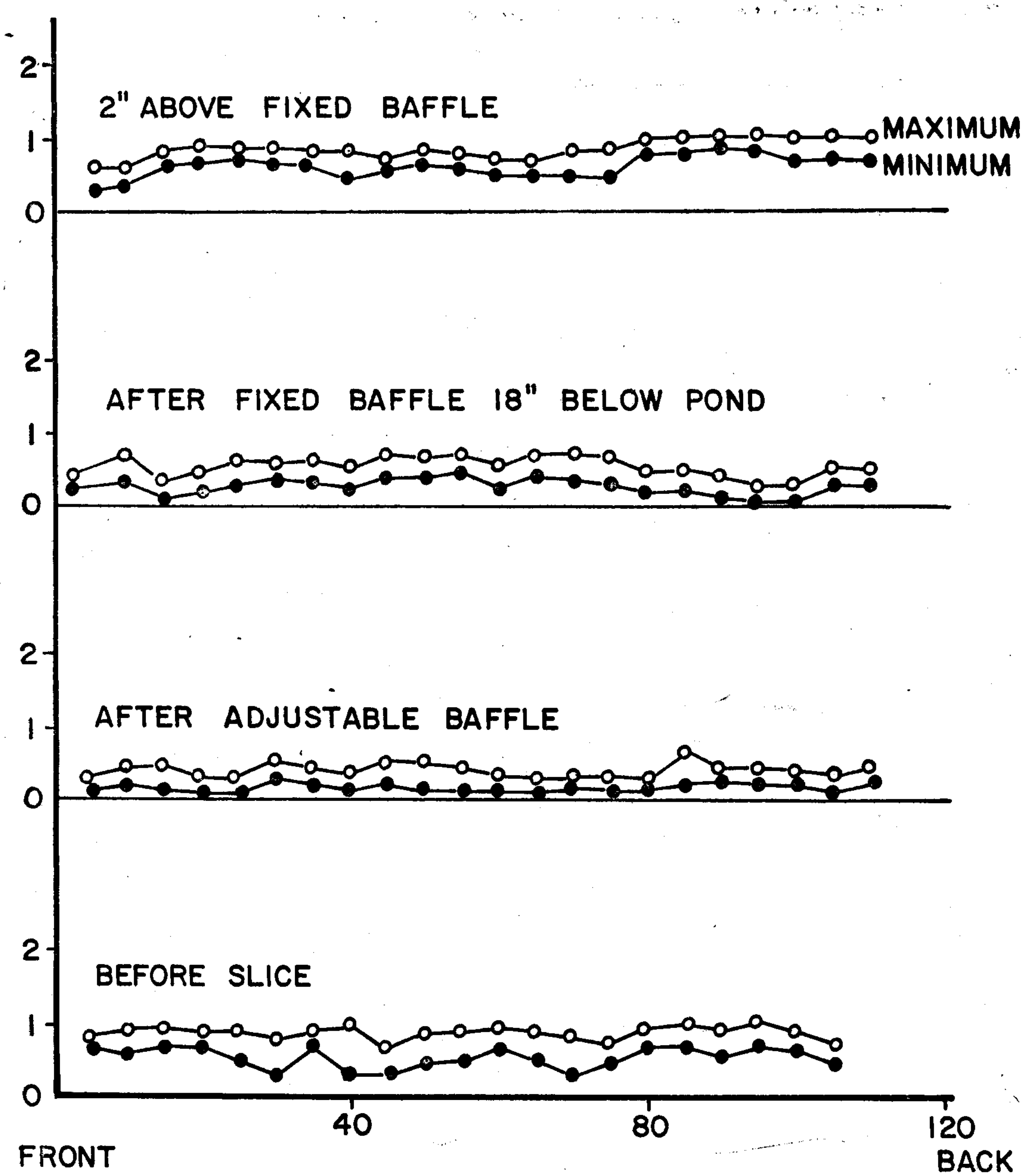


Fig. 13—Number 1 Machine Headbox Velocity Measurements Showing Variations Across Machine and with Time

Figure 22 shows the flow as measured following the baffle for, three different baffle positions; it can be seen that the baffle gap had been too small, promoting large scale turbulence. Figure 23 illustrates the correspondingly improved flow immediately prior to the back slice.

The last velocity profile of Figure 23 is with a shaped "riffle board" positioned as shown in Figure 16. The flow was made worse with this. Figure 24 shows the final and satisfactory velocity profiles obtained with this headbox.

The comparisons of similar headboxes fitted with manifold type and taper flow distribution systems has indicated many of the principles of design and operation which will be summarized at the end of this paper, A third group of machines have been selected for discussion as the constructions were such that the measurements illustrate additional principles.

Figure 25 shows the manifold system and a section through the headbox of one machine and Figure 26 that of a second machine in mill B. The manifold or distribution system of the No. 5 machine (Figure 25) is a tapered pipe with no overflow and large laterals; the manifold of the No. 6 machine is similar to that of Figure 1.

Figure 27 illustrates the flows experimentally measured below the baffle of machine 6, four inches from the bottom of the box, (Machine 6, Figure 26) and Figure 27 shows the result of impact (pitot) tube measurements in the slice.

The highest flow was found to be from the center of the three laterals with the front lateral flow was much

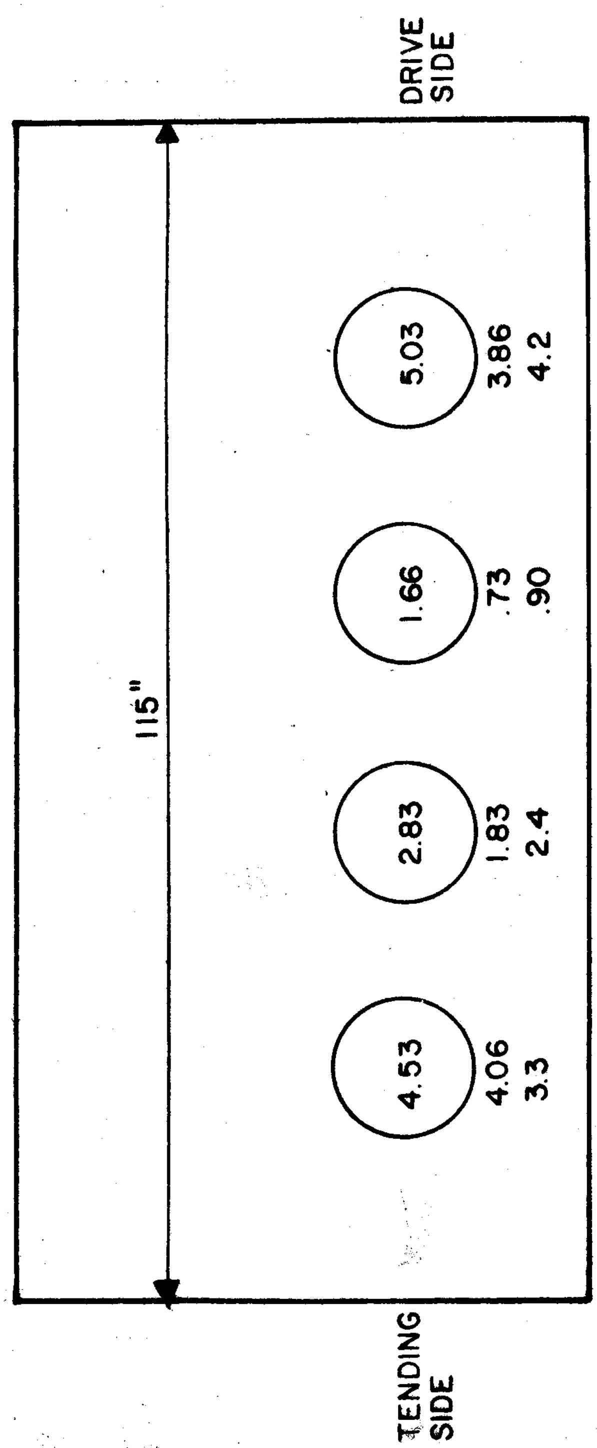


Fig. 14—Number I machine Velocity Variations In Manifold Laterals

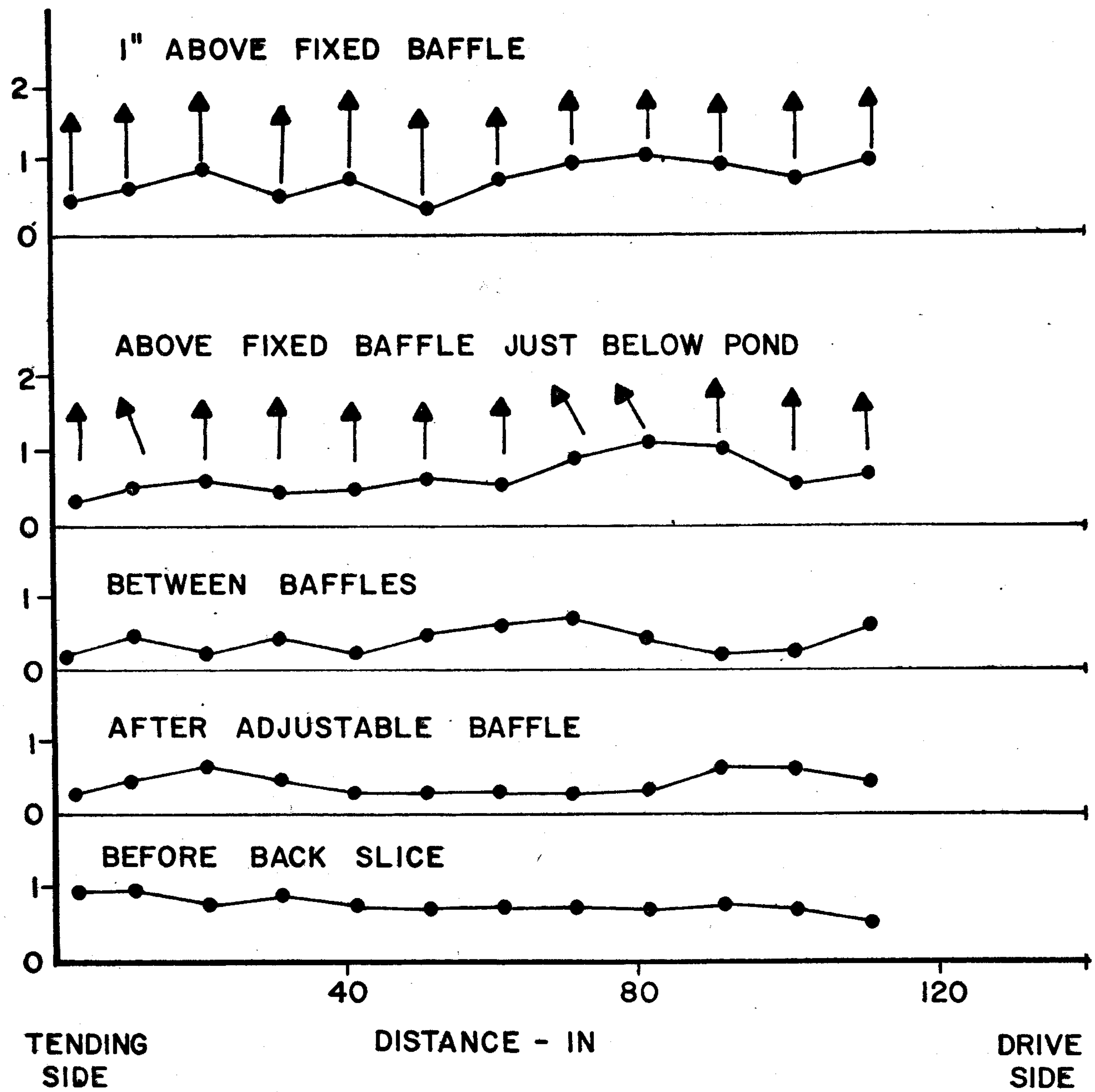


Fig. 15—Number I Machine Velocity Profiles In Headbox

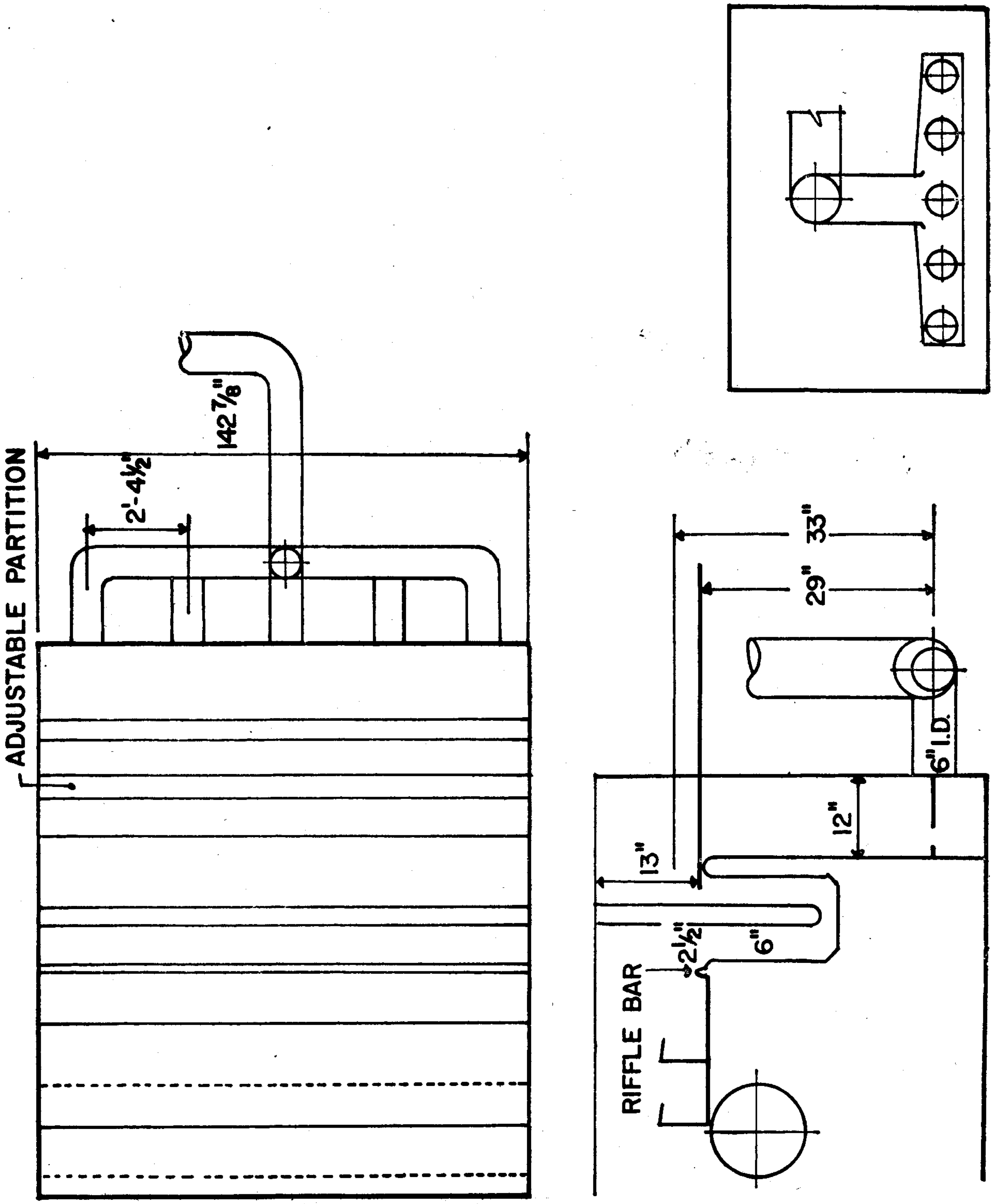


Fig. 16—Number 3 Machine Headbox

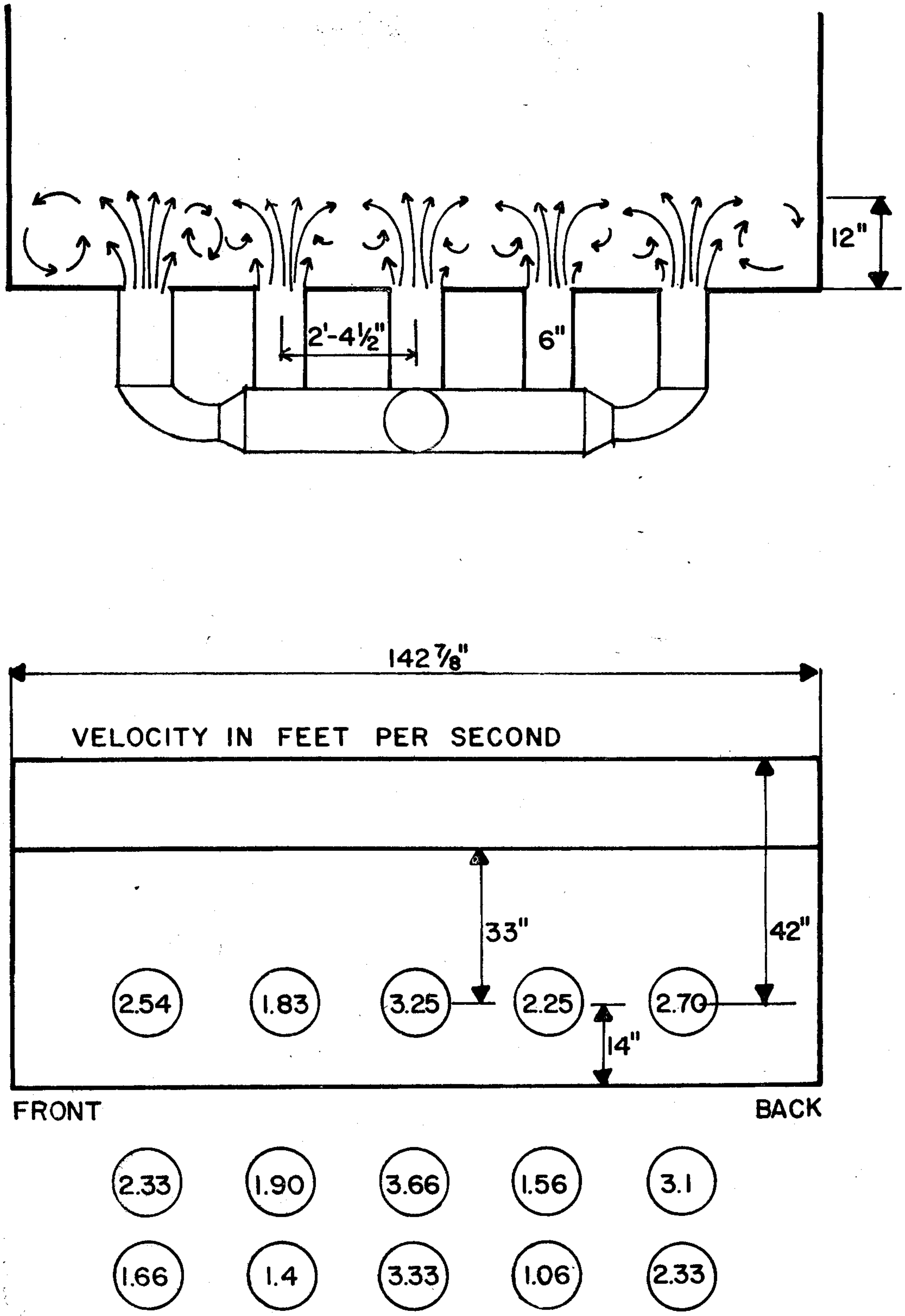


Fig. 17—Number 3 Machine Headbox Illustrating Velocity Variations In The Laterals

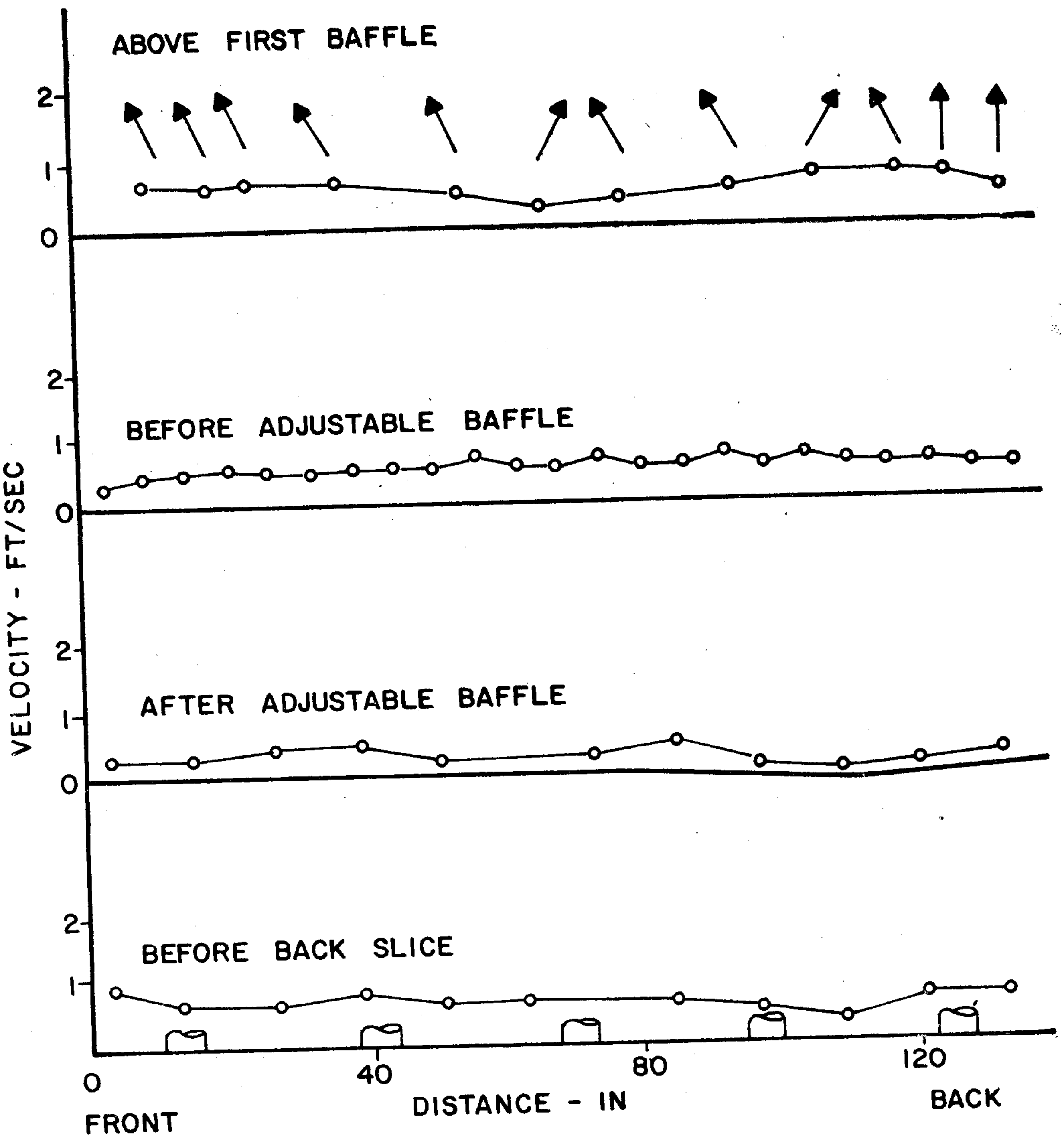


Fig. 18—Number 3 Machine Headbox Velocity Profiles Showing Effect of Different Velocities In Laterals and Spacing of Same

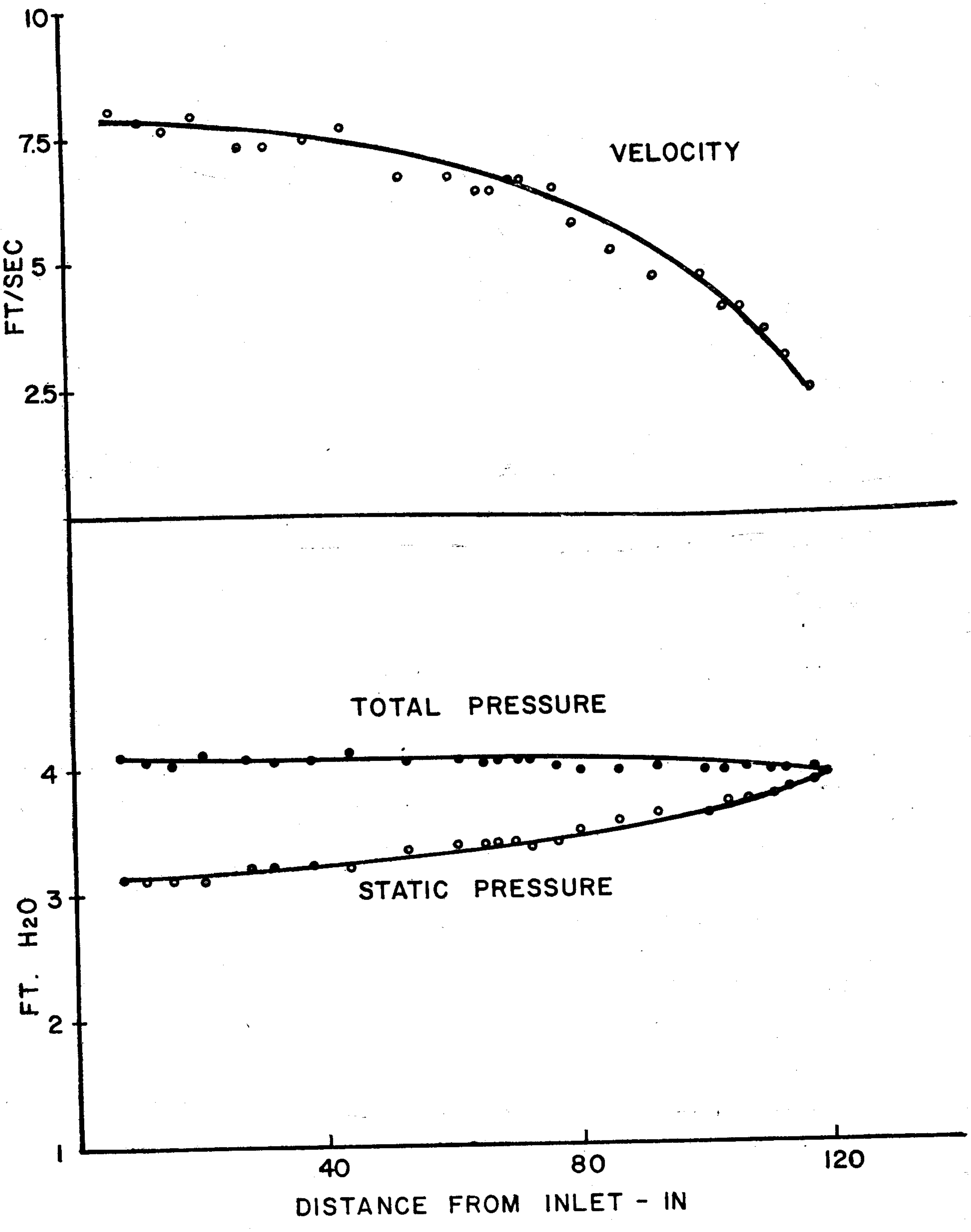


Fig. 19—Number 4 Machine Pitot Tube Measurements in Tapered Header

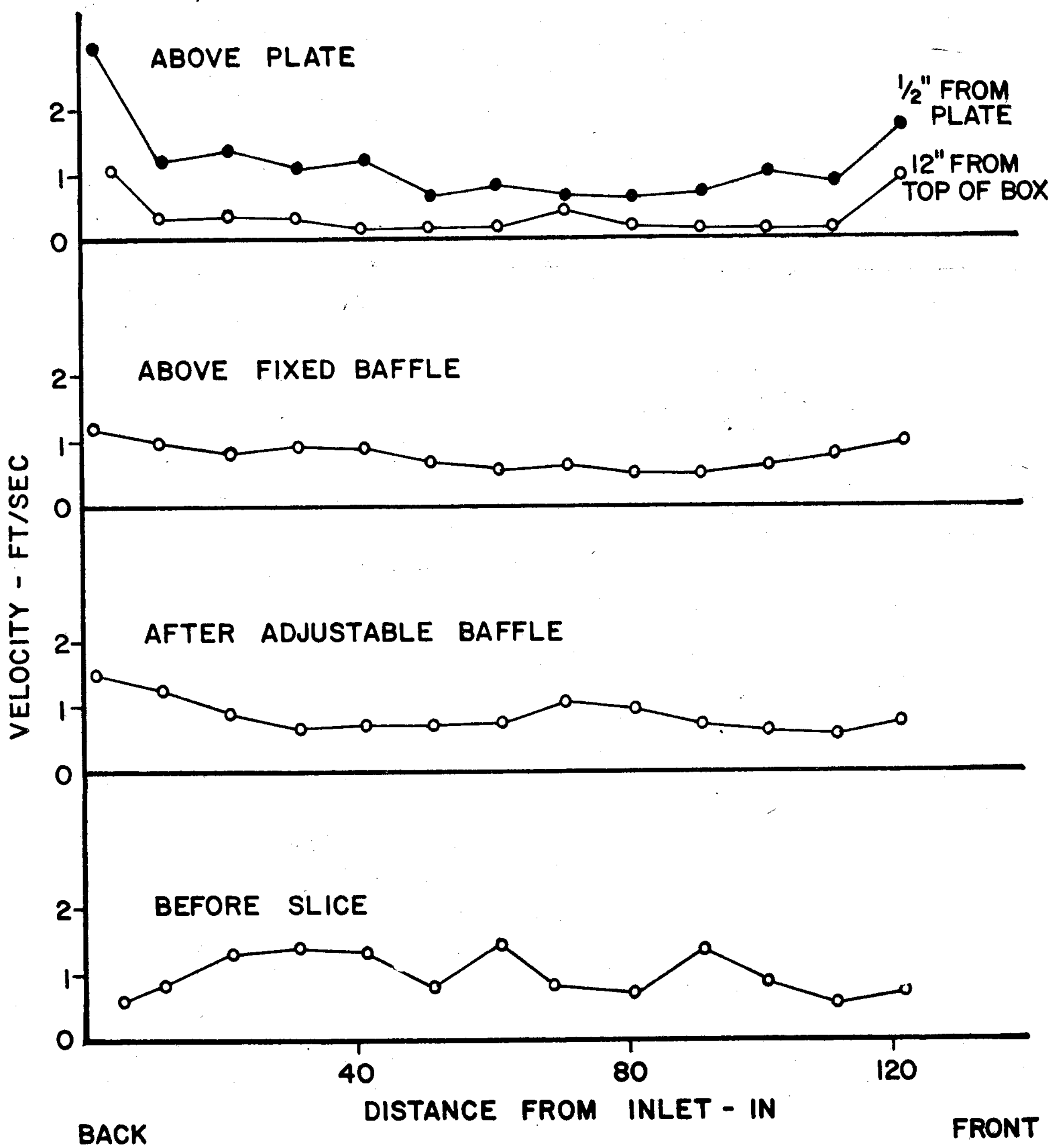


Fig. 20—Number 4 Machine Velocity Profiles in Box Showing Over Corrected Edges and Worsening of Profile Before Slice

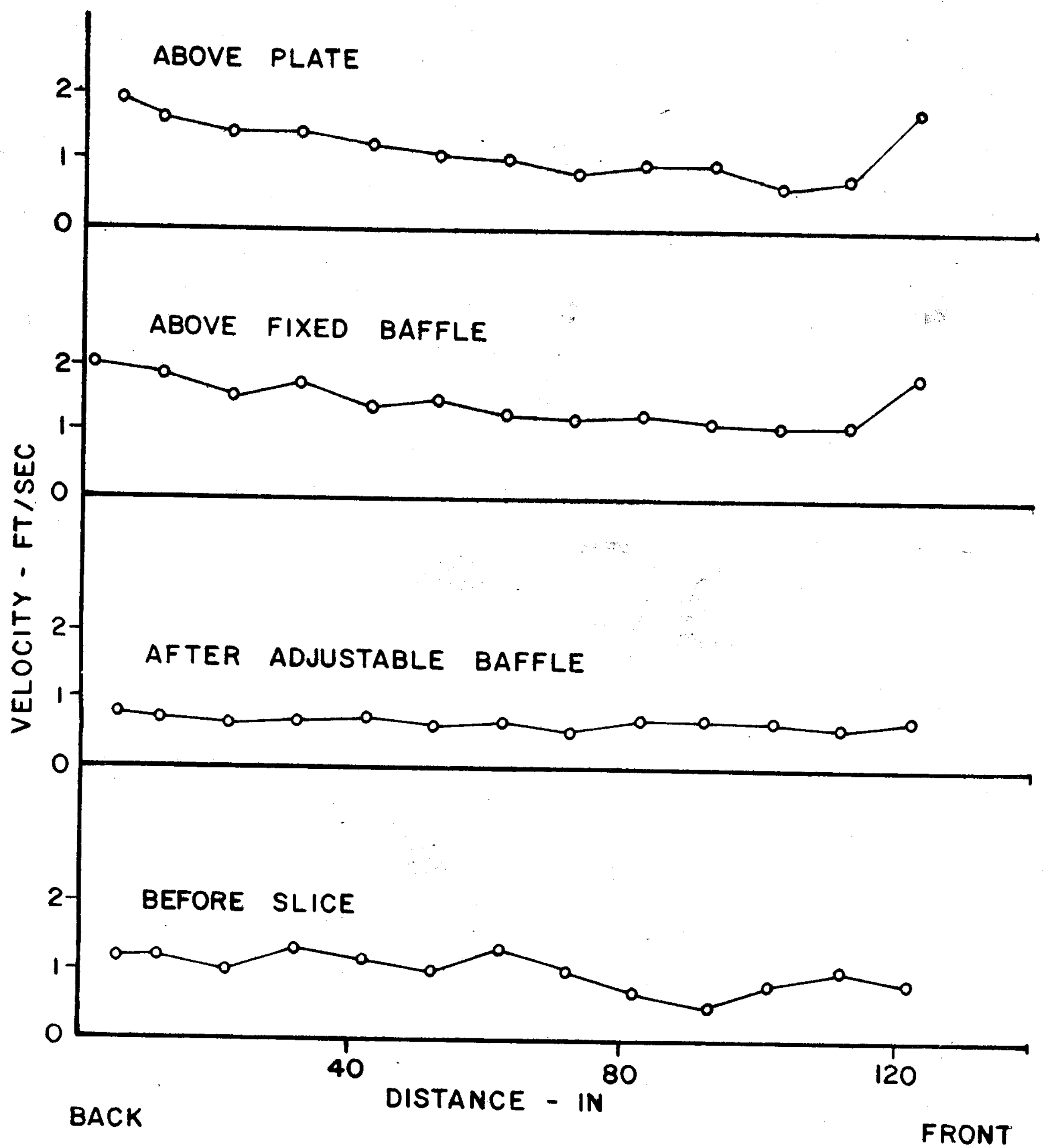


Fig. 21 – Number 4 Machine Velocity Profiles In Box Partially Corrected By Plugging End Holes

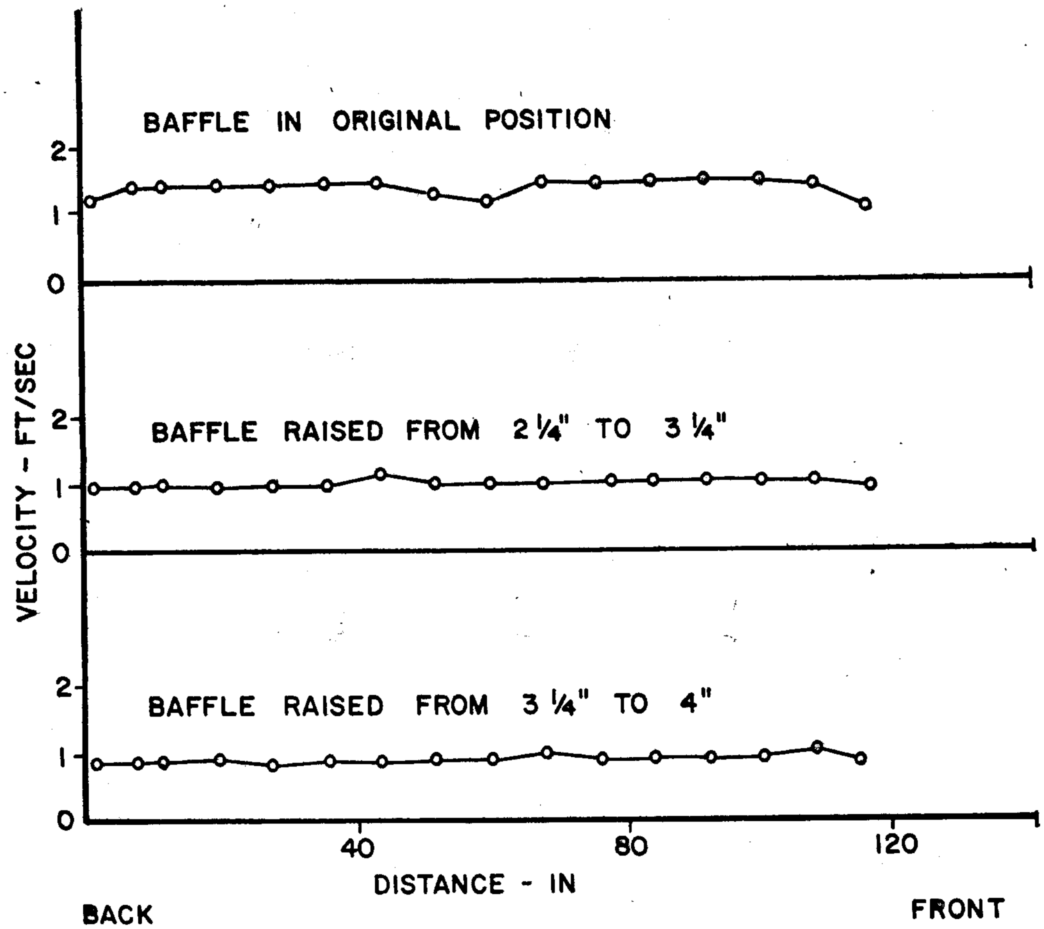


Fig. 22—Number 4 Machine Velocity Profiles Following Adjustable Baffle at Different Baffle Adjustments

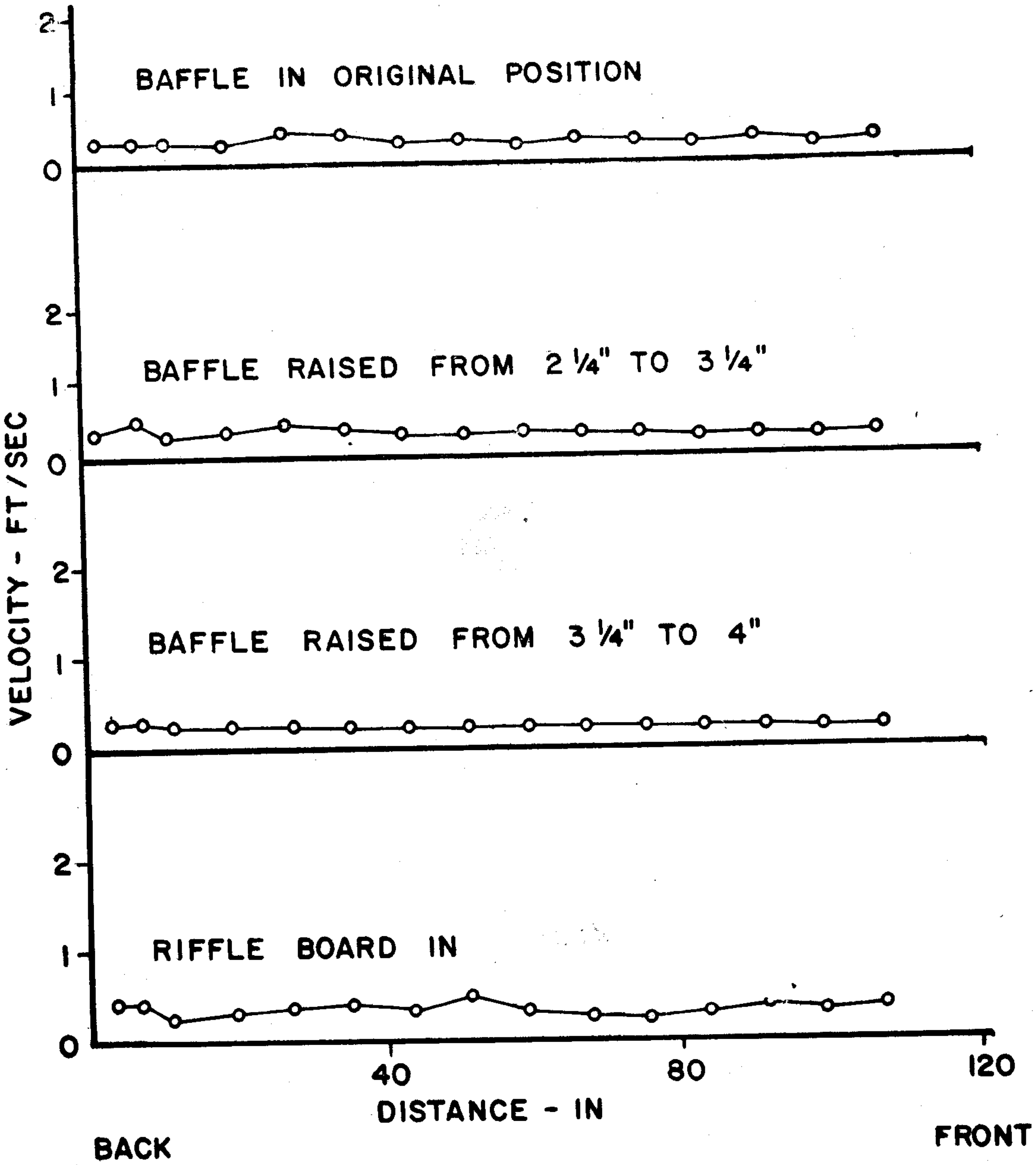


Fig. 23—Number 4 Machine Velocity Profiles Before Back Slice with Different Baffle Positions

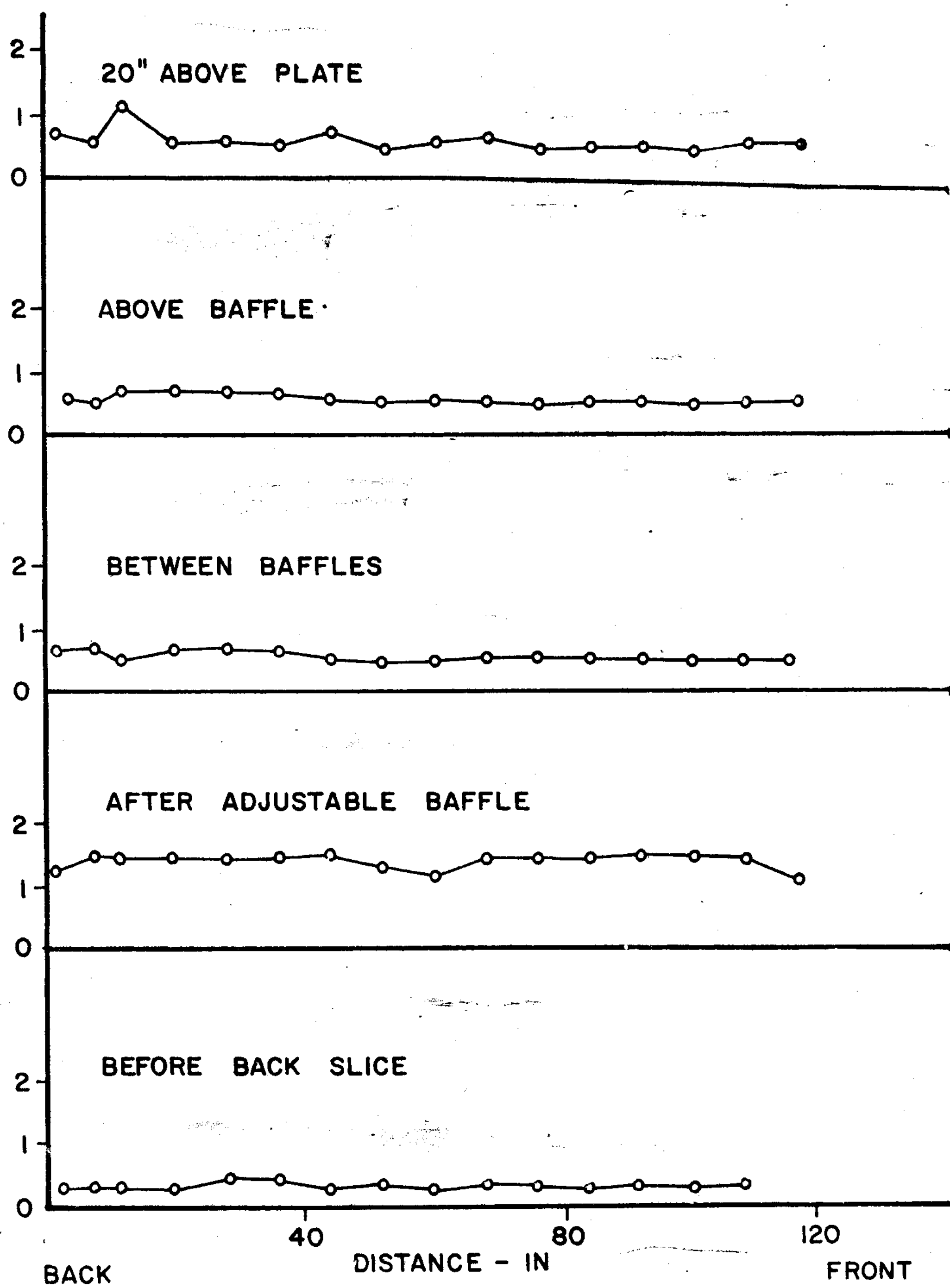


Fig. 24—Number 4 Machine Velocity Measurements at Optimum Baffle Settings and Correct Over Flow

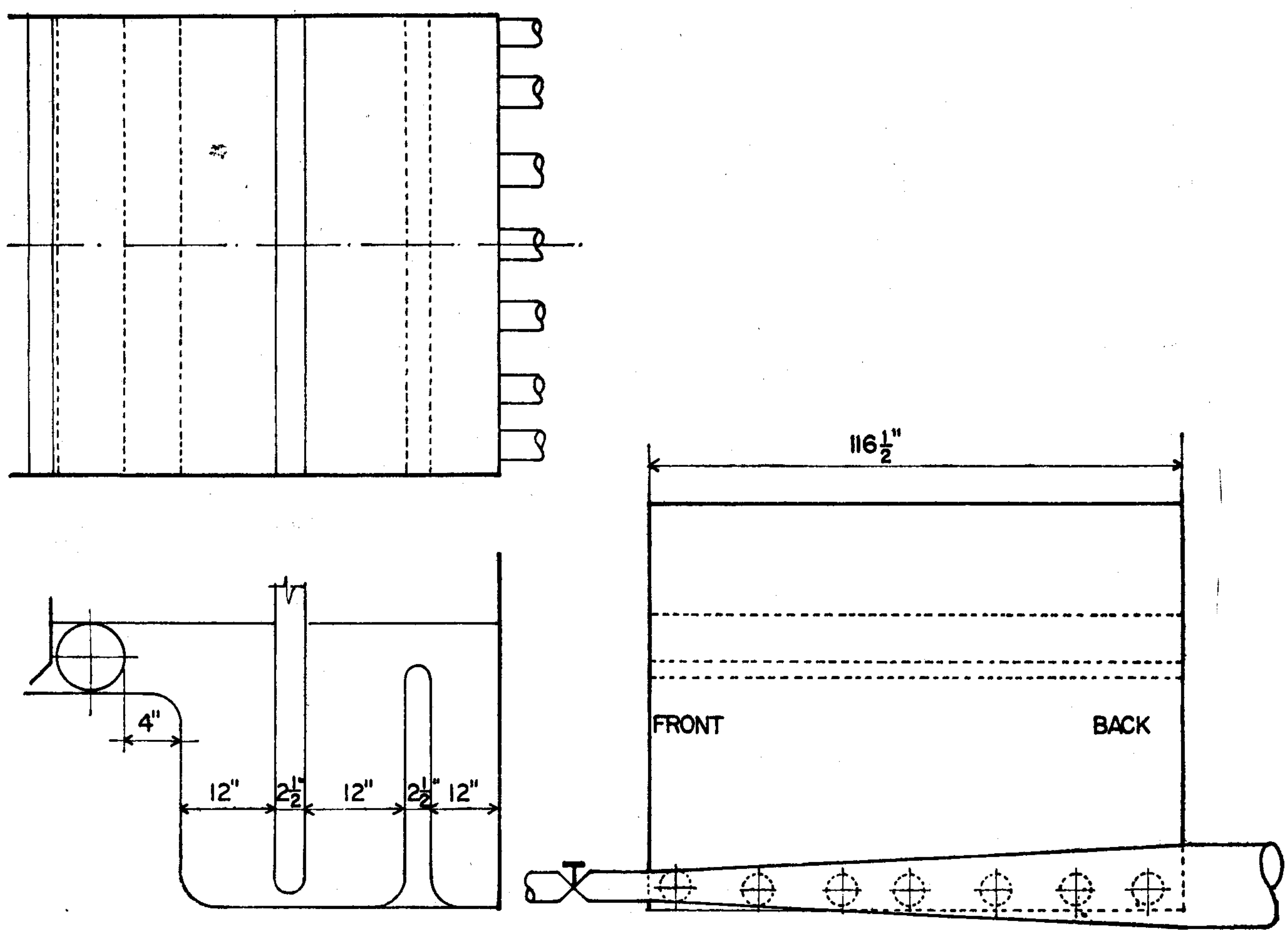


Fig. 25—Number 5 Machine Mill B Headbox

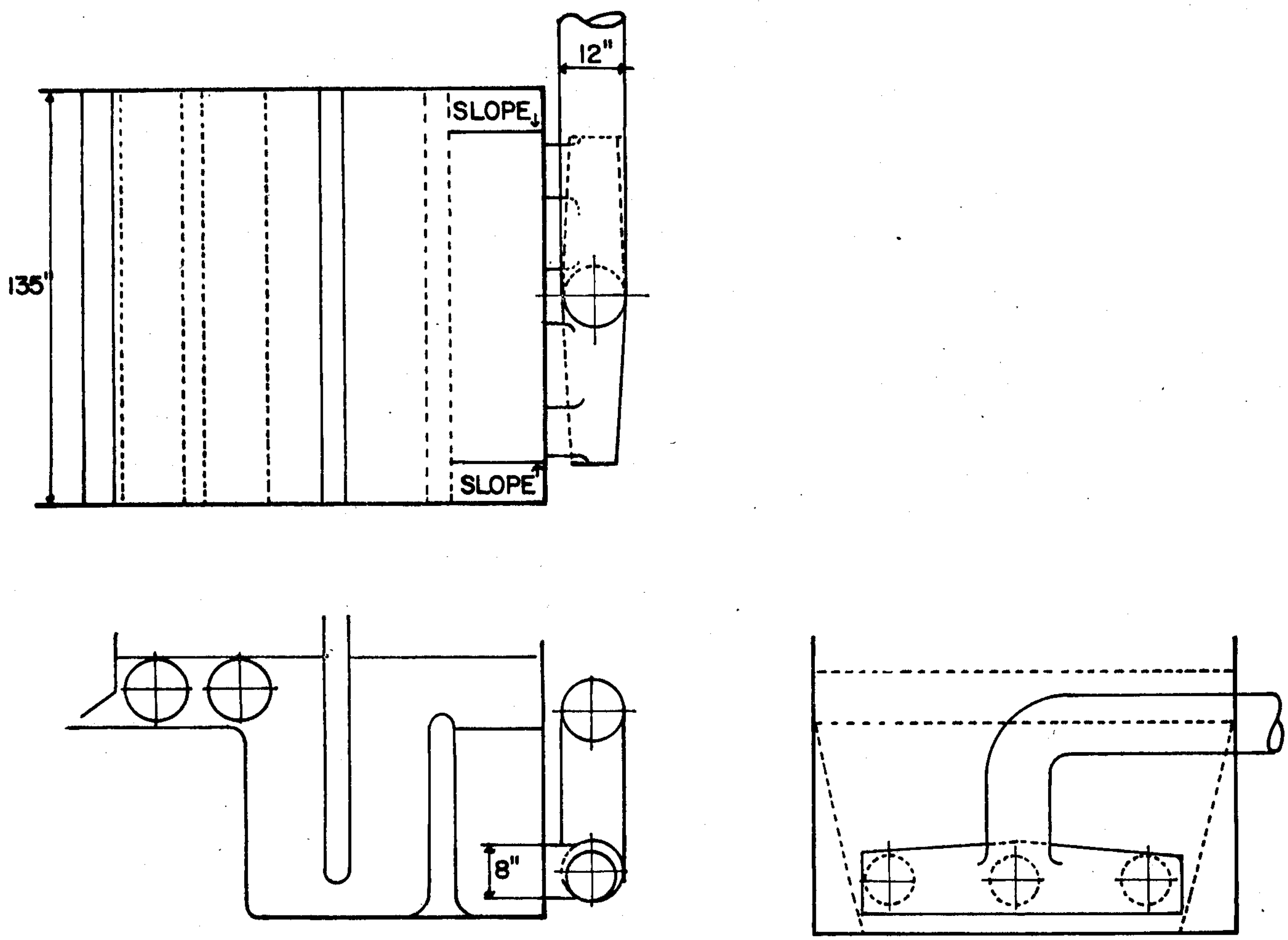


Fig. 26—Number 6 Machine Mill B Headbox

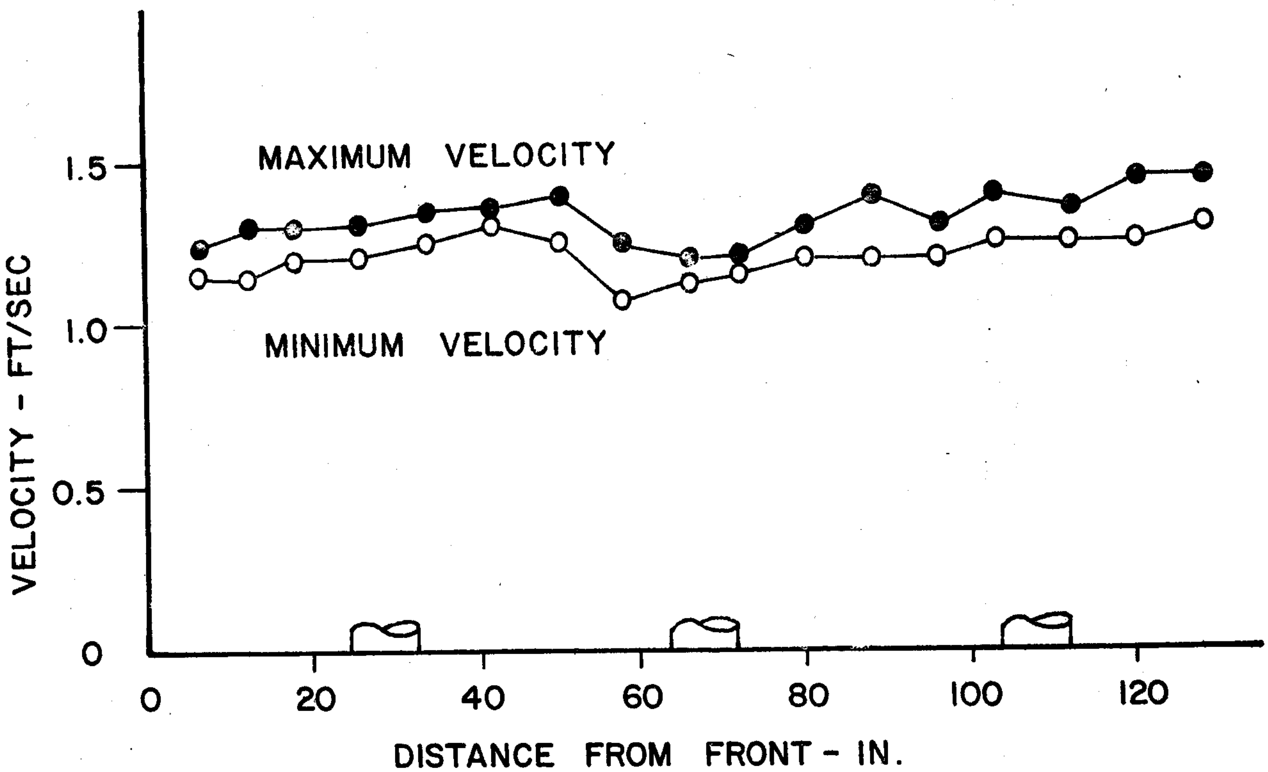


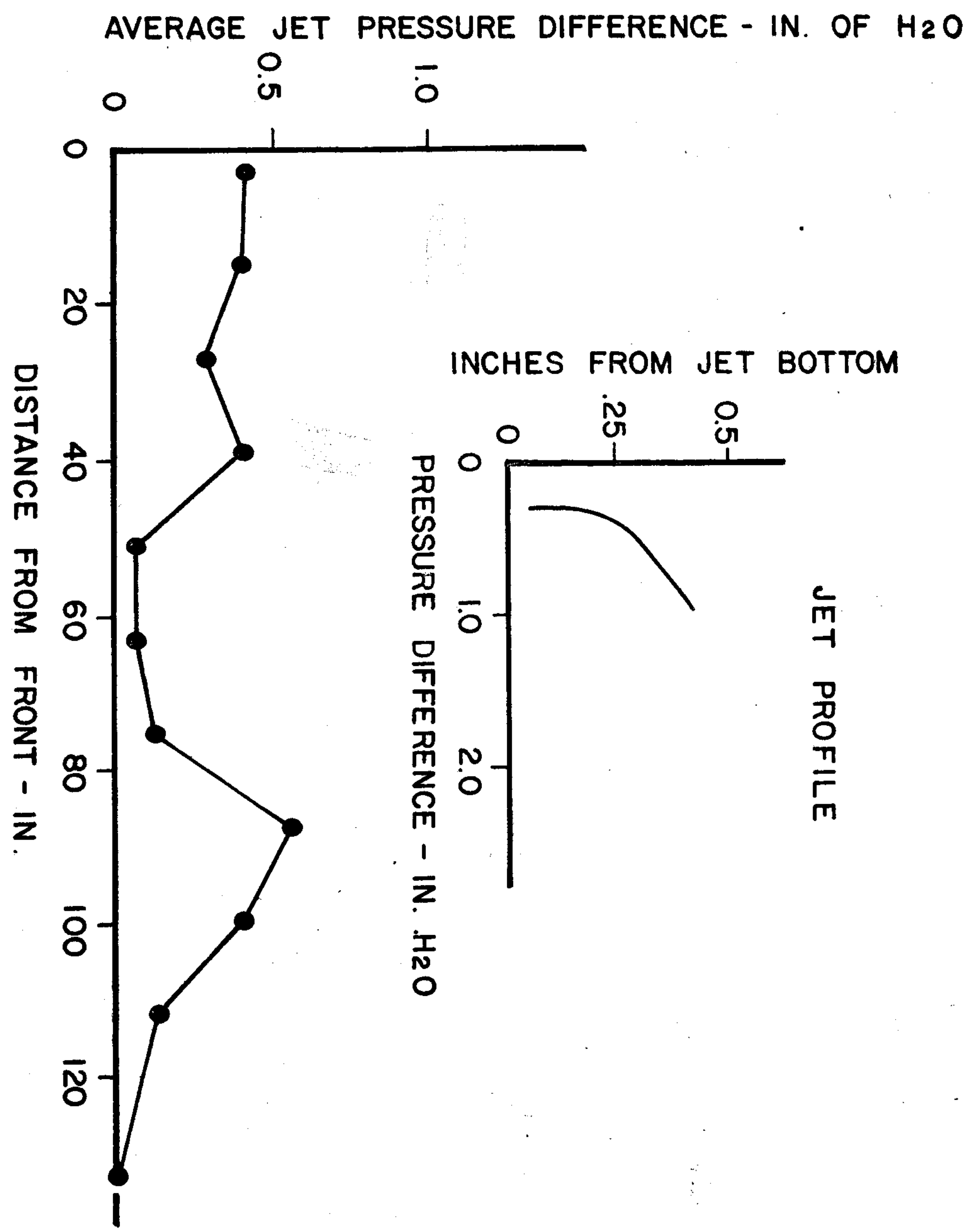
Fig. 27—Flow Measurements Number 6 Machine at Front of Baffle 4" From Bottom

greater than that from the back lateral.

POSITION	AVERAGE VELOCITY F. P. S.
Front lateral	2.93 ± 0.60
Middle lateral	3.38 ± 0.57
Back lateral	2.77 ± 0.60

The flow from the side laterals moved towards the box sides and this with the high velocity from the center lateral gave extreme turbulence in the box center. Figure 27 indicates that the high flow from the center lateral has filled in the low spots on the back of the machine leaving a slight dip near the front center; the high peak at the front lateral has moved towards the machine center, Figure 28 shows that the low spot is still present at the center (50"-60" from the front) having persisted from the baffle.

In the laterals to the headbox of



Fig, 28—Pitot Tube Measurement in Slice, No. 6 Machine

machine 4, Figure 25, very large variations were found, as indicated in the table below.

POSITION	VELOCITY F. P. S.
1st Lateral	3.81 ± 0.36
2nd Lateral	3.19 ± 0.69
3rd Lateral	3.18 ± 0.85
4th Lateral	3.53 ± 0.60
5th Lateral	2.74 ± 0.74
6th Lateral	1.25 ± 0.42
7th Lateral	0.75 ± 0.75

In the back of the box current meter measurements showed a general velocity movement towards the back of the box to fill the void caused by low flow from the first lateral. These velocity irregularities are reflected in Figure 29 measured just prior to the perforated roll. Pitot tube measurements in the slice gave a very similar pressure profile across the machine.

Formation, Wire Flow and Basis Weight

Headbox design features and the method of operation show up in formation difficulties. Over a long period of time experienced papermakers form qualitative estimates as to their interrelationships of formation measurements are made, however, not only can quantitative relationships be established, but these can be made over a few months instead of over many years and by average instead of by outstanding personnel.*

Figure 30 illustrates styalized formation curves (CD) for three conditions of operation using the back slice in the box shown in Figure 2, and using as a replacement for the back slice a ''slice'' made up of spaced rotating rods, "the rotating rod back slice" with the headbox showers on and off. It is seen that the formation is better with the rotating rod back slice and with the shower off. Because the deterioration in formation caused by the showers is from machine direction streaks, which show in the cross machine formation profiles, but not in the machine direction, or MD, profiles, there is effectively no formation difference shown in Figure 31 with showers on and off.

Figure 32 illustrates the basis weight distribution with the rotating rod-back slice in position and with the showers in use; this can be compared with Figure 33 with the back slice in use. The poor basis weight distribution is due to the intense, but large scale, turbulence from the back slice (14). The best basis weight profiles were obtained with the rotating rod back slice, but without showers, Figure 34.

These same points also show in wire flow photographs. Figure 35 shows the large scale turbulent flow previously referred to and always found when a back slice is used to control and improve formation

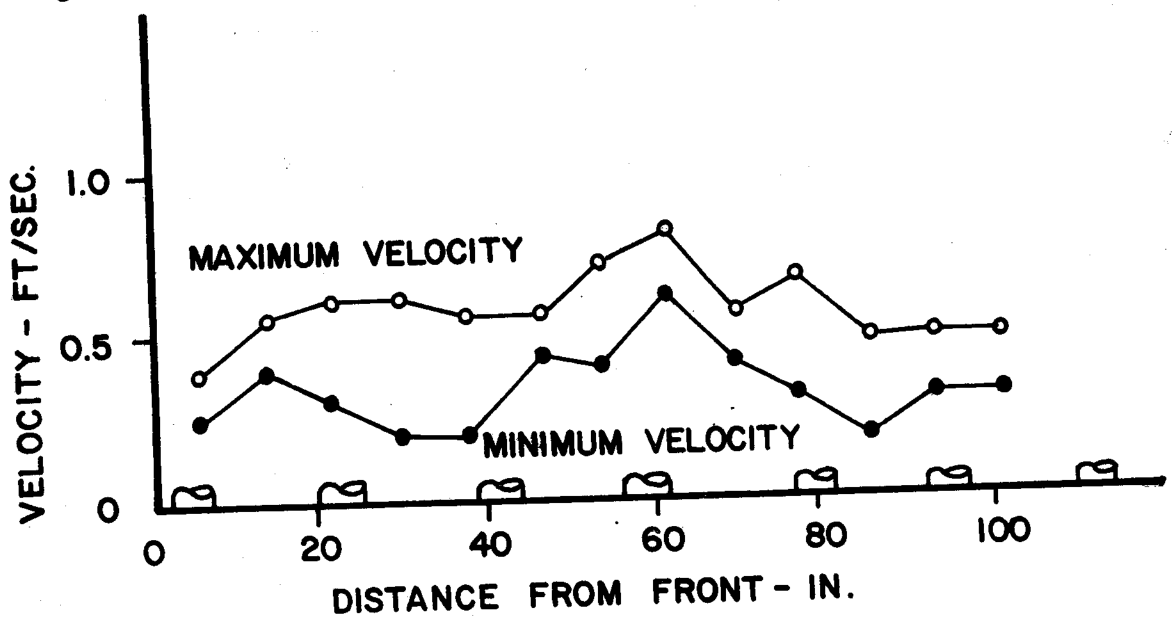


Fig. 29—Flow Measurements Number 5 Machine Before Perforated Roll 1¼ Above Bottom of Box

* Using the QNSM/Mead formation tester described by Burkhard, Wrist and Mounce (10) and its use as a paper-making tool in papers by Sankey (11), Howe and Crosgrove (12) and Manson (13)

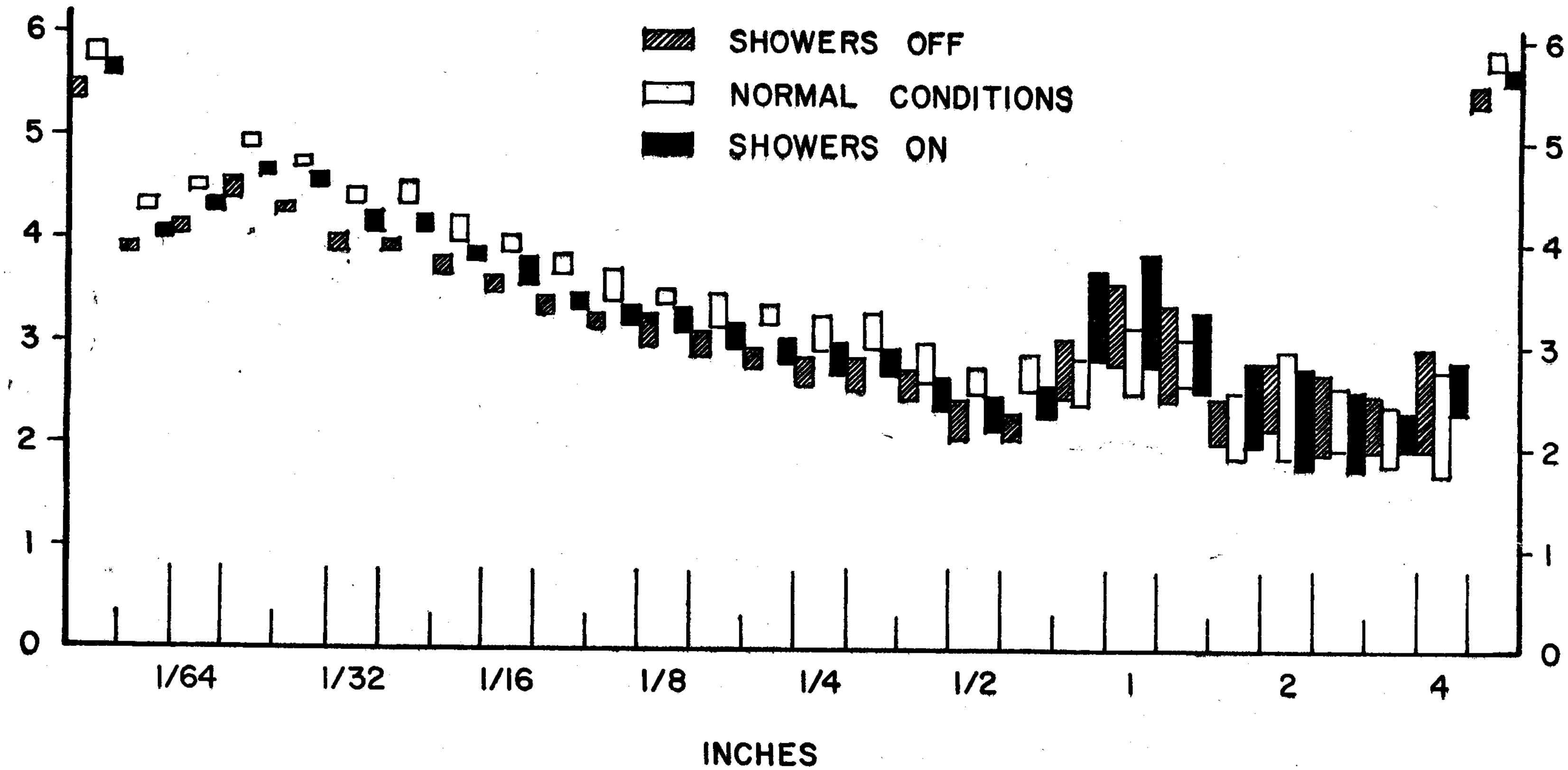


Fig. 30—Stylised Formation Curves C. D. 3 Conditions of Operation

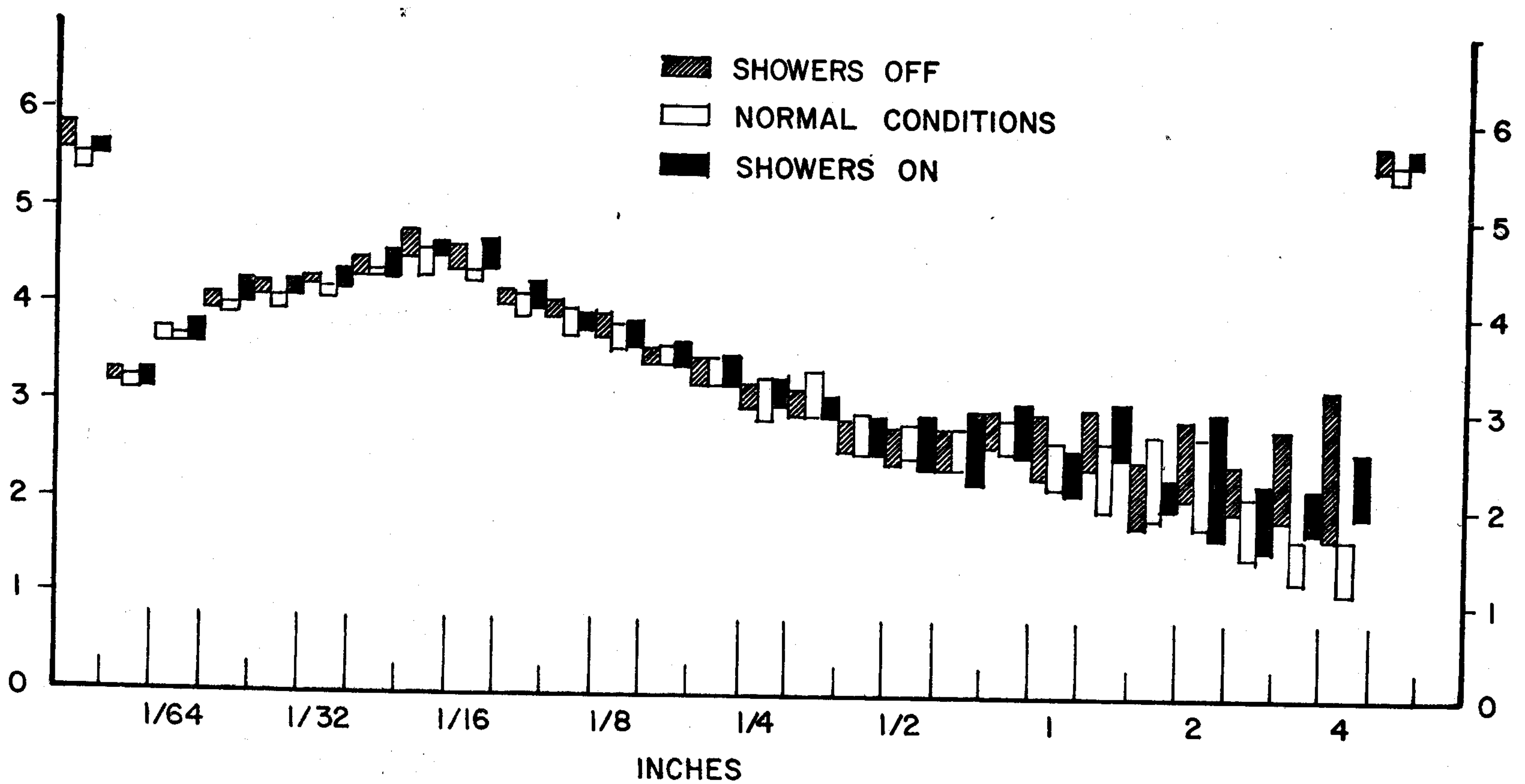


Fig. 31—Stylised Formation Curves N. D. 3 Conditions of Operation

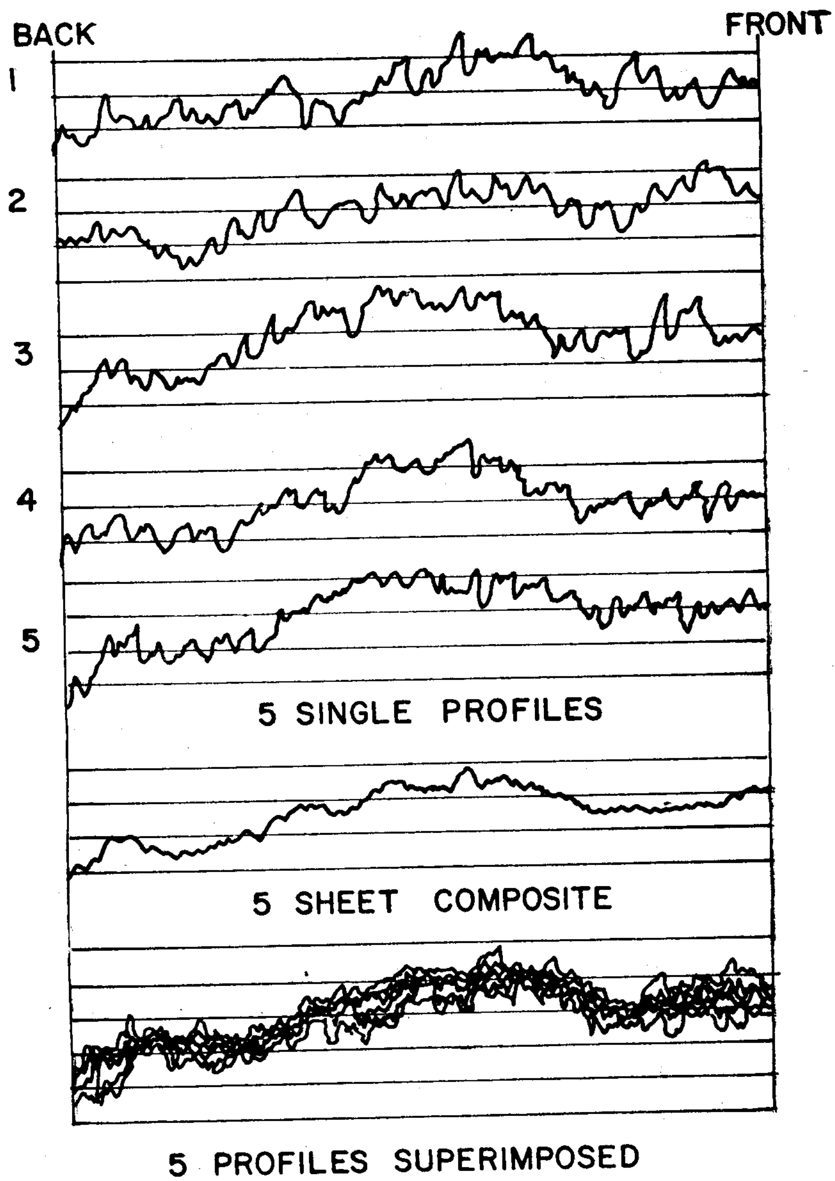


Fig. 32—Basis Weight Profiles Showers On and with Rotating Rod Back Slice

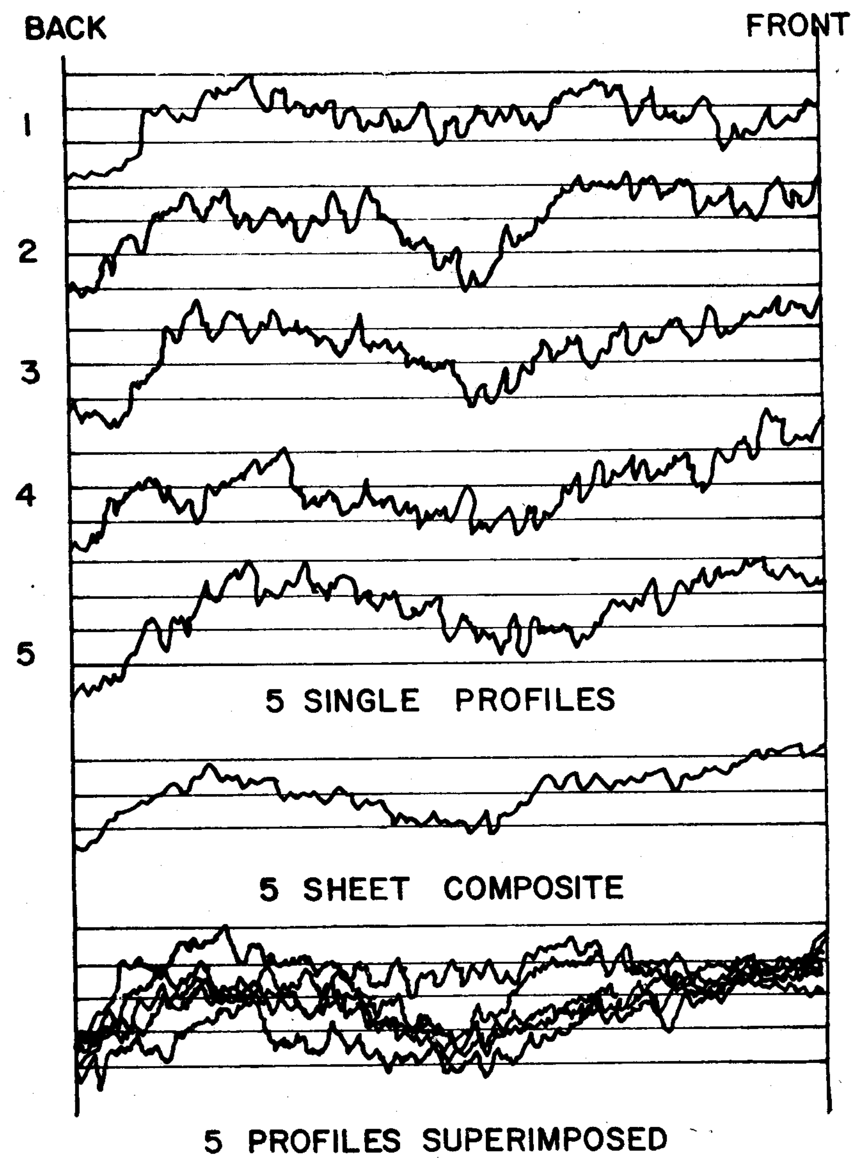


Fig. 33—Basis Weight Profiles Using Back Slice

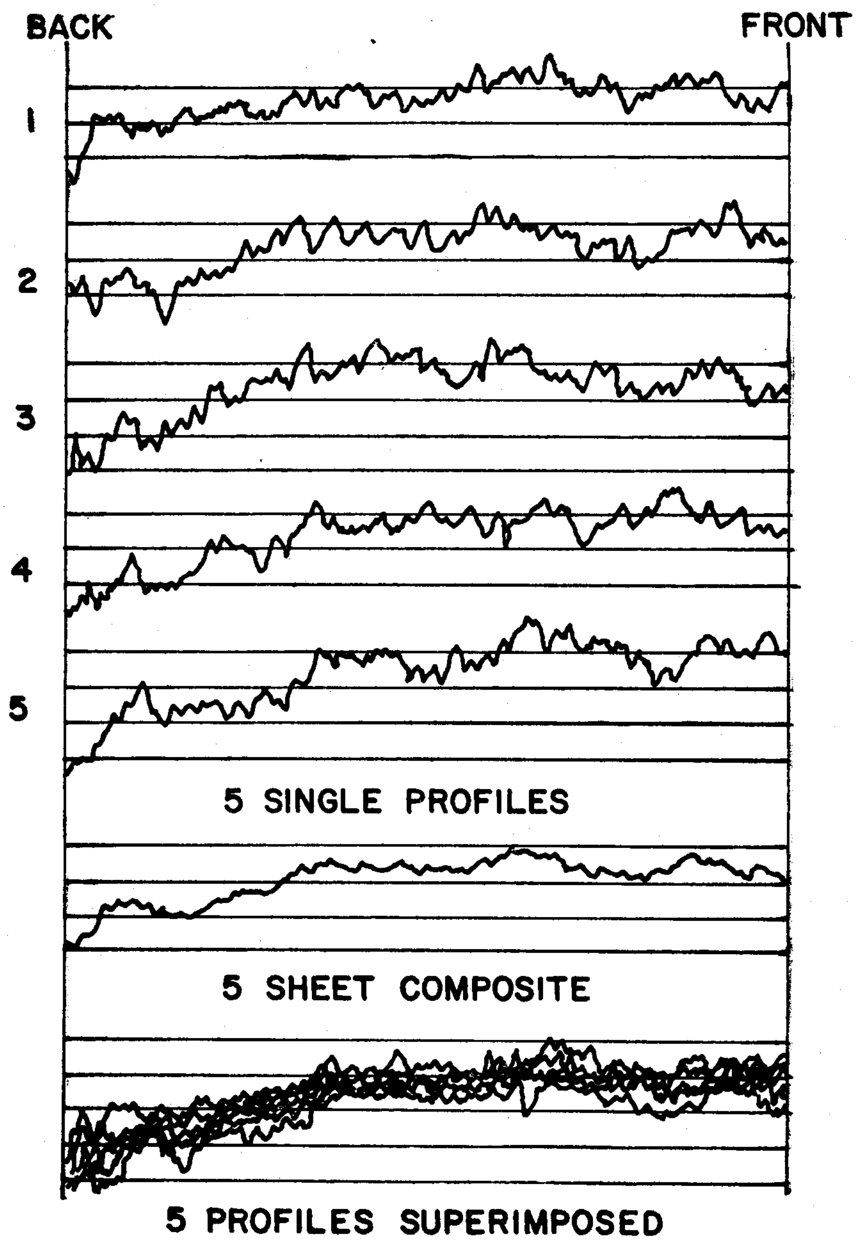


Fig. 34—Basis Weight Profiles Showers off Rotating Rod Back Slice

via turbulence generation. Dropping the back slice makes the turbulence much more severe as indicated in Figure 36. Taking the back slice up gives a smooth flow, but there are large scale vorticular disturbances present from the flow below the baffle, Figure 37. The greatly improved flow with the rotating back slice in use without the headbox showers is illustrated in Figure 38. The severe machine direction streaks caused by the showers are illustrated in Figure 39.

Discussion

The illustrations discussed in the foregoing have touched on three of the methods of gaining insight into headbox design and operation from full scale work. These are hydraulic measurement, wire flow photography and formation, and basis weight analysis.

The exact methods of measurement have not been given, but have been discussed in outline in the early part of the paper; details of the techniques are available in the cited literature. More recently, Wahren and his co-workers have applied a more modern technique to the measurement in the slice by means of the impact tube (14) (15). The techniques used by Parker are outlined in his paper, already cited (3). Whereas the more erudite methods of Parker and Wahren are beyond the average mill, any capable group should be able to make the kind of measurements in open headboxes described in the present paper. For closed headboxes techniques similar to those of Nelson (17) are necessary and this demands a specialized group.

The remaining two methods of investigation, not touched on here, are the introduction of dye or other trace material into different parts of the headbox and the determination of its distribution on the wire and in the paper, and the use of model studies.

Generally, it can be said that headbox design and operation, whilst complex subjects, have been fairly well unravelled. There is no substitute for making measurements yourself to get the "feel of the problem."

The senior author's personal views on this point may be quoted as follows:

1. Designers need, however much they know, to cultivate a humble spirit.
2. All new designs should be followed up by field measurements such as those described here; points which are barely satisfactory in one construction can be disasterous in another and such disasters can be avoided if measurements are made and the effect detected.
3. Headbox measurements should be part of the national technical effort in any country's paper industry and should embrace large and small companies. Understanding of the paper making is increased if they are made, unwise changes are prevented and sometimes major improvements can be made with a combination of knowledge and patience.

Conclusions

1. Insist on a correctly designed distribution system. For small machines with open headboxes, a startling improvement can frequently be achieved by fitting a taper flow plate type distribution system.
2. Make full scale measurements; coordinate these with wire flow photography and basis weight and formation analysis.
3. Educate the machine crew.
4. Stick to the rules of headbox operation given here as Appendix I.

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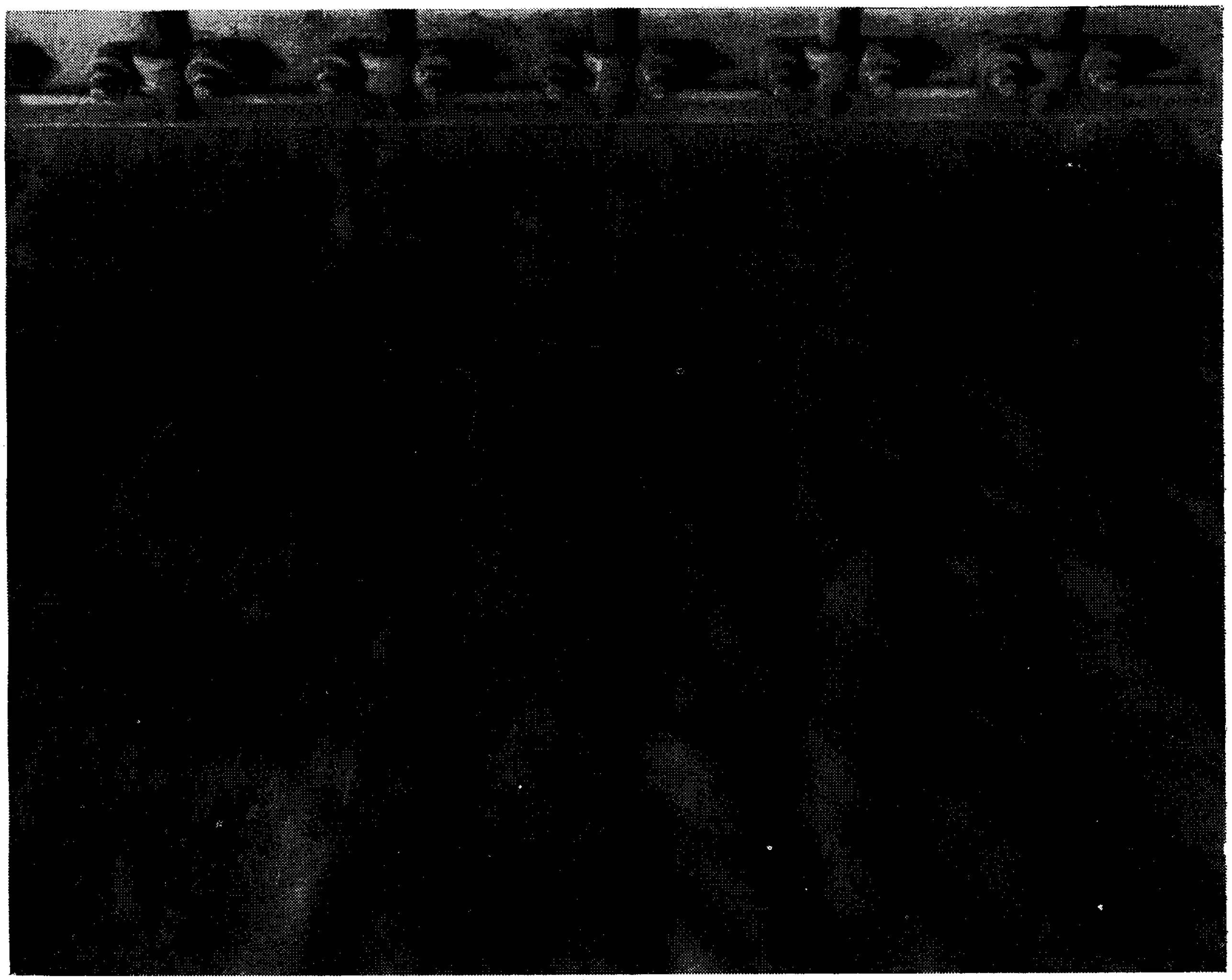

Fig. 35—Turbulent Flow with Back Slice in Use

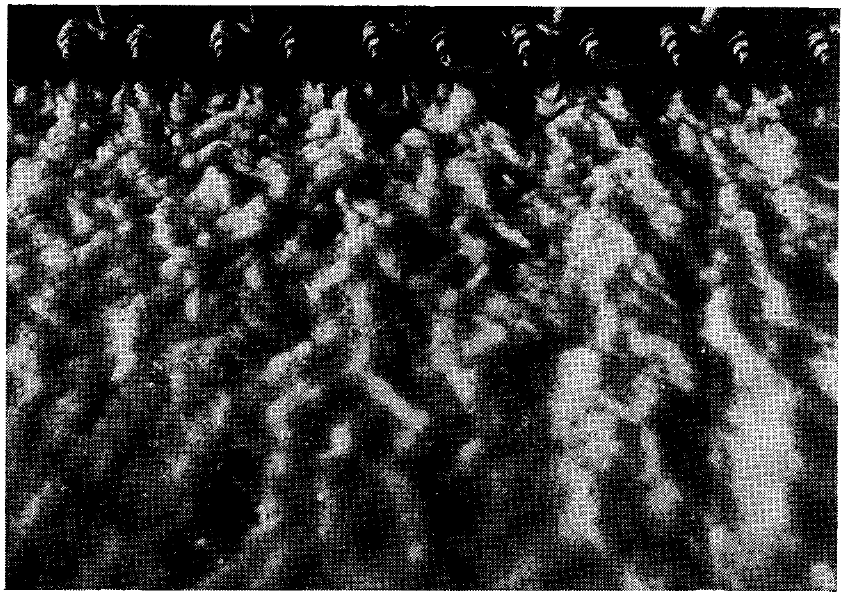

Fig. 36—Increase in Turbulence when Back Slice Lowered

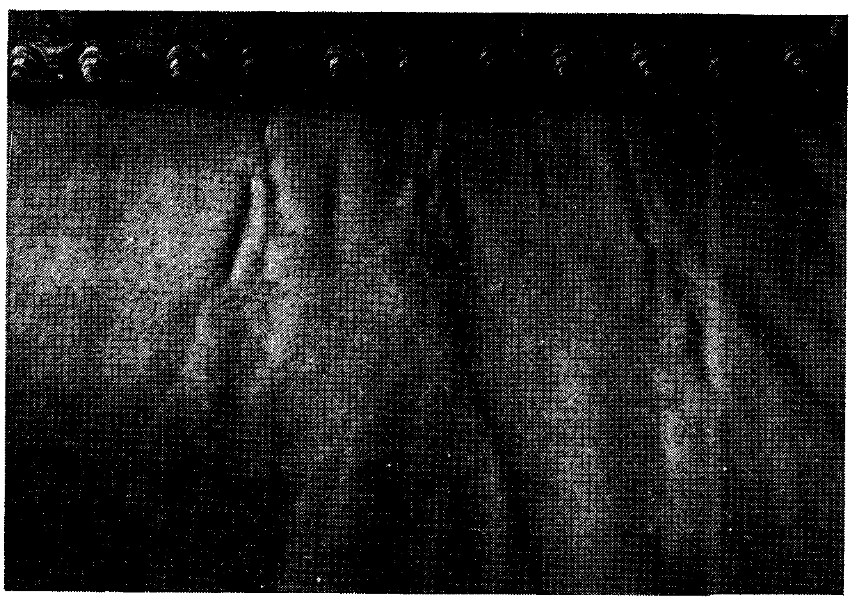

Fig. 37—Back Slice up Showing Large Scale Defects

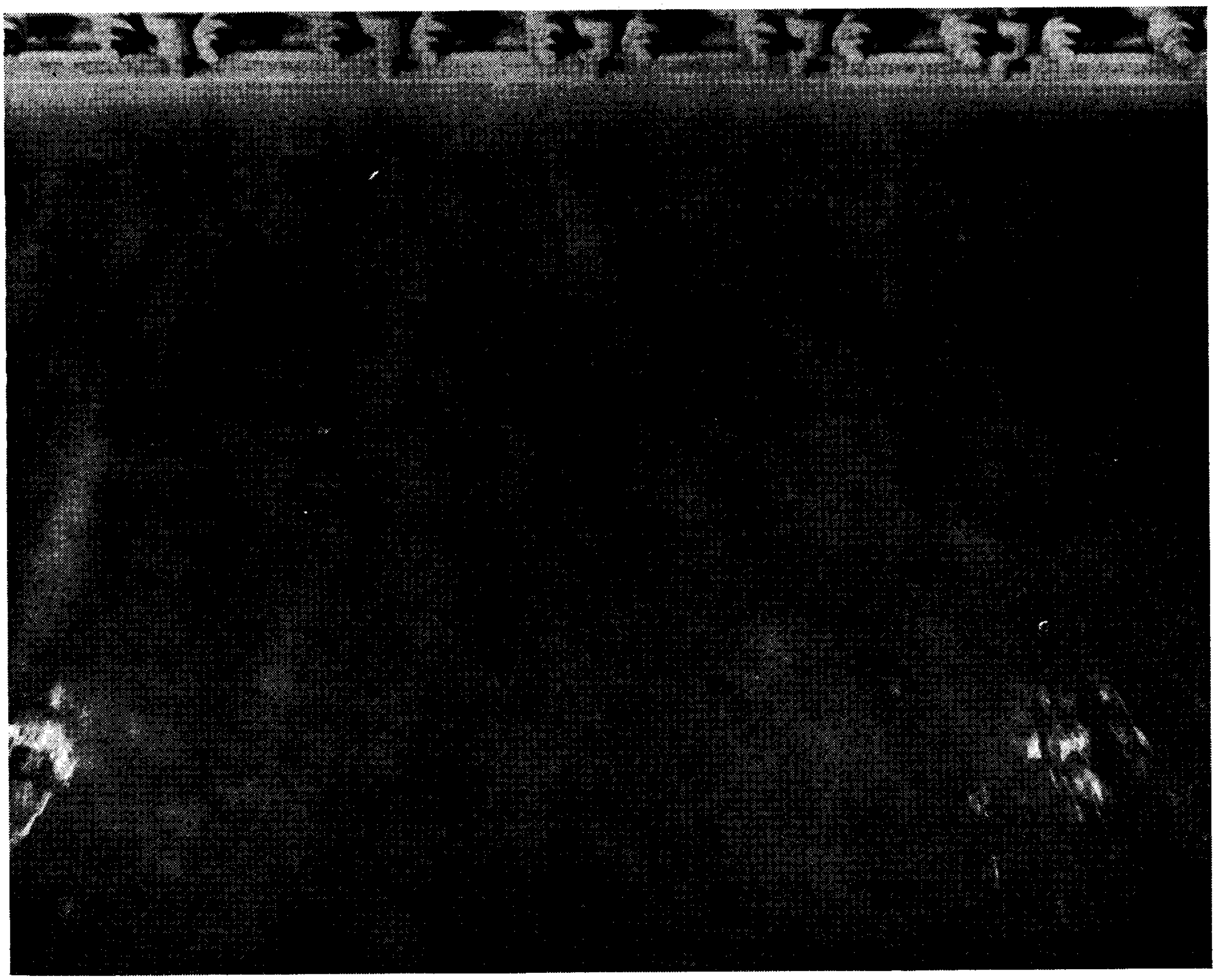

Fig. 38—Rotating Rod Back Slice and No Showers

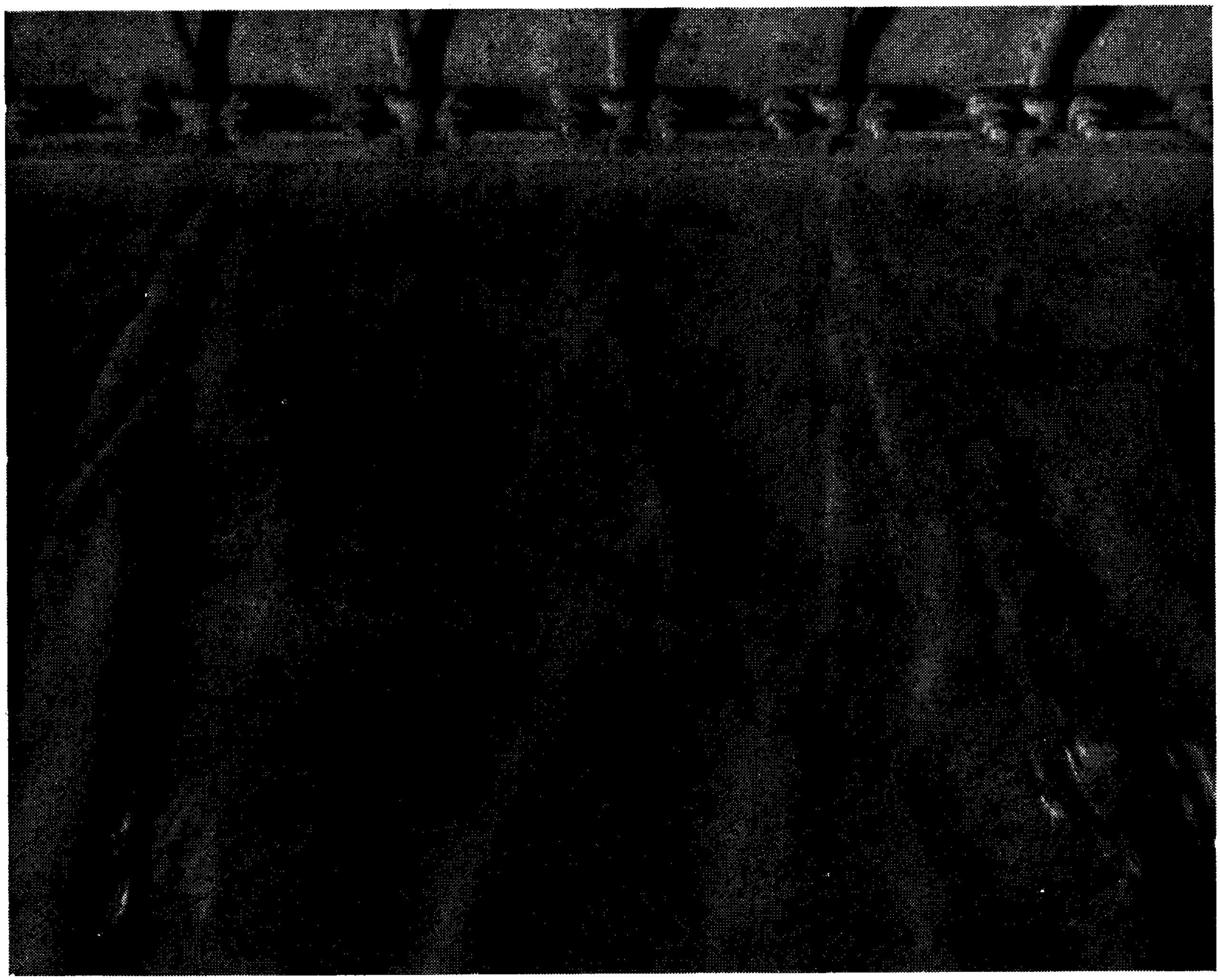

Fig. 39—Streaks Caused by Showers with Rotating Rod Slice

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