D. J. FAHEY
and W. A CHILSON

Mechanical Treatments for Improving Dimensional Stability of Paper

Studies were conducted to determine how tension applied to wet handsheets and paper webs affected their dimensional stability. Handsheets made from 14 different pulps, some of these at various freeness levels, were subjected to different degrees of stress while wet and to restraint during drying. Paper machine experiments were conducted with expander rolls located in various positions in the machine to study their effect on the dimensional stability of paper in the cross-machine direction. The amount of shrinkage that occurred during drying was found to be related to the dimensional movement of both handsheets and machine-made papers. The handsheets, which had been stretched 3% while wet and then prevented from shrinking during drying, were as stable as the experimental machine-made papers in the machine direction. The type of pulp and degree of refining had little effect on the dimensional stability of handsheets that had been restrained during drying. These factors, however, had a major influence when the sheets were dried without restraint. This explains the effect of different pulps and degrees of refining on the cross-directional movement of machine-made papers. Expander rolls installed on the paper machine in either the presses or driers, or both, were effective in widening the sheet and reducing the dimensional movement in the cross-machine direction. With expander rolls in either the presses or early driers, reduction of about 40% was obtained in cross-machine movement of a waterleaf paper made from a western softwood bleached kraft pulp. Strengths were not changed appreciably with this reduction in cross-machine dimensional movement. The dimensional movement of the paper in the machine direction was not noticeably affected when the paper was stretched in the cross-machine direction. Preliminary paper machine runs have shown that expander rolls also improve the dimensional characteristics of punchcard stock, bond, and offset papers made with blends of softwood and hardwood pulps.

DIMENSIONAL instability has plagued manufacturers of many special paper products, such as maps, charts, and punchcards. In recent years, this property has become more important in an increasingly greater number of paper and paperboard products. To minimize the problem, attempts have been made to regulate the moisture content of paper so it will be more comparable to the moisture that it will attain during conversion, storage, and use. This has not solved the problem, however, because paper may be subjected to varying moisture conditions that are uncontrollable. Changes in moisture affect sheet dimensions, and result in curling, cockling, waving, and variable register in color printing.

Work reported on handsheets *(1, 2)* has shown that fiber composition, degree of refining, and tension during drying affect the expansivity of paper. Handsheets of bleached chemical pulps have been observed to expand more than those of unbleached chemical pulps. Handsheets made from beaten pulps are less stable than those made from unbeaten pulps, and handsheets that are free to shrink during drying are not so stable as those dried under tension.

Work at the Forest Products Laboratory *(3)* has shown that impregnation of the paper with water-soluble phenolic resins can improve dimensional stability of paper. These resins penetrate the fiber wall, thereby reducing the amount of water that can penetrate and swell the fiber. The use of phenolic resins, because of their adverse effect on sheet, color, and flexibility, is limited, however, to low brightness and stiff papers.

Experiments at this laboratory have shown that cross linking with formaldehyde is also effective in substantially improving the dimensional stability of paper (4). The degree of stabilization can be quite high, but the reaction has to be limited to avoid excessive embrittlement of the paper.

Fiber bulking agents are also effective, but fairly large amounts of such chemicals are required to give a noticeable improvement in dimensional stability. Many of these treatments, in addition to being rather costly, have an adverse effect on strength properties.

This paper summarizes work at the laboratory that was begun in 1960 on stretching and mechanically restraining paper webs to achieve more stable papers. Basic information was obtained on handsheets. Studies were made to determine the effect of pulp composition, pulp freeness, and degree of restraint during drying on dimensional stability. Experimental paper machine experiments were conducted in which expander rolls were installed in various places in the wet press and drier sections of the machine in an attempt to widen the sheet sufficiently to overcome the shrinkage that occurs in the cross-machine direction during its manufacture.

A western softwood bleached kraft pulp was used in most of the machine studies. A limited number of machine runs were made with mixtures of softwood and hardwood pulps to demonstrate the effectiveness of expander rolls in the manufacture of punchcard, register bond, and offset papers. Additional work is planned to explore more fully the effect of side tension applied to paper during its manufacture on its dimensional stability.

HANDSHEET STUDIES

Materials and Procedures

Handsheets weighing approximately 70 g./sq. m. were made from a number of pulps, many of which were processed in the TAPPI test beater to various freeness levels. A list of the pulps and their respective freenesses is given in Table I.

The handsheets were made on a 7 X 9-in. rectangular sheet mold equipped with a 150-mesh wire, and the wet sheets were pressed at 60 p.s.i. between blotters. Immediately after wet pressing, opposite ends of the sheets were dried to a distance of about $^3/_4$ in. with a heat sealer and then clamped at the dried ends in jigs for oven-drying. The jigs had one stationary clamp and one movable clamp. By adjustment of the movable clamp, sheets were allowed fixed amounts of shrinkage during drying in the long dimension, with free shrinkage in the short dimension. Some sheets were stretched first, and then the amount of shrinkage was controlled. The drying was done by exposing the sheets in the jigs in an oven at 150°F. for 10 to 15 min. Sheets representing each pulp and freeness were subjected in the long dimension to each of the following conditions during drying:

D. J. FAHEY, Technologist, and W. A. Cumsox, Chemical Engineer, Forest Products Laboratory,* Forest Service, U. S. Department of Agriculture.

* Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

Table I. Dimensional Movement of Handsheets Dried Under Varying Degrees of Restraint and Made from Different Pulp Furnishes

Pulp furnish		C.S. freeness, ml.	Weight, g./m.²	Density, g./cc.	Per cent[a] increase in dimension from 30 to 90% R.H. for different sheet shrinkages						Per cent[a] increase in dimension from 30% R.H. to wet for different sheet shrinkages					
Kind	Identification				0	2	4	Unrestrained	0[b]	2[b]	0	2	4	Unrestrained	0[b]	2[b]
					Bleached Pulps											
Douglas-fir kraft	P-4145	700	78.4	0.41	0.37	0.80	0.98	1.25	0.27	0.35	1.19	2.43	3.12	3.23	0.22	0.98
		650	77.8	0.46	0.47	0.70	1.00	1.40	0.22	0.40	1.19	2.05	3.03	3.53	0.25	0.90
		530	81.1	0.52	0.45	0.72	1.00	1.75	0.33	0.38	0.97	2.15	2.69	4.08	0.23	0.78
		355	78.2	0.54	0.37	0.70	1.08	1.62	0.25	0.37	1.00	2.18	3.15	4.08	0.15	0.69
Southern pine kraft	P-4387	700	78.8	...	0.40	0.70	0.97	1.37	0.17	0.23	1.08	2.20	3.18	3.92	0.19	0.88
		600	80.9	...	0.28	0.63	0.80	1.75	0.05	0.20	0.98	2.25	3.02	4.70	0.10	1.00
		500	77.7	...	0.35	0.55	0.94	1.92	0.12	0.37	1.07	2.00	3.27	5.15	0.13	0.90
		420	79.8	0.59	0.38	0.63	1.06	2.15	0.25	0.45	1.18	2.07	3.22	5.32	0.30	1.08
		300	78.7	...	0.23	0.52	0.73	2.11	0.20	0.22	1.08	2.03	3.13	6.25	0.10	0.67
Sweetgum kraft	P-4470	700	75.4	...	0.27	0.73	0.95	0.94	0.08	0.33	0.97	2.27	2.54	2.36	0.05[c]	1.05
		600	85.0	...	0.31	0.72	1.03	1.47	...	...	0.95	2.15	3.02	3.78	...	...
		500	78.5	...	0.45	0.67	1.05	1.69	0.20	...	0.98	1.92	3.35	4.25	0.23	0.92
		430	79.0	0.55	0.48	0.62	1.10	1.52	0.31	0.48	0.97	2.03	3.50	4.71	0.35	1.02
		300	79.5	...	0.45	0.67	0.98	2.08	0.38	0.31	1.17	2.14	3.23	5.60	0.62	0.93
Western hemlock sulfite	P-4603	700	77.2	0.46	0.47	0.67	1.05	1.33	...	...	1.28	2.17	3.22	3.72	...	...
		600	76.9	0.53	0.33	0.63	0.90	1.52	0.30	0.35	1.08	1.80	3.07	4.05	0.37	0.87
		500	73.8	0.55	0.35	0.67	1.05	1.60	...	...	1.15	2.12	3.13	4.13	...	...
		280	81.9	0.57	0.45	0.65	0.98	1.72	...	...	1.23	2.10	3.03	5.07	...	...
Eastern softwood sulfite	P-4827	700	78.2	0.47	0.27	0.70	0.83	0.83	0.20	0.37	0.87	1.77	1.98	2.08	0.10	0.88
		600	72.3	0.56	1.27	0.70	0.92	1.02	0.15	0.33	0.65	1.83	2.07	2.47	0.15	0.72
		480	71.5	0.61	0.35	0.68	0.92	1.20	0.13	0.35	0.72	1.68	2.22	2.65	0.08	0.65
		380	78.0	0.63	0.42	0.57	0.95	1.45	0.17	0.28	1.05	1.68	2.70	3.48	0.22	0.60
		260	75.9	0.63	0.30	0.58	0.92	1.73	0.15	0.30	0.67	1.57	2.63	4.02	0.12	0.57
Mixed eastern hardwood NSSC	P-4846	450	85.2	0.61	0.27	0.67	0.83	0.90	0.27	...	0.73	1.65	2.03	2.13	0.33	...
Aspen cold soda	P-4759	320	77.7	0.36	0.42	0.95	1.50	1.72	0.90	0.48	1.27	2.62	4.15	4.69	...	1.17
					Unbleached Pulps											
Western softwood kraft	P-4725	700	76.2	0.43	0.42	0.77	1.15	1.33	...	...	1.13	2.42	2.97	3.25	...	...
		620	77.2	0.46	0.38	0.72	1.00	1.23	0.25	0.47	0.95	1.87	2.69	2.95	...	...
		510	77.9	0.51	0.47	0.69	0.93	1.69	...	...	1.00	1.83	3.14	4.28	...	...
		330	80.5	0.54	0.35	0.67	1.17	1.83	...	...	0.85	1.95	3.25	4.62	...	...
Southern pine kraft	P-4741	700	79.0	...	0.40	0.78	1.10	1.28	0.22	0.48	0.83	2.20	2.92	3.15	0.07	1.00
		600	80.3	...	0.31	0.69	0.95	1.68	0.30	0.42	0.83	2.15	3.33	4.13	0.23	0.92
		500	83.0	...	0.33	0.69	1.02	1.72	0.27	0.38	0.97	2.15	3.28	4.77	0.20	0.90
		370	79.6	0.52	0.33	0.67	1.23	2.36	0.22	0.35	0.88	1.92	3.60	5.68	0.12	0.85
		300	78.8	...	0.45	0.58	0.88	2.00	0.22	0.25	1.10	1.98	3.30	6.20	0.07	0.82
Western hemlock sulfite	P-4810	700	75.4	...	0.33	0.78	1.13	1.08	0.23	0.37	0.87	1.93	2.48	2.53	0.22	0.77
		600	75.3	...	0.42	0.77	1.08	1.42	0.20	0.42	1.05	2.20	2.92	3.28	0.20	0.92
		500	74.3	...	0.38	0.75	1.28	1.62	0.28	0.47	1.07	1.83	3.00	3.73	0.20	0.83
		350	81.0	0.61	0.48	0.78	1.27	1.94	0.33	0.52	1.13	2.27	3.29	4.77	0.35	1.05
		280	72.8	...	0.38	0.65	1.13	2.35	0.30	0.37	1.17	2.07	3.07	5.92	0.43	1.00
Spruce groundwood	GR-1244	100	78.8	0.35	0.60	0.98	1.23	1.31	0.42	1.02	1.23	1.92	2.33	2.44	0.39	1.92
	GR-1243	50	78.4	0.38	0.72	1.08	1.37	1.37	0.45	0.48	1.18	2.18	2.67	2.60	0.45	1.00
					Waste Paper											
Manila tabulating cards	P-4760	560	81.5	0.46	0.50	0.78	1.02	1.06	0.20	0.47	1.00	1.95	2.63	2.53	0.02	0.95
Milk carton stock	P-4826	600	76.6	0.46	0.33	0.63	0.85	0.92	0.17	0.33	0.73	1.87	2.25	2.53	0.50	0.72
Waste newsprint	P-4798	170	75.0	0.36	0.25	0.81	0.86	0.67	0.05	0.36	0.73	1.71	2.07	1.54	0.13[c]	0.95

[a] Based on length at 30% R.H. Average of 5 samples.
[b] Sheets were stretched 3% before drying except those with NSSC which were stretched only 1%.
[c] A decrease rather than an increase in sample length was noted.

(1) fully restrained (no allowance for shrinkage), (2) 2% allowance for shrinkage, (3) 4% allowance for shrinkage, and (4) free shrinkage. In addition, sheets of all pulps except semichemical were stretched 3% and fully restrained, and stretched 3% and then allowed to shrink 2%. The sheets from semichemical pulp were stretched only 1% because of damage when elongation exceeded this amount.

Testing

After drying, handsheets were conditioned at 50% R.H., 73°F., for at least 24 hr. and trimmed to 5 X 7 in. to remove the predried area and the wrinkled edges. After weighing, they were exposed to 30% R.H., 80°F., for 24 hr. Five samples 6 X 1/2 in. (±0.005 in.) were cut from sheets representing each variation with a sample die cutter. These samples were then exposed to 90% R.H., 80°F., for at least 48 hr., and their length measured in this high humidity atmosphere with a steel rule calibrated to hundredths of an inch. A magnifying glass was used in making the measurements. These samples were then soaked in water at a temperature of 73°F. for 24 hr. and again measured. The dimensional movements, from 30 to 90% R.H. and from 30% R.H. to water-soaked condition, were calculated and the movement expressed as per cent swelling based on dimension at 30% R.H. These data are given in Table I.

Results

Influence of Restraint During Drying. The data obtained are presented in Table I and in Figs. 1 to 4. Restraint during drying had a substantial effect on the dimensional movement of the handsheets. Sheets allowed to dry without restraint expanded considerably more when exposed to moisture than those sheets in which the shrinkage during drying was controlled. When the sheets were fully restrained, the movement was reduced by 65 to 85%, depending on the type of pulp and its freeness. A still further reduction in dimensional change was noted when the handsheets were stretched 3% while wet and then dried with little or no allowance for shrinkage. These sheets had a dimensional movement of about 0.5% for a moisture gain brought about by a 60% change (from 30 to 90% in relative humidity.

During papermaking, the wet web is stretched in the machine direction and held during drying under conditions similar to those for the stretched and fully restrained handsheets. In the cross-machine direction, a machine. made sheet is dried without side tension, thus accounting for the great difference in dimensional movement between the two principal directions of the sheet.

Effect of Type of Pulp. The type of pulp had a considerable effect on the dimensional changes of sheets that were dried without tension similar to the conditions existing in the cross direction of machine-made papers. The dimensional movement is plotted for sheets made with bleached pulp in Fig. 1 and with unbleached pulp in Fig. 2. The unrestrained sheets of southern pine bleached and unbleached kraft pulps exhibited the greatest dimensional movement. Spruce groundwood pulp was the most stable of the unbleached pulps, and the Douglas-fir kraft and eastern softwood sulfite pulps were the most stable of the bleached pulps. Bleached western softwood kraft pulp sheets were more

394 Vol. 46, No. 7 July 1963 / Tappi

stable than sheets of bleached western hemlock sulfite pulp. This was true also for both unbleached pulps. Table I shows that the dimensional movements of wastepaper furnishes are, in general, less than for virgin pulps. When the handsheets were restrained during drying, the difference between pulps was *small.*

Influence of Degree of Refining. Figure 3 shows the effect of reducing the freeness of the southern pine bleached kraft on the dimensional movement of the unrestrained and restrained sheets. Similar data are plotted in Fig. 4 for the Doublas-fir bleached kraft pulp. For those sheets dried without tension, stock freeness was a major factor influencing the dimensional movement of a sheet of paper. This correlates with information reported by numerous authors. The data show also that if the sheet can be restrained during drying, a low freeness stock is just as effective as a higher freeness stock in producing a paper with a minimum of expansivity.

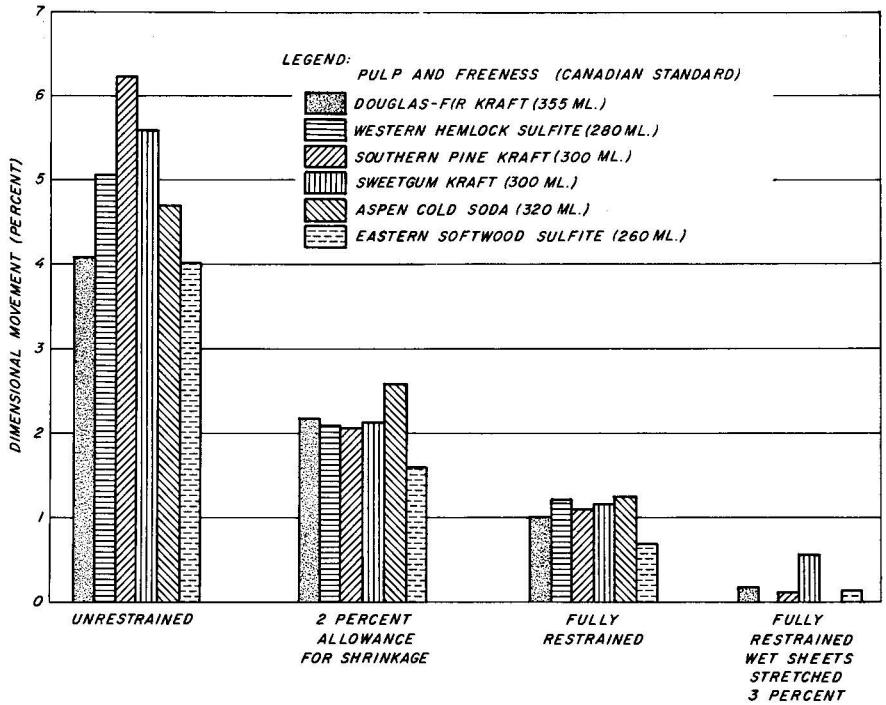

Fig. 1. Effect of type of bleached pulp on the dimensional movement (30% R.H. to wet) of handsheet dried under varying degrees of restraint

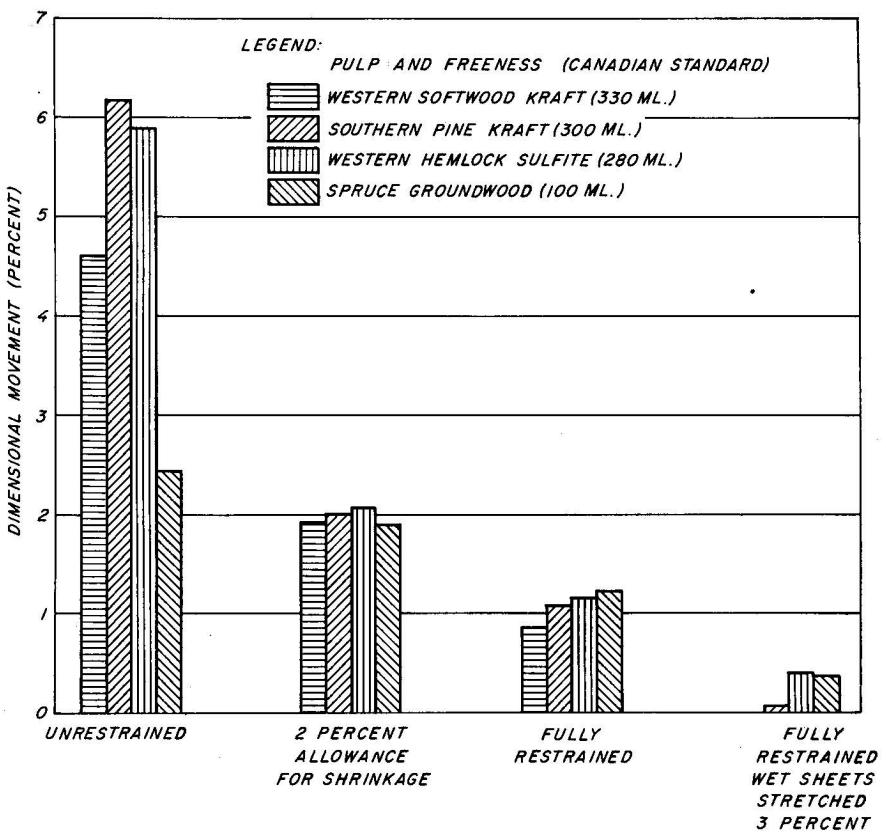

Fig. 2. Effect of type of unbleached pulp on the dimensional movement (30% R.H. to wet) of handsheets dried under varying degrees of restraint

PAPER MACHINE EXPERIMENTS

Handsheet studies show that more dimensionally stable papers can be produced by stretching a wet sheet and then restraining it from shrinking during drying. Machine-made papers are subjected to these forces in the machine direction, and they are relatively stable in this direction. Tension, however, is not applied in the cross-machine direction during manufacture and the paper expands and contracts in this direction with changes in moisture content. Experiments were therefore directed toward the application of tension in the cross-machine direction.

Expander rolls of the type now used by the paper industry to remove the wrinkles from paper webs and to open up wet felts were installed in various positions in the wet press and drier sections of the Laboratory's experimental machine to widen paper webs. With this equipment, a number of paper runs were made to investigate the use of these rolls for altering the cross-machine expansivity of machine-made papers.

Equipment

The experimental fourdrinier paper machine used in these experiments produces a wet web about $12^1/_2$ in. wide at the wire. It is equipped with four plain wet presses: two straight-through presses, a reversing press, and a smoothing press. The paper machine driers are divided into two sections, one with 12 and the other with 8 driers. In these experiments, the machine speed was adjusted so that all of the drying was done in the first section. The top drier felt was removed for most of the runs to permit making width measurements of the sheet at each top drier.

Eight 19-in. face expander rolls were used in this study. Three were $1^1/_2$ in.-diam., variable bow curved rolls with a maximum bow of $^5/_{16}$ in. for 12 in. of face, three were $1^1/_2$ in.-diam., fixed bow rolls with $^1/_8$-in. bows and two were 2-in. diam., fixed rolls with $^1/_4$-in. bows.

Materials and Procedures

Commercial western softwood bleached kraft pulps were used in the majority of the papermaking experiments. These

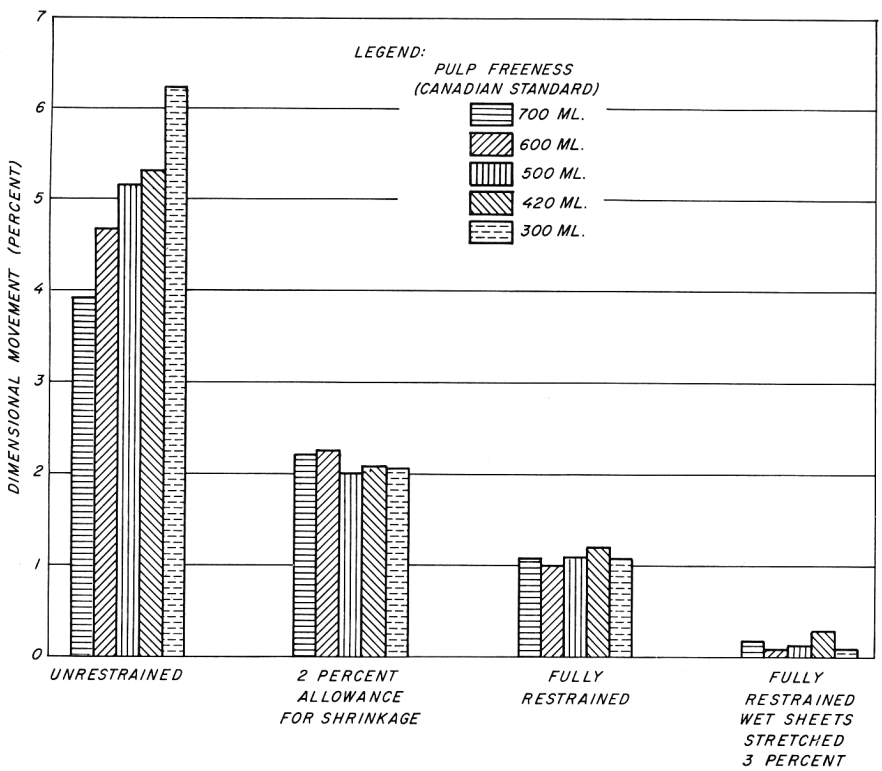

Fig. 3. Effects of freeness of southern pine bleached kraft pulp on the dimensional movement (30% R.H. to wet) of handsheets dried under varying degrees of restraint

were refined to about 575 ml. C.S. freeness, using a beater, and then jordaned to a C.S. freeness of 350 to 400 ml. The stock furnishes, which contained no filler or size, were converted into a waterleaf sheet weighing approximately 80 lb./3000 sq ft Limited paper runs were made producing (1) punchcard stock, (2) a 20-1b. register bond paper, and (3) a 50-lb. offset book paper. The furnishes for these consisted of mixtures of softwood and hardwood pulps.

Expander rolls were used singly or in groups of up to eight rolls placed in various parts of the paper machine (see Figs. 5 and 6). Cross-machine shrinkage was determined by measurements taken of the width of the sheet at various locations on the machine from the wire to the reel with a ruler graduated in units of 1/16in. Moisture samples of the sheet were taken at the expander rolls.

Testing

The machine-made sheets were evaluated for dimensional movement in both the machine and cross-machine direction for moisture increases due to changes in exposure from 30 to 90% R.H. and from 30% R.H. to water soak. The same procedure that was used for the handsheets was followed for the machine-made papers. In addition, selected sheets were evaluated for strength properties in accordance with TAPPI Standard Methods.

Results

Tables II, III, and IV contain the data on properties of sheets made on the experimental paper machine.

Influence of Sheet Shrinkage. It was shown in the handsheet studies that the dimensional movement of the sheet correlated closely with the shrinkage during drying. The same was true for the sheets made on the paper machine with the expander rolls. In Fig. 7, the dimensional movement in the cross direction is plotted against shrinkage for a number of waterleaf papers produced on the paper machine with and without expander rolls. While there is some scatter of data, in general the points can be reasonably well represented by a single straight line. The points at the top of the line generally represented the control runs in which no side stress was put on the sheet. These papers had about 6 to 8% shrinkage during manufacture. The more stable sheets were those with the minimum overall shrinkage If this line is extended below the *X* axis to the Y axis, stretching the sheet approximately 3% in the cross-machine direction and main taining this width throughout the papermaking operation could produce a sheet that is as stable in the cross-machine direction as in the machine direction. Thus to obtain the highest efficientcy the expander rolls must be located where they would produce the greatest overall widening of the sheet.

Expander Rolls in the Drier Section. The early paper runs were concerned with installations of expander rolls in the drier section and particularly in the final stages of drying. Width measurements taken during the manufacture of the sheet showed that the greatest shrinkage occurred after the sheet had reached a solids content of about 65 %.

The 5778 series (Table II) was designed to study the use of the ex-

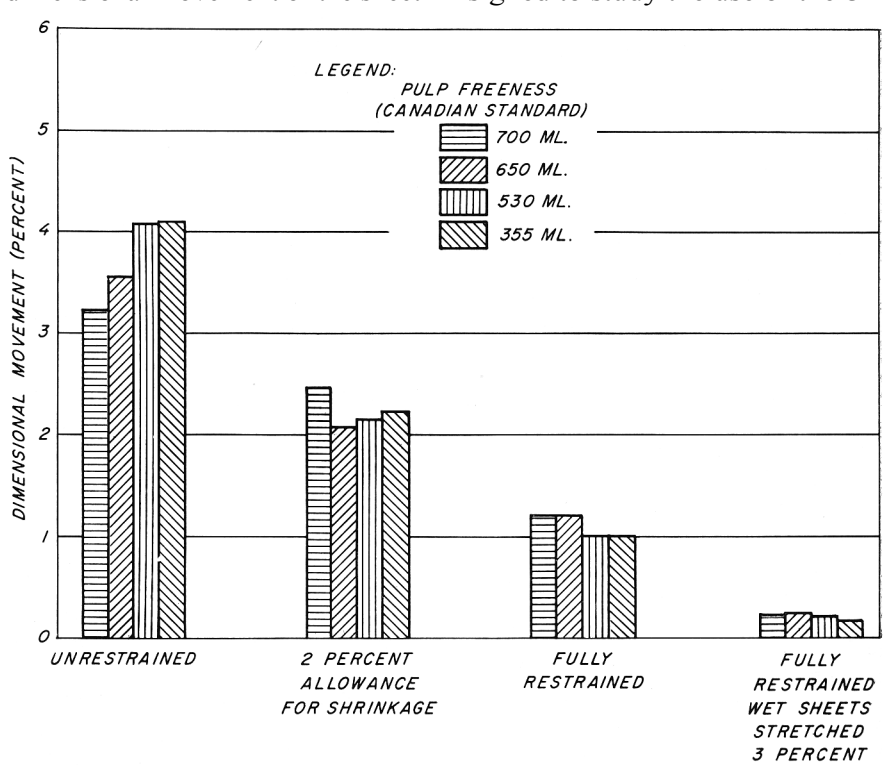

Fig. **4.** Effect of *freeness of* Douglas-fir bleached kraft pulp *on the dimensional movement* (30% R.H. to wet) of handsheets dried under varying degrees of restraint

pander rolls to prevent this sheet shrinkage. Single variable expander rolls with nearly maximum curvature were placed in this critical area. A 12% reduction in dimensional movement was noted with one expander roll used against the sheet when the solids content was about 68%. A similar roll against the web at a solids content of 78% had no measurable effect on the dimensional characteristics of the sheet.

Subsequent series were conducted with multiple groups of rolls in different locations in the drier section. The 5784 series shown in Table II had either four or five rolls contacting the sheet in the early stages of drying, when the solids content of the web was between 43 and 68%. Five rolls, for example, in the early stages were effective in increasing the overall width about 5%, and these papers were at least 40% more stable than the control for the extreme exposure conditions.

In a later series (6073, Table II), two variable expander rolls, each with a bow of about $^1/_4$ in. in 12 in. of face, were used concurrently, starting with one before and one after each of seven driers at sheet solids contents, varying from 44 to 75%. Again the stability of the sheet was found to improve as the roll positions were shifted toward the wet end of the machine.

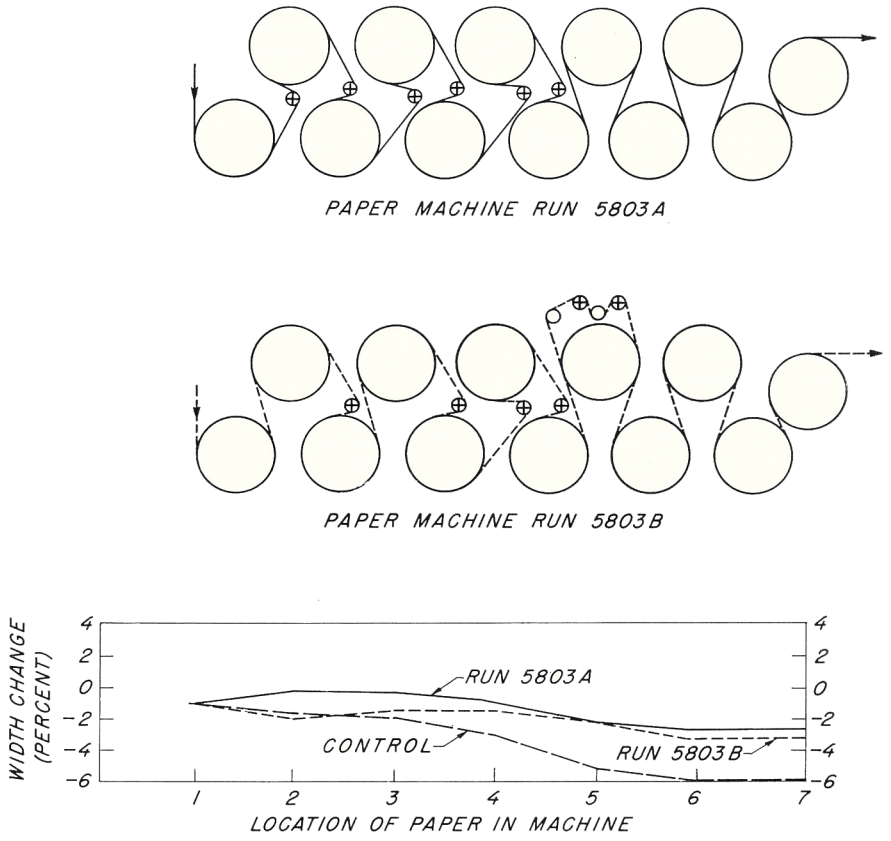

Fig. 5. Effect of expander rolls (e) in early and late part of the drier section on She sheet width

The expander rolls in the early stages of drying were effective in stretching the sheet beyond its original width, but when the rolls were used in the later stages of drying, no actual stretching could be observed. The rolls in this area, however, have been effective in partially restraining the webs from shrinking. The sheets with this side tension were wider and more dimensionally stable than those made without expander rolls. In all cases, some sheet shrinkage was observed.

The six small diameter expander rolls were used in two different arrangements in series 5803 (Fig. 5). While the sheet at the reel, in both arrangements, was wider than the control made without the expander rolls, the increase in width in 5803 B was obtained by offsetting part of the shrinkage that occurred during the control run. In 5803 A, with more of the rolls in the early driers, the sheet was stretched beyond its original width. The roll ahead of drier no. 2 was highly effective in accomplishing this, and the subsequent rolls assisted in partially offsetting the shrinkage This arrangement produced a wider sheet, which did not expand as much when exposed to moisture as the sheet made with the arrangement used in 5803 B.

With expander rolls in the drier section only, as much as a 40% improvement in cross-machine dimensional stability has been obtained. This im-

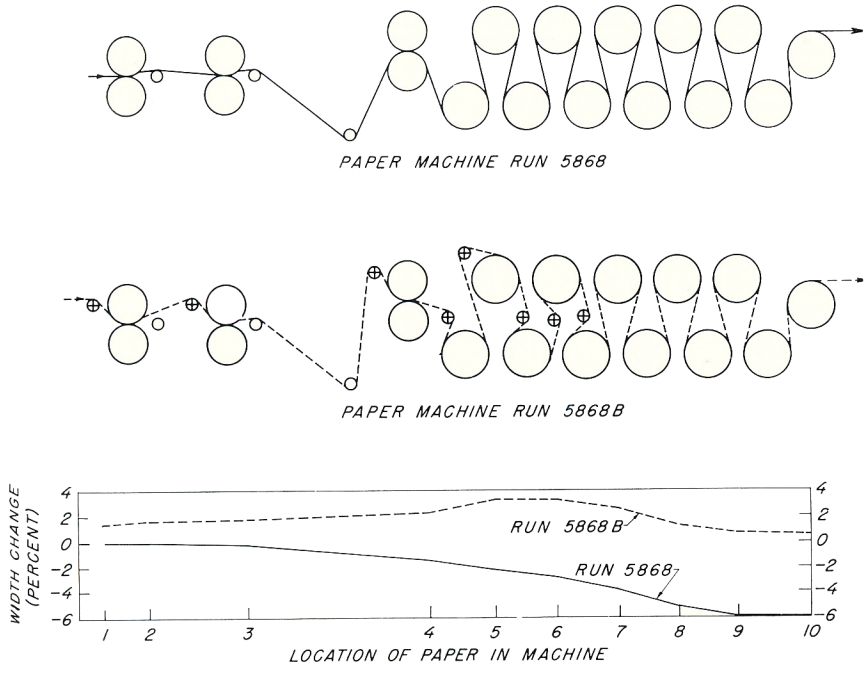

Fig. 6. Effect of expander rolls (e) in press and drier sections on sheet width. Expander rolls were not used for paper machine run 5868

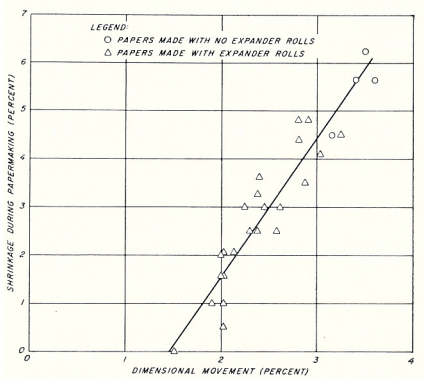

Fig. 7. Relationship between cross-machine dimensional movement (30% R.H. to wet) and shrinkage during papermaking for waterleaf papers

Table II. Dimensional Movement of Waterleaf Papers Made with Expander Rolls in Various Locations in the Press and Drier Sections of the Experimental Paper Machine

Machine run no.	Pulp[a] shipment no.	Cross machine shrinkage,[b] %	Expander rolls No.	Expander rolls Location[d]	Solids content of sheet at expander rolls, %	Dimensional movement[c] Machine direction 30 to 90% R.H., %	Machine direction 30% R.H. to wet, %	Cross direction 30 to 90% R.H., %	Cross direction 30% R.H. to wet, %
				Expander Rolls in Drier Section					
5778[e]	4205	8.4				0.17	0.05	1.28	4.02
5778B	4205	7.2	1	D_5	68	0.15	0.08	1.30	3.57
5778C	4205	7.6	1	D_7	78	0.12	0.15	1.43	4.07
6073[e]	4912	6.7				0.17	0.27	1.60	4.37
6073A	4912	5.6	2	D_8D_9	71–75	0.13	0.27	1.43	3.70
6073B	4912	5.1	2	D_7D_8	62–71	0.17	0.17	1.47	3.57
6073C	4912	4.6	2	D_6D_7	55–61	0.07	0.17	1.33	3.50
6073D	4912	4.1	2	D_5D_6	49–56	0.10	0.20	1.27	3.27
6073E	4912	4.1	2	D_4D_5	45–49	0.13	0.17	1.33	3.30
6073F	4912	3.6	2	D_3D_4	44–45	0.13	0.17	1.23	3.10
6073G	4912	3.6	2	D_2D_3	44–44	0.13	0.17	1.30	3.23
5784[e]	4205, 4369	8.4				0.14	0.00	1.31	4.17
5784E	4205, 4369	4.8	4	$D_1D_3D_5D_7$	43–68	0.17	0.10	1.08	2.83
5784F	4205, 4369	3.5	5	$D_1D_2D_3D_5D_7$	43–68	0.13	0.17	0.95	2.37
5784G	4205, 4369		5	$D_2D_2D_3D_5D_7$	43–60	0.10	0.30	0.87	2.31
5803[e]	4756	5.9			...	0.17	0.12	1.18	3.42
5803A	4756	3.0	6	$D_2D_3D_4D_5D_6D_7$	...	0.17	0.22	0.97	2.23
5803B	4756	3.5	6	$D_3D_5D_6D_7D_8D_8$[f]	53–88	0.12	0.08	1.23	2.88
				Expander Rolls in Press Section					
5868[e]	4822	6.6				0.13	...	1.32	3.25
5868A	4822	0.5	4	$W_1W_2W_2$[f] Sm	19–42	0.13	0.02	1.00	2.03
5868E	4822	1.0	3	W_1W_2 Sm	19–42	0.15	0.03	0.78	2.03
				Expander Rolls in Press and Drier Section					
5867[e]	4822	5.5			...	0.10	...	...	3.17
5867D	4822	0.0	8	W_1W_2 $SmD_1D_3D_4D_5D_7$	...	...	...	0.67	1.52
5868[e]	4822	6.6			...	0.13	...	1.32	3.25
5868B	4822	1.0[g]	8	$W_1W_2SmD_1D_2D_3D_4D_5$	19–55	0.06	0.06	0.77	1.45
5868C	4822	0.5[g]	5	$W_1W_2SmD_1D_2$	19–47	0.13	0.05	0.75	1.62
5868D	4822	0.5[g]	4	$W_1W_2SmD_1$	19–41	0.13	0.08	0.73	1.63

[a] Western softwood bleached kraft pulp.
[b] Difference between width of the web at the wire and the width of the paper at the reel based on width at the wire.
[c] Based on dimension at 30% R.H.
[d] Expander rolls located before the following; D—drier, W—wet press, and Sm—smoothing press. Subnumbers indicate position of roll or press, for example, D_1—first drier, W_1—first press.
[e] Reference run with expander rolls.
[f] Two expander rolls were used in series with a guide roll between to allow for more wrap on the expander rolls.
[g] An increase in overall width rather than a decrease.

Table III. Properties.. of WaterleaW1W2W2 Papersb Made with Expander Rolls in Various Locations in the Press and Drier Sections of the Experimental Paper Machine

Machine run no.	Reduction in cross machine expansion[c] (30% R.H. to wet), %	Weight 3000 sq. ft., lb.	Weight g./sq. m.	Density, g./cc.	Bursting strength, pts.	Tearing resistance Machine direction, g.	Tearing resistance Cross direction, g.	Tensile strength Machine direction, lb./in.	Tensile strength Cross direction, lb./in.	Folding endurance Machine direction, double folds	Folding endurance Cross direction, double folds
					Expander Rolls in Drier Section						
6073	...	81.5	132.5	0.79	97.4	188.0	232.0	75.0	25.0	...	...
6073A	15.3	81.3	132.2	0.79	99.9	192.8	237.6	75.3	26.9	...	...
6073B	18.3	76.6	124.5	0.79	95.0	184.8	208.0	66.8	26.9	...	...
6073C	19.9	77.5	126.0	0.79	94.7	188.8	212.8	67.1	28.4	...	...
6073D	25.2	77.9	126.6	0.78	94.7	184.0	214.4	69.8	28.4	...	...
6073E	24.5	78.1	127.0	0.77	84.7	191.2	220.0	66.0	29.8	...	...
6073F	29.1	81.0	131.6	0.78	89.4	201.6	228.8	65.6	29.5	...	...
6073G	26.1	79.5	129.3	0.76	84.5	190.4	229.6	58.9	28.7	...	...
5784	...	77.9	126.6	0.63	42.6	167.1	230.0	49.6	19.4	...	...
5784F	43.2	77.6	124.5	0.58	38.4	156.0	176.4	41.0	21.6	...	...
5803	...	77.8	126.5	0.73	52.5	139.6	164.0	58.2	29.0	333	130
5803A	34.8	76.9	125.1	0.70	54.4	134.4	162.0	52.6	29.1	276	125
5803B	15.8	73.4	119.4	0.72	56.0	126.0	149.6	57.8	26.9	325	98
					Expander Rolls in Press Section						
5868	...	79.9	130.0	0.74	63.0	204.0	210.4	61.2	28.3	1061	748
5868A	37.6	78.7	128.0	0.71	59.3	179.2	199.2	57.1	26.1	1089	881
5868E	37.6	85.8	139.5	0.72	64.1	241.6	250.4	57.8	35.8	1371	1178
					Expander Rolls in Press and Drier Sections						
5868	...	79.9	130.0	0.74	63.0	204.0	210.4	61.2	28.3	1061	748
5868B	55.4	79.3	129.0	0.69	55.8	196.0	221.6	50.7	29.5	1048	600
5868C	50.2	74.4	121.0	0.67	53.1	190.4	200.0	51.5	26.1	1292	801
5868D	50.1	79.9	130.0	0.68	49.6	196.8	221.6	51.1	27.9	1080	817

[a] Strength, weight, and density determinations were made in accordance with TAPPI Standard Methods.
[b] Pulp furnish consisted of 100% western softwood bleached kraft pulps.
[c] $\frac{\text{Movement of the control} - \text{Movement of the paper made with expander rolls}}{\text{Movement of the control}} \times 100.$

Table IV. Propertiesa of Punchcard Stock, Bond, and Offset Papers Made with Expander Rolls Located in Various Places in the Press and Drier Sections of the Experimental Paper Machine

Machine run no.	Expander rolls No.	Expander rolls Location[d]	Cross machine shrinkage[b]	Dimensional movement[c] (cross direction) 30 to 90% R.H., %	Dimensional movement[c] (cross direction) 30% R.H. to wet, %	Weight Ream,[e] lb.	Weight g./sq.m.	Density, g./cc.	Bursting strength, pts.	Tearing resistance Machine direction, g.	Tearing resistance Cross direction, g.	Tensile strength Machine direction, lb./in.	Tensile strength Cross direction, lb./in.
Puncheard Stock—80% Southern Pine Bleached Kraft and 20% Sweetgum Bleached Kraft With 0.5% Rosin Size													
5901[f]	..	.....	5.2	1.18	3.55	91.0	149	0.87	46.4	154.5	178.8	51.1	21.4
5901A	8	$W_1W_2SmD_1D_2D_3D_4D_5$	0	0.87	2.07	86.4	141	0.81	39.8	132.8	164.0	42.2	20.8
5901C	5	$W_1W_2SmD_1D_2$	1.0	0.98	2.28	86.7	141	0.82	39.4	139.6	155.2	42.9	21.2
Bond Paper—60% Oak-Maple NSSC, 20% Southern Pine Kraft, 20% Western Hemlock Sulfite With 8% Clay Filler and 1% Rosin Size													
5899[f]	..	.....	4.7	1.27	3.39	21.0	79.0	0.74	15.5	65.2	68.8	23.1	10.5
5899B	7	$W_1W_2SmD_2D_3D_5D_6$	1.7	0.92	2.37	19.8	74.4	0.71	13.4	62.4	67.2	21.1	10.0
5899G[f,g]	..	.....	5.7	1.22	3.32	21.1	79.2	0.78	33.2	56.0	70.0	38.8	15.0
5899F[g]	7	$W_1W_2SmD_1D_2D_3D_6$	1.6	1.02	2.35	20.2	75.8	0.75	37.3	50.8	64.0	40.3	18.1
Offset Book—50% Eastern Softwood Kraft, 50% Sweetgum Kraft Pulps With 20% Clay Filler, 3% Titanium, and 0.5% Rosin Size													
5824[f]	..	.....	5.2	1.48	3.70	46.4	68.6	0.76	12.6	39.6	49.2	17.5	8.1
5824A	6	$SmD_1D_2D_6D_7D_9$	3.7	1.58	3.28	48.8	72.3	0.75	12.1	41.0	47.2	19.8	9.3

[a] All tests except dimensional movement were made in accordance with TAPPI Standard Methods.
[b] Difference in the width of the web at the wire and the width of the paper at the reel based on the width at the wire.
[c] Based on dimension at 30% R.H.
[d] Expander rolls were located before the following: D—drier, W—wet press, and Sm—smoothing press. Subnumbers indicate position of roll or press, for example, D_1—first drier, W_1—first press.
[e] Ream size for punchcard (24 × 36—500); for bond paper (17 × 22—500); and for offset book (25 × 38—500).
[f] Reference run with no expander rolls.
[g] Paper surface sized at size press with a 10% mixture of an ethylated cornstarch.

provement was achieved with little or no change in the strength properties of the sheet.

Widening the sheet in the cross direction did not seem to have an appreciable effect on the machine direction movement. Therefore, the ratio of the cross to machine direction movement was decreased when the sheet was widened in the cross direction.

Expander Rolls in the Press Sections. Limited experiments were conducted to investigate the use of expander rolls in the wet presses. The sheet in these zones, particularly in the early press sections, is very vulnerable and care must be taken when expander rolls are used to prevent distortion. The tension due to the draw between these sections stretches the sheet in the machine direction. The waterleaf sheet, for example, was stretched about 3% from the wire to the driers. This tension, which normally causes a decrease in cross-machine width, reduced the sheet width about 1% before entering the driers.

Expander rolls were positioned ahead of each of three wet presses. In series 5868 (Table II), one expander roll was installed ahead of the first press, either one or two ahead of the second press, and one ahead of the smoothing press. These rolls increased the sheet width by 2.5% before the sheet entered the driers. The sheets at the reel were correspondingly wider than the control. Widening the sheet while wet with no side tension during drying gave the same improvement in dimensional stability in the cross-machine direction with fewer expander rolls than were required in the early part of the drying section.

Expander Rolls in Both Presses and Driers. The greatest improvement in dimensional stability was obtained with expander rolls in both press and drier sections.

In run 5868 B with eight rolls (Fig. 6) one ahead of each of the first two wet presses, the smoothing press, and each of the first five driers, the sheet at the reel was about as wide as the web laid down on the wire. In this run, the web had been widened prior to the driers by an amount equal to the shrinkage encountered in the drying. This sheet when exposed to the extreme moisture conditions was 55% more stable than the control. There was about a 12% loss in bursting strength and a 16% loss in machine-direction tensile, but the other strength properties did not seem to be affected (Table III).

Expander Rolls for Punchcard, Bond, and Offset Papers

A few runs have been made to demonstrate the feasibility of using expander rolls for stabilizing punchcard stock, bond,and offset papers in the cross-machine direction. These were made with mixtures of softwood and hardwood pulps. Rolls were used in both the press and drier sections. The results are presented in Table IV. A 32% improvement in the stability of punchcard stock was noted with a total of eight expander rolls positioned in the press and drier sections (machine run 5901 A). Eliminating three of the rolls in the drier section gave a slightly narrower sheet, and the improvement in the stability was accordingly less (machine run 5901 C). The cross-machine tensile strength did not change, but there was a slight loss in other strength properties.

Improvement in dimensional stability of bond papers was obtained with seven expander rolls arranged both in the press and drier sections. The improvement was apparent even after the paper, which had been stretched, was surface sized with a starch mixture. The reduction in swelling attained was 30% and this was achieved with little or no loss in strength properties.

Only one trial involving expander rolls has been conducted with an offset furnish containing 23% filler. One expander roll was used ahead of the smoothing press and five rolls were installed in the drier section. This arrangement gave a 12% reduction in dimension movement without a loss in strength.

CONCLUSIONS

Dimensional stability of paTappian be improved by stretching and restraining it during water removal. Pulp type and degree of processiR.H ad little effect on tg./sq.m nsional movement when shrinkage was cptsrolled.

Expander rolls can be used on the paper machine to widen paper webs and to improve the dimensional stability of papers in the cross-machine direction without appreciable loss in strength. They are most effective in stretching the web at high moisture content and can be used to partially offset shrinkage in the drier section.

Additional experiments are needed to improve further the dim tability in the cross-machine direction.

LITERATURE CITED

1. George, H. O., *Tappi 41 (1):* 31-33 (1958).
2. Nordman, Lars S., *Tappi* 41 (1): 23-30 (1958).
3. Baird, P. K., Seidl. R. J. and Fahey, D. J., "Effect of Phenolic Resins on the Physical Properties of Kraft Paper," U. S.Forest Products Laboratory Rpt. 1750 (1956).
4. Cohen, W. E., Stamm, A. J. and Fahey, D. J., *Tappi* 42 (12): 934-940 (1959).

RECEIVED Jan. 14, 1963. Presented at the 48th Annual Meeting of the Technical Association of the Pulp and Paper Industry, held in New York, N. Y., Feb. 17-21, 1963.