A STUDY OF THE CONTRACTION AND EXPANSION OF CARBON STEELS.

A THESIS

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I

OBJECT AND SCOPE OF THE INVESTIGATION.

With the increased price of steel and its increased use throughout every branch of industry the importance of salvaging parts, which have been machined oversize, has begun to be realized. There has been no accurate estimate of the value of parts which, due to careless machine work, are nearly a total loss each year, but it is needless to say that it is a large one.

In view, therefore, of the increasing importance of salvaging these parts the object of the present investigation is an experimental study of the application of heat treatment to the problem in order to furnish men in charge of such work exact information as to the limitations and results attainable.

With a view to making the results of this investigation available to those who have not had special technical training, the authors have presented the results by a series of curves which should be clear to the average reader, however, in order to make a complete report, all experimental data has been included so that readers may familiarize themselves with the methods employed in investigating the various questions which have been considered.

II

THEORY

We find that in quenching a piece of steel, during the process of heat treating, if the piece is not handled properly it is liable to warp due to the unequal contractions and expansion in the steel. This characteristic is particularly emphasized in forgings or tools of unequal thickness. If it were possible to cool each particle of the piece in the time and order desired the resulting dilatation could be regulated with regard to direction.

We know as a result of recent research work that when a piece of steel is heated through its critical range the formation of Austenite takes place with a decrease in volume, and that a somewhat corresponding and opposite increase in volume takes place when it is cooled through the same critical range.

Sauveur states - "that the metal which in cooling above the upper critical point was contracting, as is the rule with all cooling bodies, on passing through the upper critical point undergoes suddenly a marked dilatation amounting to over one thousandth of its length, immediately followed again by a normal contraction. Such dilatation implies that the change of Gamma into Beta iron takes place with an augementation of volume or in other words that Gamma iron is denser, has a higher Specific Gravity, than Beta iron". The dilatation occurring at the upper critical point, on cooling, for steels containing respectively 0.05 to 1.5 percent carbon are shown graphically by Sauveur in plate IB. On heating at the upper critical point a spontaneous contraction occurs of the same magnitude as the dilatation on cooling. Benedick's determined with great care the dilatation of pure iron between 700° and 950° centigrade and some of his results are shown on plate IA. The particular point to be noted is the occurence of a marked dilatation at C, the upper critical point.

There has been considerable discussion as to whether or not a dilatation occurs at the second transformation point. It is true that there is no such marked change, as occurs at the upper critical point and it is questionable whether there is any change. At the first transformation point a third dilatation takes place on cooling. The maximum dilatation which can occur is in the case of a eutectoid steel when cooling through its single critical point. All changes of course vary with the carbon content of the steel.

The preceding theory is shown graphically on plate II. In heating from a to b there is an expansion (marked +). On passing through the critical range there is a contraction (marked -). On heating still further a positive action takes place again. On cooling through the same curve the ranges will change in sign.

A theory which has been advanced, but not published is that if the steel is heated too fast the positive forces will predominate and the finished piece will be larger than the original and that if the steel is heated too slow the negative forces will predominate and the finished piece will be smaller than the original.

III

APPARATUS AND MATERIAL

All laboratory work was done in the Michigan Agricultural College heat treatment laboratory and forge shop. This is a modern shop equipped with several small furnaces and one large one. These furnaces are gas fired, using Lansing city gas having a quality of about 580 B.T.U. Air is furnished by a Root's Positive Pressure Blower, with a constant pressure exhaust valve to keep the pressure on the furnaces constant regardless of the number of furnaces in operation.

In this investigation a surface combustion style C. furnace was used exclusively. This type of furnace has an automatic valve for maintaining a constant mixture of gas and air. The flame enters the combustion chamber at the level of the hearth but inclined downward so that it would normally pass beneath it. The space between the hearth and the walls of the furnace is filled with loose pieces of carborundum so as to break up the flame and produce complete combustion. There is an adjustment on the mixing valve for varying the porportion of gas to air. During this investigation a slightly rich mixture was used at all times to prevent oxidation of the samples.

A Leeds and Northrup potentiometer attached to an iron-constantin thermocouple was used to measure the temperature.

A quenching bath of water at a temperature of sixty degrees fahrenheit was used for cooling the samples. This temperature was measured by a mercury thermometer and was kept constant by removing warm water and adding cold water.

The apparatus used in measuring the samples consisted of micrometers, telescope gages, thickness gages and scales which were borrowed from the college machine shop and are described in detail elsewhere. A pin gage, used in measuring the pitch diameter, was constructed by the authors.

The material tested consisted of automobile transmission gears, and were of Reo B-15 forged stock whose analysis is identical with S.A.E. 1020. These gears had been completely machined but not carburized. The countershaft drive gear was selected as being typical of all such pieces, and because of its large diameter the change in size would be greater.

IV

MEASUREMENTS OF SAMPLES.

In order to ascertain the amount of shrinkage resulting from any heat treatment it is evident that an accurate overall measurement of the gear must be made before and after the treatment. In addition, to be of value, the measurements must be made with the same instruments and at the same spot on the gear, since the variation in the surface might cause readings to be obtained which, if not taken at the same points, would be greatly in error. In order to insure the readings being taken at the same point a drawing of the gear was made and the dimensions on which measurements were to be taken, were indicated and numbered. In addition to this the points on the rim were marked with a prick punch to locate the teeth on which the diameters were measured. In order to eliminate errors due to taking the same measurement with several different micrometers, the same micrometers were used for all corresponding measurements.

Numbers one to three inclusive were measurements of the diameter on the pitch circle. This showed the change in the outside diameter and was taken as a base rather than the top or bottom of the teeth, because of its greater importance in determining the running qualities of the gears. Numbers four and five were the distances from the plane of the end of the hub to the plane of the rim of the gear. This gave a check upon warping caused by the forces set up in shrinking. Numbers six to nine inclusive were measurements of the inside diameter of the hub, the most important of all the measurements taken, since the object of the whole process was to reduce this diameter. This was measured in two directions at right angles and at each end of the hub. It was necessary to measure at each end of the hub as the hole was counterbored near the center leaving a short surface near each end for a bearing on the shaft. It was necessary to measure at right angles in order to tell whether the hole grew out of round. Numbers ten, eleven and twelve were measurements on the thickness of the rim through specified points. These showed actual shrinkage of the metal.

MEASURING INSTRUMENTS.

In order to measure the pitch diameter it was necessary to construct a pair of gage pins which would fit between the teeth and bear upon the tooth at each side at the circumference of the pitch circle. These pins were made from drill rod, hardened and ground to proper size. By use of these pins together with a pair of six to seven inch outside micrometers, a very accurate measurement could be taken checking to within five ten-thousandths of an inch. An accurate measurement of the pitch diameter could not be obtained since there was an odd number of teeth in the gear, a condition which brought a tooth opposite each space. Since a comparative measurement was all that was required this did not cause a sensible error in the results.

The distance from the plane of the end of the hub to the plane of the rim was measured by means of a set of thickness gages and a scale. A heavy scale was used and the gages inserted between the scale and the hub end. Readings were taken at the ends of two diameters at right angles and the readings for each diameter averaged. These readings would show any tendency to warp or dish.

The measurement of the hole, which was the most important and also the most difficult to accurately obtain, was secured by means of a telescope gage and outside micrometers. Due to the roughness of the inside surface it was rather hard to get a close check on this reading, consequently it was necessary to take several readings and record the average.

The measurements of numbers ten, eleven and twelve were obtained directly with a pair of one inch micrometer calipers. These readings were taken at the base of corresponding teeth on all gears.

V

DESCRIPTION OF TESTS.

It was necessary in order to make the results useful, that similar conditions should exist in all tests, therefore the first step was to determine the method of heating the samples. This was done by heating several samples to the same temperature but at different rates. One extreme was to place the gear in a cold furnace and bring both up to temperature together. Another extreme was to bring the furnace up to temperature and then place the gear in it. The last extreme was productive of the best results and was adopted for all tests.

In preparing the samples (transmission gears) for test the hole in the center was filled with moist fire clay and packed hard. The clay was rounded well over the edge of the hole to prevent any oxidation near this important point of measurement.

In placing the sample in the furnace great care was used to locate each one in the same spot, which was adjacent to and partly covering the thermo-couple. This assured that the conditions, during heating, would be the same for all tests.

The quenching water was kept at sixty degrees by means of frequent changes.

All gears were left in the furnace for a period of thirty minutes.

The furnace temperatures were very closely regulated.

All measurements were made and checked by the same man.

In order to distinguish between the pieces, after heating, they were numbered with steel dies.

VI

CONCLUSIONS.

A careful study of the data of these tests has led the writers to the following conclusions:

1. It is shown by curves 6, 7, 8 and 9 that it is possible to obtain a shrink, on parts such as gears, of about ten thousandths of an inch by successive heat treatments.

2. It is shown by curve number 3A that it is possible to obtain a large enough shrink, on parts such as gears, in one heat treatment to salvage a large portion of such parts which have been machined oversize, because the average oversize error is not over two thousandths of an inch.

3. That, as has been proven in previous research, a portion of the shrink is due to a change in volume of the iron in going from one state to another.

4. That, because of the observed tendency of the web and rim to cool first, a considerable portion of the shrink is due to the shape of the sample.

VII

DATA - Differences.

Gear #1. 1350°

M# 1	2	3	4	5	6	7	8	9	10	11	12
.0014	.0033	.0010	.0005	.003	.002	.0015	.004	.0038	.0022	.0006	.0015
.011	.0146	.0122	.00089	.001	.0013	.0015	.0009	.00115	.0003	.0014	.0005
.0045	.006	.0048	.00289	.003	.0017	.0015	.0026	.00175	.0043	.0024	.0053
.0015	.0045	.0052	.006	.008	.0008	.0005	.0000	.004	.0018	.0004	.0033
.0035	.0015	.0023	.005	.006	.0000	.001	.0005	.0005	.002	.0005	.001
.004	.0045	.003	.001	.002	.000	.001	.004	.001	.0012	.0035	.001
.0015	.0018	.0035	.0045	.0045	.0001	.001	.003	.0045	.0002	.000	.0002

Gear #2. 1375°.

.005	.0022	.0034	.002	.0025	.0005	.001	.002	.0018	.0002	.001	.001

Gear #3. 1425°.

.0018	.0039	.004	.001	.0015	.0031	.0015	.0019	.0014	.0006	.001	.000

1500°.

.0085	.0072	.0052	.0045	.006	.0002	.0049	.0025	.0015	.0002	.000	.000

Gear #4. 1500°.

.001	.0006	.0046	.0015	.0025	.0005	.0008	.0002	.0012	.001	.0002	.0000

Gear #5. 1500°

.0113	.011	.0105	.0025	.0005	.0055	.005	.0016	.0015	.0009	.0007	.0016

Gear #6. 1500°.

.0036	.002	.003	.001	.0005	.0004	.0000	.0014	.0013	.0004	.0003	.0005

Gear #1. As Rec. to 1350°.

1	2	3	4	5	6
6.1211	6.1203	6.1185	.0085	.011	1.372

Heat to 1350°. Q. in water at 60°.

6.1225	6.1236	6.1195	.009	.014	1.370

Temp. of gear brought up gradually with the furnace.

Reheated to 1350°.

6.1115	6.1090	6.1075	.00811	.013	1.3687

Oven up to temp. then gear placed in for 35 minutes and quenched in water.

Reheated to 1350°.

6.107	6.103	6.1025	.011	.016	1.3668

Reheated to 1350°

6.1055	6.0985	6.0973	.017	.024	1.366

Reheated to 1350°

6.102	6.097	6.095	.022	.030	1.366

Reheated to 1350°

6.098	6.0925	6.092	.023	.032	1.366
6.0965	6.0907	6.0885	.0275	.0365	1.3659

Gear #1. As Rec. to 1350° (Continued)

7	8	9	10	11	12
1.371	1.371	1.371	.882	.884	.881

Heat to 1350°. Q. in water at 60°

1.3695	1.367	1.3678	.8842	.8846	.8825

Temp. of gear brought up gradually with the furnace.

Reheated to 1350°.

1.368	1.3661	1.36675	.8845	.886	.883

Oven up to temp. then gear placed in for 35 minutes and quenched in water.

Reheated to 1350°

1.3665	1.3635	1.365	.8802	.8836	.8777

Reheated to 1350°

1.366	1.3635	1.361	.882	.884	.881

Reheated to 1350°

1.365	1.363	1.3605	.880	.8835	.880

Reheated to 1350°

1.364	1.359	1.3595	.8788	.880	.879
1.363	1.356	1.355	.8786	.880	.8788

Gear #2. As Received.

Heat to 1375°

Quench in H_2O .

1	2	3	4	5	6	7	8	9	10
6.118	6.1182	6.1184	0.0	0.0	1.372	1.372	1.3715	1.371	.882
6.113	6.116	6.115	0.002	0.0025	1.3725	1.373	1.3698	1.3692	.8818

Temperature of water = 60°.

(Continued)

11	12
.8825	.882
.8815	.881

Temperature of water = 60°.

Gear #3. As received.

1	2	3	4	5	6	7	8	9	10	11	12
6.1141	6.1165	6.1205	.011	.0105	6.3717	1.3724	1.3714	1.3714	.8788	.879	.879

Furnace heated to 1375° before gear was put in, then raised above 1425° for 35 minutes and quenched in water at 60° from 1425°.

6.1123	6.1126	6.1165	.010	.012	1.3686	1.3709	1.3695	1.370	.8782	.880	.879

Heated to 1500° and Quenched.

6.104	6.1054	6.1110	.0145	.018	1.3684	1.366	1.367	1.3655	.878	.880	.879

Gear #4. As Received to 1300° and Quenched.

1	2	3	4	5	6
6.1185	6.1162	6.1141	.0075	.0055	1.3725
6.1175	6.1156	6.1095	.009	.008	1.372

(Continued)

7	8	9	10	11	12
1.373	1.3715	1.3715	.879	.8788	.8788
1.3722	1.3706	1.3706	.878	.879	.8788

Gear #5. As Received to 1500°

1	2	3	4	5	6
6.1371	6.131	6.1315	.004	.004	1.3715
6.1159	6.120	6.121	.0065	.0045	1.366

(Continued)

7	8	9	10	11	12
1.372	1.372	1.372	.8804	.8793	.8796
1.367	1.3704	1.3704	.8795	.8786	.878

Gear #6. As Received to 1300°

1	2	3	4	5	6
6.1196	6.119	6.120	.0045	.005	1.3715
6.116	6.117	6.117	.0035	.0045	1.37

(Continued)

Measure Numbers 8 and 9 near edge.

7	8	9	10	11	12
1.3715	1.3718	1.3718	.8804	.880	.8799
1.3715	1.3704	1.3705	.880	.8803	.8794

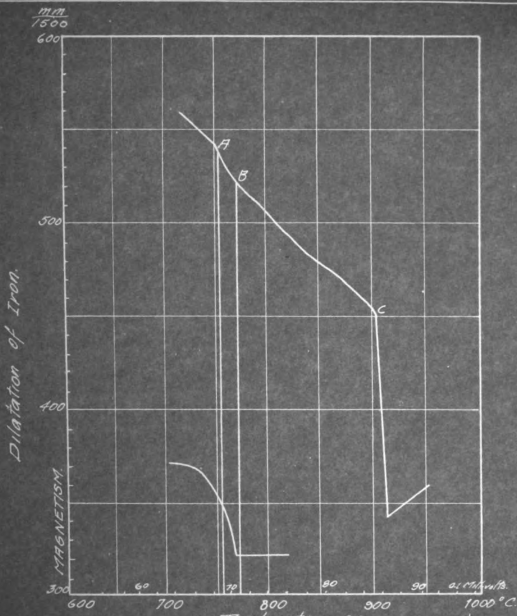

PLATE-I A.

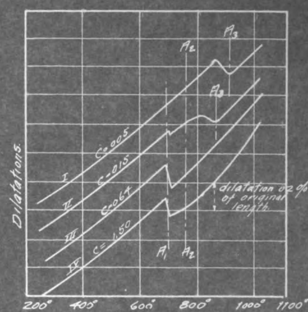

PLATE-I B.

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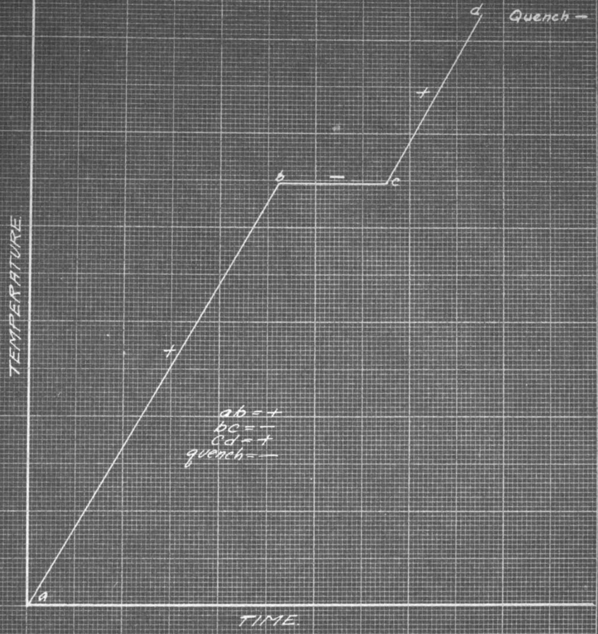
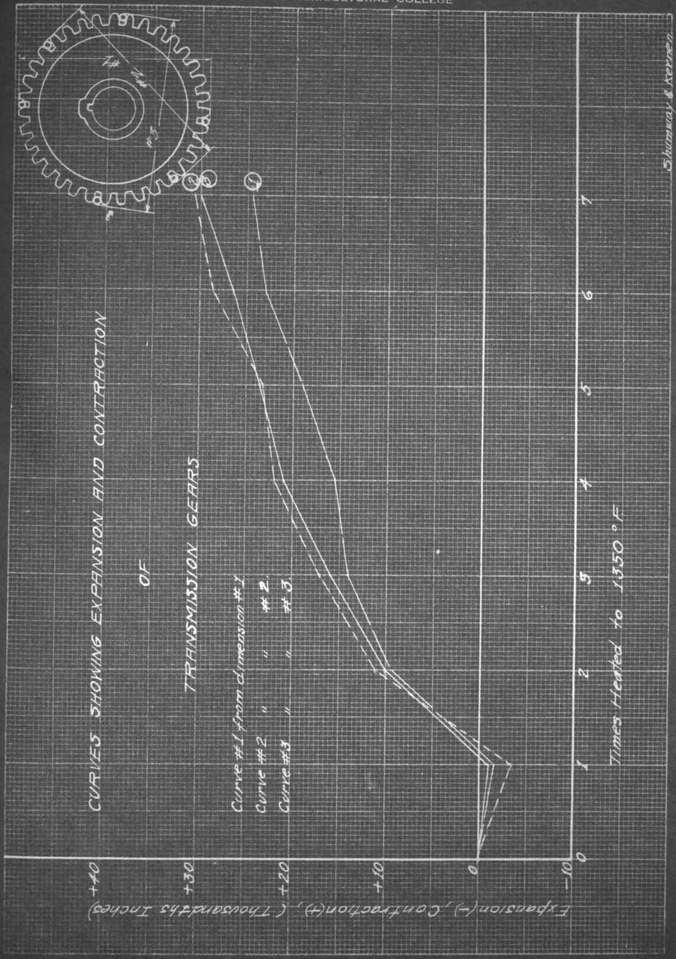
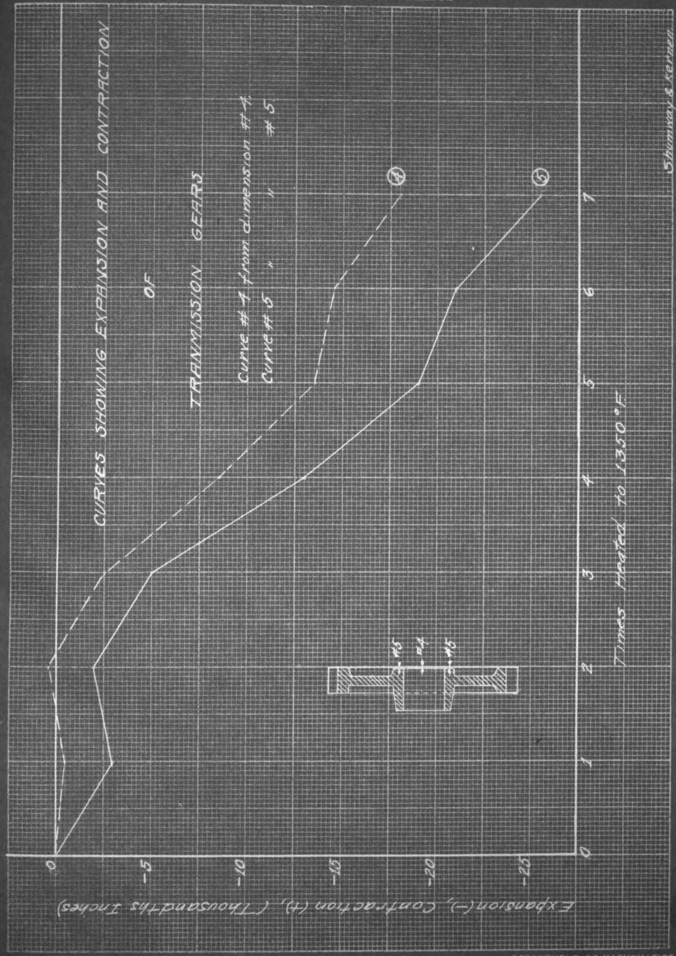
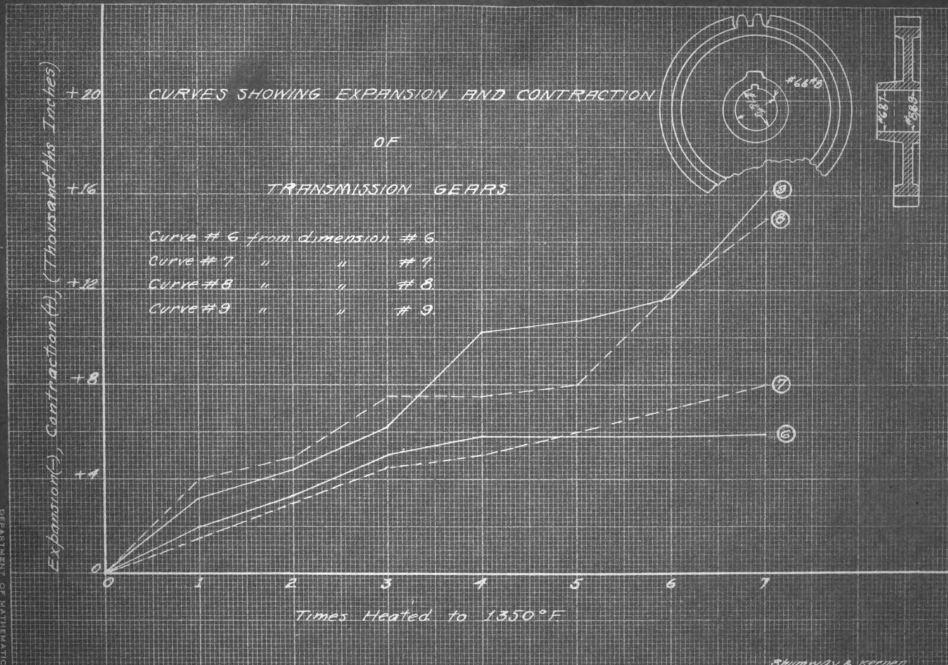


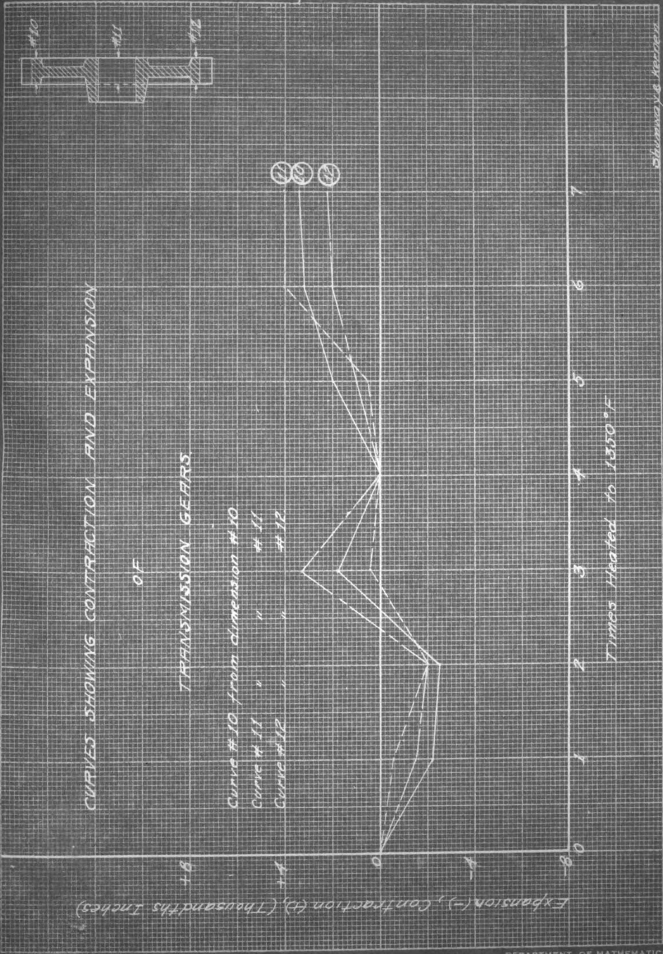
Heating Curve.

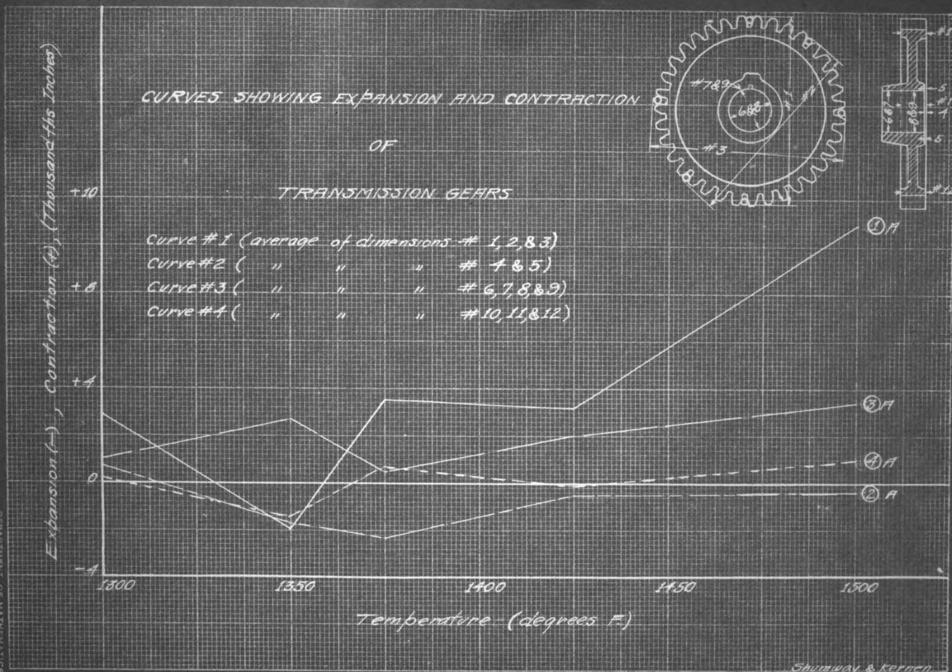
PLATE – II.


CURVES SHOWING EXPANSION AND CONTRACTION
OF
TRANSMISSION GEARS
Curve #1 from dimension #1
Curve #2 " " #2
Curve #3 " " #3
#1
#2
#3
Times Heated to 1350 °F
0
1
2
3
4
5
6
7
Expansion(−), Contraction(+), (Thousandths Inches)
+40
+30
+20
+10
0
−10
Shumway & Kernen


CURVES SHOWING EXPANSION AND CONTRACTION
OF
TRANMISSION GEARS
Curve # 4 from dimension # 4
Curve # 5 " " # 5
4
5
#5
#4
#5
0
1
2
3
4
5
6
7
Times Heated to 1350 °F
0
-5
-10
-15
-20
-25
Expansion (−), Contraction (+), (Thousandths Inches)
Shumway & Kennen


CURVES SHOWING EXPANSION AND CONTRACTION
OF
TRANSMISSION GEARS.
Curve # 6 from dimension # 6.
Curve # 7 " " # 7.
Curve # 8 " " # 8.
Curve # 9 " " # 9.
Expansion(−), Contraction(+), (Thousandths Inches)
+20
+16
+12
+8
+4
0
0
1
2
3
4
5
6
7
Times Heated to 1350° F.
6
7
8
9
#66 #8
#687
#689
Shumway & Kernen


CURVES SHOWING CONTRACTION AND EXPANSION
OF
TRANSMISSION GEARS
Curve #10 from dimension #10
Curve #11 " " #11
Curve #12 " " #12
#10
#11
#12
Times Heated to 1350°F
0
1
2
3
4
5
6
7
Expansion (−), Contraction (+), (Thousandths Inches)
+8
+4
0
−4
−8


CURVES SHOWING EXPANSION AND CONTRACTION
OF
TRANSMISSION GEARS
Curve #1 (average of dimensions # 1, 2, & 3)
Curve #2 (" " " # 4 & 5)
Curve #3 (" " " # 6, 7, 8, & 9)
Curve #4 (" " " # 10, 11, & 12)
Expansion (—), Contraction (+), (Thousandths Inches)
+10
+6
+4
0
-4
1300
1350
1400
1450
1500
Temperature (degrees F.)
1 A
3 A
4 A
2 A
#1
#2
#3
#7&9
#10
#11
#12
.688
.687
5
4
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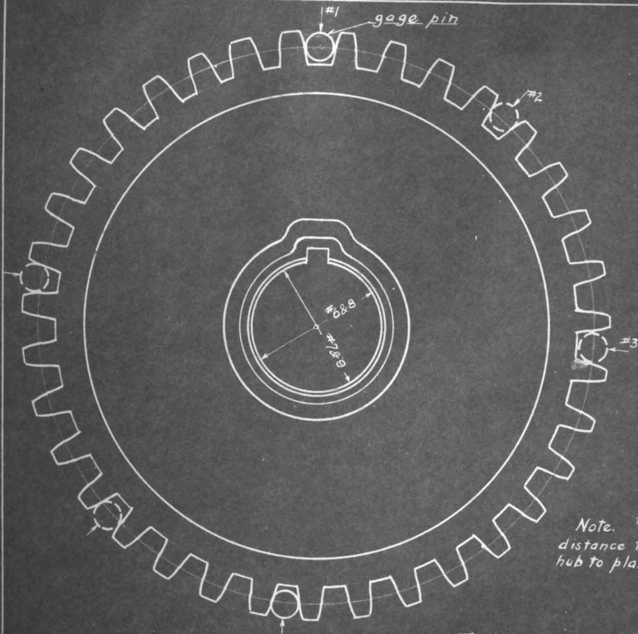

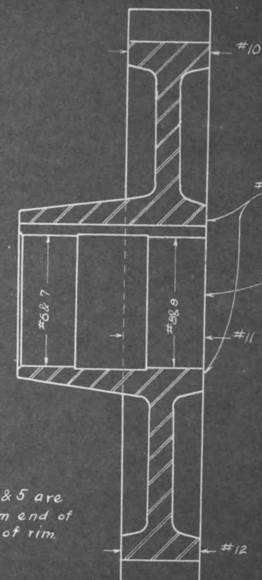

Note. #4 & 5 are distance from end of hub to plane of rim.

Transmission Gear.

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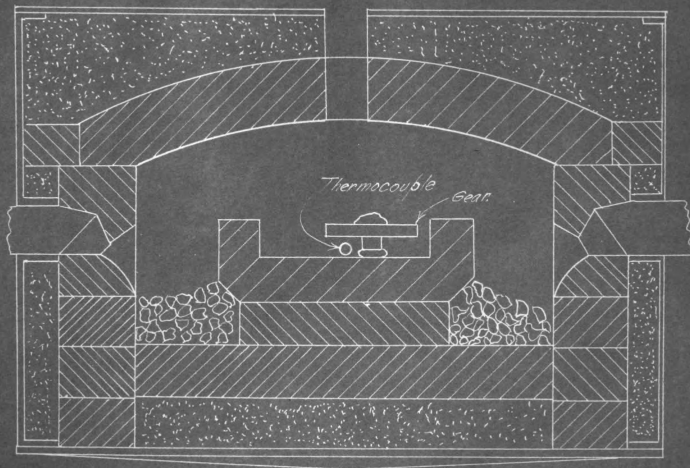

Surface Combustion Furnace.

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