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SECOND REPORT ON MEASUREMENT OF RESIDUAL STRESSES IN LACING WIRES OF Y-100 EXPERIMENTAL STAGE 8 MAIN ROTOR DISC FOR RCN DESTROYER ESCORT VESSELS

by

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PHYSICAL METALLURGY DIVISION

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SUMMARY OF RESULTS

Stresses induced by fitting and brazing lacing wire and by fitting and rivetting shrouding, and total residual stresses, in the lacing wires of four segments of a Y-100 experimental Stage 8 main rotor disc were measured. Results indicated that maximum combined bending and axial stresses, induced by brazing the wire were approximately 27,000 psi tension and 35,000 psi compression, by fitting the shroud approximately 17,000 psi tension and 13,000 psi compression, and by rivetting the shroud approximately 32,000 psi tension and 24,000 psi compression. Maximum total residual stresses were approximately 30,000 psi tension and 20,000 psi compression. There was no conclusive evidence that varying brazing and rivetting sequences reduced total residual stresses.

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INTRODUCTION

The second phase of the investigation of residual stresses in lacing wires in an experimental Stage 8 rotor disc has been completed, and the results are presented in this report.

As noted in the introduction to the first report (Mines Branch Investigation Report IR 65-99, December 21, 1965), the disc was shipped to Toronto in July 1965 for brazing of the lacing wire in the remaining segments. The disc, with the brazing completed on four more segments, and the shrouding for these segments punched and loosely fitted, was returned to these Laboratories on November 22, 1965. After strain gauges had been mounted, a Canadian General Electric Company fitter, Mr. R. Ratsep, fitted and rivetted the shrouding, allowing time for strain measurements to be made after each blade was rivetted. Subsequently, all stresses in the wires were relieved, completing the measurements to be made at this time.

METHOD OF TEST

The system of segment and blade numbering followed in the first report (Mines Branch Investigation Report IR 65-99, December 21, 1965), has been continued, i.e.: segments are numbered in sequence from the lock-up position, in a clockwise direction when viewing the disc from the inlet side. Blades within each segment are numbered in sequence in a counter-clockwise direction. Details of the numbering system are indicated in Figure 1. Tests carried out on segments 1, 2, 3A, 3B, 4A and 4B are reported in Mines Branch Investigation Report IR 65-99, and the present report deals with tests on segments 6A, 6B, 7A and 7B. Segment 5 was not tested. When the disc was received from Toronto, lacing wire had been fitted in segment 5, but was not brazed, and no shrouding had been fitted.

Segments 6A and 6B were labelled "A" on the disc, and segments 7A and 7B were labelled "B".

In instructions to the manufacturer, file No. ROTO.6900-19, 6900-DDE/ME-3.2, dated August 31, 1965, para. (a) states that in two adjacent sections of lacing wire covering seven blades each, brazing was to be in sequence 1 to 7. Para. (b) states that in two adjacent sections of lacing wire covering seven blades each brazing was to be in sequence 1, 7, 4, 2, 6, 3, 5. However, in a letter from the Resident Naval Overseer, Toronto, to the Chief of Technical Services, file No. ROTO. 6900-DDE/ME-3.2, dated November 12, 1965, para. (2) states that "Two additional sections of 16 blades have been brazed and the shrouding loosely fitted and taped in place. The order of brazing of each 8 blade segment has been marked in black marking pencil on the blade roots." The brazing sequence, as marked on the blade roots, is given in Table 1, and it should be noted that this order does not conform with that given in the original instructions.

Para. 3 of the same letter states: "It will be noted that the shrouding on Section "A" has been marked in way of two of the blades. These two blades are not quite in line with their neighbours, resulting in the tenon clearances being all on one side of the shrouding tenon holes. The direction of the blade misalignment is marked with arrows on the shrouding...." The blades, so marked, were blade No. 2, segment 7B, misaligned toward the inlet side, and blade No. 3, segment 7A, misaligned toward the outlet side (see Figure 1).

Strain gauges, cement, waterproofing, and instrumentation were the same as employed in the previous tests, and described in Mines Branch Investigation Report IR 65-99. Gauges were mounted in pairs, as explained previously, but only in the radial disc direction. Pairs of gauges were installed between blades 1 and 2, 4 and 5, and 7 and 8 in all segments except 6A. Since there was a large amount of brazing material on the lacing wire between blades 4 and 5, segment 6A, gauges were mounted between blades 3 and 4 of this segment. Figure 2 is a photograph of a gauge pair installation, and Figure 3 shows the complete instrumentation.

When all gauges had been installed and checked for zero drift, Mr. R. Ratsep of the Canadian General Electric Company removed the shrouding. Zero readings were then taken. Following refitting of the shrouding, readings were taken on all gauges, compared with a temperature compensator individually, and compared with each other, in pairs. This method of reading was followed throughout the tests to permit computation of both axial stresses in the wire direction, and bending stresses in the plane of the disc. A value of 30×10^6 psi was assumed for the modulus of elasticity of the lacing wire material in reducing the gauge readings to stress values.

When the shrouding had been fitted, and readings obtained, rivetting was carried out by Mr. R. Ratsep, in the order indicated in Table 1 and Figure 1, for both segments and blade numbers. After each blade was rivetted, readings were taken on all gauges.

When rivetting and all readings had been completed, the lacing wire was cut through with a jewellers' saw, as close as possible to each pair of gauges. Cuts were made in sequence from the lower to higher numbered blades, starting at segment 7B, and readings were taken on all gauges after each cut was completed. Measurements of the gaps in all severed wires were made after each cut was made to estimate the movement of the wire as stresses were relieved.

Since the method of testing provided a measure of stresses induced in the wire by laying on the shroud, by rivetting, and by relieving all stresses, the stresses induced by installing and brazing the wires could be easily obtained. Thus, the total residual stresses could be broken down into components induced during each stage of assembly of the experimental disc, for the segments examined.

TEST RESULTS

All results are given below in Tables 1 to 19.

TABLE 1

Details of Segments, Experimental Disc

Segment No.	No. of Blades	Brazing Sequence	Rivetting Sequence
5	15	Lacing wire not brazed, shrouding not fitted	
6A	8	1, 8, 4, 6, 3, 5, 2, 7	4, 5, 3, 6, 2, 7, 1, 8
6B	8	1, 8, 4, 6, 3, 5, 2, 7	8, 7, 6, 5, 4, 3, 2, 1
7A	8	4, 5, 3, 6, 2, 7, 1, 8	4, 5, 3, 6, 2, 7, 1, 8
7B	8	4, 5, 3, 6, 2, 7, 1, 8	8, 7, 6, 5, 4, 3, 2, 1

TABLE 2

Stresses Induced in Segment 6A by Laying on Shroud, in psi

+ Tensile — A - Axial

- Compressive — B - Bending (x - convex toward shroud; (y - concave toward shroud

C - Combined, first value at outer radius

Stress	Blade Numbers		
	1-2	3-4	7-8
A	- 600	+ 1500	- 2400
B	x 300	y 1200	y 2700
C	- 300 - 900	+ 300 + 2700	- 5100 + 300

TABLE 3

Stresses Induced in Segment 6B by Laying on Shroud, in psi

+ Tensile

- Compressive

A - Axial

B - Bending (x - convex toward shroud
(y - concave toward shroud

C - Combined, first value at outer radius

Stress	Blade Numbers		
	1-2	4-5	7-8
A	- 5400	- 3900	- 900
B	y 7700	y 600	x 300
C	-13100 + 2300	- 4500 - 3300	- 600 - 1200

TABLE 4

Stresses Induced in Segment 7A by Laying on Shroud, in psi

+ Tensile

- Compressive

A - Axial

B - Bending (x - convex toward shroud
(y - concave toward shroud

C - Combined, first value at outer radius

Stress	Blade Numbers		
	1-2	4-5	7-8
A	+ 3600	+ 600	0
B	x 7800	x 5700	x 3500
C	+ 11400 - 4200	+ 6300 - 5100	+ 3500 - 3500

TABLE 5

Stresses Induced in Segment 7B by Laying on Shroud, in psi

+ Tensile

- Compressive

A - Axial

B - Bending (x - convex toward shroud
(y - concave toward shroud

C - Combined, first value at outer radius

Stress	Blade Numbers		
	1-2	4-5	7-8
A	+ 10500	+ 3500	- 1200
B	x 6300	y 6500	y 4700
C	+ 16800 + 4200	- 3000 + 10000	- 5900 + 3500

TABLE 6

Stresses Induced in Segment 6A during Rivetting of Segment 6A, in psi

+ Tensile — A - Axial

- Compressive — B - Bending (x - convex toward shroud; (y - concave toward shroud

C - Combined, first value at outer radius

Blade No. Rivetted, 6A	Stress	Blade Numbers 1-2	Blade Numbers 3-4	Blade Numbers 7-8
4	A	+ 1300	+ 600	- 200
	B	y 1500	y 1800	y 3000
	C	- 200	- 1200	- 3200
		+ 2800	+ 2400	+ 2800
5	A	+ 1300	+ 600	+ 1100
	B	y 1200	y 1800	y 4800
	C	+ 100	- 1200	- 3700
		+ 2500	+ 2400	+ 5900
3	A	+ 1500	+ 3000	+ 1100
	B	x 2100	y 900	y 2700
	C	+ 3600	+ 2100	- 1600
		- 600	+ 3900	+ 3800
6	A	+ 900	+ 1100	+ 900
	B	x 1500	y 2100	y 4200
	C	+ 2400	- 1000	- 3300
		- 600	+ 3200	+ 5100
2	A	+ 1400	+ 5300	+ 500
	B	x 600	y 6500	y 7800
	C	+ 2000	- 1200	- 7300
		+ 800	+ 11800	+ 8300
7	A	+ 1200	+ 3900	+ 15300
	B	y 300	y 7800	y 1500
	C	+ 900	- 3900	+ 13800
		+ 1500	+ 11700	+ 16800
1	A	+ 7200	+ 5400	+ 15300
	B	x 31500	y 11700	y 5400
	C	+ 38700	- 6300	+ 9900
		- 24300	+ 17100	+ 20700
8	A	+ 7200	+ 5400	+ 17000
	B	x 31500	y 11100	y 5400
	C	+ 38700	- 5700	+ 11600
		- 24300	+ 16500	+ 22400

TABLE 7

Stresses Induced in Segment 6B during Rivetting of Segment 6A, in psi

+ Tensile — A - Axial

- Compressive — B - Bending (x - convex toward shroud; (y - concave toward shroud

C - Combined, first value at outer radius

Blade No. Rivetted, 6A	Stress	Blade Numbers 1-2	4-5	7-8
4	A	+ 500	+ 500	+ 1200
	B	x 3200	x 4100	x 3000
	C	+ 3700	+ 4600	+ 4200
		- 2700	- 3600	- 1800
5	A	+ 2100	+ 800	+ 1200
	B	x 3800	x 3900	x 2800
	C	+ 5900	+ 4700	+ 4000
		- 1700	- 3100	- 1600
3	A	+ 500	- 600	+ 300
	B	x 1700	x 2100	x 3000
	C	+ 2200	+ 1500	+ 3300
		- 1200	- 2700	- 2700
6	A	+ 500	0	+ 300
	B	x 1200	x 1200	x 2400
	C	+ 1700	+ 1200	+ 2700
		- 700	- 1200	- 2100
2	A	+ 800	+ 900	+ 900
	B	x 4800	x 5400	x 3900
	C	+ 5600	+ 6300	+ 4800
		- 4000	- 4500	- 3000
7	A	+ 800	+ 1100	+ 800
	B	x 4500	x 5000	x 3000
	C	+ 5300	+ 6100	+ 3800
		- 3700	- 3900	- 2200
1	A	+ 600	+ 2300	+ 1100
	B	x 8100	x 9700	x 4100
	C	+ 8700	+ 12000	+ 5200
		- 7500	- 7400	- 3000
8	A	+ 500	+ 2300	+ 1200
	B	x 8200	x 10100	x 4800
	C	+ 8700	+ 12400	+ 6000
		- 7700	- 7800	- 3600

TABLE 8

Stresses Induced in Segment 6A during Rivetting of Segment 6B, in psi

+ Tensile
- Compressive

A - Axial

B - Bending (x - convex toward shroud
(y - concave toward shroud

C - Combined, first value at outer radius

Blade No. Rivetted, 6B	Stress	Blade Numbers		
		1-2	3-4	7-8
8	A	+ 5400	+ 4500	+ 16800
	B	x 30000	y 12000	y 6300
	C	+ 35400	- 7500	+ 10500
		- 24600	+ 16500	+ 23100
7	A	+ 5600	+ 4800	+ 17000
	B	x 29600	y 12300	y 6800
	C	+ 35200	- 7500	+ 10200
		- 24000	+ 17100	+ 23800
6	A	+ 5700	+ 4800	+ 17000
	B	x 28700	y 13400	y 7700
	C	+ 34400	- 8600	+ 9300
		- 23000	+ 18200	+ 24700
5	A	+ 5700	+ 4700	+ 17100
	B	x 27900	y 14000	y 8100
	C	+ 33600	- 9300	+ 9000
		+ 22200	+ 18700	+ 25200
4	A	+ 6000	+ 4500	+ 17100
	B	x 27500	y 14400	y 8700
	C	+ 33500	- 9900	+ 8400
		- 21500	+ 18900	+ 25800
3	A	+ 6000	+ 4500	+ 17100
	B	x 27000	y 15000	y 9000
	C	+ 33000	- 10500	+ 8100
		- 21000	+ 19500	+ 26100
2	A	+ 6000	+ 4500	+ 17100
	B	x 26500	y 15500	y 9600
	C	+ 32500	- 11000	+ 7500
		- 20500	+ 20000	+ 26700
1	A	+ 6000	+ 4500	+ 17300
	B	x 26100	y 15900	y 10100
	C	+ 32100	- 11400	+ 7200
		+ 20100	+ 20400	+ 27400

TABLE 9

Stresses Induced in Segment 6B during Rivetting of Segment 6B, in psi

+ Tensile — A - Axial

- Compressive — B - Bending (x - convex toward shroud; (y - concave toward shroud)

C - Combined, first value at outer radius

Blade No. Rivetted, 6B	Stress	Blade Numbers 1-2	Blade Numbers 4-5	Blade Numbers 7-8
8	A	0	+ 1100	- 900
	B	x 9600	x 13400	x 1400
	C	+ 9600	+ 14500	+ 500
		- 9600	- 12300	- 2300
7	A	0	+ 900	+ 2100
	B	x 10300	x 14400	x 8200
	C	+ 10300	+ 15300	+ 10300
		- 10300	- 13500	- 6100
6	A	0	- 1500	+ 4500
	B	x 10300	x 13500	x 6000
	C	+ 10300	+ 12000	+ 10500
		- 10300	- 15000	- 1500
5	A	0	+ 2900	+ 5400
	B	x 12500	x 8100	x 4800
	C	+ 12500	+ 11000	+ 10200
		- 12500	- 5200	+ 600
4	A	- 300	+ 6500	+ 6000
	B	x 12900	x 8600	x 4100
	C	+ 12600	+ 15100	+ 10100
		- 13200	- 2100	+ 1900
3	A	+ 500	+ 7100	+ 6200
	B	x 12800	x 7400	x 3500
	C	+ 13300	+ 14500	+ 9700
		- 12300	- 300	+ 2700
2	A	+ 500	+ 8400	+ 6300
	B	x 4100	x 6000	x 3000
	C	+ 4600	+ 14400	+ 9300
		- 3600	+ 2400	+ 3300
1	A	+ 2100	+ 8400	+ 6500
	B	0	x 5700	x 2600
	C	+ 2100	+ 14100	+ 9100
		+ 2100	+ 2700	+ 3900

TABLE 10

Stresses Induced in Segment 7A during Rivetting of Segment 7A, in psi

+ Tensile — A - Axial

- Compressive — B - Bending (x - convex toward shroud; (y - concave toward shroud

C - Combined, first value at outer radius

Blade No. Rivetted, 7A	Stress	Blade Numbers		
		1-2	4-5	7-8
4	A	0	- 1200	0
	B	x 1400	y 6200	0
	C	+ 1400	- 7400	0
		- 1400	+ 5000	0
5	A	0	+ 3900	+ 300
	B	x 1500	y 7500	y 3300
	C	+ 1500	- 3600	- 3000
		- 1500	+ 11400	+ 3600
3	A	+ 1500	+ 3200	0
	B	x 2400	y 10100	y 4500
	C	+ 3900	- 6900	- 4500
		- 900	+ 13300	+ 4500
6	A	+ 1200	+ 1500	+ 300
	B	x 2300	y 10200	y 4500
	C	+ 3500	- 8700	- 4200
		- 1100	+ 11700	+ 4800
2	A	+ 3900	+ 800	+ 200
	B	x 2300	y 11000	y 5300
	C	+ 6200	- 10200	- 5100
		+ 1600	+ 11800	+ 5500
7	A	+ 3500	- 600	+ 1500
	B	x 2300	y 12300	y 13500
	C	+ 5800	- 12900	- 12000
		+ 1200	+ 11700	+ 15000
1	A	+ 9800	+ 1200	+ 1100
	B	x 16300	y 17200	y 18200
	C	+ 26100	- 16000	- 17100
		- 6500	+ 18400	+ 19300
8	A	+ 9800	+ 500	+ 4500
	B	x 15200	y 18500	y 20000
	C	+ 25000	- 18000	- 15500
		- 5400	+ 19000	+ 24500

TABLE 11

Stresses Induced in Segment 7B during Rivetting of Segment 7A, in psi

+ Tensile — A - Axial

- Compressive — B - Bending (x - convex toward shroud; (y - concave toward shroud

C - Combined, first value at outer radius

Blade No. Rivetted, 7A	Stress	Blade Numbers 1-2	4-5	7-8
4	A	- 900	- 800	0
	B	y 1800	y 500	0
	C	- 2700	- 1300	0
		+ 900	- 300	0
5	A	- 1100	- 800	+ 200
	B	y 1700	y 500	x 200
	C	- 2800	- 1300	+ 400
		+ 600	- 300	0
3	A	- 1700	- 900	0
	B	y 1500	x 1400	x 1700
	C	- 3200	+ 500	+ 1700
		- 200	- 2300	- 1700
6	A	- 1700	- 900	0
	B	y 1500	x 1500	x 1700
	C	- 3200	+ 600	+ 1700
		- 200	- 2400	- 1700
2	A	- 2000	- 900	+ 300
	B	y 1800	x 1500	x 2000
	C	- 3800	+ 600	+ 2300
		- 200	- 2400	- 1700
7	A	- 2100	- 900	+ 200
	B	y 2700	x 1100	x 1400
	C	- 4800	+ 200	+ 1600
		+ 600	- 2000	- 1200
1	A	- 3900	- 1100	+ 200
	B	y 2300	x 3200	x 1500
	C	- 6200	+ 2100	+ 1700
		- 1600	- 4300	- 1300
8	A	- 4200	- 900	+ 200
	B	y 3500	x 2700	x 800
	C	- 7700	+ 1800	+ 1000
		- 700	- 3600	- 600

TABLE 12

Stresses Induced in Segment 7A during Rivetting of Segment 7B, in psi

+ Tensile

- Compressive

A - Axial

B - Bending (x - convex toward shroud
(y - concave toward shroud

C - Combined, first value at outer radius

Blade No. Rivetted, 7B	Stress	Blade Numbers		
		1-2	4-5	7-8
8	A B C	+ 6900 x 15000 + 21900 - 8100	- 600 y 19200 - 19800 + 18600	+ 4100 y 20800 - 16700 + 24900
7	A B C	+ 7100 x 14700 + 21800 - 7600	- 800 y 19500 - 20300 + 18700	+ 4100 y 21300 - 17200 + 25400
6	A B C	+ 7100 x 14200 + 21300 - 7100	- 800 y 19900 - 20700 + 19100	+ 4100 y 21800 - 17700 + 25900
5	A B C	+ 7100 x 14100 + 21200 - 7000	- 600 y 20200 - 20800 + 19600	+ 4100 y 22100 - 18000 + 26200
4	A B C	+ 7200 x 13500 + 20700 - 6300	- 600 y 20900 - 21500 + 20300	+ 4100 y 22500 - 18400 + 26600
3	A B C	+ 7200 x 13200 + 20400 - 6000	- 600 y 21300 - 21900 + 20700	+ 3900 y 24200 - 20300 + 28100
2	A B C	+ 7200 x 12200 + 19400 - 5000	- 600 y 22500 - 23100 + 21900	+ 3900 y 24200 - 20300 + 28100
1	A B C	+ 7500 x 11600 + 19100 - 4100	- 500 y 23000 - 23500 + 22500	+ 4100 y 24600 - 20500 + 28700

TABLE 13

Stresses Induced in Segment 7B during Rivetting of Segment 7B, in psi

+ Tensile — A - Axial

- Compressive — B - Bending (x - convex toward shroud; (y - concave toward shroud

C - Combined, first value at outer radius

Blade No. Rivetted, 7B	Stress	Blade Numbers		
		1-2	4-5	7-8
8	A	- 4100	- 600	+ 5100
	B	y 900	x 4800	y 6600
	C	- 5000	+ 4200	- 1500
		- 3200	- 5400	+ 11700
7	A	- 4400	- 1100	+ 7800
	B	y 300	x 5600	y 7200
	C	- 4700	+ 4500	+ 600
		- 4100	- 6700	+ 15000
6	A	- 5100	- 2000	+ 8100
	B	y 900	x 7500	y 8300
	C	- 6000	+ 5500	- 200
		- 4200	- 9500	+ 16400
5	A	- 6300	- 4100	+ 7700
	B	y 2700	x 6800	y 8100
	C	- 9000	+ 2700	- 400
		- 3600	- 10900	+ 15800
4	A	- 8700	- 2900	+ 8000
	B	y 4200	x 6200	y 8700
	C	- 12900	+ 3300	- 700
		- 4500	- 9100	+ 16700
3	A	+ 2000	+ 900	+ 9000
	B	x 7500	x 1200	y 9800
	C	+ 9500	+ 2100	- 800
		- 5500	- 300	+ 18800
2	A	+ 7400	+ 3000	+ 9500
	B	x 10200	0	y 11100
	C	+ 17600	+ 3000	- 1600
		- 2800	+ 3000	+ 20600
1	A	+ 3800	+ 1800	+ 9500
	B	x 17700	y 300	y 11700
	C	+ 21500	+ 1500	- 2200
		- 13900	+ 2100	+ 21200

TABLE 14

Stresses Induced in Segments 7B and 7A during Cutting of Lacing Wire, in psi

+ Tensile
- Compressive

A - Axial

B - Bending (x - convex toward shroud; (y - concave toward shroud

C - Combined, first value at outer radius

Segment	Blade No. for Cut	Stress	Blade Numbers: Segment 7B 1-2	Segment 7B 4-5	Segment 7B 7-8	Segment 7A 1-2	Segment 7A 4-5	Segment 7A 7-8
7B	1-2	A	- 9600	- 3000	- 600	0	0	- 100
		B	x 5800	x 500	x 200	0	y 200	y 200
		C	- 3800	- 2500	- 400	0	- 200	- 300
			- 15400	- 3500	+ 800	0	+ 200	+ 100
	4-5	A		- 12900	- 2600	0	0	
		B		y 600	x 1400	0	y 200	y 200
		C		- 13500	- 1200	0	- 200	- 200
				- 12300	- 4000	0	+ 200	+ 200
	7-8	A			- 5700	+ 300	0	0
		B			y 13200	x 200	x 200	y 200
		C			- 18900	+ 500	+ 200	- 200
					+ 7500	+ 100	- 200	+ 200
7A	1-2	A				- 9500	- 3000	- 600
		B				x 9500	x 500	x 100
		C				0	- 2500	- 500
						- 19000	- 3500	- 700
	4-5	A					- 2600	- 500
		B					x 3500	x 100
		C					+ 900	- 400
							- 6100	- 600
	7-8	A						- 2000
		B						x 21300
		C						+ 19300
								- 23300

TABLE 15

Stresses Induced in Segments 6B and 6A during Cutting of Lacing Wire, in psi

+ Tensile
- Compressive

A - Axial

B - Bending (x - convex toward shroud; y - concave toward shroud)

C - Combined, first value at outer radius

Segment	Blade No. for Cut	Stress	Segment 6B: 1-2	Segment 6B: 4-5	Segment 6B: 7-8	Segment 6A: 1-2	Segment 6A: 3-4	Segment 6A: 7-8
6B	1-2	A	- 300	- 1200	0	0	+ 200	0
		B	y 13100	x 500	x 500	0	x 200	x 200
		C	- 13400	- 700	+ 500	0	+ 400	+ 200
			+ 12800	- 1700	- 500	0	0	- 200
	4-5	A		- 6900	- 1500	0	+ 200	0
		B		y 22800	x 1200	x 300	x 500	x 500
		C		- 29700	- 300	+ 300	+ 700	+ 500
				+ 15900	- 2700	- 300	- 300	- 500
	7-8	A			- 7200	0	+ 200	0
		B			x 2600	x 300	x 300	x 300
		C			- 4600	+ 300	+ 500	+ 300
					- 9800	- 300	- 100	- 300
6A	1-2	A				- 6300	- 3000	- 500
		B				y 7700	x 600	x 300
		C				- 14000	- 2400	- 200
						+ 1400	- 3600	- 800
	3-4	A					- 7400	- 1200
		B					x 19800	x 200
		C					+ 12400	- 1000
							- 27200	- 1400
	7-8	A						- 6000
		B						x 20500
		C						+ 14500
								- 26500

TABLE 16

Final Stresses in Segments 6A and 6B, in psi

+ Tensile — A - Axial

- Compressive — B - Bending (x - convex toward shroud; y - concave toward shroud)

C - Combined, first value at outer radius

Segment	Blade No.	Stress	Stress Induced By: Installing Wire and Brazing	Laying on Shroud	Rivetting	Residual Stress
6A	1-2	A	+ 900	- 600	+ 6000	+ 6300
		B	y 18700	x 300	x 26100	x 7700
		C	- 17800	- 300	+ 32100	+ 14000
			+ 19600	- 900	- 20100	- 1400
	3-4	A	+ 1400	+ 1500	+ 4500	+ 7400
		B	y 2700	y 1200	y 15900	y 19800
		C	- 1300	+ 300	- 11400	- 12400
			+ 4100	+ 2700	+ 20400	+ 27200
	7-8	A	- 8900	- 2400	+ 17300	+ 6000
		B	y 7700	y 2700	y 10100	y 20500
		C	- 16600	- 5100	+ 7200	- 14500
			- 1200	+ 300	+ 27400	+ 26500
6B	1-2	A	+ 3600	- 5400	+ 2100	+ 300
		B	x 20800	y 7700	0	x 13100
		C	+ 24400	- 13100	+ 2100	+ 13400
			- 17200	+ 2300	+ 2100	- 12800
	4-5	A	+ 2400	- 3900	+ 8400	+ 6900
		B	x 17700	y 600	x 5700	x 22800
		C	+ 20100	- 4500	+ 14100	+ 29700
			- 15300	- 3300	+ 2700	- 15900
	7-8	A	+ 1600	- 900	+ 6500	+ 7200
		B	y 5500	x 300	x 2600	y 2600
		C	- 3900	- 600	+ 9100	+ 4600
			+ 7100	- 1200	+ 3900	+ 9800

TABLE 17

Final Stresses in Segments 7A and 7B, in psi

+ Tensile
- Compressive

A - Axial

B - Bending (x - convex toward shroud
(y - concave toward shroud

C - Combined, first value at outer radius

Segment	Blade No.	Stress	Stress Induced By: Installing Wire and Brazing	Laying on Shroud	Rivetting	Residual Stress
7A	1-2	A	- 1600	+ 3600	+ 7500	+ 9500
		B	y 28900	x 7800	x 11600	y 9500
		C	- 30500	+ 11400	+ 19100	0
			+ 27300	- 4200	- 4100	+ 19000
	4-5	A	+ 2500	+ 600	- 500	+ 2600
		B	x 13800	x 5700	y 23000	y 3500
		C	+ 16300	+ 6300	- 23500	- 900
			- 11300	- 5100	+ 22500	+ 6100
	7-8	A	- 2100	0	+ 4100	+ 2000
		B	y 200	x 3500	y 24600	y 21300
		C	- 2300	+ 3500	- 20500	- 19300
			- 1900	- 3500	+ 28700	+ 23300
7B	1-2	A	- 4700	+ 10500	+ 3800	+ 9600
		B	y 29800	x 6300	x 17700	y 5800
		C	- 34500	+ 16800	+ 21500	+ 3800
			+ 25100	+ 4200	- 13900	+ 15400
	4-5	A	+ 7600	+ 3500	+ 1800	+ 12900
		B	x 7400	y 6500	y 300	x 600
		C	+ 15000	- 3000	+ 1500	+ 13500
			+ 200	+ 10000	+ 2100	+ 12300
	7-8	A	- 2600	- 1200	+ 9500	+ 5700
		B	x 29600	y 4700	y 11700	x 13200
		C	+ 27000	- 5900	- 2200	+ 18900
			- 32200	+ 3500	+ 21200	- 7500

TABLE 18

Gap in Wires after Cutting, in in. x 10^3

Segment	Blade No. for Cut	Blade Numbers											
		1-2	4-5	7-8	1-2	4-5	7-8	1-2	4-5	7-8	1-2	3-4	7-8
7B	1-2	+1											
	4-5	+1	+1										
	7-8	+1	+1	+2									
7A	1-2	+1	+1	+2	+3								
	4-5	+1	+1	-2	+3								
	7-8	+1	+1	+1	+1	-2	0						
6B	1-2							+1					
	4-5							0	+2				
	7-8							0	+1	+3			
6A	1-2							0	+1	+3	+2		
	3-4							0	+1	+2	+1	+1	
	7-8							-2	0	0	0	0	0

TABLE 19

Combined Residual Stresses in psi

+ Tensile
- Compressive First value at outer radius

Blade No.	Segment Number			
	6A	6B	7A	7B
1				
	+ 14000 - 1400	+ 13400 - 12800	0 + 19000	+ 3800 + 15400
2				
3				
	- 12400 + 27200			
4				
		+ 29700 - 15900	- 900 + 6100	+ 13500 + 12300
5				
6				
7				
	- 14500 + 26500	+ 4600 + 9800	- 19300 + 23300	+ 18900 - 7500
8				

DISCUSSION OF RESULTS

Tables 2 to 5 indicate that maximum axial and radial bending stresses of the order of 10,000 psi may be induced by laying on the shrouding, after the wires have been brazed. The highest stresses recorded were between blades 1 and 2 of segments 6B, 7A and 7B. Because of the misaligned blades in segments 7A and 7B, these stresses would be expected to be high, but it would appear that normally aligned blades, as in segment 6B, may result in equally high induced stresses. The reason for the relatively low stresses in segment 6A is not apparent.

Tables 6 and 10 suggest that when rivetting is started on a segment, stresses in excess of about 10,000 psi are seldom induced until the last few blades are rivetted, where the rivetting order is from the centre toward each end. Tables 7 and 11 indicate that stresses induced in the segment adjacent to the one being rivetted, but connected to it by the shrouding, are generally very low, although all stations in segment 6B showed a marked increase in stress (about 2 to 5 times) when blades 2 and 1 (nearest section 6B) were rivetted.

From Tables 8 and 12, it is seen that stresses in a segment already rivetted, do not change significantly when the adjacent segment is rivetted. It is interesting to note, however, that in both cases, bending stresses at corresponding stations are in the same direction, and that in all cases bending stresses change in a direction to make the wire less convex toward the shroud, while axial stresses remain essentially unchanged.

Tables 9 and 13 show that when the last segment covered by a length of shrouding is rivetted, in sequence from one end to the other, the bending stresses in corresponding stations are not in the same direction, and the direction of change is not uniform. Axial stresses show significant changes in both magnitude and direction.

Examination of Tables 10 to 13 suggests that misalignment of blade 3 in segment 7A, and blade 2 in segment 7B, did not significantly affect the measured stresses induced during the rivetting operation.

From Tables 14 and 15, it is seen that relieving stresses at one end of a segment affects stress distribution throughout the segment, and, to a measurable extent, in the adjoining segment. This effect is comparable to that observed in segments 2, 3A, 3B, 4A and 4B, (see Tables 3 to 7, Mines Branch Investigation Report IR 65-99), and the stress magnitudes are of the same order. It is noteworthy that both axial and bending stress directions for all segments tested were, in nearly every case, in the same direction. When comparing Tables 14 and 15 with results in Mines Branch Investigation Report IR 65-99, it is important to note that induced stresses are given in the former, and residual stresses in the latter, so that the signs for one set of results must be reversed.

Referring to Tables 16 and 17, it is seen that stresses induced by installing and brazing the wires are, in general, somewhat higher when the brazing order is from the centre toward the ends, rather than from the ends to the centre and toward the ends. Although the highest stresses, both axial and bending, are, in most cases, highest at the ends of the segments, there appears to be no systematic pattern to stress distribution. However, the fact that maximum bending and combined stresses in segments 6A and 6B are about 30% lower than those in segments 7A and 7B would suggest that brazing sequence is of some significance.

Stresses induced by laying on the shroud are nearly all higher for segments 7A and 7B, and in these sections again, the maximum stresses are 20% or more greater than those in segments 6A and 6B. However, the difference here could be attributed to variations in punching the shroud, as well as to the order of brazing. Combined stresses are, with few exceptions, quite low compared to stresses induced during brazing, for all segments. Highest stresses were recorded between blades 1 and 2 for all segments except 6A. Stresses between blades 1 and 2 of segments 7A and 7B, and between blades 4 and 5 of segment 7A, would be expected to show a marked increase, if the misaligned blades were responsible for high stresses. However, there appears to be little evidence of this.

Rivetting stresses were generally quite high, and were of the same order of magnitude as the brazing stresses. Maximum stresses for segments 7A and 7B were between 6% and 40% lower than those for segments 6A and 6B, which tends to offset the advantage gained in the brazing sequence used in segments 6A and 6B. The fact that rivetting stresses are generally somewhat lower for segments 6B and 7B, compared respectively with those for segments 6A and 7A, would suggest that a rivetting sequence from one end to the other may have some advantage over a sequence from the centre toward each end. It should be noted that segments 6A and 7A were completely rivetted before segments 6B and 7B were started, which may have had some effect on stress distribution.

Residual stresses, which are simply the stresses induced by cutting the lacing wire, but with reversed signs, represent the total stresses induced by installing and brazing the wire, laying on the shroud, and rivetting. Maximum residual axial stresses in segments 6A and 6B are about 40% lower than those in segments 7A and 7B, but maximum bending and combined stresses in segments 7A and 7B are lower, by 6% and 20%, respectively, than those in segments 6A and 6B. Comparing residual stresses in 6A and 7A with those in 6B and 7B, it is seen that all maximum stresses in the A segments are between 6% and 25% lower than those in the B segments. Thus, it would appear that advantages apparently gained by one brazing or rivetting sequence, over another, are lost when the entire assembly is completed.

The measured gaps in the severed wires, as given in Table 18, are qualitatively what would be expected from the stress measurements, and are similar to, though in some cases smaller than, gaps measured in the first segments tested.

Examination of combined residual stresses, as given in Table 19, reveals that maximum stress in segment 7B is about 20% lower than in the other segments, and that the highest stress in segments 7A and 7B is about 14% lower than that in segments 6A and 6B. This would suggest that the brazing order used for segments 7A and 7B would be preferred, even though this order produced the highest brazing stresses. However, since stresses induced by fitting and rivetting the shroud are not exclusively in a direction that tend to reduce the total residual stresses, this preference cannot be stated conclusively, particularly since it is on the basis of only one test. Comparing these results with those for segments 2 to 4B inclusive, given in the first report (Table 14), it is seen that combined residual stresses are of the same order.

CONCLUSION

Measurement of stresses in the axial direction of the lacing wire, induced by fitting and brazing the lacing wire, and by fitting and rivetting the shrouding, indicates that somewhat lower stresses are induced by brazing from the ends to the centre, then toward the ends, rather than from the centre towards the ends, and that rivetting stresses are slightly lower for a sequence from one end to the other, rather than from the centre toward the ends. However, there is little evidence that these stresses will invariably combine in such a manner that the lowest possible total residual stress will result. There was no conclusive evidence that two misaligned blades produced high residual stresses.

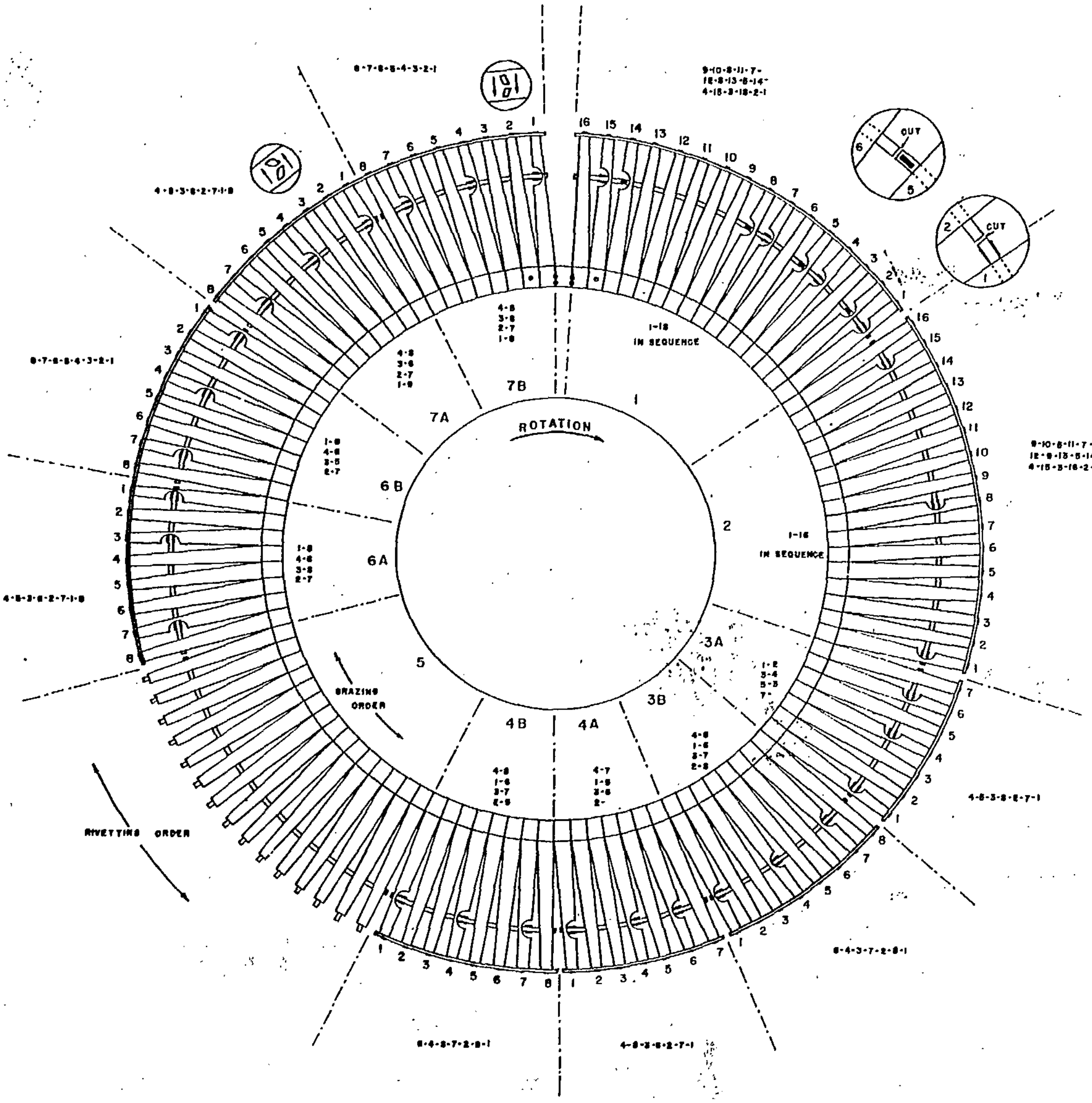

Figure 1. Numbering system for segments and blades, brazing and rivetting sequences, and indication of misaligned blades.

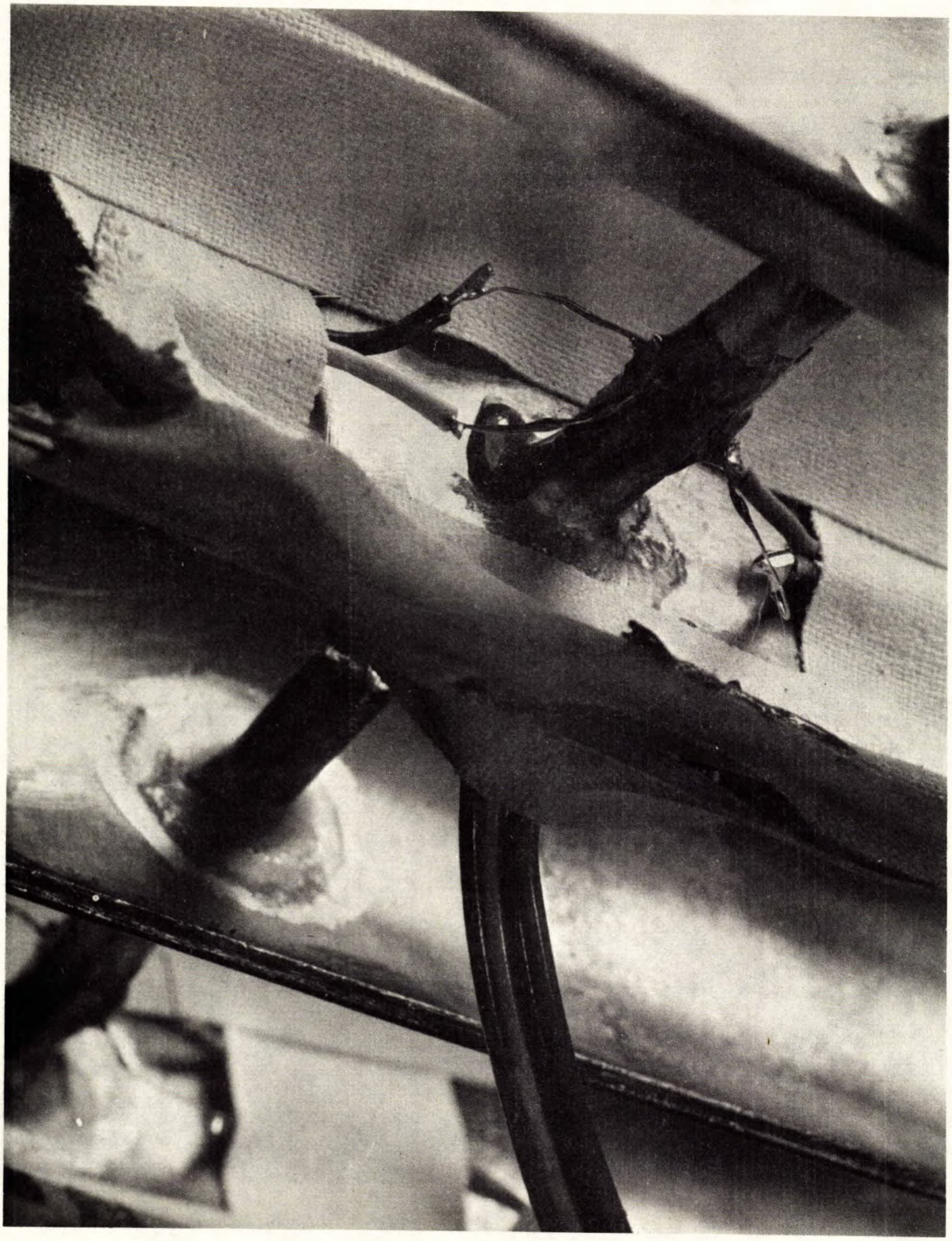

Figure 2. Close-up of a gauge pair installation.

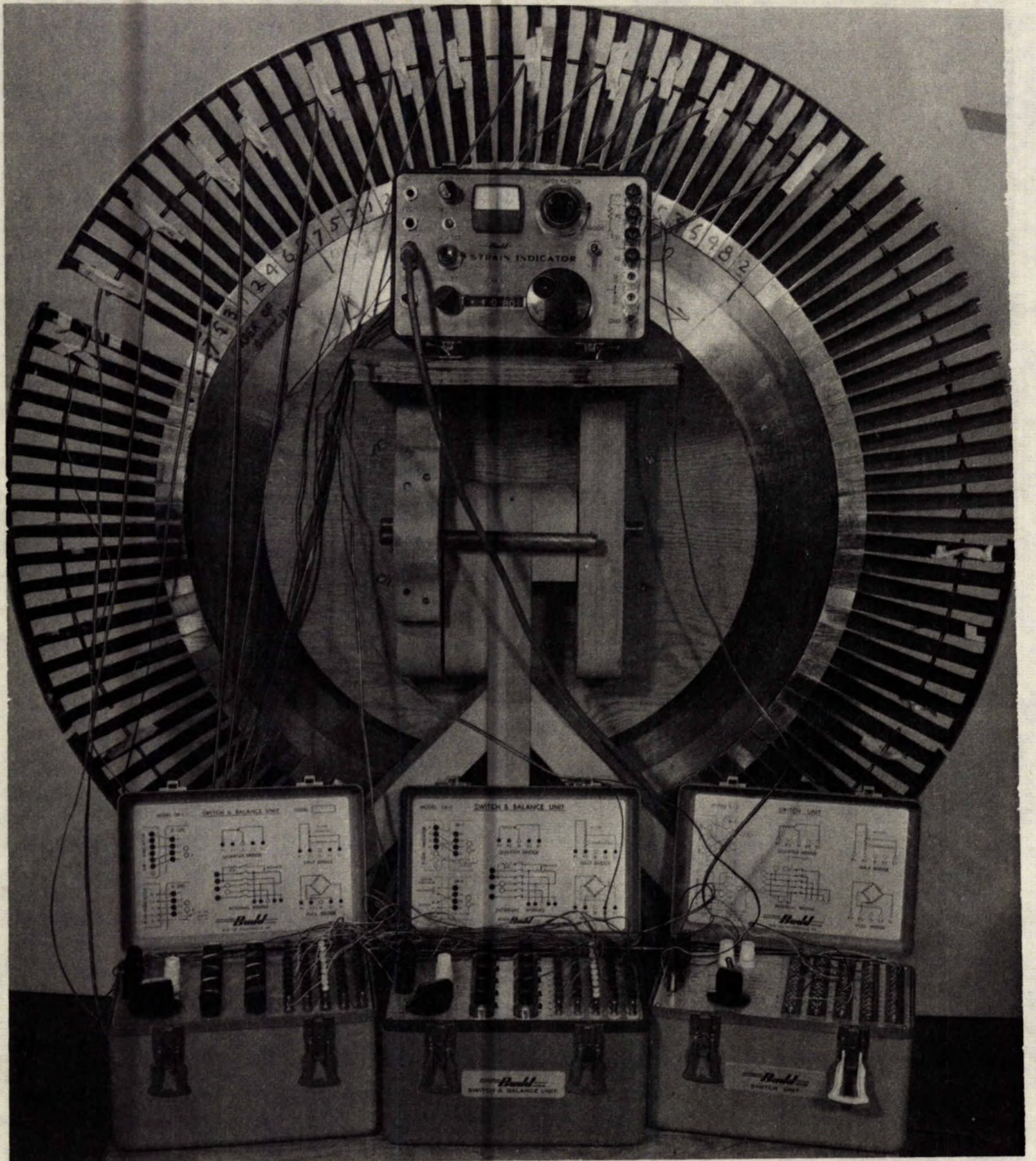

Figure 3. Complete instrumentation.