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OTTAWA August 1st, 1944.

R E P O R T

of the

ORE DRESSING AND METALLURGICAL LABORATORIES.

Investigation No. 1692.

The Measurement of Stresses in a New Design
of Steel Belleville Spring for 9.2-Inch
Coast Defense Gun.

(Copy No. 10.)

Bureau of Mines
Division of Metallic
Minerals

Physical Metallurgy
Research Laboratories

CANADA

DEPARTMENT
OF
MINES AND RESOURCES

Mines and Geology Branch

OTTAWA August 1st, 1944.

REPORT

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ORE DRESSING AND METALLURGICAL LABORATORIES.

Investigation No. 1692.

The Measurement of Stresses in a New Design
of Steel Belleville Spring for 9.2-Inch
Coast Defense Gun.

Purpose of Investigation:

On June 27th, 1944, the Division of Metallurgy of the Army Engineering Design Branch, Department of Munitions and Supply, Ottawa, Ontario, submitted Requisition No. 651 (A.E.D.B. Lot No. 544, Report No. 13, Test No. 64) requesting these Laboratories to make and test a Belleville spring designed by Mr. Carleton Craig of the Army Engineering Design Branch.

On June 6th, P.M. Lab. Report No. 7197, covering a test of a Belleville spring taken from service, had been issued. It was found that the service spring gave an unequal stress distribution on the top surface and it was desired to design a spring with an equal stress distribution on both the top and bottom. The drawing of the old spring specifies that under a

(Purpose of Investigation, cont'd) -

proof load of 37,600 pounds the spring shall deflect 0.08 inch.

Although the calculations were made for a spring tapered equally at both top and bottom, the springs tested were made with a flat top and the bottom only was tapered. Figure 1 (see Page 5) is a sketch of the new spring and the positions of the SR-4 electrical strain gauges are shown thereon.

Experimental Work:

Two springs were machined from 1½-inch armour plate (a deep-hardening steel). The springs were oil-quenched and drawn to 40 Rockwell 'C'. A yield strength of about 170,000 p.s.i. would be expected with this hardness. The bottom surface of each spring was lapped in order to provide perfectly flat mating surfaces.

1. - Deflection Measurements -

Two plugs were machined so that they would fit into the hole to about ¼ inch and overlap about the same amount. One spring rested flat side down on this plug. The other spring was placed on this spring and the other plug was placed in the hole. The unit was now placed in a 100-ton Amsler Universal testing machine and loaded in the sequence shown in Table 12. The deflections were noted by means of a dial gauge, for each increment of load. The reason for the dial gauge not returning to its zero reading was that there was some permanent deformation of the plugs.

2. - Stress Measurements -

SR-4 electrical strain gauges were then cemented to one of the springs in the positions shown in Figure 1. The manner in which the gauges were affixed is described in Appendix I (see Page 18).

(Continued on next page)

(Experimental Work, cont'd) -

The springs were positioned as in the deflection test. The unit was then placed in the Amsler tensile machine and loaded in the sequence shown in Tables 1 to 10 inclusive.

The strain value for each gauge was recorded for every load by means of an SR-4 strain indicator. Values of strain and stress are given in Tables 1 to 10 inclusive.

No correction for gauge factor was necessary since it was set on the recording instrument. However, the reference switch values for the instrument were corrected by multiplying them by $\frac{2.00}{\text{gauge factor}}$, which in this case was $\frac{2.00}{1.92} = 1.04$. Table 11 lists the corrected reference switch values.

No correction for gauge resistance was made, since the value was considered to be negligible.

In calculating values of stress, the strain was multiplied by 30,000,000 (the modulus of elasticity of steel). The true value is not known but the one used is approximately correct.

CONCLUSIONS:

1. On the flat surface the tangential stresses are compressive, increasing from the outside to the centre for a given load. The radial stresses are tensile and fairly low.

2. On the tapered surface the tangential stresses are tensile and are fairly uniform all over. The radial stresses are compressive but relatively low.

3. This spring was originally designed to taper at both the top and bottom. Such a design should give a uniform stress at the top and bottom of the spring. It may be seen, however, that the flat top causes extremely high stresses near

(Conclusions, cont'd) -

the centre hole where no doubt the elastic limit has been exceeded when loaded with 40,000 pounds.

4. In view of the fact that the tapered portion of the spring shows uniform stresses, it is thought that if both top and bottom were tapered the stresses would be uniform all over the spring.

5. This spring was too stiff and did not give the desired deflection, as may be seen from Table 12.

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(Figure 1, Tables 1 to 12,
and Appendix I now follow,
on Pages 5 to 18 inclusive.)

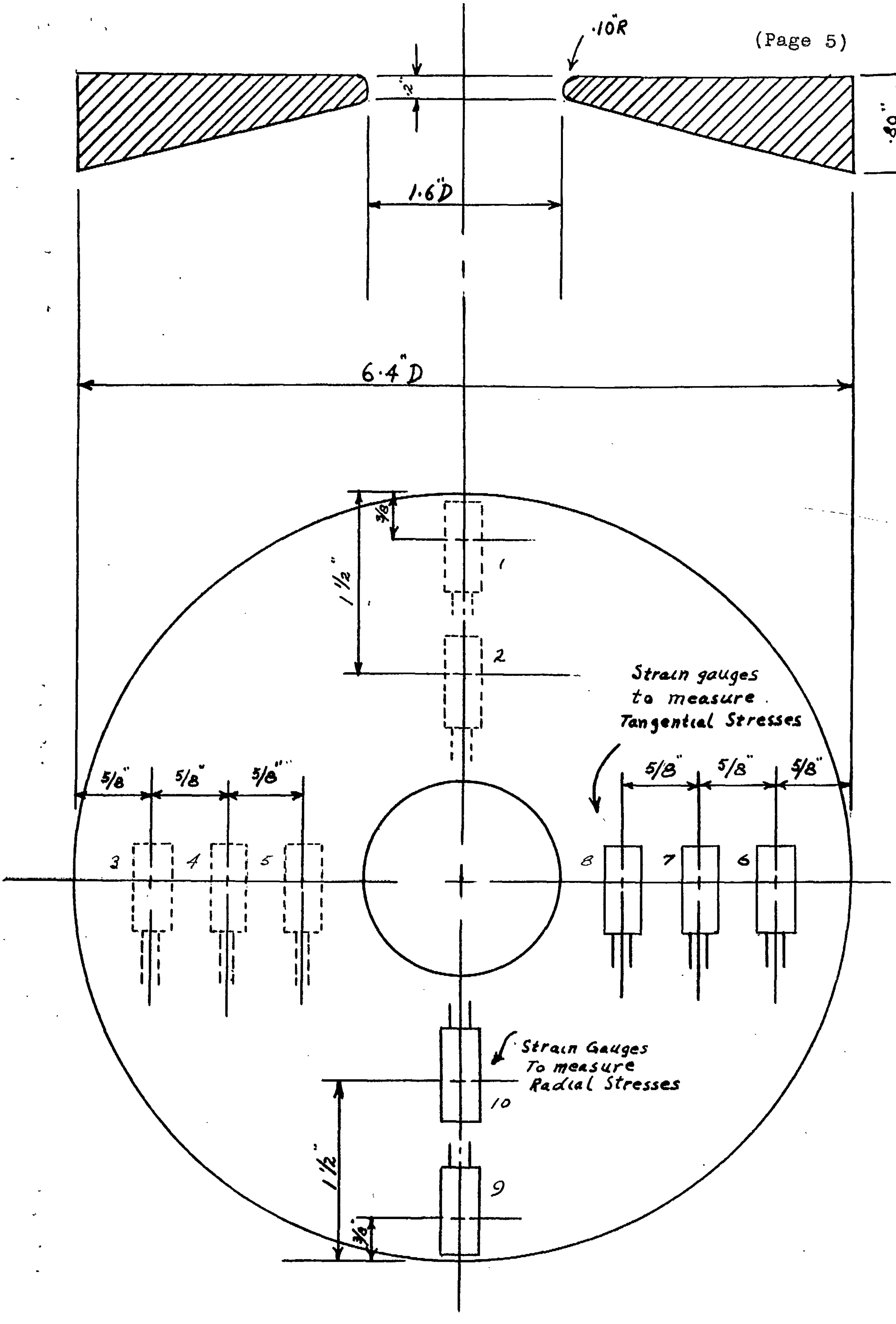

FIGURE 1. - NEW DESIGN OF STEEL BELLEVILLE SPRING FOR COAST DEFENSE GUN MOUNTING

(Note: This drawing should be used in conjunction with Tables 1 to 10, inclusive.)

TABLE NO. 1 - GAUGE NO. 1.

Sequence of Loading	Load, pounds	Reference Switch Position	Dial Reading	Corrected Ref. Switch Values	Change in Dial Readings	Strain, micro in. per in.	Total Accumulated Strain, micro in. per in.	Stress, lb./sq.in.
1	0	8	675	-	0	0	0	0
2	5,000	7	1553	-1040	+878	-162	-162	- 4,860
3	10,000	7	1361	-	-192	-192	-354	-10,620
4	15,000	7	1161	-	-200	-200	-554	-16,620
5	20,000	7	961	-	-200	-200	-754	-22,620
6	25,000	7	762	-	-199	-199	-953	-28,590
7	30,000	6	1600	-1045	+838	-207	-1160	-34,800
8	35,000	6	1392	-	-208	-208	-1368	-41,040
9	40,000	6	1185	-	-207	-207	-1575	-47,250
10	0	8	675	-	-	-	-	-
3A	5,000	7	1553	-	-	-	-	-
5A	5,000	7	1553	-	-	-	-	-
7A	5,000	7	1553	-	-	-	-	-
8A	5,000	7	1550	-	-	-	-	-
9A	5,000	7	1550	-	-	-	-	-

TABLE NO. 2 - GAUGE NO. 2.

Sequence of Loading	Load, pounds	Reference Switch Position	Dial Reading	Corrected Ref. Switch Values	Change in Dial Readings	Strain, micro in. per in.	Total Accumulated Strain, micro in. per in.	Stress, lb./sq.in.
1	0	7	695	-	0	0	0	0
2	5,000	7	381	-	-314	-314	-314	- 9,420
3	10,000	6	1090	-1045	+709	-336	-650	-19,500
4	15,000	6	762	-	-328	-328	-978	-29,240
5	20,000	5	1456	-1020	+694	-326	-1304	-39,120
6	25,000	5	1136	-	-320	-320	-1624	-48,720
7	30,000	4	1845	-1031	+709	-322	-1946	-58,380
8	35,000	4	1518	-	-327	-327	-2273	-68,190
9	40,000	4	1185	-	-333	-333	-2606	-78,180
10	0	7	709	-	-	-	-	-
3A	5,000	7	372	-	-	-	-	-
5A	5,000	7	380	-	-	-	-	-
7A	5,000	7	380	-	-	-	-	-
8A	5,000	7	385	-	-	-	-	-
9A	5,000	7	391	-	-	-	-	-

TABLE NO. 3 - GAUGE NO. 3.

Sequence of Loading	Load, pounds	Reference Switch Position	Dial Reading	Corrected Ref. Switch Values	Change in Dial Rea dings	Strain, micro in. per in.	Total Accumulated Strain, micro in. per in.	Stress, lb./sq.in.
1	0	7	1259	-	0	0	0	0
2	5,000	8	645	+1040	-614	+426	+426	+12,780
3	10,000	8	1130	-	+485	+485	+911	+27,330
4	15,000	8	1618	-	+488	+488	+1399	+41,970
5	20,000	9	1105	+1008	-513	+495	+1894	+56,820
6	25,000	10	600	+1014	-505	+509	+2403	+72,090
7	30,000	10	1101	-	+501	+501	+2904	+87,120
8	35,000	10	1608	-	+507	+507	+3421	+102,630
9	40,000	-	-	-	-	+507*	+3928*	+117,840*
10	0	7	1242	-	-	-	-	-
3A	5,000	8	648	-	-	-	-	-
5A	5,000	8	645	-	-	-	-	-
7A	5,000	8	630	-	-	-	-	-
8A	5,000	8	625	-	-	-	-	-
9A	5,000	8	625	-	-	-	-	-

* Estimated.

TABLE NO. 4 - GAUGE NO. 4.

Sequence of Loading	Load, pounds	Reference Switch Position	Dial Reading	Corrected Ref. Switch Values	Change in Dial Readings	Strain, micro in. per in.	Total Accumulated Strain, micro in. per in.	Stress, lb./sq.in.
1	0	8	1191	-	0	0	0	0
2	5,000	9	595	+1008	-596	+412	+412	+12,360
3	10,000	9	1050	-	+455	+455	+867	+26,010
4	15,000	9	1522	-	+472	+472	+1339	+40,170
5	20,000	10	990	+1014	-532	+482	+1821	+54,630
6	25,000	10	1465	-	+475	+475	+2296	-67,880
7	30,000	10	1951	-	+486	+486	+2782	+83,460
8	35,000	-	-	-	-	+490*	+3272*	+98,160*
9	40,000	-	-	-	-	+490*	+3762*	+112,860*
10	0	8	1178	-	-	-	-	-
3A	5,000	9	600	-	-	-	-	-
5A	5,000	9	595	-	-	-	-	-
7A	5,000	9	580	-	-	-	-	-
8A	5,000	9	574	-	-	-	-	-
9A	5,000	9	580	-	-	-	-	-

* Estimated.

TABLE NO. 5 - GAUGE NO. 5.

Sequence of Loading	Load, pounds	Reference Switch Position	Dial Reading	Corrected Ref. Switch Values	Change in Dial Readings	Strain, micro in. per in.	Total Accumulated Strain, micro in. per in.	Stress, lb./sq.in.
1	0	8	921	-	0	0	0	0
2	5,000	8	1259	-	+338	+338	+338	+10,140
3	10,000	8	1670	-	+411	+411	+749	+22,470
4	15,000	9	1095	+1008	-575	+433	+1182	+34,460
5	20,000	9	1530	-	+435	+435	+1617	+48,510
6	25,000	10	971	+1014	-559	+455	+2072	+62,160
7	30,000	10	1431	-	+460	+460	+2532	+75,960
8	35,000	10	1898	-	+467	+467	+2999	+89,970
9	40,000	-	-	-	-	+470*	+3469*	+104,070*
10	0	8	911	-	-	-	-	-
3A	5,000	8	1258	-	-	-	-	-
5A	5,000	8	1259	-	-	-	-	-
7A	5,000	8	1245	-	-	-	-	-
8A	5,000	8	1245	-	-	-	-	-
9A	5,000	8	1245	-	-	-	-	-

* Estimated.

TABLE NO. 6 - GAUGE NO. 6.

Sequence of Loading	Load, pounds	Reference Switch Position	Dial Reading	Corrected Ref. Switch Values	Change in Dial Readings	Strain, micro in. per in.	Total Accumulated Strain, micro in. per in.	Stress, lb./sq.in.
1	0	7	859	-	0	0	0	0
2	5,000	7	575	-	-284	-284	-284	-8,520
3	10,000	6	1312	-1045	+737	-308	-592	-17,760
4	15,000	6	1005	-	-307	-307	-899	-26,970
5	20,000	5	1708	-1020	+703	-317	-1216	-36,480
6	25,000	5	1385	-	-323	-323	-1539	-46,170
7	30,000	5	1053	-	-332	-332	-1871	-56,130
8	35,000	5	712	-	-345	-345	-2216	-66,480
9	40,000	4	1395	-1031	+683	-348	-2564	-76,920
10	0	7	870	-	-	-	-	-
3A	5,000	7	572	-	-	-	-	-
5A	5,000	7	575	-	-	-	-	-
7A	5,000	7	581	-	-	-	-	-
8A	5,000	7	581	-	-	-	-	-
9A	5,000	7	582	-	-	-	-	-

TABLE NO. 7 - GAUGE NO. 7.

Sequence of Loading	Load, pounds	Reference Switch Position	Dial Reading	Corrected Ref. Switch Values	Change in Dial Readings	Strain, micro in. per in	Total Accumu-lated Strain, micro in. per in.	Stress, lb./sq. in.
1	0	7	1044	-	0	0	0	0
2	5,000	7	625	-	-419	-419	-419	-12,570
3	10,000	6	1222	-1045	+597	-448	-867	-26,010
4	15,000	6	774	-	-448	-448	-1315	-39,450
5	20,000	5	1332	-1020	+558	-462	-1777	-53,310
6	25,000	5	878	-	-454	-454	-2231	-66,930
7	30,000	5	420	-	-458	-458	-2689	-80,670
8	35,000	4	918	-1031	+498	-533	-3222	-96,660
9	40,000	4	490	-	-428	-428	-3650	-109,500
10	0	7	1085	-	-	-	-	-
3A	5,000	7	621	-	-	-	-	-
5A	5,000	7	635	-	-	-	-	-
7A	5,000	7	650	-	-	-	-	-
8A	5,000	7	660	-	-	-	-	-
9A	5,000	7	662	-	-	-	--	-

TABLE NO. 8 - GAUGE NO. 8.

Sequence of Loading	Load, pounds	Reference Switch Position	Dial Reading	Corrected Ref. Switch Values	Change in Dial Readings	Strain, micro in. per in.	Total Accumulated Strain, micro in. per in.	Stress, lb./sq. in.
1	0	8	1635	-	0	0	0	0
2	5,000	8	955	-	-680	-680	-680	-20,400
3	10,000	7	1252	-1040	+297	-743	-1423	-42,690
4	15,000	6	1548	-1045	+296	-749	-2172	-65,160
5	20,000	6	801	-	-747	-747	-2919	-87,570
6	25,000	5	1081	-1020	+280	-740	-3659	-109,770
7	30,000	5	345	-	-736	-736	-4395	-131,850
8	35,000	4	615	-1031	+270	-761	-5156	-154,680
9	40,000	3	882	-1022	+267	-755	-5911	-177,330
10	0	8	1725	-	-	-	-	-
3A	5,000	8	955	-	-	-	-	-
5A	5,000	8	985	-	-	-	-	-
7A	5,000	8	1020	-	-	-	-	-
8A	5,000	8	1032	-	-	-	-	-
9A	5,000	8	1042	-	-	-	-	-

TABLE NO. 9 - GAUGE NO. 9.

Sequence of Loading	Load, pounds	Reference Switch Position	Dial Reading	Corrected Ref. Switch Values	Change in Dial Readings	Strain, micro in. per in.	Total Accumulated Strain, micro in. per in.	Stress, lb./sq. in.
1	0	8	1225	-	0	0	0	0
2	5,000	8	1300	-	+75	+75	+75	+ 2,250
3	10,000	8	1381	-	+81	+81	+156	+ 4,680
4	15,000	8	1462	-	+81	+81	+237	+ 7,110
5	20,000	9	553	+1008	-909	+99	+336	+10,080
6	25,000	9	643	-	+ 90	+90	+426	+12,780
7	30,000	9	735	-	+ 92	+92	+518	+15,540
8	35,000	9	836	-	+101	+101	+619	+18,570
9	40,000	9	940	-	+104	+104	+723	+21,390
10	0	8	1215	-	-	-	-	-
3A	5,000	8	1298	-	-	-	-	-
5A	5,000	8	1300	-	-	-	-	-
7A	5,000	8	1295	-	-	-	-	-
8A	5,000	8	1295	-	-	-	-	-
9A	5,000	8	1293	-	-	-	-	-

TABLE NO. 10 - GAUGE NO. 10.

Sequence of Loading	Load, pounds	Reference Switch Position	Dial Reading	Corrected Ref. Switch Values	Change in Dial Readings	Strain, micro in. per in.	Total Accumulated strain, micro in. per in.	Stress, lb./sq. in.
1	0	6	1111	-	0	0	0	0
2	5,000	6	1271	-	+160	+160	+160	+ 4,800
3	10,000	6	1445	-	+174	+174	+334	+10,020
4	15,000	6	1634	-	+189	+189	+523	+15,690
5	15,000	7	782	+1045	-852	+193	+716	+21,480
6	25,000	7	962	-	+180	+180	+896	+26,880
7	30,000	7	1152	-	+190	+190	+1086	+32,580
8	35,000	7	1356	-	+204	+204	+1290	+38,700
9	40,000	7	1570	-	+214	+214	+1504	+45,120
10	0	6	1100	-	-	-	-	-
3A	5,000	6	1272	-	-	-	-	-
5A	5,000	6	1272	-	-	-	-	-
7A	5,000	6	1262	-	-	-	-	-
8A	5,000	6	1260	-	-	-	-	-
9A	0	6	1261	-	-	-	-	-

TABLE NO. 11.

Switch Position	Micro in. per in.	Micro in. per in. X correction factor $\left(\frac{2.00}{1.92} = 1.04\right)$ *
0-1	976	1015
1-2	989	1030
2-3	990	1031
3-4	982	1022
4-5	990	1031
5-6	980	1020
6-7	1002	1045
7-8	1000	1040
8-9	969	1008
9-10	975	1014

* Correction factor is obtained by dividing $\frac{2.00}{\text{actual gauge factor}}$.

TABLE NO. 12.

Load, pounds		DEFLECTION (two springs), in inches	Load, pounds		DEFLECTION (two springs), in inches
500	-	0.0000	15,500	-	0.0656
5,500	-	0.0200	10,500	-	0.0476
500	-	0.0007	5,500	-	0.0292
10,500	-	0.0385	500	-	0.0078
500	-	0.0009	5,500	-	0.0276
15,500	-	0.0559	10,500	-	0.0451
500	-	0.0010	15,500	-	0.0627
20,500	-	0.0740	20,500	-	0.0804
500	-	0.0012	25,500	-	0.0989
25,500	-	0.0926	30,500	-	0.1172
500	-	0.0016	35,500	-	0.1355
30,500	-	0.1117	40,500	-	0.1543
500	-	0.0020	45,500	-	0.1753
35,500	-	0.1307	40,500	-	0.1585
500	-	0.0030	35,500	-	0.1400
37,600	-	0.1394	30,500	-	0.1213
40,500	-	0.1510	25,500	-	0.1028
500	-	0.0048	20,500	-	0.0844
45,500	-	0.1749	15,500	-	0.0660
40,500	-	0.1580	10,500	-	0.0481
35,500	-	0.1396	5,500	-	0.0298
30,500	-	0.1209	500	-	0.0082
25,500	-	0.1025	45,500	-	0.1758
20,500	-	0.0840	500	-	0.0084

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APPENDIX I.

PREPARATION OF SPRING FOR STRESS MEASUREMENT.

Two springs were machined from 1½-inch armour plate and heat-treated to an approximate yield strength of 170,000 p.s.i.

The bottom surface of each spring was lapped in order to provide perfectly flat mating surfaces.

SR-4 electrical strain gauges Type A-7 were used. Each gauge had a resistance of 121 ±5 ohms, a gauge factor of 1.92 ± 2 per cent, and a gauge length of [illegible] inch.

The surface of one spring was roughened with emery cloth to ensure good adhesion of the gauges. A thin coat of SR-4 Precoat Cement 15-3 was applied and allowed to dry for 20 minutes. SR-4 Cement 15-41 was then applied in liberal amounts and the gauges were fixed in position, covered with thin cellophane paper and a sponge rubber pad, and weighted. The gauges were permitted to dry for 24 hours.

A compensating gauge was cemented, as described above, to a piece of steel 6 in. x 4½ in. x ½ in. This gauge was used as a temperature compensating gauge.

Lead wires 5 feet long were soldered to all gauges and firmly fixed so that there would be no pull on the gauges.

Spring and compensating gauges were placed in an oven and held at 75° C. for one hour. Upon removal, all gauges were covered with a liberal coat of melted Petrosene wax to protect them from moisture.

The lead wires from the spring were connected to a Leeds & Northrup 10-point rotary switch which, in turn, was connected by a 12-foot lead wire to a Baldwin-Southwark SR-4 portable strain recorder. All lead wires were single-strand wire 0.03 inch in diameter.

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