THE UNIVERSITY OF MISSOURI BULLETIN

VOLUME 21 NUMBER 4

ENGINEERING EXPERIMENT STATION

SERIES 20

ENERGY NECESSARY TO SHEAR STEEL AT HIGH TEMPERATURES

by

GUY D. NEWTON

Associate Professor of Engineering Drawing
and Machine Design

ISSUED THREE TIMES MONTHLY; ENTERED AS SECOND-CLASS MATTER AT THE POSTOFFICE AT COLUMBIA, MISSOURI—1,500

FEBRUARY, 1920

THE UNIVERSITY OF MISSOURI BULLETIN

VOLUME 21 NUMBER 4

ENGINEERING EXPERIMENT STATION

SERIES 20

ENERGY NECESSARY TO SHEAR STEEL AT HIGH TEMPERATURES

by

GUY D. NEWTON

Associate Professor of Engineering Drawing
and Machine Design

ISSUED THREE TIMES MONTHLY; ENTERED AS SECOND-CLASS MATTER AT THE POSTOFFICE AT COLUMBIA, MISSOURI—1,500

FEBRUARY, 1920

Energy Necessary to Shear Steel at High Temperatures

INTRODUCTION

Experimental data concerning the resistance of metals at high temperatures are very limited. One reason for this doubtless is that special apparatus must be constructed to make the necessary tests, as ordinary testing machines operate too slowly to be used with materials that must be manipulated at the high temperatures. But probably a more significant reason lies in the fact that the practical use and application of such information is restricted to a special field, since designers usually have to deal with materials at atmospheric temperatures. In designing certain machines, however, such as shears and presses for working hot steel, it is important to know the shearing resistance of the metal dealt with at the working temperatures. It was in the hope of gaining some information on this subject that the tests herein reported were undertaken.

The experimental shear was first constructed with rotary blades designed to cut stock ranging up to three inches in diameter. However, after a number of tests were made with this design, the rotary blades were replaced by an attachment which converted the machine into a straight shear. By this means it becomes possible to make a comparison of the power required by the two methods of shearing.

While the results are admittedly incomplete and somewhat erratic due to imperfections in the apparatus, it is hoped that they may prove of some interest to designers of this type of machinery and that others may be encouraged to inaugurate further tests in this field.

APPARATUS

The Rotary Shear.—The shear as shown by Figs. 1 and 2 consists of a heavy fly-wheel mounted on a shaft with suitable bearings, and connected by intermediate gears to two parallel shafts which carry the rotary blades. The speed of the fly-wheel, which is twenty times that of the blades, is recorded by means of a Schaeffer and Budenberg stroke counter operated by a lever which engages a protruding key on the intermediate shaft. The stroke counter may be seen at the point *d*, Fig. 1. As the intermediate shaft revolves only one-fifth as fast as the fly-wheel, it is necessary to multiply the counter readings by 5 to get the speed of the fly-wheel. This arrangement was found necessary as the stroke counter would not record accurately at the fly-wheel speed.

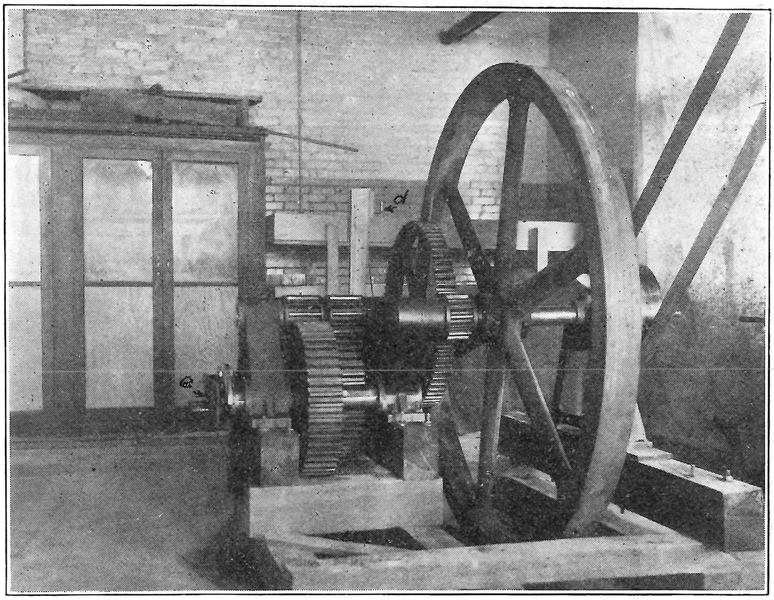

FIG. 1

The piece to be sheared is caught between the blades as shown in Fig. 3. These blades are so shaped that each makes a spiral-shaped cut from the stock as it is revolved between them. In order that the blades should not burn off they were made rather blunt, and as it is necessary that they should be exactly in line with each other it will be seen that the action is not strictly a shear in the ordinary sense of this term, but that the blades really crush their way thru the metal. It is believed, however, that the energy required in this action is not widely different from the energy required for actual shearing except as it develops a tensile stress in the specimen.

For holding the stock in position between the blades a special steel plate, shown at *e,* Fig. 1, was provided. This plate has holes at the ends made to fit over the ends of the blade shafts, and a third hole of suitable size at the center thru which the stock is inserted.

The shear is driven by means of a belt from a line shaft to a

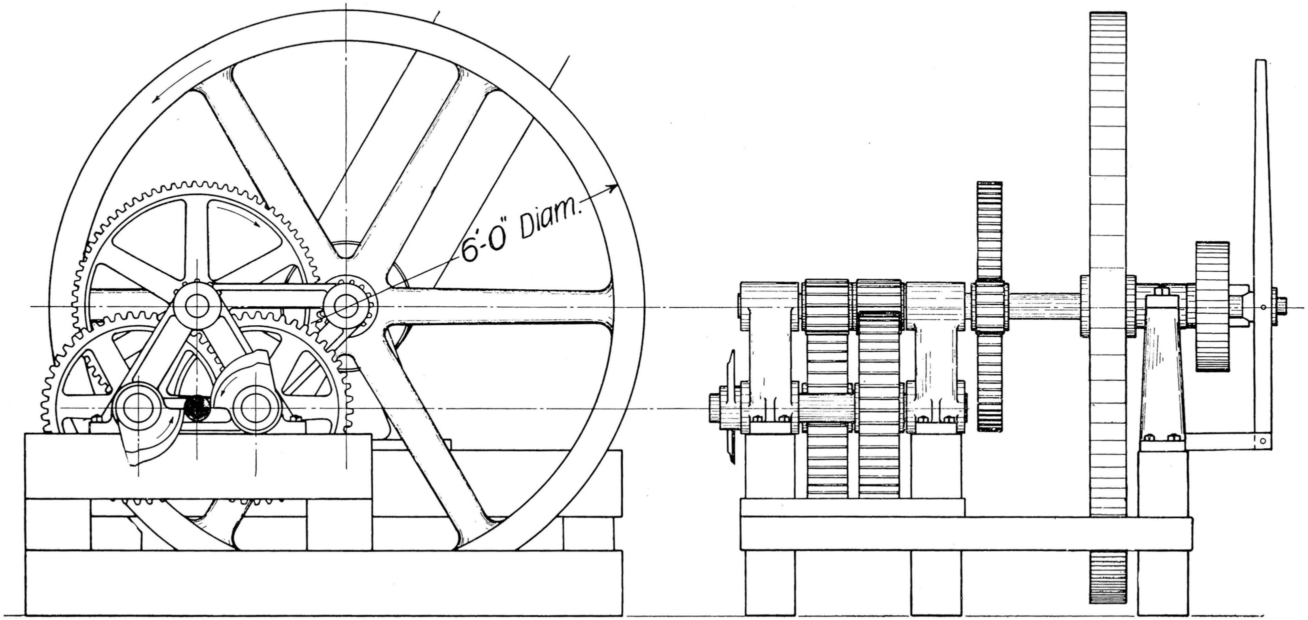

Fig. 2. Experimental Shear, showing Rotary Blades.

clutch pulley on the fly-wheel shaft. The energy for shearing the specimen is supplied by that left in the fly-wheel after the clutch is thrown out. By counting the revolutions of the fly-wheel from the time the clutch is thrown out until it comes to rest, and making due allowance for friction, the energy necessary to shear the specimen is determined.

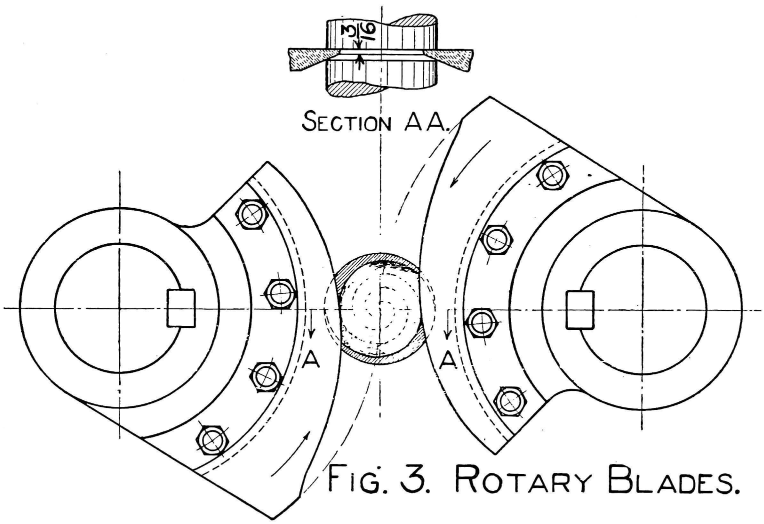

FIG. 3. ROTARY BLADES.

The Straight Shear.—The straight shear attachment, as shown in Fig. 4 is driven by one only of the rotary blade shafts. The attachment consists of a stationary blade (A) and a reciprocating blade (B) which is operated by the eccentric (C). Two cast iron guide blocks (D) hold the blades in their proper positions and these guide blocks are bolted through and held by two steel plates (E) which are threaded over the driving shaft on either side of the eccentric. The outside plate (E) is not shown in the figure.

Furnace.—The metal was heated in a gas fired furnace made by the Denver Fire Clay Company.

Pyrometer.—The temperatures were taken with a Hoskins Thermo-Electric Pyrometer, used as shown in Fig. 5 the end of the couple being inserted to the mid-point of the specimen thru a hole just large enough to receive it freely. This arrangement was decided upon after other schemes had been tried and it is believed that it resulted in giving very nearly the true temperatures of the steel.

METHOD OF CONDUCTING TEST

A piece of steel exactly the same dimensions as the piece to be sheared, with the pyrometer attached as in Fig. 5, is placed in the furnace. When the desired temperature is reached the sample is withdrawn and the temperature read every 10 seconds during the cooling process. By repeating this operation several times it became

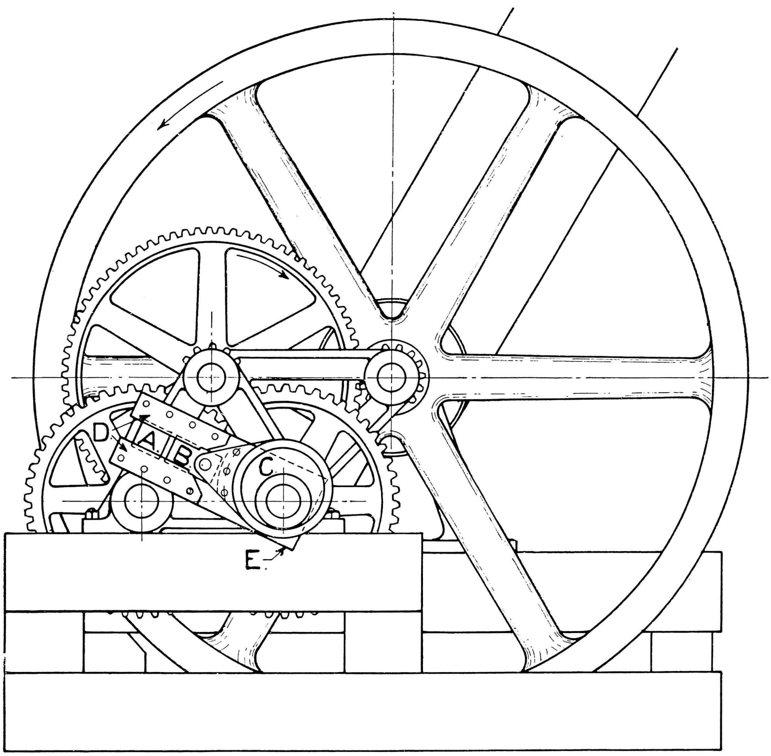

Fig. 4.- Straight Shear Attachment.

possible to plot a curve of temperatures related to time (Fig. 10) by means of which the temperature of the sample at intervals during the time of shearing might be approximately known.

After these temperature tests, the sample is again placed in the furnace, together with the duplicate piece to be sheared. While the specimens are being heated, the shear apparatus is started and its friction determined. This is done by throwing off the power after the fly-wheel has attained a known speed, and allowing it to come to rest without interference. The friction of the whole apparatus in foot pounds per revolution is the kinetic energy in the fly-wheel at the initial speed, divided by the number of revolutions it makes after the clutch is thrown out.

When the specimens are at the desired temperature, the shear is again started. After the fly-wheel speed has been recorded, the clutch is thrown out and the specimen withdrawn from the furnace

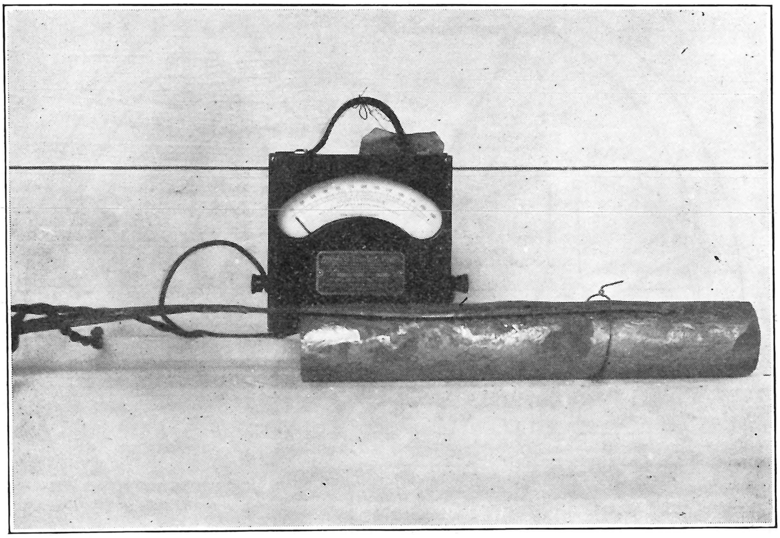

FIG. 5

and inserted in the shear. The pyrometer reading at the time the steel leaves the furnace, the time required to withdraw the specimen and place it in the shear, and the number of revolutions it makes before coming to a stop are recorded.

RESULTS

The original records and computed results of each series of tests are arranged in Tables I to V.

Column 1 gives the test number. Two series of tests were made, the first numbered from 1 to 25 and the second from 1 to 110.

In column 2 the speeds of the fly-wheel are given. These are the initial speeds of the wheel at the time the power was thrown off.

In column 3 are recorded the kinetic energies of the fly-wheel at the initial speeds recorded in column 2. These figures give us therefore, the energy available for overcoming the friction of the machine and for shearing the specimen. These values were computed as follows:—

K. E. = ½ I w^2.

Where w = the angular velocity of the wheel in radians per second.

I = its moment of inertia, W/g k^2 = 217.875 (units, foot and pound).

W = the weight of the wheel in pounds.

g = the acceleration due to gravity = 32.2 (units, foot and second).

This value for I was determined by taking the average of several independent computations.

In column 4 are recorded the number of revolutions made by the fly-wheel after the power was thrown off.

The figures in column 5 give the energy in foot pounds consumed by friction during each revolution of the fly-wheel. The friction of the shear varied considerably, especially during the first series of tests when the machine was new. For this reason friction tests were made frequently, usually before and after each shearing test. It was found that oiling the machine regularly was very effective in keeping the friction within a narrow range of variation.

The total friction required to stop, column 6, is the product of the friction per revolution (col. 5), into the number of revolutions recorded in column 4. This gives the energy, in foot pounds, consumed by friction while the shear was coming to rest.

The shearing energy, column 7 is the difference between the total available energy in the fly-wheel, (col. 3) and the energy consumed by friction (col. 6). This therefore is the total energy expressed in foot pounds required to overcome the resistance of the metal to shear.

Column 8 gives the areas in square inches of steel sheared. It will be seen that the smaller specimens were sometimes cut two or more times during the same test.

Column 9 gives the shearing energy in foot pounds per square inch. This is equal to the total shearing energy from column 7, divided by the area sheared.

Column 10 gives the temperature of the specimen at the time of shearing. These figures were found by subtracting the fall in temperature during the time the specimen had been out of the furnace, as shown by the temperature curves, from its temperature at the furnace. In cases where two or more cuts were made the average time was used. Temperature curves for several sizes of steel are shown in Fig. 10.

Column 11 gives the dimensions of the specimens sheared.

In tables I and II the results of tests with the rotary shear are tabulated. Table I gives the results with several sizes of cold rolled steel shafting; Table II, the results with 1¼" chrome vanadium steel. As a comparison of the strengths of these two grades of steel, the shearing energies required from Tables I and II are plotted against temperatures in Fig. 6.

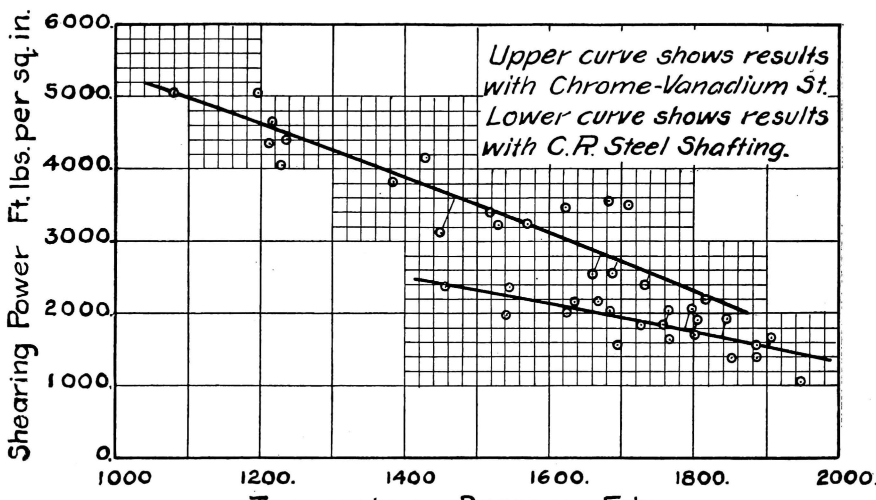

FIG. 6 RESULTS WITH THE ROTARY SHEAR.

Tables III, IV and V show the results obtained by shearing various specimens of steel with the straight shear.

The curves in Fig. 7 were plotted from data in Tables II and III. As the test specimens in both cases were 1¼" chrome vanadium steel, the curves allow a comparison of the energy required by the two styles of shear to cut the same material.

As would be expected from the shape of its blades, the rotary shear required much more energy. The action is in fact more nearly a double shear.

Fig. 8 shows the energy required in straight shear to cut Illinois Steel Company's medium grade test specimens. The data are from Table IV.

Fig. 9 shows the power required to cut two grades of steel in straight shear. One of these specimens was a rather high carbon steel bar 1" x 1½", while the others were very soft steel in bars about ½ x 2" cut flatwise. The data are from Table V.

Fig. 10 shows the drop in temperature for various specimens at half-minute time intervals.

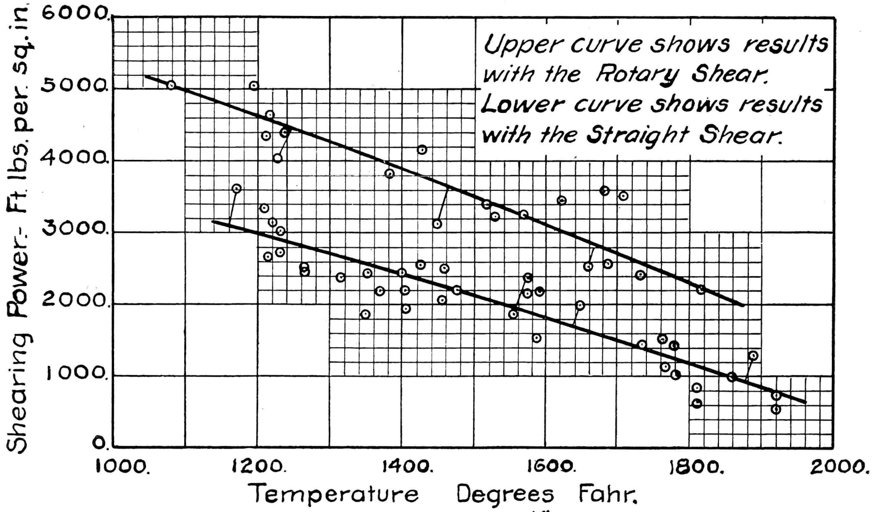

FIG. 7. A COMPARISON OF 1¼" CHROME-VANADIUM STEEL WITH ROTARY AND STRAIGHT SHEARS.

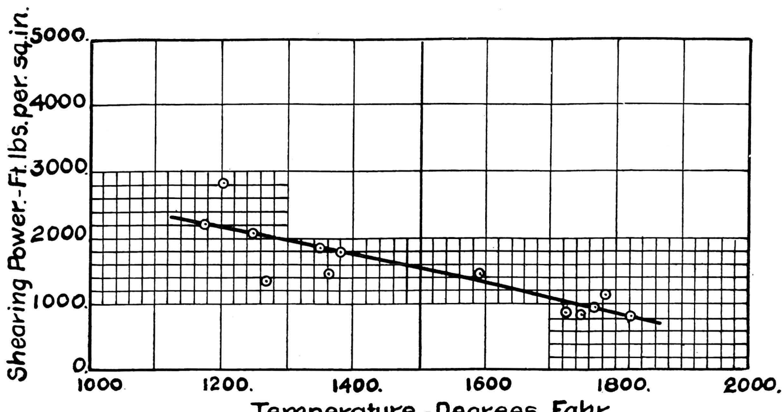

FIG. 8. MED. GRADE ILL. ST. CO. TEST SPECIMEN.

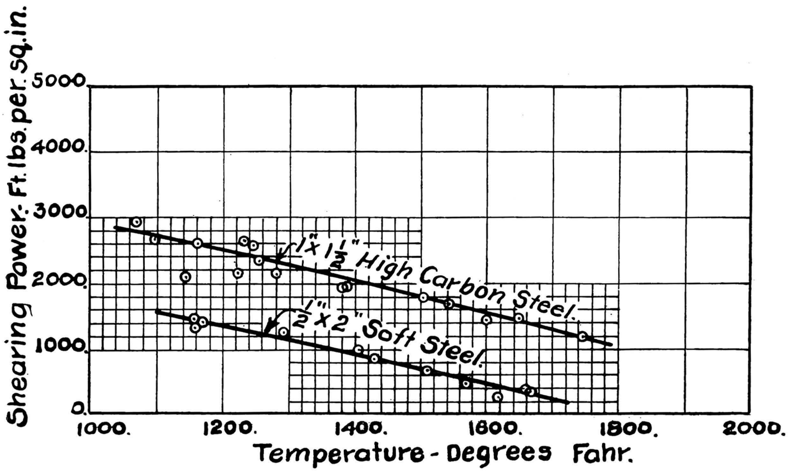

FIG. 9. A COMPARISON OF TWO SPECIMENS.

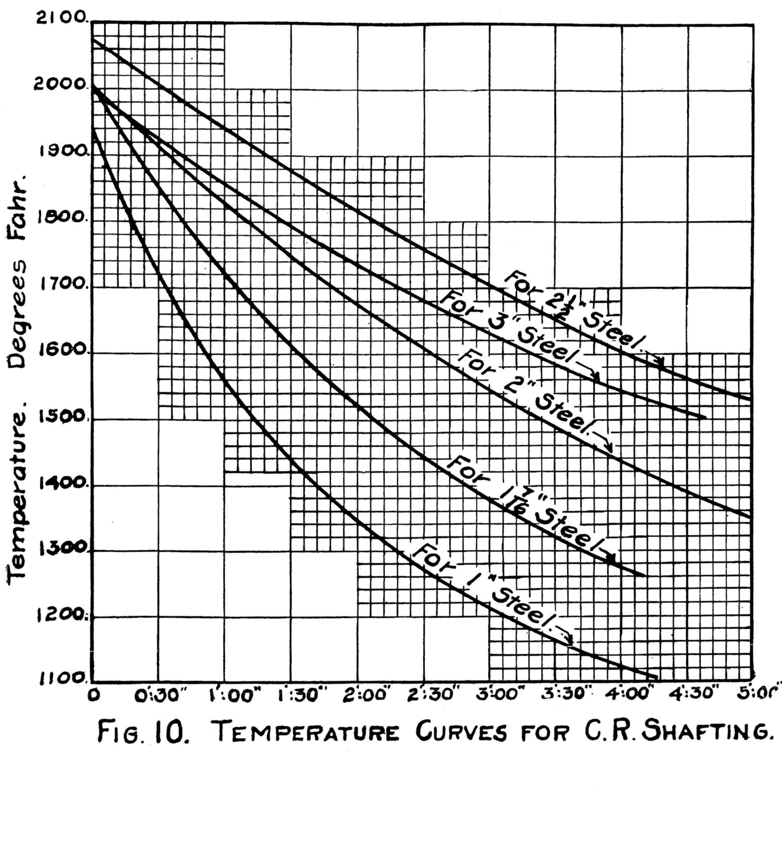

FIG. 10. TEMPERATURE CURVES FOR C. R. SHAFTING.

CONCLUDING REMARKS

The shearing energies could have been represented fairly well by straight lines within the range of temperatures thru which it had been possible to work. The points indicate, however, that a slight curve as shown is more nearly correct. The curves should probably meet the zero line at the melting temperature, and become more nearly horizontal as atmospheric temperatures are approached.

The greatest source of error was doubtless due to difficulties in determining the friction of the machine, as an error of a few pounds in the friction for each revolution would make a considerable difference in the results. This is especially true when the fly-wheel makes a large number of revolutions in coming to rest. By making frequent friction tests an attempt was made to reduce the error from this cause as much as possible.

In shearing specimens of small diameter with the rotary shear it was difficult to make some of the specimens revolve while the cutting was in process. This practical trouble caused the rejection of a number of tests, as in these cases the piece was not completely cut off.

The exact composition of these specimens was not known. At the time this work was carried on, it was practically impossible to purchase special steel, and these specimens were from ordinary stock.

The shearing strength has not been referred to because it is impossible to formulate an expression for the shearing strength in terms of the energy required that will hold true for all temperatures and all grades of steel.

The energy required to shear hot steel is usually assumed to equal the product of the shearing strength in pounds per square inch, times the area in square inches, times the stroke in feet, the result being in foot pounds. The stroke in these experiments is of course equal to the thickness of the metal sheared. But the foregoing expression for the energy is manifestly not true, because the resistance which the blade encounters is not constant, but decreases as the stroke proceeds. For very hot metal the resistance at any point in the stroke is approximately equal to the product of the shearing strength multiplied by the area yet to be sheared. It is also true that the working stroke is never equal to the thickness of the metal sheared, except when the steel is very hot, as rupture takes place usually before the stroke is completed. The cooler the metal, the earlier in the stroke will rupture take place. It is probable also that the point of rupture will vary with different grades of steel even at the same temperatures.

TABLE I.

C. R. STEEL SHAFTING WITH ROTARY SHEAR.

1. Test Number.	2. Revs. per min. of Fyl-wheel.	3. Kinetic Energy in Fly-wheel. Ft. lbs.	4. No. of Revs. to Stop.	5. Friction per Rev.-Ft. lbs.	6. Total Friction to Stop. Ft. lbs.	7. Total Shearing Power. Ft. lbs.	8. Area Sheared. Sq. Inches.	9. Shearing Power. Ft. lbs. per. sq. in.	10. Temperature of Specimen. Degrees. Fahr.	11. Size of Specimen in inches.
1	116	16080	267	38.0	10140	5940	3.25	1827	1760	1 7/16 D.
2	119	16910	303	"	11500	5410	"	1665	1765	"
3	120	17200	197	"	7490	9710	4.87	1990	1540	"
4	120	17200	156	"	5490	11260	"	2370	1455	"
5	115	15800	90	48.0	4340	11460	"	2350	1545	"
6	118	16640	187	54.1	10120	6520	3.14	2075	1798	2 D.
7	119	16910	256	45.5	11630	5280	"	1682	1800	"
8	119	16910	296	"	13460	3450	"	1098	1945	"
9	115	15800	273	39.0	10650	5150	"	1640	1695	"
10	118	16640	264	"	10300	6340	"	2010	1625	"
11	116	16080	325	35.7	11600	4480	"	1427	1885	"
12	115	15800	305	"	10880	4920	"	1565	1885	"
13	117	16350	309	"	11040	5310	"	1690	1905	"
14	112	14980	223	36.7	8170	6810	"	2170	1636	"
15	113	15285	354	30.8	10910	4375	"	1394	1853	"
16	114	15512	297	"	9150	6362	"	2013	1685	"
17	114	15512	286	"	8800	6712	"	2140	1668	"
22	118	16640	395	27.6	10900	5740	"	1825	1723	"
23	115	15800	225	28.1	6325	9475	4.90	1932	1846	2½ D.
24	118	16640	240	"	6750	9890	"	2021	1765	"
25	117	16350	234	"	6580	9770	"	1992	1806	"

TABLE II.

CHROME-VANADIUM STEEL WITH ROTARY SHEAR.

1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
1	115	15800	253	38.3	9680	6120	2.45	2500	1660	1¼ D.
2	115	15800	249	"	9540	6260	"	2555	1690	"
3	115	15800	205	"	7860	7940	"	3220	1530	"
4	115	15800	325	35.4	11505	4295	1.227	3500	1710	"
5	116	16080	338	36.4	12303	3777	"	3080	1450	"
6	118	16640	384	"	13977	2663	"	2170	1820	"
7	117	16350	310	"	11284	5066	"	4125	1430	"
10	118	16640	270	38.8	10746	6164	"	5025	1200	"
11	119	16910	309	"	11989	4921	"	4010	1230	"
14	119	16910	288	"	11180	5730	"	4670	1220	"
15	117	16350	285	"	11060	5290	"	4315	1215	"
16	117	16350	365	34.0	12410	3940	"	3210	1570	"
17	118	16640	361	34.6	12500	4140	"	3375	1520	"
18	117	16350	350	"	12110	4240	"	3450	1625	"
19	119	16910	404	"	13980	2930	"	2390	1735	"
20	119	16910	359	"	12430	4480	"	3650	1685	"
21	119	16910	353	"	12214	4696	"	3812	1385	"
22	118	16640	325	"	11245	5395	"	4400	1240	"
23	119	16910	353	"	10760	6150	"	5010	1080	"

TABLE III.

CHROME-VANADIUM STEEL IN STRAIGHT SHEAR.

1. Test Number.	2. Revs. per min. of Fly-wheel.	3. Kinetic Energy in Fly-wheel. Ft. lbs.	4. No. of Revs. to Stop.	5. Friction per Rev.-Ft. lbs.	6. Total Friction to Stop. Ft. lbs.	7. Total Shearing Power. Ft. lbs.	8. Area Sheared. Sq. Inches.	9. Shearing Power. Ft. lbs. per. sq. in.	10. Temperature of Specimen. Degrees. Fahr.	11. Size of Specimen in inches.
24	117	16350	345	40.3	13900	2450	2.454	998	1860	1¼ D.
25	117	16350	270	40.3	10880	5470	3.681	1485	1765	”
29	120	17200	270	34.0	9180	8020	3.681	2175	1575	”
30	117	16350	443	30.0	13290	3060	1.227	2490	1460	”
32	118	16640	458	30.0	13750	2890	”	2355	1575	”
34	118	16640	489	29.0	14200	2440	”	1975	1650	”
35	119	16910	490	29.0	14220	2690	”	2190	1590	”
36	120	17200	500	29.0	14500	2700	”	2200	1475	”
37	120	17200	489	29.0	14200	3000	”	2445	1400	”
38	120	17200	517	28.0	14500	2700	”	2200	1370	”
39	120	17200	517	28.0	14500	2700	”	2200	1405	”
40	119	16900	500	30.7	15350	1560	”	1272	1890	”
41	120	17200	535	”	16410	790	”	644	1815	”
43	120	17200	536	”	16475	725	”	590	1925	”
44	120	17200	526	”	16300	900	”	734	1920	”
47	120	17200	462	”	14175	3025	”	2460	1355	”
48	121	17490	464	”	14250	2920	”	2380	1315	”
49	121	17490	484	”	14850	2290	”	1865	1350	”
50	121	17490	480	”	14740	2410	”	1965	1405	”
52	118	16640	238	30.0	7140	9550	3.681	2580	1425	”
53	117½	16480	320	”	9600	6880	”	1870	1555	”
54	121	17490	408	”	12250	5240	”	1425	1735	”
55	121½	17670	415	”	12440	5230	”	1420	1780	”
56	122	17780	468	”	14040	3740	”	1015	1785	”
57	121	17490	482	”	14440	3050	”	827	1815	”
58	122	17780	476	28.7	13650	4130	”	1122	1770	”
59	121½	17670	420	”	12050	5620	”	1525	1590	”
60	125	18640	390	”	11200	7440	”	2020	1460	”
61	125	18640	330	”	9475	9165	”	2490	1265	”
62	125	18640	335	”	9620	9020	”	2450	1265	”
63	122½	17880	282	”	8080	9800	”	2660	1215	”
64	124½	18500	297	”	8525	9975	”	2710	1232	”
65	124	18350	240	”	6880	11470	”	3110	1220	”
66	124	18350	255	”	7320	11030	”	3000	1230	”
67	123	18074	187	31.0	5840	12234	”	3320	1210	”
68	122	17780	140	32.0	4480	13300	”	3610	1175	”

TABLE IV.

ILL. ST. CO.'S MED. GRADE TEST SPEC. IN STRAIGHT SHEAR.

1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
Test Number.	Revs. per min. of Fly-wheel.	Kinetic Energy in Fly-wheel. Ft. lbs.	No. of Revs. to Stop.	Friction per Rev.-Ft. lbs.	Total Friction to Stop. Ft. lbs.	Total Shearing Power. Ft. lbs.	Area Sheared. Sq. Inches.	Shearing Power. Ft. lbs. per. sq. in.	Temperature of Specimen. Degrees. Fahr.	Size of Specimen in inches.
69	118	16640	501	26.0	13000.	3640	4.1	888	1725	15/16x2 3/16
70	120	17200	554	"	14400	2800	3.46	810	1820	15/16x1 ½
71	120	17200	516	"	13400	3800	4.23	877	1745	"
72	120	17200	510	"	13250	3950	4.23	935	1765	"
73	121½	17670	586	"	15220	2450	2.05	1195	1785	15/16x2 3/16
74	119½	17050	445	"	11570	5480	3.75	1460	1590	1x2¼
76	120	17200	457	"	11880	5320	3.00	1770	1380	1x1½
77	120	17200	452	"	11750	5450	3.00	1830	1350	"
78	120	17200	577	"	15000	2200	1.50	1465	1365	"
79	120	17200	586	"	15200	2000	1.50	1332	1270	"
80	120	17200	534	"	13900	3300	1.50	2200	1175	"
81	119	16910	325	"	8450	8460	3.00	2800	1205	"
82	120	17200	300	"	7800	9400	4.50	2090	1250	1 x2¼

TABLE V.

MISCELLANEOUS SPECIMENS IN STRAIGHT SHEAR.

83	118	16640	490	30.	14700	1940	2.9	669	1510	½x2.1
84	119	16910	518	29.	15050	1860	4.0	465	1570	"
85	119	16910	532	"	15420	1490	5.25	284	1618	"
86	116	16080	491	"	14200	1880	5.25	358	1625	"
87	118	16640	509	"	14770	1870	5.25	356	1665	"
88	119.5	17050	509	"	14770	2280	6.30	362	1660	"
89	119.	16910	400	"	11600	5310	4.50	1180	1745	1x1.5
90	119	16910	358	"	10380	6530	4.50	1450	1650	"
92	120	17200	410	"	11900	5300	6.00	884	1430	½x2.
93	120	17200	338	"	9800	7400	4.50	1645	1545	1x1.5
94	120	17200	320	"	9280	7920	4.50	1760	1508	"
95	120	17200	388	"	11250	5950	6.00	993	1405	½x2
96	119.5	17050	382	"	11080	5970	3.00	1987	1390	1x1.5
97	120.5	17380	427	"	12370	5010	4.00	1255	1295	½x2
98	121.	17490	385	"	11150	6340	3.00	2150	1280	1x1.5
99	120	17200	328	"	9500	7700	3.00	2570	1245	"
100	120	17200	322	"	9350	7850	3.00	2620	1235	"
101	120	17200	394	"	11425	5775	4.00	1445	1160	½x2
102	119.5	17050	391	"	11340	5910	4.20	1420	1165	½x2.1
103	119.5	17050	392	"	11370	5680	4.20	1355	1160	"
104	117.5	16480	450	27.	12140	4340	3.0	1450	1600	1x1.5
105	117.	16350	368	"	10420	5930	"	1975	1385	"
106	117.5	16480	350	"	9450	7030	"	2345	1255	"
107	119.	16910	336	"	9070	7840	"	2610	1155	"
108	118.5	16810	294	"	7940	8870	"	2950	1070	"
109	119	16910	390	"	10500	6410	"	2135	1145	"
110	117.5	16480	375	"	10100	6380	"	2130	1225	"
111	117.5	16480	316	"	8540	7940	"	2645	1100	"

THE
UNIVERSITY OF MISSOURI BULLETIN

ENGINEERING EXPERIMENT STATION SERIES

EDITED BY

E. J. McCAUSTLAND

Dean of the Faculty of Engineering, Director of the Engineering Experiment Station

Some Experiments in the Storage of Coal, by E. A. Fessenden and J. R. Wharton. (Published in 1908, previous to the establishment of the Experiment Station.)

Vol. 1, No. 1.—Acetylene for Lighting Country Homes, by J. D. Bowles, March, 1910.

Vol. 1. No. 2.—Water Supply for Country Homes, by K. A. McVey, June, 1910.

Vol. 1, No. 3.—Sanitation and Sewage Disposal for Country Homes, by W. C. Davidson, September, 1910.

Vol. 2, No. 1.—Heating Value and Proximate Analyses of Missouri Coals, by C. W. Marx and Paul Schweitzer. (Reprint of report published previous to establishment of Experiment Station.) March, 1911.

Vol. 2, No. 2.—Friction and Lubrication Testing Apparatus, by Alan E. Flowers, June, 1911.

Vol. 2, No. 3.—An Investigation of the Road Making Properties of Missouri Stone and Gravel, by W. S. Williams and R. Warren Roberts.

Vol. 3, No. 1.—The Use of Metal Conductors to Protect Buildings from Lightning, by E. W. Kellogg.

Vol. 3, No. 2.—Firing Tests of Missouri Coal, by H. N. Sharp.

Vol. 3, No. 3.—A Report of Steam Boiler Trials under Operating Conditions, by A. L. Westcott.

Vol. 4, No. 1.—Economics of Rural Distribution of Electric Power, by L. E. Hildebrand.

Vol. 4, No. 2.—Comparative Tests of Cylinder Oils, by M. P. Weinbach.

Vol. 4, No. 3.—Artesian Waters in Missouri, by A. W. McCoy.

Vol. 4, No. 4.—Friction Tests of Lubricating Oils and Greases, by A. L. Westcott.

No. 14.—Effects of Heat on Missouri Granites, by W. A. Tarr and L. M. Neuman.

No. 15.—A Preliminary Study Relating to the Water Resources of Missouri, by T. J. Rodhouse.

No. 16.—The Economics of Electric Cooking, by P. W. Gumaer.

No. 17.—Earth Roads and the Oiling of Roads, by H. A. LaRue.

No. 18.—Heat Transmission Thru Boiler Tubes, by E. A. Fessenden and J. W. Haney.

No. 19.—Geology of Missouri, by E. B. Branson.

The University of Missouri Bulletin—issued three times monthly; entered as second class matter at the postoffice at Columbia, Missouri—1,500