File

DEPARTMENT OF MINES AND RESOURCES

BUREAU OF MINES

CANADA

Ottawa, December 18, 1946.

R E P O R T

of the

ORE DRESSING AND METALLURGICAL LABORATORIES.

Investigation No. 2154.

(Subsequent to Investigation Reports Nos. 2060 and 2061, June 1946.)

Stress Analysis Performed on a Cast Magnesium Piano Plate. PART III: Using Bonded Wire Strain Gauges.

(Copy No. 8.)

(Report of Investigation)
(No. 2154.)

Abstract.

Preliminary examination of the stresses produced in a cast magnesium piano plate by tuning the strings to the normal pitch was carried out qualitatively by the application of "Stresscoat," a brittle lacquer made by the Magnaflux Corporation. The results are reported in Part I and Part II, Investigations No. 2060 and No. 2061 respectively. From this work the position of the most highly stressed sections of the piano plate and the approximate directions of the principal stresses were obtained.

The present report (Part III) deals with the application of bonded-wire electrical resistance strain gauges to the problem. The strain gauges were affixed to the piano plate at points specially selected, after consideration of the stresscoat analysis, to give the maximum information. Strain measurements were taken immediately after tuning the strings and again after several days to determine the amount of creep. The results of this investigation are discussed and suggestions made for changes in design in order to redistribute the load more efficiently.

CANADA

Bureau of Mines

Mineral Dressing and Metallurgy Division

Physical Metallurgy Research Laboratories

DEPARTMENT OF MINES AND RESOURCES

Mines and Geology Branch

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1. Origin of the Investigation:

The cast magnesium piano plate was submitted by Dominion Magnesium Limited, Toronto, Ontario, for a stress analysis investigation in order to check the present design and to obtain suggestions for improvements which should be applied in production.

2. Introduction:

The qualitative distribution of the stresses produced in the piano plate by tuning the strings to normal pitch had been previously examined using a brittle lacquer sprayed on to the surface (see Investigation Reports No. 2060,

(Introduction, cont'd) -

dated June 5, 1946, and No. 2061, dated June 15, 1946). In order to determine the magnitude of the principal stresses, SR-4 bonded resistance wire strain gauges were attached to the plate at positions and in directions selected on the basis of the brittle lacquer experiments. These gauges consist of a fine wire filament bonded to paper, and they are cemented to the surface of the structure to be tested. Subsequent strain in the structure will produce strain in the wire of the gauge and a corresponding change in its resistance; this change can be accurately measured.

3. Description of the Piano Plate Assembly:

As received, the piano plate was mounted on a wooden frame 3 inches thick. A sketch of the plate is shown in Figures 1 and 2, and a general view is shown in Figure 3. The plate was made from Magnesium Alloy AZ80X, cast in a green sand mould, and afterwards sandblasted. No heat treatment was applied. The magnesium metal used had been produced by the silicon reduction process.

The mechanical properties of the alloy are given in Table I.

TABLE I. - Properties of Magnesium Alloy AZ80X, As Cast.

TENSILE PROPERTIES									
Ult. Tensile Str., p.s.i.		0.2% Proof Stress, p.s.i.		% Elongation in 2 Inches		Compressive Str., p.s.i.		Modulus of Elasticity, p.s.i.	Brinell Hardness (50-kg. load, 10-mm. ball)
Typical	Minimum	Typical	Minimum	Typical	Minimum	Ultimate	Yield		
28,000	23,000	14,000	10,000	5.0	3.0	48,000	11,500	6.5×10^6	52

4. Method of Test:

A total of 90 strain gauges of different types were used in this investigation. General particulars of the

(Method of Test, cont'd) -

various types are given in Table II.

TABLE II. - Particulars of Strain Gauges Employed.

Type	Number of Gauges Used	Effective Gauge Length, inches	Approximate Resistance, ohms	Gauge Factor	Remarks
AR-1	14	13/16	120	2.05	Three gauges in rosette arrangement.
A-3	31	13/16	"	2.11	Single gauge.
AX-5	6	1/2	"	2.01	Two gauges at right angles.
A-5	12	1/2	"	2.00	Single gauge.
A-8	4	1/8	"	1.83	Single gauge.
A-11	23	1	"	2.05	Single gauge.

The surface of the plate at the selected points was slightly roughened with 000 emery cloth, and then cleaned with acetone. Each gauge in turn was also cleaned and affixed to the plate with Duco cement. During the drying period each gauge was covered with a piece of sponge rubber held in place by a small weight or a suitable clamp, depending upon the position of the gauge. The gauges were allowed to dry for 24 hours, tested for continuity and leakage resistance, and then coated with Socony Vacuum Petroseno "A" wax to prevent any change in moisture content.

The strain measurements were carried out using an SR-4 Portable Strain Indicator, manufactured by The Foxboro Company for the Baldwin Southwark Division. This instrument consists essentially of a Wheatstone bridge network, with a built-in 1000 c.p.s. power supply, and is designed to indicate the strain directly in micro-inches when used with a 120-ohm resistance gauge. Connection to the gauge leads was made through a special mercury-in-glass connector designed to minimise contact resistance variations. The initial balance reading was found for each gauge, using a gauge of

(Method of Test, cont'd) -

the same type for compensating purposes. The load was then applied by tuning the strings to the normal pitch, and a further set of strain readings was taken. In order to obtain an indication of the creep at the more highly stressed points, successive sets of readings were taken after periods of 3, 7 and 15 days.

Twenty of the strain gauges were not affixed until 6 days after the plate had been tuned. This step was considered desirable in order to supplement the information already obtained at certain points. Readings for these extra gauges were included in the sets of measurements taken on the seventh, fifteenth and sixteenth days after loading. The no-load balance readings were obtained finally on all gauges after the strings had been relaxed.

The general disposition of the gauges on the piano plate can be seen in Figure 3; somewhat more detailed photographs are shown in Figures 4 to 15. The results of the strain gauge measurements are given in Tables III and IV.

(Tables III and IV follow,
on Pages 5 to 10.)

TABLE III. - Results of Strain Measurements on Gauges Attached at Commencement of Test.

Gauge	Type	Gauge Factor	Strain Gauge Readings: Initial, no load	Immediately after loading	3 days after loading	7 days after loading	15 days after loading	Strain, micro-inches: Maximum	Total	Final Reading, unloaded	"No Load" change
1A	AR1	2.05	1648	1455	1452	1451	1442	-217	-206	1691	+43
B			449	644	652	657	677	+228	+228	514	+65
C			1109	597	418	470	680	-712	-429	1573	+264
2A	"	"	499	615	630	669	730	+231	+231	610	+111
B			849	740	758	911	899	+62 / -109	+50	1000	+151
C			1060	1397	1349	1362	1381	+337	+321	1092	+32
3A	"	"	970	949	943	946	997	+27 / -27	+27	1018	+48
B			782	1162	1185	1238	1240	+458	+458	913	+131
C			783	330	310	315	352	-473	-431	850	+67
4A	"	"	798	565	549	573	640	-249	-158	887	+89
B			1410	1760	1762	1978	1972	+568	+562	1712	+302
C			1112	1261	1254	1280	1312	+200	+200	1210	+98
5A	"	"	1262	641	632	630	650	-632	-612	1308	+46
B			956	1015	1038	1047	1070	+114	+114	1030	+74
C			947	1091	1109	1150	1170	+223	+223	1062	+115
6A	"	"	822	696	685	690	760	-137	-62	980	+158
B			933	977	940	940	949	+44	+16	933	0
C			759	513	510	539	627	-249	-132	848	+89
7A	"	"	1448	1152	1125	1119	1112	-336	-336	1435	-13
B			964	1068	1064	1085	1120	+156	+156	1050	+86
C			1175	992	988	1008	1052	-187	-123	1243	+68

(Continued)

(Method of Test, contd.) (Page 5)

TABLE III. - Results of Strain Measurements on Gauges Attached at Commencement of Test. (Cont'd)

Gauge	Type	Gauge Factor	Strain Gauge Readings: Initial, no load	Immediately after loading	3 days after loading	7 days after loading	15 days after loading	Strain, micro-inches: Maximum	Total	Final Reading, unloaded	"No Load" change
8A	AR1	2.05	676	290	205	339	350	-471	-326	840	+164
B			1220	1343	1351	1456	1552	+332	+332	1428	+208
C			608	601	617	670	718	-7 +110	+110	772	+164
9A	"	"	1430	950	928	942	980	-502	-450	1505	+75
B			1408	1556	1558	1566	1576	+168	+168	1451	+43
C			1262	1371	1368	1378	1391	+129	+129	1310	+48
10A	"	"	1223	1032	1033	1032	1092	-203	-134	1339	+115
B			1153	1108	1104	1112	1121	-49	-32	1205	+50
C			782	882	902	896	916	+134	+134	875	+91
11A	"	"	1354	1179	1164	1163	1178	-191	-176	1361	+7
B			1302	1235	1222	1222	1247	-80	-55	1352	+50
C			1041	622	603	612	660	-432	-381	1081	+40
12A	"	"	468	327	315	325	390	-153	-78	527	+59
B			979	997	1045	1149	1168	+189	+189	1195	+216
C			950	812	818	979	1029	-138 +79	+79	1160	+210
13A	"	"	590	820	905	1083	1078	+493	+488	955	+365
B			1092	872	908	915	930	-220	-162	1130	+38
C			856	840	840	902	1052	+196 -16	+196	1112	+256
14A	"	"	1118	1058	1098	1127	1197	-60 +79 -95	+79	1251	+133
B			905	810	810	990	1053	+148	+148	1118	+213
C			853	659	628	680	710	-225	-143	955	+85

(Continued)

TABLE III. - Results of Strain Measurements on Gauges Attached at Commencement of Test. (Cont'd)

Gauge	Type	Gauge Factor	Strain Gauge Readings: Initial, no load	Immediately after loading	3 days after loading	7 days after loading	15 days after loading	Strain, micro-inches: Maximum	Total	Final Reading, unloaded	"No Load" change
15	A3	2.11	512	302	328	330	326	-210	-186	530	+18
			A 1057	852	830	852	948	-227	-109	1069	+12
16	AX5	2.01	B 1572	1705	1702	1739	1942	+370	+370	1838	+266
			A 1097	958	947	967	1057	-150	-40	1142	+45
17	"	"	B 403	460	450	476	560	+157	+157	492	+89
18	A5	2.00	2392	770	760	771	812	-1632	-1580	2322	-70
19	"	"	1789	633	629	636	668	-1160	-1121	1781	-8
20A	A3	2.11	610	1153	1149	1155	1149	+545	+539	690	+80
B			1484	248	248	262	300	-1236	-1184	1501	+17
21	"	"	625	10	5	15	38	-620	-587	657	+32
22	A8	1.83	1197	202	215	295	488	-995	-709	1350	+153
23	A3	2.11	1451	959	957	960	982	-494	-469	1459	+8
24	A11	2.05	902	1391	1380	1461	1512	+610	+610	1010	+108
25	"	"	470	1080	1070	1133	1150	+680	+680	544	+74
26	A3	2.11	2679	831	813	789	774	-1905	-1905	2555	-126
27	"	"	4232	1152	1114	1080	1073	-3159	-3159	4058	-174
28	A5	2.00	2632	1377	1410	1482	1560	-1255	-1072	2729	+97
29	"	"	3931	1497	1472	1481	1545	-2459	-2386	4011	+80
30	A3	2.11	2830	1216	1208	1186	1146	-1684	-1684	2726	-104
31	A11	2.05	1636	580	576	580	640	-1060	-996	1626	-10
32	"	"	2772	883	865	1025	1056	-1907	-1716	2781	+9
33	A11	2.05	888	1497	1479	1478	1567	+679	+679	986	+98
34	"	"	702	1531	1551	1562	1607	+905	+905	801	+99
35	A5	2.00	1751	872	900	1120	1188	-879	-563	1991	+240

(Continued)

(Method of Test, cont'd)

TABLE III. - Results of Strain Measurements on Gauges Attached at Commencement of Test. (Cont'd)

Gauge	Type	Gauge Factor	Strain Gauge Readings: Initial, no load	Immediately after loading	3 days after loading	7 days after loading	15 days after loading	Strain, micro-inches: Maximum	Total	Final Reading, unloaded	"No Load" change
36	A3	2.11	975	388	397	393	402	-587 (-72	-573	961	-14
37	A11	2.05	690	618	668	690	700	(+10	+10	715	+25
38	A3	2.11	785	970	968	1008	1070	+285	+285	896	+111
39	"	"	1223	62	91	87	97	-1161	-1126	1180	-43
40	"	"	1090	1260	1249	1220	1222	+170	+132	1097	+7
41	A11	2.05	580	530	570	563	660	(-50 (+80	+80	660	+80
42	A3	2.11	1252	1572	1570	1580	1609	+357	+357	1341	+89
43	"	"	1358	790	792	828	862	-568	-496	1386	+28
44	"	"	1198	1480	1480	1482	1490	+292	+292	1260	+62
45	"	"	1039	870	866	875	891	-173	-148	1060	+21
46	"	"	2115	530	515	520	530	-1600	-1585	2024	-91
47	A11	2.05	862	580	576	692	668	-286	-194	894	+32
48	"	"	961	971	971	984	1026	+65	+65	987	+26
			A 1385	1342	1323	1431	1448	-62 +63	+63	1416	+31
49	AX5	2.01	B 808	849	792	872	989	-16 +181	+181	908	+100
50	A11	2.05	1286	675	671	782	849	-615	-437	1401	+115
51	A11	2.05	4001	1182	1218	1220	1270	-2819	-2731	3815	-188
52	"	"	1846	1308	1310	1331	1455	-538	-391	1934	+88
53	A3	2.11	1669	602	597	590	610	-1079	-1059	1590	-79
54	"	"	1410	1345	1353	1359	1369	-65	-41	1420	+10
55	A5	2.00	2994	1322	1333	1399	1520	-1672	-1474	3055	+41
56	A3	2.11	910	730	733	730	747	-180	-163	916	+6

(Continued)

(Method of Test, cont'd) -

(Page 8)

TABLE III. - Results of Strain Measurements on Gauges Attached at Commencement of Test. (Concluded)

Gauge	Type	Gauge Factor	Strain Gauge Readings: Initial, no load	Immediately after loading	5 days after loading	7 days after loading	15 days after loading	Strain, micro-inches: Maximum	Total	Final Reading, unloaded	"No Load" change
57	A5	2.00	2102	980	973	1041	1080	-1129	-1022	2141	+59
58	A3	2.11	1639	532	538	532	552	-1107	-1087	1601	-38
								(-10			
59	A5	2.00	952	942	950	980	1060	(+108	+108	1059	+107
60	A3	2.11	708	842	848	858	868	+160	+160	754	+46
61	A5	2.00	786	872	865	957	1056	+270	+270	944	+158
62	"	"	2422	1000	1039	1140	1192	-1422	-1260	2500	+78
63	A11	2.05	760	122	185	162	262	-638	-498	760	0
64	"	"	815	1310	1226	-	-	+495	-	887	+72
								(-8			
65	A3	2.11	810	820	809	802	818	(+10	+8	830	+20
66	"	"	1303	1412	1419	1420	1429	+126	+126	1371	+68
67	"	"	716	922	930	931	940	+224	+224	790	+74
68	"	"	653	798	790	792	806	+153	+153	691	+38
69	A11	2.05	770	892	928	942	990	+220	+220	797	+27

(Method of Test, Form 7A)

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TABLE IV. - Results of Strain Measurements on Gauges Attached After Commencement of Test.

Gauge	Type	Gauge Factor		7 days after loading	After 9 days	After 11 days	After 15 days	After Unloading	Total Strain, micro-inches
7A	AX5	2.01	A	1478	1422	1400		1652	-252
			B	968	915	1066		960	+106
7B	AX5	2.01	A	1318	1290	1373		1586	-213
			B	572	607	749		552	+197
7C	AX5	2.01	A	960	890	980		953	+27
			B	1171	1091	1312		1205	+107
19A	A8	1.83		1370	1348	1379	1580	2006	-426
23A	A11	2.05		1010	994	1100		1522	-422
27A	A5	2.00		865	847	882		2348	-1466
34A	A8	1.83		653	677	670	800	1461	-661
37A	A11	2.05		770	796	919		1410	-491
39A	A8	1.83		1148	1238	1143	1258	1276	-38
43A	A3	2.11		1289	1320	1302		1465	-163
43B	A3	2.11		810	822	852		1810	-958
43C	A3	2.11		715	665	-	733	4209	-3476
61A	A11	2.05		625	611	770		1080	-310
62A	A11	2.05		1149	1150	1276		2379	-1103
65A	A5	2.00		1072	1132	1212		1878	-666
66A	A11	2.05		602	570	655		1412	-757
67A	A11	2.05		1381	1365	1457		1749	-292
53A	A3	2.11					1510	1523	-213
55B	A3	2.11					538	719	-181
53C	A11	2.05					763	897	-134

(Method of Tests, cont'd)

(Page 10)

5. Discussion of Results:

The results obtained from the strain gauge readings were analysed from two principle viewpoints, namely:

(a) To determine the overstressed sections of the piano plate on the basis of an allowable stress of 6,500 p.s.i. (about 1,000 micro-inches/inch strain).

(b) To determine the understressed sections, i.e., those sections from which material could be removed with safety to lighten still further the casting.

(a) Overstressed Sections -

It can be seen from the progressive changes in many of the readings that creep and some redistribution of load have taken place during the test. The most highly stressed sections appear to be in the strengthening ribs marked B and D in the photographs, and to a lesser extent in rib A. In particular the tapered end of rib B, where it runs into the string terminals, and the tapered end of rib D were very highly stressed. These results indicate the sections whose dimensions should be increased in order that the working stresses should not exceed the allowable value of 6,500 p.s.i.

(b) Understressed Sections -

It is obvious from the results in Tables III and IV that there are many sections in which the stresses, either tensile or compressive, are very light. At positions marked C, E, H, K, L, M, O, P, Q and S, shown in the photographs, the measured strain was less than 100 micro-inches per inch. Material can be removed from these sections, to reduce the weight of the piano plate, without appreciably affecting its strength.

Conclusions:

As a result of an extensive strain gauge investigation of the cast magnesium piano plate supplied, the

(Conclusions, cont'd) -

following suggestions are put forward to serve as the basis for a more efficient design of casting:

(a) The cross-sectional dimensions of the three strengthening ribs marked A, B and D in the photographs should be increased.

(b) Material should be removed mainly from the edges, marked O, P and M; from the centre portion F (by providing one or more holes); from portions L and K (by increasing the size of the existing holes); and from the rib C.

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TWW:RCAT:LB.

(Figures 1 to 15 follow, on Pages 13 to 21.)

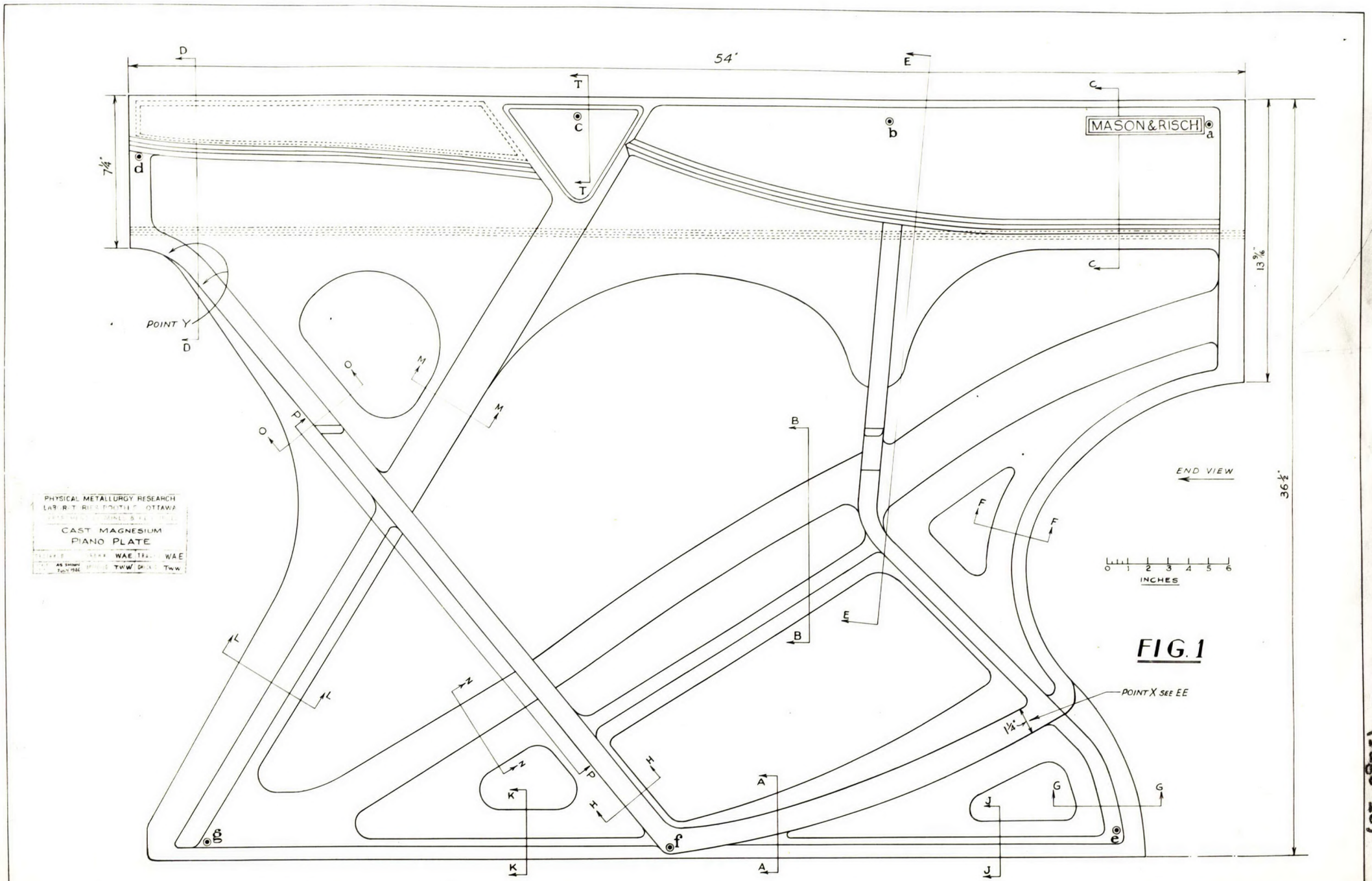

54'
7¼"
13 9/16"
36½"
MASON & RISCH
POINT Y
POINT X SEE EE
END VIEW
INCHES
0 1 2 3 4 5 6
PHYSICAL METALLURGY RESEARCH
CAST MAGNESIUM
PIANO PLATE
WAE
TWW
1½"

FIG. 1

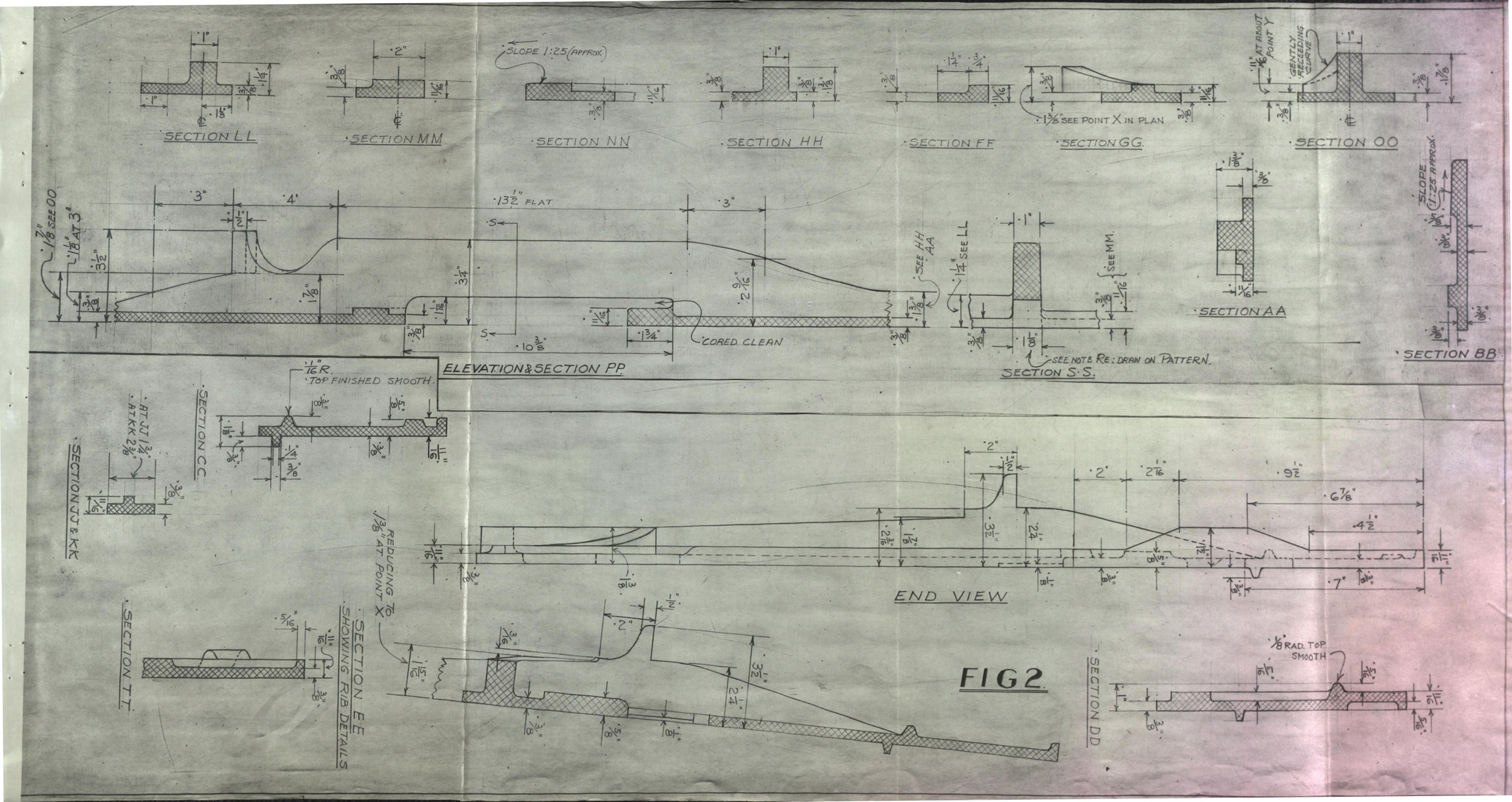
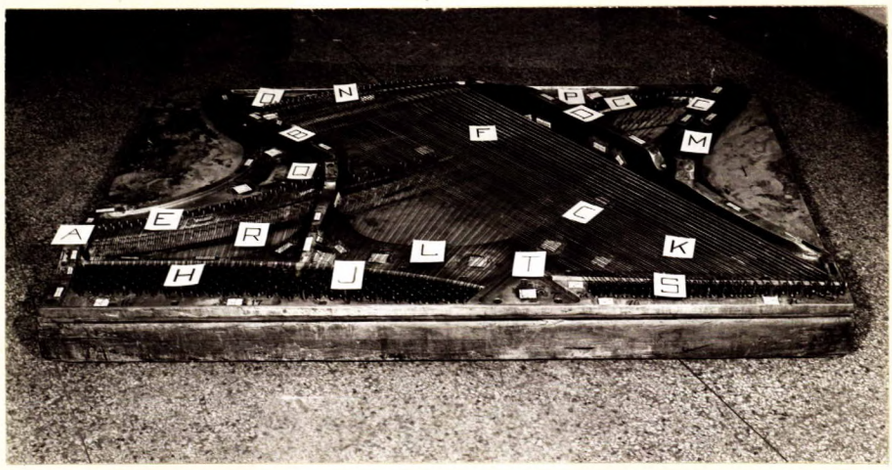

SECTION LL
SECTION MM
SLOPE 1:25 (APPROX.)
SECTION NN
SECTION HH
SECTION FF
1 3/8" SEE POINT X IN PLAN
SECTION GG.
AT ABOUT POINT Y
GENTLY RECEDING CURVE
SECTION OO
SLOPE (1:25 APPROX.)
SECTION BB
SECTION AA
SEE HH
AA
SEE LL
SEE MM.
SECTION S.S.
SEE NOTE RE: DRAW ON PATTERN.
13 1/2" FLAT
CORED CLEAN
ELEVATION & SECTION PP
1/16" R.
TOP FINISHED SMOOTH
SECTION CC
AT JJ 1 3/4"
AT KK 2 3/8"
SECTION JJ & KK
REDUCING TO 1/8" AT POINT X
SECTION EE
SHOWING RIB DETAILS
END VIEW
SECTION TT.
SECTION DD
1/8" RAD. TOP SMOOTH

FIG 2

2154

(Page 14)
Figure 2.

Figure 3.



GENERAL VIEW OF PIANO PLATE WITH
STRAIN GAUGES AFFIXED.

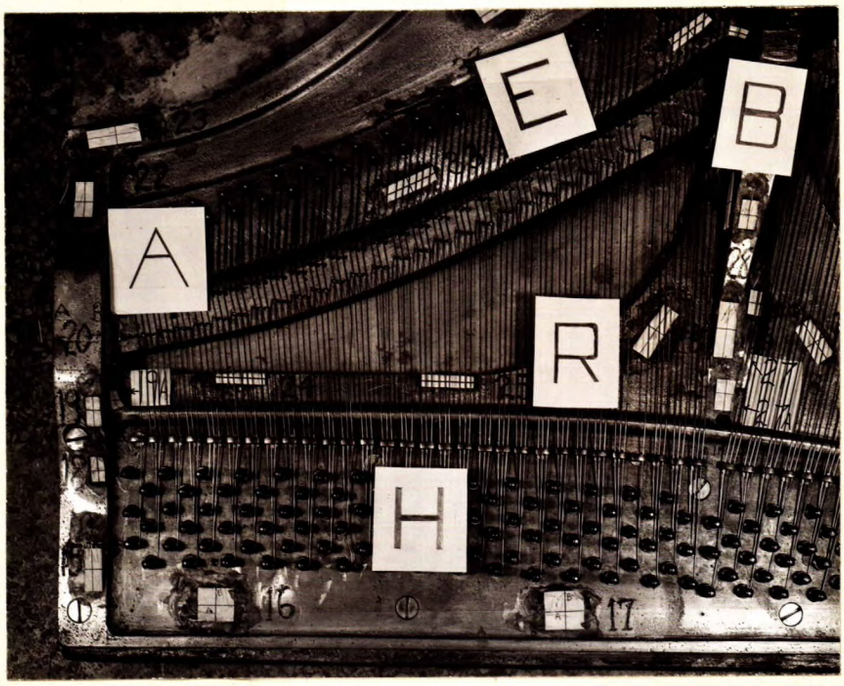
-

Figure 4.

PART OF PIANO PLATE, SHOWING SECTIONS
MARKED A, B, E, N, O, Q AND R.

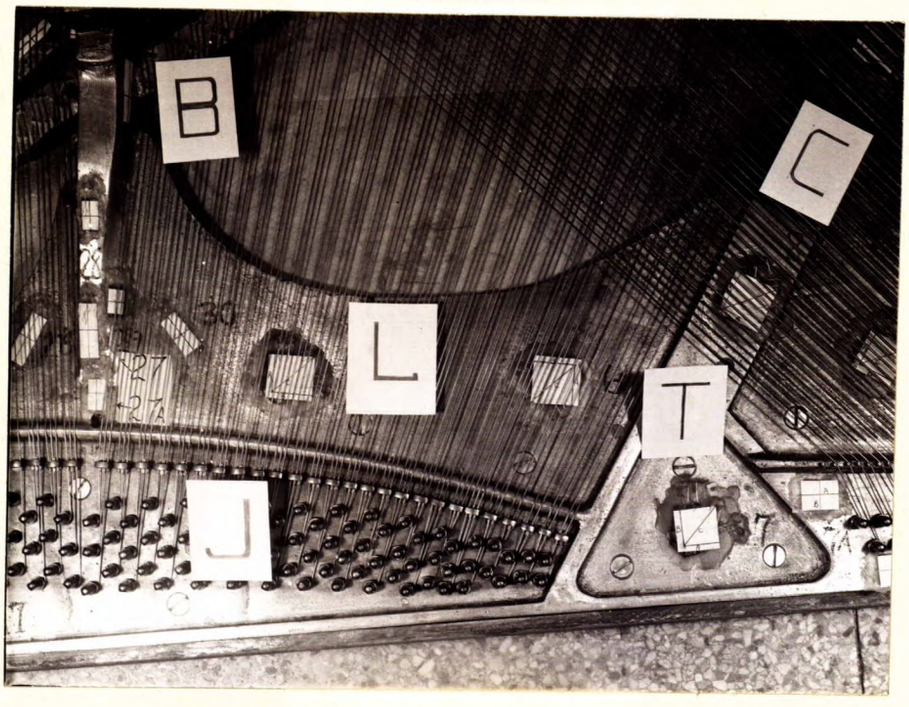
-

Figure 5.



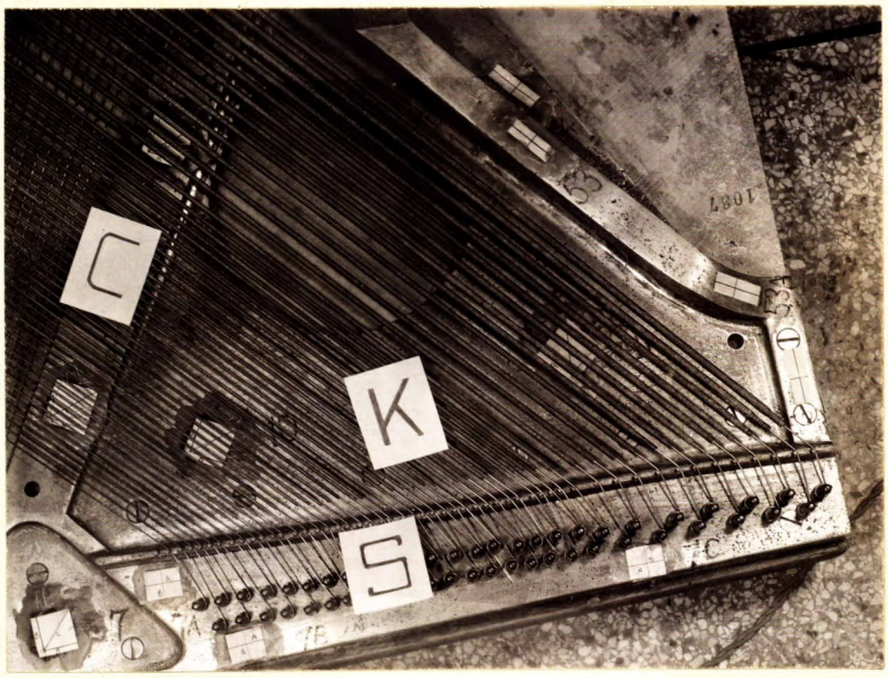
PART OF PIANO PLATE, SHOWING SECTIONS MARKED A, B, E, H AND R.

Figure 6.



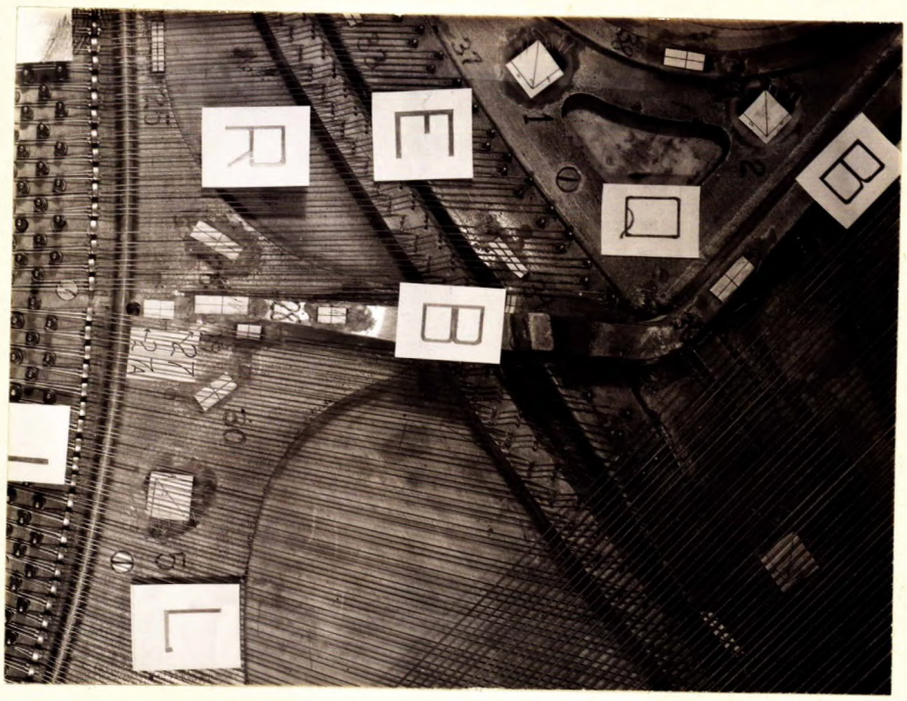
PART OF PIANO PLATE, SHOWING SECTIONS MARKED B, C, J, L AND T.

Figure 7.



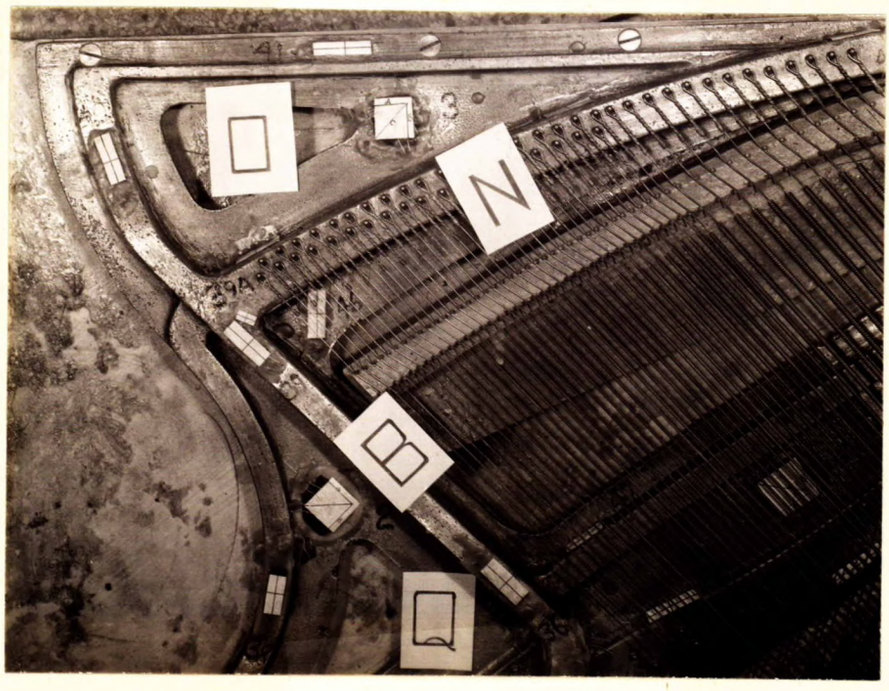
PART OF PIANO PLATE, SHOWING SECTIONS
MARKED C, K AND S.

Figure 8.



PART OF PIANO PLATE, SHOWING SECTIONS
MARKED B, E, L, Q AND R.

Figure 9.



PART OF PIANO PLATE, SHOWING SECTIONS
MARKED B, N, O AND Q.

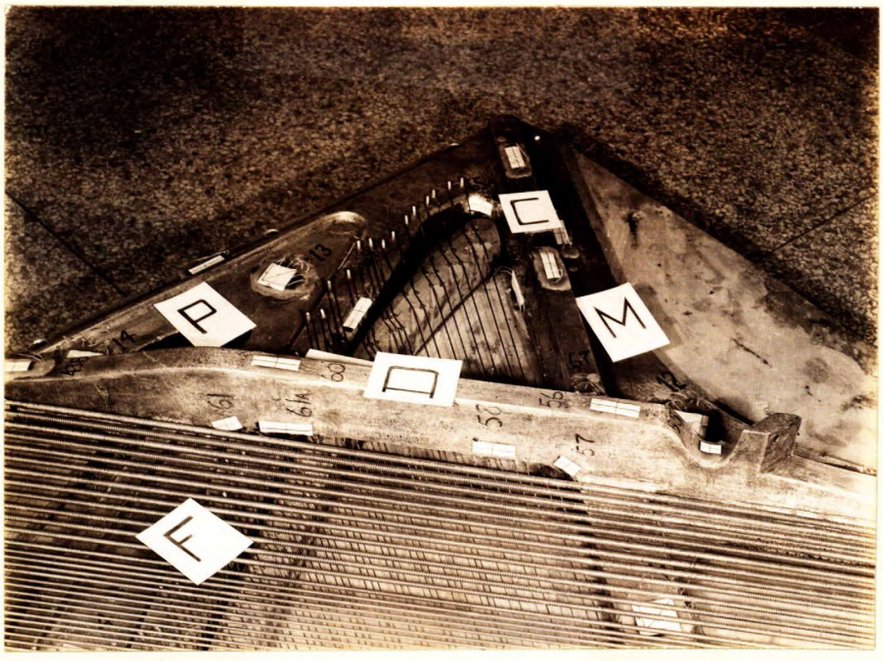
Figure 10.

PART OF PIANO PLATE, SHOWING SECTIONS
MARKED F, G AND P.

Figure 11.

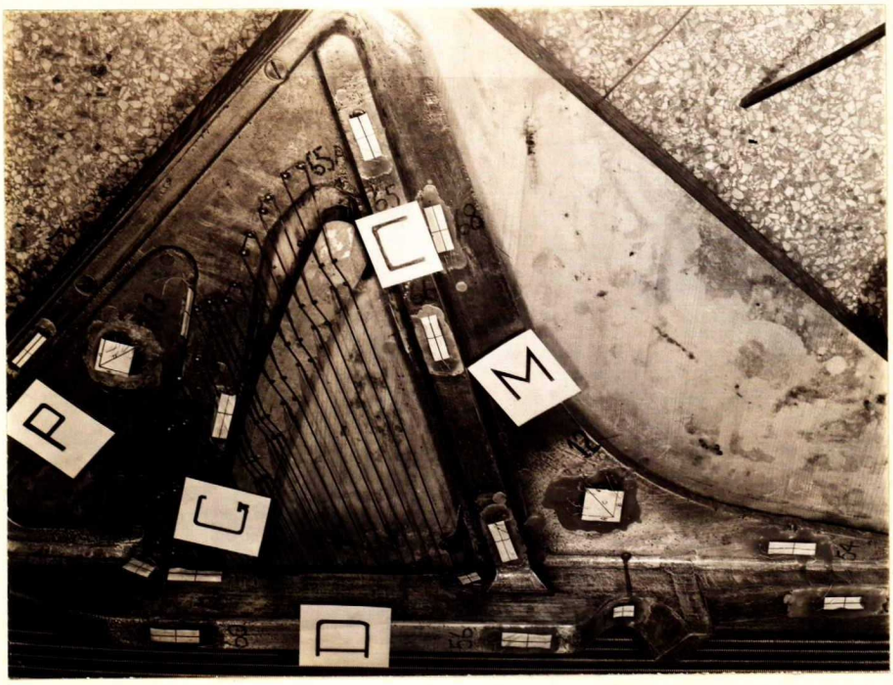
PART OF PIANO PLATE, SHOWING SECTIONS
MARKED D AND M.

Figure 12.



PART OF PIANO PLATE, SHOWING SECTIONS
MARKED C, D, F, M AND P.

Figure 13.



PART OF PIANO PLATE, SHOWING SECTIONS MARKED C, D, G, M AND P.

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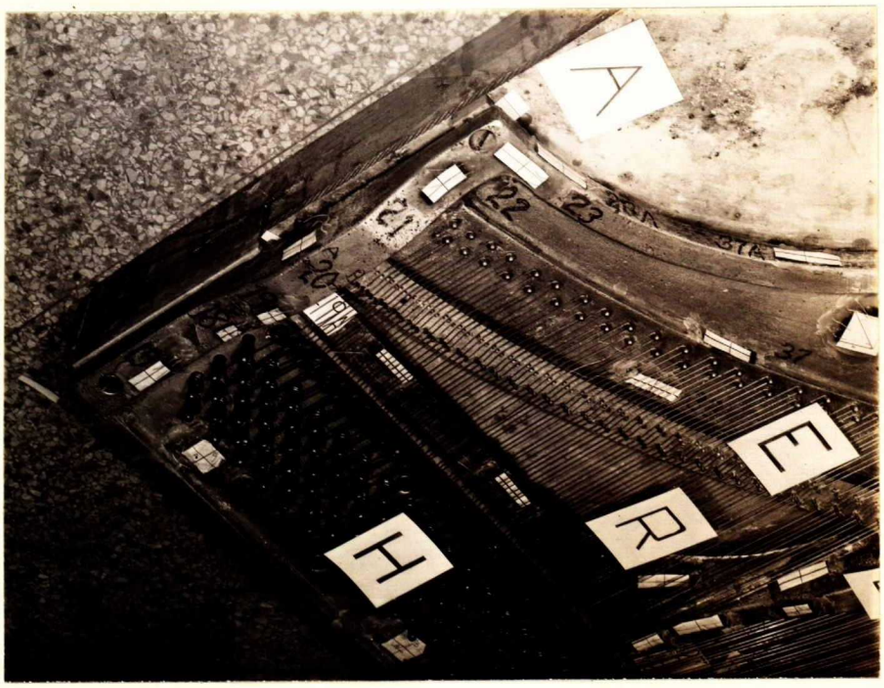
Figure 14.



PART OF PIANO PLATE, SHOWING SECTIONS MARKED A, E, H AND R.

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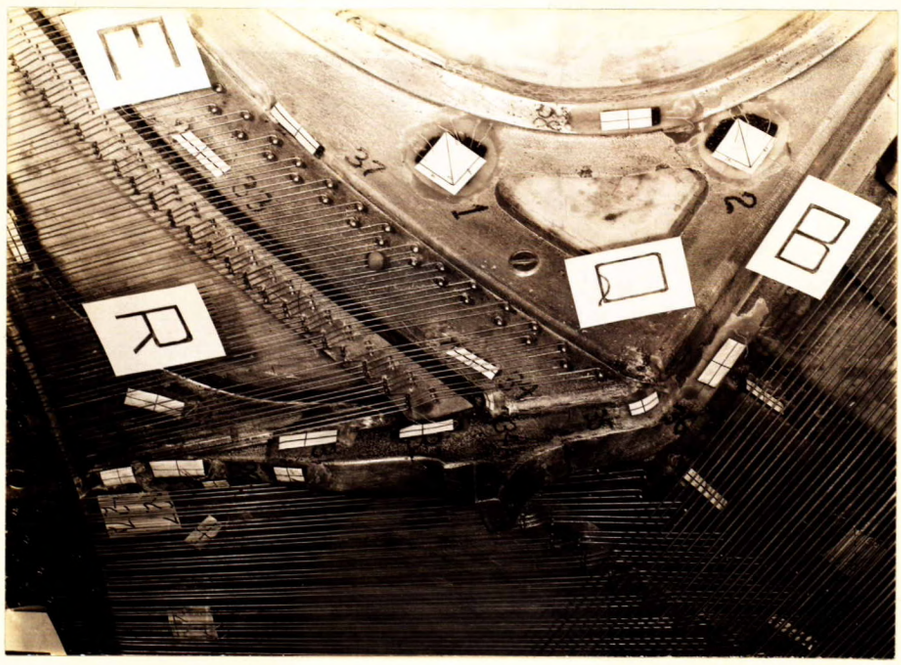
Figure 15.



PART OF PIANO PLATE, SHOWING SECTIONS
MARKED B, E, Q AND R.

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TWW:RCAT:LB.