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Design of a Secondary Headbox for the WMU Pilot Plant Fourdrinier Paper Machine

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DESIGN OF A SECONDARY HEADBOX FOR THE WMU PILOT PLANT FOURDRINIER PAPER MACHINE

by

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ABSTRACT

A secondary headbox has been designed for the WMU pilot plant fourdrinier papermachine to facilitate research into the formation and final sheet properties of two-ply webs. A thorough literature search was undertaken to determine the design criteria of a headbox and the means used to meet those goals. The result was a hydraulic secondary headbox. The stock for the second ply enters the headbox, passes over one baffle and under another, then flows through a closed channel with eight bends in it. The stock then flows through a short straight section, makes a 90° turn, and then flows to the slice. A Coanda element has been added at the exit of the slice to cause the jet to leave the headbox parallel to the wire, in effect, laying the second ply on the first ply. The secondary headbox should be built and operated on the papermachine to determine its ability to make two-ply sheets.

Keywords: Headbox, Secondary headbox, Coanda effect, two-ply printing papers, multi-ply papers

TABLE OF CONTENTS

INTRODUCTION

One method of manufacturing multi-ply paper on a fourdrinier paper machine is through the use of a secondary headbox. The secondary headbox is very similar in design to the primary headbox. It is placed a certain distance away from the primary headbox, over the wire, and delivers a second layer of stock onto the first. The combined sheet is then conventionally drained, or drained using a twin wire. Most secondary headboxes are used to produce linerboard, a two-ply board used in the production of corrugated boxes.

Lately, interest has grown in the production of multi-ply printing papers. By making several plys, different furnishes can be used to maximize the printing and appearance properties of the top and bottom layer of the sheet and the strength and runnability properties of the inner layers of the sheet. There is interest on the part of the students and faculty of Western Michigan University in studying the mechanics of formation and the structure of two-ply papers in general, and multi-ply printing papers in particular.

An engineering project has been undertaken, the objective of which is to design and install a secondary headbox on WMU's pilot fourdrinier paper machine. The installation of the headbox will facilitate the production of two-ply papers and will allow the students and faculty to study the fluid flow phenomena found in a headbox.

BACKGROUND

Benefits of a Stratified Sheet

There are a couple of key properties of paper which can be improved with the use of a two-ply sheet. The rotogravure printing process demands a sheet which is very smooth and somewhat compressible. These two properties

ensure that the ink will be wicked from every cell in the gravure roll. A number of constituents of the top layer can be varied to achieve a smooth printing surface. For example, shorter hardwood fibers or highly refined softwood fibers could be used to form a tighter fiber network. The furnish for the top layer could also have different fillers or a higher filler content than the base sheet furnish. The fillers will fill in the hills and valleys in the sheet, providing a smoother printing surface. The base sheet, in turn, would be made with a long fibered softwood pulp to provide the sheet with the needed strength and runnability properties(1). The proper mixture of long and short fibers will provide the sheet with the compressibility needed in the rotogravure printing process.

Stiffness is important for sheet handling, especially for feeding. We do not want the sheet to curl or collapse as the printing press is trying to grab it. A study done using various amounts of groundwood and kraft fibers in the top layer of the sheet indicated that if the sheet had 33% groundwood in the facing, a 10% increase in the stiffness of the sheet could be realized. Though the increase is not large, it is significant and will improve the handling of the sheet(2).

One concern, however, in using a two-ply sheet is curl. The difference in furnish type between the two layers can result in a serious curl problem as the two layers will potentially react differently to changing humidity. This property will require further study.

Basics of Headbox Design

Otto Kallmes and Ben Thorp presented a paper at the 1984 TAPPI Paper-maker's conference analyzing the basic requirements of a headbox. Kallmes and Thorp list three primary requirements of a headbox. The headbox must be able to deliver a uniform flow of stock across the width of the machine.

Secondly, the headbox should ensure a reasonably uniform dispersion of the fibers delivered to the wire. Finally, the headbox must be free of large and small-scale flow disturbances. These disturbances include MD pulses, CD eddy currents, and excessively intense fine scale pulses such as turbulence which can disrupt the jet of stock in free flight to the wire. Ideally, the stock will issue from the slice completely free of flocs. This provides the best opportunity for even sheet formation. Studies done using a 35mm camera and a high intensity strobe light of the stock discharge from a serrated slice illustrate the rapid formation of flocs on the forming board as the shear and turbulence generated in the headbox decays. Clearly, shear and turbulence must be maintained in the headbox to ensure that unflocced stock is delivered to the wire. Headboxes used today have serious deficiencies according to the aforementioned requirements. Rectifier roll headboxes lack any means of controlling flow through them, aside from one or two rectifier rolls. Secondly, these headboxes typically have a roll located directly before the slice. Despite the critical need for this roll, its placement tends to create non-uniformities in the stock right where uniform stock flow is imperative. Finally, the tubes from the manifold to the headbox become clogged with time and create major velocity variations in the stock.

Hydraulic headboxes are notorious for allowing pulsations generated in the approach system to pass through the headbox unabated. Secondly, when these headboxes are run at flows higher then design, the stock is excessively turbulent exiting the slice. Finally, when operated below designed flow rates, the stock often has perfectly formed flocs in it as it hits the wire.

The ideal headbox would provide modest flow resistance in the cross

direction. This flow resistance serves three purposes. It eliminates flow fluccutations induced by the manifold tubes, it eliminates or largely reduces MD pulses, and helps to keep the stock in a partially deflocculated state. Secondly, the headbox would have a large amount of free surface area parallel to the flow resistance for pulse attenuation. Finally, a short zone of divergence, followed by a zone of convergence, would follow the last rectifier roll. Two means of controlling cross direction basis weight and moisture would be utilized. First, a segmented slice would be used. Secondly, a bank of valved tubes would be placed at close intervals before the last rectifier roll to deliver small amounts of whitewater at key points in the sheet to even out the stock distribution(3).

The January 1987 issue of TAPPI Journal contains a review article, written by Michael Waller, which discusses headbox design and looks at some of the headboxes currently available. The properties of the fiber network formed on the paper machine depend most strongly on fiber length, stock consistency, and turbulence induced shear. And in the headbox, it is the intensity and scale size of the turbulence that will determine the flocculation characteristics of the fiber suspension. The rapid decay of this turbulence on the fourdrinier wire makes the elements of the fourdrinier table also important in formation.

Although the mission of the headbox, to distribute stock uniformly across the width of the paper machine, has remained basically unchanged over the years, the technology available for carrying out this mission has changed dramatically. The generic headbox system of today, besides carrying out the aforementioned tasks, must have a means of dampening pulsations induced by equipment in the approach system. All modern systems have tapered inlet headers to create uniform pressure and flow across the

machine. Finally, all modern headboxes have a segmented slice, continuously controlled by a computer, for CD profile control(4).

Fluid Flow in a Headbox

Fluid flow in the headbox is an extremely critical factor in the final formation of the sheet. Many methods of creating the desired flow characteristics at the slice exist today. Thus, after a brief review of turbulence generation, a review of some of the current technology will be presented.

There are a number of means of creating turbulence in fluid flowing through a closed channel. The simplest method is to pass the fluid through a pipe or closed channel at a velocity high enough to achieve a Reynold's number above 2300, the threshold of turbulent flow(5). However, the turbulence created in this fashion is often not enough for our needs. Therefore, other adjustments must be made. For example, bends and curves can be placed in the fluid's path. As the fluid passes around these curves, its velocity is high enough that the fluid will not follow the curved wall. Eddy currents and turbulence will occur in the gap between the fluid and the wall. This phenomenon also occurs when the pipe or channel is suddenly expanded. Since the fluid cannot follow the channel walls, a gap is created in which turbulence occurs(6). A 90° turn in the channel will also create turbulence because the fluid will "crash" into the wall in front of it, completely upsetting the flow. The 90° turn also causes a significant head loss. The degree of turbulence created by each of these structures can be estimated. These calculations will be considered once the headbox flow channel design is chosen.

The above discussion focused on the means of creating turbulence used in a hydraulic headbox. It was mentioned earlier that in an air padded or

atmospheric headbox the major turbulence generating device is the rectifier roll. Hydraulic headboxes use other devices to create turbulence. Escher Wyss has created a device called a step diffusor. Figure 1 illustrates its design. This device uses the principle of sudden expansion discussed above. The step diffusor has proven to be very effective in producing a high-quality fiber dispersion while reducing microturbulence to such an extent that companies can manufacture headboxes without extra turbulence generators such as rectifier rolls(7). Valmet has designed a headbox which uses two banks of tubes to create turbulence in the stock flow. Figure 2 shows its design. Both banks of tubes take advantage of the natural turbulence created in a pipe at higher velocities. These two banks of tubes and the intermediate attenuation chamber also serve to lower the head of the stock before it reaches the slice. In figure 3, the consistency profile created by two types of tube arrangements is illustrated. When stock flows through a round pipe, the consistency of the stock is at its maximum at the center line of the tube and diminishes towards the edges. The tube arrangement on the left of figure 3 overlaps the consistency profiles enough to make the resulting basis weight variations minimal across the sheet(8). A headbox developed for high consistency forming utilizes the principle of the 90° turn. The device is often referred to as a "U-tube". The abrupt 90° turn causes a considerable pressure loss and dispersion on a fairly small scale(9). Sandy Hill has designed a rather unique turbulence zone. This zone contains a series of cross machine triangular ridges. The gap formed by these ridges is adjustable and generates a fine scale, moderate intensity turbulence in the stock which helps deflocculate the stock(4). Finally, figure 4 illustrates what I believe to be a Japanese headbox described in a U.S. patent. After passing through a bank of tubes, the stock passes into a

Figure 1. Close-up of the Escher Wyss Step Diffusor.

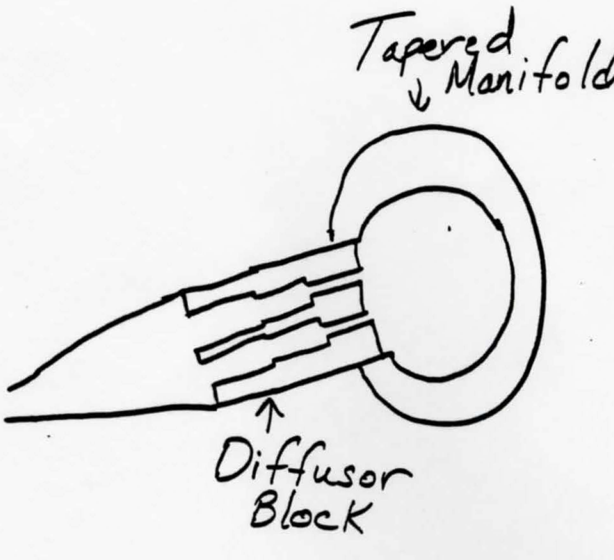


Figure 2. Valmet's Sym-Flo Headbox(8).

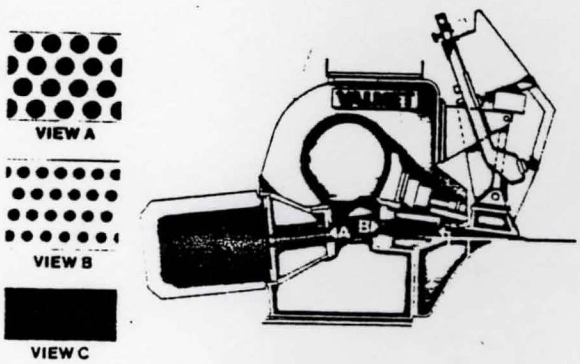


Figure 3. Tube arrangement possibilities in Sym-Flo Headbox(8).

(A) (B)

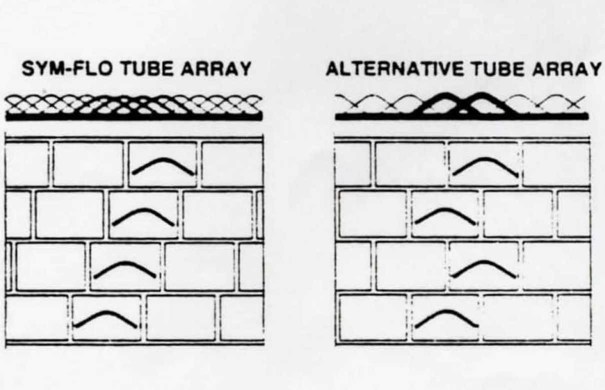
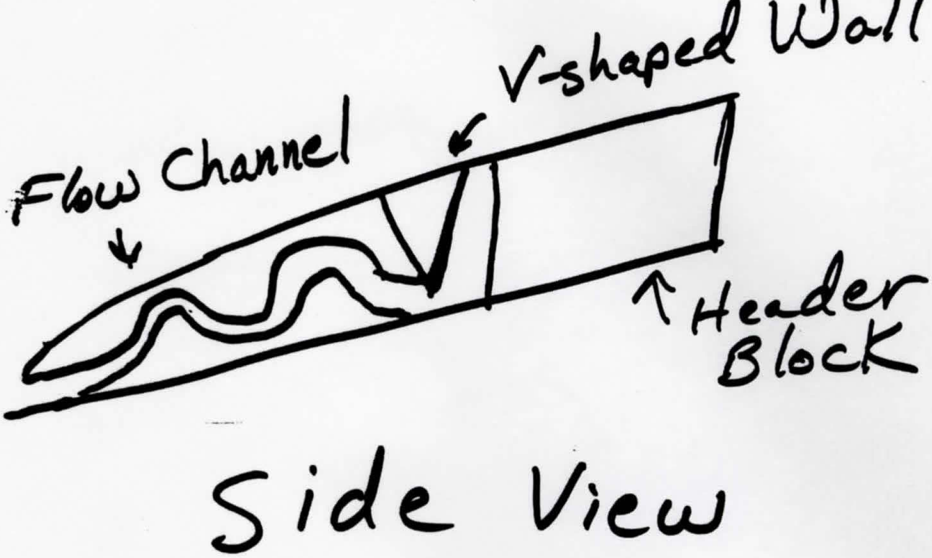


Figure 4. Proposed design of Japanese headbox.



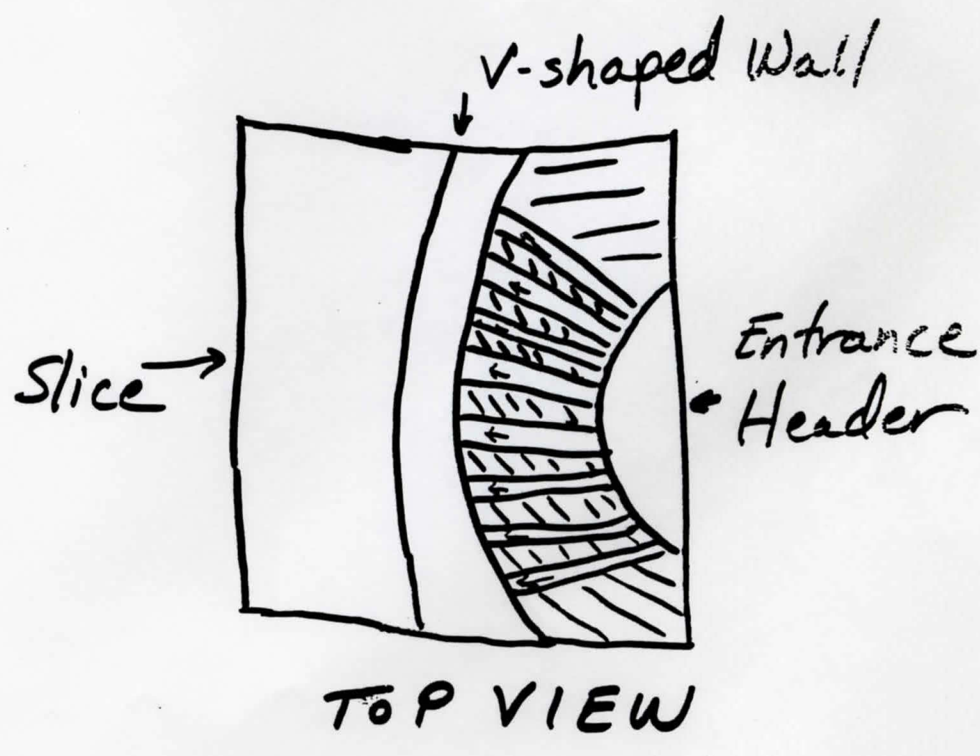


Figure 5. Impact of a jet on a frictionless plate(11).

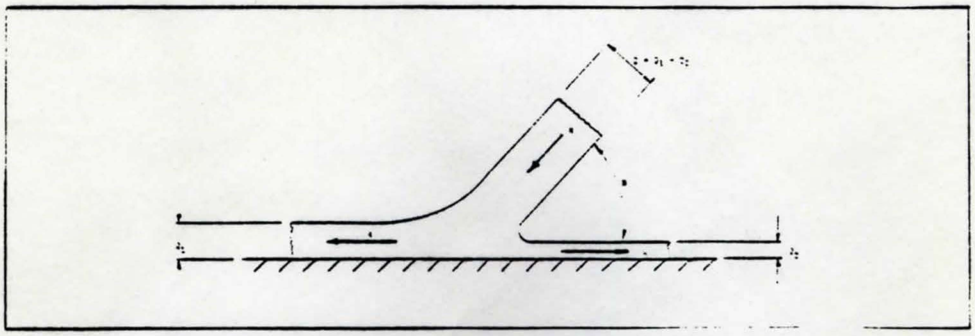


Figure 6. Principle of the Coanda Effect(11).

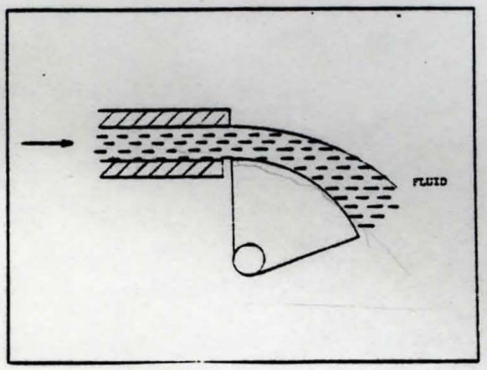
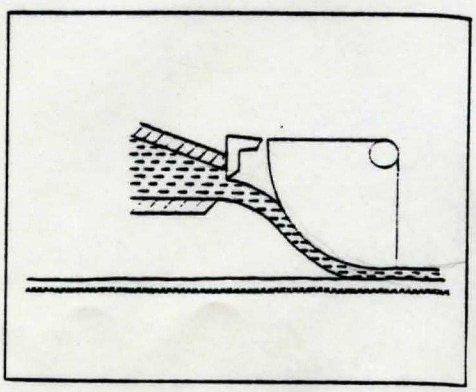


Figure 7. Coanda effect applied to multi-ply forming(11).



layer after the consistency of the first layer has reached the 12 to 16% range. At this consistency, the yield strength of the web is high enough that the force of the second jet will not significantly disturb the first web. Finally, the distance between the bottom lip of the headbox and the wire should be as small as possible to minimize the impact felt by the first web(11).

DESIGN OF THE SECONDARY HEADBOX

Specifications and Initial Calculations

Table 1 lists the primary specifications for the headbox. The desired product, 20 lb/1300 ft^2 (51 lb/3300 ft^2) printing paper, was chosen as a good representative printing grade to produce. This might be a heavy grade for our purposes. However, since the sheet is two-ply, the heavy weight is probably a good starting point. The information in table 1 was used to calculate the required slice opening and fluid head at the slice. These calculations are contained in Appendix 2. The results of these calculations are:

Slice opening -- 0.3 inches

Fluid head at slice -- 0.254 inches

The required head is very small. This could pose a problem in delivery of the fluid to the headbox. To help solve this problem, the stock will flow to the headbox with a larger fluid head and the headbox will be used to dissipate the excess head.

Potential Flow Channel Designs

Which type of headbox should be used? The headbox could be a simple

Table 1. Primary design specifications for the headbox.

Product -- 20 lb/1300 ft^2 printing paper

% of total sheet weight in second ply -- 10 to 50%

Estimated wire speed -- 70 fpm

Rush/Drag ratio -- 1

open headbox or a hydraulic headbox. Modern secondary headboxes are usually hydraulic. The pilot plant secondary headbox will also be a hydraulic headbox for two reasons. First, a hydraulic headbox will generate better shear and turbulence than the open, gravity headbox. Secondly, the head required is so small that little, if any, mixing could be provided or achieved in an open headbox.

Two proposed designs are illustrated in figure 8. The main reason for the flow channel types used is the likelihood of having to lower the head of the entering stock by a factor of at least 10.

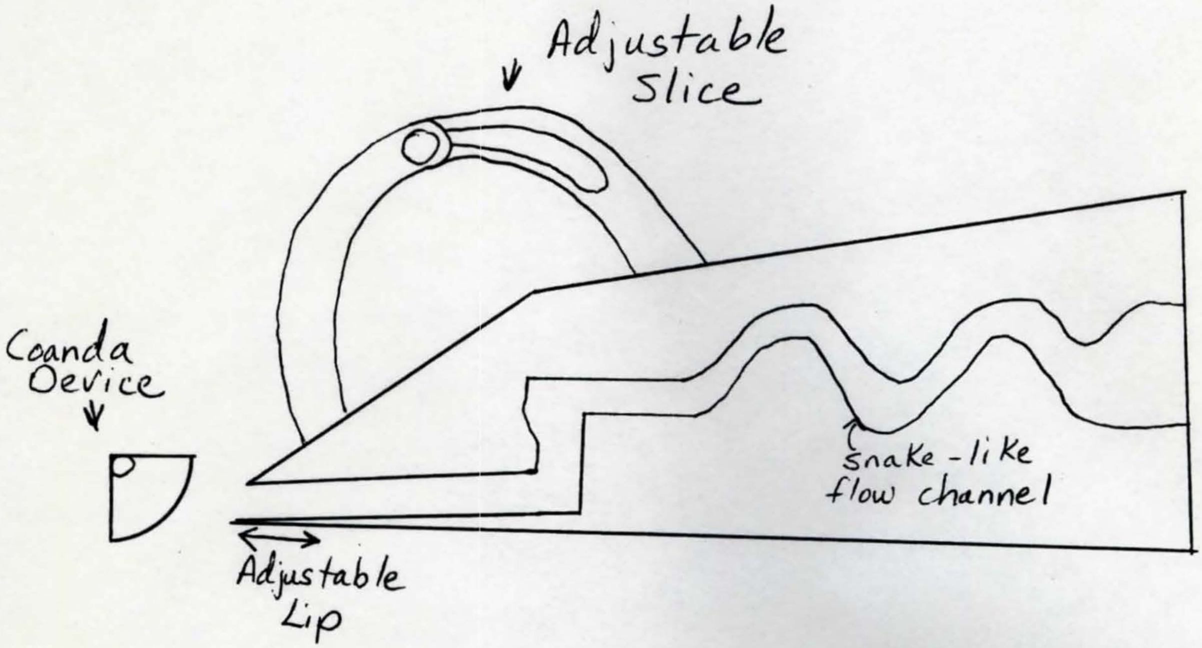
Design A was selected for two reasons. First, the bends and curves will generate more shear and turbulence in the stock than design B. Secondly, the construction of design A, in principle, should be easier than the construction of design B. This is important considering our limited financial resources and our desire to do much of the construction ourselves.

Calculation of Flow Channel Length

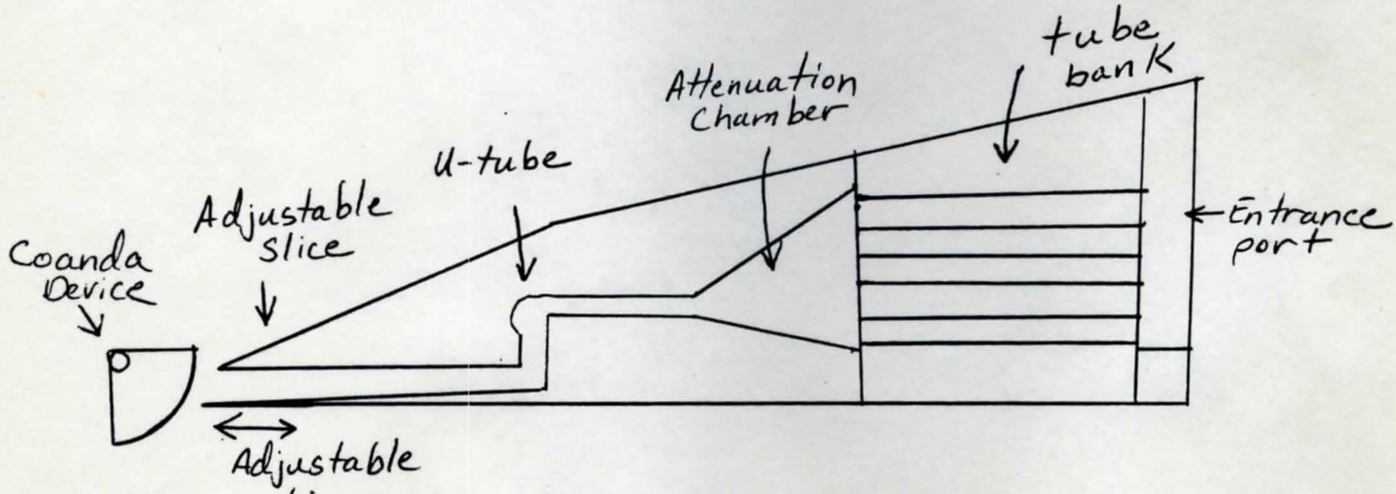
The next step in the design process is to calculate the length of the flow channel necessary to lower the delivered fluid head to 0.254 inches. These calculations, contained in appendix 3, utilize Bernoulli's equation (Eq. 1) and were carried out in two steps. The headbox was to be designed to permit delivery of the stock with a fluid head of 3-4 inches of water, with a

Figure 8. Proposed designs of secondary headbox.

Design A



Design B



channel length limited to 10-12 inches. To find the necessary length, Bernoulli's equation was solved for L, the channel length. Then, part A of equation two was used, with delta P varied. Table 2 shows the results of these calculations. The highest head achievable with a straight channel was 2.5 inches. This is not enough. To solve this problem, the correction for the channel bends, part B, was added. The bends were considered to be 90° bends. With the addition of eight bends to the flow channel, the delivered fluid length could be increased to 4 inches, as shown in table 2, and the channel length would be approximately 11 inches. These are acceptable figures.

Headbox Modelling

Two pieces of the headbox design had to be examined in the laboratory. The first part of the study was to determine the design of the entrance to the headbox. The last part of the study was to determine the design and placement of the Coanda element. A small mock-up of the headbox, pictured in figure 9, was constructed for this study.

The use of a tapered manifold for this headbox was ruled out due to the difficulty in constructing such a manifold. The problem was then to determine how to obtain an even distribution of stock across the width of the box. Different combinations of baffles were placed in the model and an observation of the fluid flow was made. The best combination of baffles is pictured in figure 10. The first baffle distributes the incoming flow evenly across the headbox, while the second baffle helps to even out the jet of stock entering the flow channel and prevents air entrainment by closing up the back of the headbox. The first gap at the back of the headbox clearly was too small for the flow supplied, roughly 5 gpm. Therefore, the entering gap, as a first approximation, should be about double the estimated size of

Table 2. Calculation of channel length.

	Pressure Drop	(A) Length (in.)	Bends	(B) Length (in.)	
	0	0.000	1	1.17048	
	0.5	2.560	2	2.34096	
	1	5.121	3	3.51144	
	1.5	7.681	4	4.68192	
	2	10.241	5	5.8524	
	2.5	12.802	6	7.02288	
	3	15.362	7	8.19336	
	3.5	17.923	8	9.36384	<------
------>	4	20.483	9	10.53432	
	4.5	23.043	10	11.7048	
	5	25.604	11	12.87528	
	5.5	28.164	12	14.04576	
	6	30.724	13	15.21624	
	6.5	33.285	14	16.38672	
	7	35.845	15	17.5572	
	7.5	38.406	16	18.72768	
	8	40.966	17	19.89816	

Eq. (1)

$$\frac{P_a}{\rho} + \frac{g Z_a}{g_c} + \frac{\alpha_a \bar{V}_a^2}{2 g_c} = \frac{P_b}{\rho} + \frac{g Z_b}{g_c} + \frac{\alpha_b \bar{V}_b^2}{2 g_c} + h_f$$

Eq. (2)

(A) (B)

$$L = \frac{\Delta P g_c D}{2 f V^2} - \frac{K D}{4 f}$$

Figure 9. Laboratory model of headbox.

Figure 10. Entry baffle configuration.

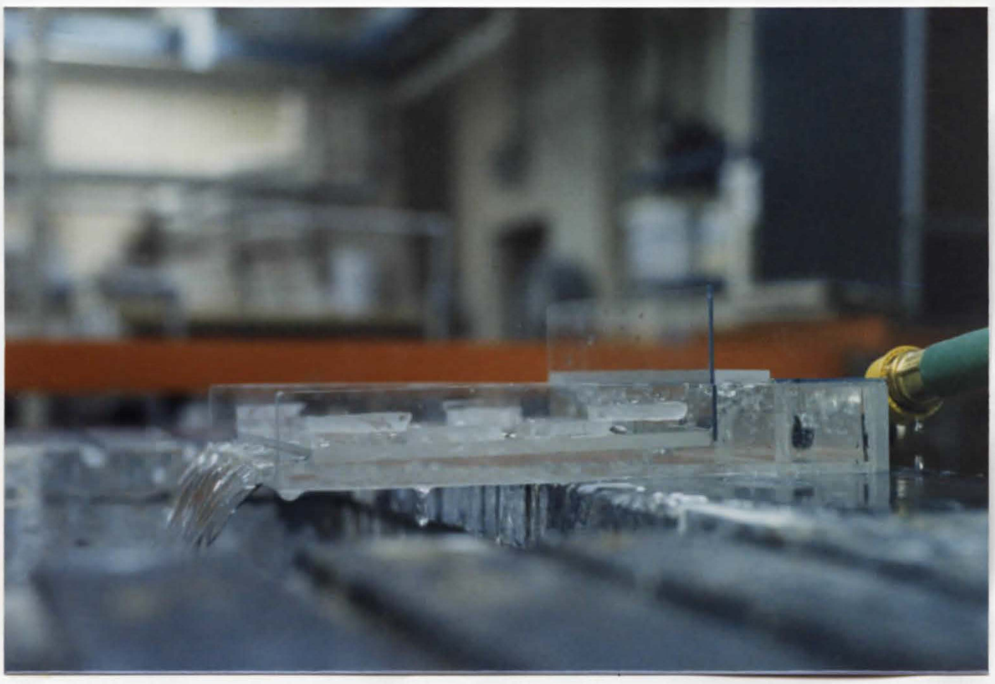


Figure 11. "Stock" flow when Coanda element in place.

2 inches for the full scale headbox.

Once an acceptable flow was achieved through the model headbox, different rods were studied as possible Coanda elements. Rods of various diameters were used, made of both metal and plastic. The goal in this stage of the study was to find which rod did the best job of pulling the jet parallel to the plane of the "wire" while maintaining an even jet across its width. The best rod and the resulting jet is pictured in figure 11. The rod diameter is approximately twice the size of the slice gap and is made of metal. The plastic rod would pull the jet parallel to the wire, however, the jet tended to channel on the surface of the plastic. For the Coanda effect to work properly, the fluid must evenly wet the entire surface of the rod with which it is in contact. The metal rod allowed this wetting to occur because the surface tension of the rod is similar to that of water.

THE SECONDARY HEADBOX

Figure 12 contains a diagram of the complete secondary headbox. The channel gap is 5/16 of an inch, slightly larger than the calculated value, to aid in construction and provide some extra capacity in the event that a larger flow is necessary. In the back view, four entering nozzles are shown, each with a diameter of 0.75 inches. The four nozzles are there because the weir box directly before the headbox (designed in a separate thesis), uses four hoses with a diameter of 0.75 inches to achieve the required flow of 32 gpm. The four nozzles, in theory, should also provide a more uniform distribution of stock across the width of the headbox. The entry section of the headbox is shown to be 4 inches long. This dimension should be confirmed in the lab by running water through the full scale headbox prior to installation on the papermachine. The slice lip design utilizes a rod on each end, mounted in a groove, allowing movement laterally as well as facilitating the widening or narrowing of the slice gap. A flexible rubber gasket is shown underneath the slice lip to prevent leakage of stock through the gap between the slice lip and the channel wall. The exact placement of the Coanda element may differ slightly from that shown, but can only be determined by trial and error on the papermachine.

Construction of the full scale headbox was begun, in hopes that it could be run as part of this engineering project. The headbox flow channel construction was done by Plastics Unlimited, a local firm specializing in plastics work. Unfortunately, they had some difficulties in putting the channel together because they were not properly equipped for such a large piece and the large number of bends required. The channel is probably not usable in its present form and will have to be redone. The rest of the headbox was not completed because of the time constraints on the project.

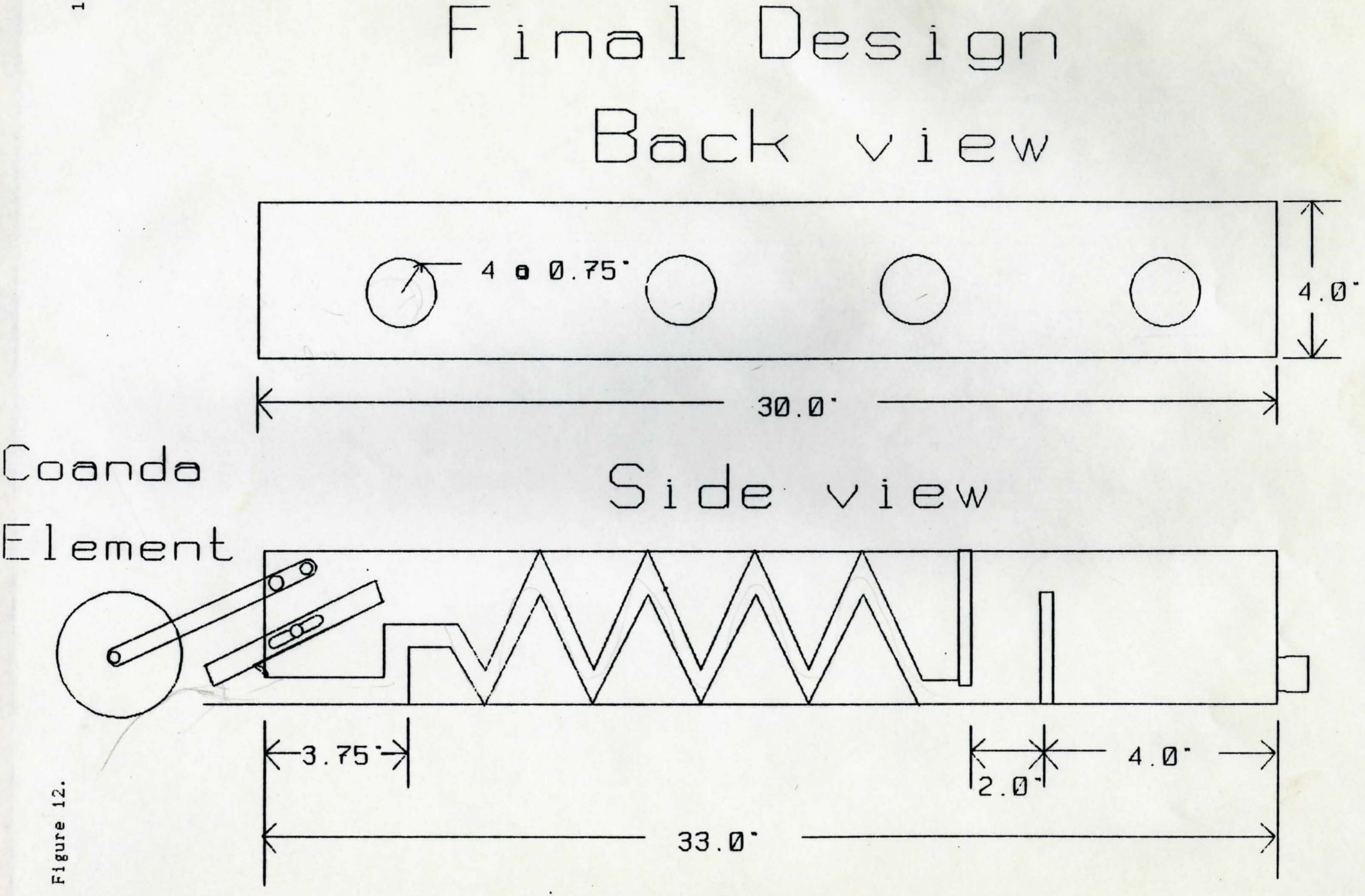

Final Design
Back view
4 ø 0.75"
4.0"
30.0"
Coanda
Element
Side view
3.75"
2.0"
4.0"
33.0"

Figure 12.

RECOMMENDATIONS

The following steps are required to complete the design of the secondary headbox and provide the equipment necessary for manufacture of two-ply printing papers on the pilot plant fourdrinier papermachine. They are:

1) Complete construction of the full-scale secondary headbox. This includes the inner flow channel.

2) Design and construct the mountings for the headbox. The headbox will have to be slightly tilted when mounted. Also, the mountings should permit vertical movement of the complete headbox assembly.

3) Installation and trial of the complete secondary headbox system. The initial furnish was determined in a separate thesis.

4) A thorough analysis of the flow characteristics of the headbox system, along with an analysis of the resulting paper, must be made. In particular, the formation of the secondary ply should be studied to determine what deficiencies, if any, exist in the headbox design presented.

5) Make necessary modifications to the headbox design. A usable secondary headbox should be the product of the procedure outlined above.

Once completed, manufacture of two-ply papers can begin on Western's pilot plant fourdrinier papermachine. At this point, the ultimate goal of the project will be achieved.

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APPENDIX 1

Impact Forces on Original Web (<u>11</u>)

EXAMPLE 1.
Let wire velocity $V = 60m/min = 1m/sec$.
Stock density $W = 1{,}000kg/m^3$.
Gravitational acceleration $g = 10m/sec^2$.
Stock depth $t = 5mm = 5 \times 10^{-3}m$.
Then, the rates of flow:
volumetric: $Q = V \cdot t = 5 \times 10^{-3} m^3/sec$ m. width.
mass: $Q \cdot W = 5kg/sec$ m. width.

Let now the clearance-height d be:	5 $= 5 \times 10^{-3}$	10 $= 10 \times 10^{-3}$	15 $= 15 \times 10^{-3}$	25 $= 25 \times 10^{-3}$	mm m
then, the velocity at impact: $R = \sqrt{V^2 + 2gd}$	1.05	1.09	1.14	1.23	m/sec
the proportion of the backflow: $Q^2/Q = (1/2)(R-V)/R$	2	4	6	9	per cent
this proportion 'undershoots' by: $R + V$	2.05	2.09	2.14	2.23	m/sec
similarly, the proportion of the forward flow: Q_1/Q	98	96	94	91	per cent
and it 'undershoots' by $R-V$	0.05	0.09	0.14	0.23	m/sec

EXAMPLE 2.

Let the wire velocity $V = 300m/min = 5m/sec$. and the clearance height d as before:	5 $= 5 \times 10^{-3}$	10 $= 10 \times 10^{-3}$	15 $= 15 \times 10^{-3}$	25 $= 25 \times 10^{-3}$	mm m
then, the velocity at impact, R	5.00	5.01	5.03	5.05	m/sec
the proportion of backflow Q_2/Q	–	–	3	4.5	per cent
this proportion 'undershoots' by	–	–	10.03	10.05	m/sec
whilst the proportion of forward flow Q_1/Q	100	100	97	95.5	per cent
and, it 'overshoots' by	–	–	0.03	0.05	m/sec
In both examples, the shear stress caused by the backflow is "s" = t.w.g.d.	0.25	0.5	0.75	1.25	N/m width
It acts over the length A, suppose A = 1mm approximately, then, the shear stress intensity = I_s	250	500	750	1250	N/m^2

APPENDIX 2

Calculation of Flow and Head

Product from secondary headbox:

10 lb/1300 ft^2 @ 70 fpm

wire width: 30 inches.

Area/sec.

$$30\text{in.} \left| \frac{1\,ft}{12\,in} \right| \frac{70\,ft}{min} \left| \frac{min}{60\,sec} \right. = 2.92\,ft^2/sec$$

Weight/sec

$$\frac{10\,lb}{1300\,ft^2} \left| \frac{2.92\,ft^2}{sec} \right. = 22.46 \times 10^{-3}\,lb/sec \text{ paper}$$

@ 5% moisture

Fiber/sec

$$22.46 \times 10^{-3} \frac{lb}{sec} \text{ paper} \left| \frac{95\,lb.\ OD\ fiber}{100\,lb.\ paper} \right. = 21.34 \times 10^{-3} \frac{lb}{sec} \text{ OD fiber}$$

Assume 95% retention of secondary stock

thus, Fiber/sec = 22.46×10^{-3} lb/sec OD fiber

Stock to headbox at 0.5% consistency (min.)

$$22.46 \times 10^{-3} \frac{lb}{sec} \text{ OD fiber} \left| \frac{100\,lb.\ stock}{0.5\,lb.\ fiber} \right. = 4.492 \frac{lb}{sec} \text{ stock}$$

Volume flow

$$4.492 \frac{lb}{sec} \text{ stock} \left| \frac{ft^3}{62.4\,lb} \right. = 7.199 \times 10^{-2}\,ft^3/sec$$

$$7.199 \times 10^{-2} \frac{ft^3}{sec} \left| \frac{7.481\,gal}{ft^3} \right| \frac{60\,sec}{min} = 32.31 \text{ gpm of stock}$$

Slice opening

$$7.199 \times 10^{-2} \frac{ft^3}{sec} \text{ stock} \left| \frac{min}{70 ft} \right| \frac{60 sec}{min} \left| \frac{1}{30 in} \right| \frac{144 ft^2}{ft^2}$$

$$= \underline{\underline{0.2962 \text{ inch}}}$$

Req'd. stock head @ slice

$$V = \sqrt{2gh}$$

speed

$$70 \frac{ft}{min} \left| \frac{min}{60 sec} \right. = 1.167 \, ft/sec$$

$$V^2 = 2gh \Rightarrow h = \frac{V^2}{2g}$$

$$h = \frac{(1.167 \, ft/sec)^2}{2(32.174 \, ft/sec^2)} = 21.15 \times 10^{-3} \, ft.$$

$$21.15 \times 10^{-3} \, ft \left| \frac{12 in}{ft} \right. = \underline{\underline{0.254 \text{ in.}}}$$

Derive equation for channel Length.

$$\Delta P = \frac{2fLV^2}{g_c D} \Rightarrow \Delta P g_c D = 2fLV^2$$

$$\Delta P = \left[\frac{4fL}{D} + K\right]\frac{V^2}{2g_c}$$

$$\Delta P = \frac{2fLV^2}{g_c D} + \frac{KV^2}{2g_c}$$

$$\Delta P - \frac{KV^2}{2g_c} = \frac{2fLV^2}{g_c D}$$

$$L = \frac{\Delta P g_c D}{2fV^2} - \frac{KV^2 g_c D}{2g_c 2fV^2}$$

$$L = \frac{\Delta P g_c D}{2fV^2} - \frac{KD}{4f} \quad \text{Eq. (2)}$$