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O T T A W A March 14, 1946.

REPORT

of the

ORE DRESSING AND METALLURGICAL LABORATORIES.

Investigation No. 1960A.

(Subsequent to Investigation Report)
(No. 1960, dated November 9, 1945.)

Distortion in Flame Hardening Naval Gun Racer Plates.

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(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 March 14, 1946.

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Introduction:

At the request of Commander (E) G. Taylor R.N.V.R., of the British Admiralty Technical Mission, Ottawa, Canada, an investigation was undertaken by these Laboratories to determine the practicability of flame hardening of naval gun racer plates. The report of this investigation (Investigation No. 1960, dated November 9, 1945) showed that a desirable increase in hardness could be obtained on the race surface over the entire range of chemical composition encountered in the production of these plates. However, since all work reported in this investigation was done on small samples of racers the question of distortion of a complete plate naturally arose. This report concluded with a recommendation that one or more complete plates be hardened and measurements be made to detect any distortion which might take place.

This report gives the results of checks for distortion

(Introduction, cont'd) -

on two complete racer plates after hardening. These plates were of comparable composition to those on which hardening experiments were conducted in these Laboratories. These experiments were conducted at the Longueuil plant of the Dominion Engineering Co., Longueuil, Quebec, in co-operation with the Dominion Oxygen Co. Limited.

Object of Investigation:

To detect any distortion of racer plates that might take place as a result of flame hardening the racers.

PROCEDURE:

(1). Two, twin Bofors cast steel racer plates, were secured from National Munitions, Montreal, Quebec. The following table lists the stated analyses of the heats from which these plates were made. To continue the plate numbering system used in the previous report, these plates are designated as No. 3 and No. 4, respectively.

TABLE NO. I.

		Plate No. 3	Plate No. 4
		- Per Cent -	
Carbon	-	0.23	0.36
Phosphorus	-	0.017	0.021
Sulphur	-	0.022	0.020
Manganese	-	0.69	0.58
Silicon	-	0.39	0.44

Racer Plate No. 3.

(2). The experimental arrangements were as follows. A lower racer plate was set up on four surface blocks placed at equal distances around the periphery of the plate. This racer plate functioned solely as a table. On this was set a complete inverted training base which, with its gears, provided a means of rotation. On top of the training base was set the racer plate (Plate No. 3) to be hardened. Power to drive the train-

(Procedure, cont'd) -

ing base was obtained from a milling machine through a dividing head and a coupling shaft.

The flame hardening apparatus (the same as used in the previous investigation) was set up and clamped to an independent set of surface blocks. Water connections were made to the flame head and quenching fixture. The flame head was adjusted at right angles to the racer surface and to provide complete flame coverage of the race without overlapping at the edge. Figure 1 shows the arrangements at this stage of preparation.

An independent set of surface blocks diametrically opposite the flame head was set up to support a vertical stand and horizontal arm. This was clamped to the surface blocks to prevent moving. The horizontal arm carried over the surface of the race and supported a dial gauge reading in thousandths of an inch. Unfortunately the race was in the rough machined condition and numerous surface projections were noted. These will be removed by filing but the surface was still sufficiently rough to make accurate measurements difficult.

A second check for race surface levelness was made by positioning the finger of the dial gauge at the centre of the race and making one complete revolution, noting the gauge readings at the equally spaced stations around the race. The dial was set to zero at an arbitrarily selected starting point and readings made until this point was reached for a second time. This indicated that the race surface was level to within 0.005 inch which was considered to be of no practical importance.

In order to detect non-uniformity of the race surface prior to hardening, a series of measurements was made as follows. A bar 12 x $2\frac{1}{2}$ x 1/2 inches with accurately ground parallel sides was laid across the race surface on the 1/2-inch face. The outer end of the bar was aligned with the outer edge of the racer plate, the remainder of the bar projecting through

(Procedure, cont'd) -

a lightening hole in the flange with the inside end pointing towards the hub. At each of 12 stations equally placed around the circumference, dial gauge readings were taken at each end of the upper surface of the bar. At the starting point (Station No. 1) the dial gauge was set to zero at the outer end of the bar and this setting was not changed during this series of measurements. The following table lists the results secured:

TABLE NO. II. - Bar End Readings - Thousands of In.

Station No.	Outside	Inside	Max. Difference Between Readings
1	0.000	+0.004	0.004
2	-0.002	+0.004	0.006
3	-0.010	-0.007	0.003
4	-0.023	-0.012	0.011
5	-0.026	-0.014	0.012
6	-0.019	-0.013	0.006
7	-0.018	-0.012	0.006
8	-0.025	-0.013	0.012
9	-0.022	-0.013	0.009
10	-0.019	-0.008	0.011
11	-0.010	-0.006	0.004
12	-0.001	-0.003	0.002

It is conceded that this method of measurement would exaggerate any lack of symmetry of the race surface by a factor depending on the length of the bar from the point of measurement to a slight projection or raised area on the race surface. However, the measurements do indicate that the surface of the race does not show any appreciable variations in surface level.

(3). In flame hardening, the speed of rotation of the race was adjusted and measured by positioning on indexing arm over the centre of the race and measuring the distance travelled in a unit of time. A speed of 3-3/8 inches per minute was selected in view of the low carbon content and the necessity of attaining a high austenizing temperature. The detail procedure was as follows: (1) start rotation (2) light torch

(Procedure, cont'd) -

(3) water quench turned on when depth of heat penetration was deemed sufficient (4) position at start of quench marked on flange surface. Gas pressures were; oxygen 8 pounds, acetylene 10 pounds. These are gauge readings at gas manifolds. The acetylene pressure was reduced by the torch valve to give a neutral flame.

Shortly after the start of the operation it was noticed that two jets were producing surface melting of the race. This condition may be counteracted by either (1) increasing speed of travel or (2) increasing distance between flame head and race surface. These adjustments were made simultaneously. Speed was increased to 4¼ inches per minute and height of end of cones above race surface was increased to 1/8 inch. This eliminated all melting with the exception of one jet which had apparently worn over-size. A slight increase of flame head height completely eliminated this but not before approximately one half the total race surface had been marred.

Figure 2 shows the operation in progress. It will be noted that the back flare of the flame is playing on the inside surface of the flange. When the operation was completed it was estimated that the flange was at a temperature of at least 300° F. This degree of heat is highly undesirable in that a heavy member at this temperature can cause severe distortion of thinner sections.

Rough measurements by the same method as reported above showed an upward bulge in the centre of the race in the order of 0.025 inch. This distortion was far greater than had been anticipated by the writer and is far greater than that ordinarily considered correctable by grinding. For this reason the "after hardening" measurements were not completed.

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(Procedure, cont'd) -

Racer Plate No. 4.

(4). The experimental arrangement for hardening the race of this plate was generally the same as with Plate No. 3 with the following exceptions. The plate to be hardened was supported six inches above the training base by means of four surface blocks placed at equal intervals around the plate. These blocks were placed just inside the underside of the race. This procedure permitted placing a water jet directly under the water quenching fixture attached to the flame head. The jet was clamped to the surface blocks supporting the flame hardening apparatus. The water jet was made from 1/2-inch steel water pipe and supplied by a line of that size. The jet orifice was flattened which gave a thin stream of water moving at considerable velocity. The stream of high velocity water would be more effective in removing heat from the thin centre of the race than a solid stream of water moving with lower velocity. The bottom jet was aligned so that it was directly under the water-quench fixture which was attached to the flame head.

The surface of this race was finished ground which permitted measurements directly on the race surface. The same dial gauge and supporting apparatus was used as described above to check the surface before hardening. Level was checked by positioning the dial finger on the centre of the race and making one complete revolution. Dial readings were taken at 12 stations around the complete race at equally spaced distances. The plate showed a maximum deviation of 0.0035 inch from true level which is of no practical significance.

(5). In order to detect non-uniformity of race surface prior to hardening, a series of measurements were made as follows. The total race circumference was marked off into

(Procedure, cont'd) -

eight equally spaced sections. One station (No. 1) was arbitrarily selected as the starting point and marked on the flange by a double pop mark. The remaining seven stations were marked with a single pop mark. The plate was rotated until the double pop mark of the Station No. 1 and the finger of the dial gauge were in line. The finger was thus adjusted as close to the inside edge of the race as possible and the dial adjusted to read zero. The plate was then rotated to the remaining stations in a clockwise direction, finger and pop marks aligned and dial reading noted. At Station 1 the indexing arm and dial finger were adjusted so that the finger was in the centre of the race and the dial set to zero. One complete revolution was made noting the dial reading at each station. This was repeated for the outside of race position. The following table lists the results of this series of measurements.

TABLE NO. III. - Before Hardening.

Station No.		Inside	Race Centre	Outside
1	-	0.000	0.000	0.000
2	-	-0.006	-0.0025	-0.005
3	-	-0.007	-0.0075	-0.008
4	-	-0.009	-0.0085	-0.008
5	-	-0.005	-0.005	-0.0045
6	-	-0.006	-0.006	-0.005
7	-	-0.004	-0.004	-0.0035
8	-	-0.001	-0.001	-0.0015
1	-	±0.000	-0.001	+0.002

These measurements, in effect, show the variations in surface of three concentric rings. Since at each position the dial gauge was set to zero there is no relationship between the three rings. It will be noted that there is a maximum variation in level of 0.009 inch, 0.0085 and 0.010 inch respectively of the inside, centre and outside rings respectively. It will be noted also that there is a noteworthy uniformity of readings transverse to the race surface at

(Procedure, cont'd) -

each station.

(6). In order to detect any distortion of the flange the following system was adopted. At four equally spaced points around the flange and hub, pop marks were made on the flange and hub with a fixed length arm bearing a punch at each end. These distances were to be gauged after hardening with the same instrument.

(7). In flame hardening, the speed of rotation of the race was measured as with Plate No. 3 by means of an indexing arm positioned over the centre of the race. The speed was set at 5.4 inches per minute, this being the closest available to the desired 6 inches per minute. The sequence of operations was the same as previously described with the exception that the underwater jet was turned on simultaneously with the quench. Gas pressures were; oxygen 9 pounds, acetylene 11 pounds. These are gauge readings at the gas manifolds. The acetylene pressure was reduced at the torch valve to give a neutral flame.

Prior to the hardening operation all jet sizes were checked with a No. 56 drill and several oversize jets removed and replaced with new jets. Flame head height above the race surface was adjusted to bring the end of the cones 1/16 inch from the race surface. Unfortunately one jet caused a slight melting action on the race surface which, while not important with regard to this experiment, would be cause for grave concern in a production run.

(8). At the completion of the operation, and while the flange was at its maximum temperature, the hub-to-flange distances were checked at the four stations. It was found that the flange had distorted outward from the hub approximately

(Procedure, cont'd) -

1/16 inch at each station. However, when cold, a second check revealed that the flange had returned to its original position.

(9). After hardening, measurements of the race surface was made by the system outlined above in Section 5. The following table lists the results secured:

TABLE NO. IV. - After Hardening.

Station No.		Inside	Race Centre	Outside
1	-	0.000	0.000	0.000
2	-	-0.005	-0.006	-0.006
3	-	-0.004	-0.006	-0.009
4	-	-0.005	-0.005	-0.016
5	-	+0.002	+0.004	+0.0015
6	-	+0.001	+0.004	+0.010
7	-	±0.000	+0.0055	+0.010
8	-	-0.002	+0.004	+0.006
1	-	-0.001	+0.003	+0.007

It will be noted that with regard to the centre and outside positions that the dial gauge does not return to zero at Station No. 1 after one complete revolution. This indicates that the stand or horizontal arm was insufficiently rigid and had allowed a small movement to take place. These readings are therefore of doubtful value. However, the measurements of the inside of the race indicate a maximum difference of level of 0.007 inch which compares favourably with a difference of 0.009 inch detected before hardening. This table is included for completeness of record and will not be discussed further.

(10). After hardening, a series of measurements to detect distortion were made by Mr. A. G. Hinchcliffe, B.A.T.M., and reported to these Laboratories. The following is the method stated to have been used. The racer plate was removed from the training base and placed on a surface plate 6 x 6 feet.

(Continued on next page)

(Procedure, cont'd) -

the surface plate was level and accurate to within 0.001 inch. Since the outside rim of the racer plate was not in contact with surface plate this upward distortion was measured by means of thickness feelers (see Sketch No. 1 below). The distortion measured at the eight stations are shown in the following table.

Sketch No. 1.

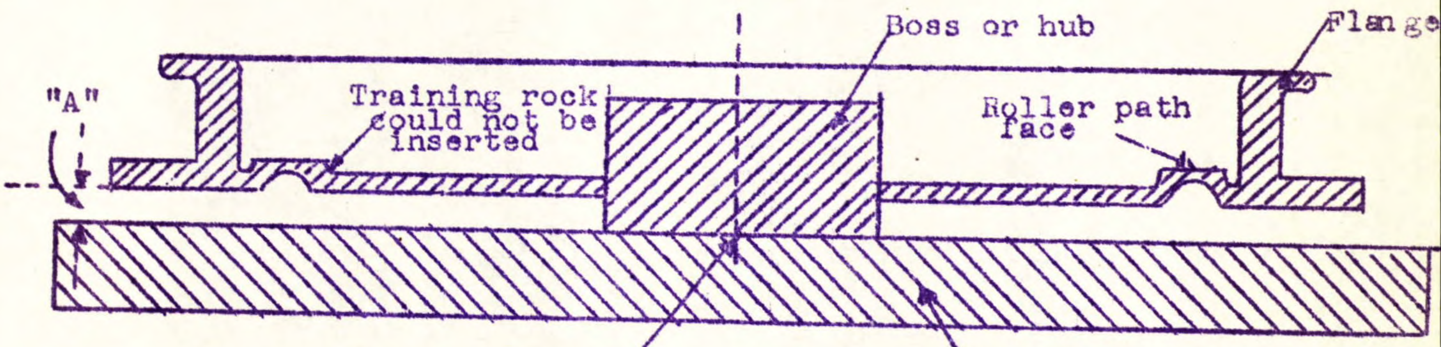


TABLE NO. V.

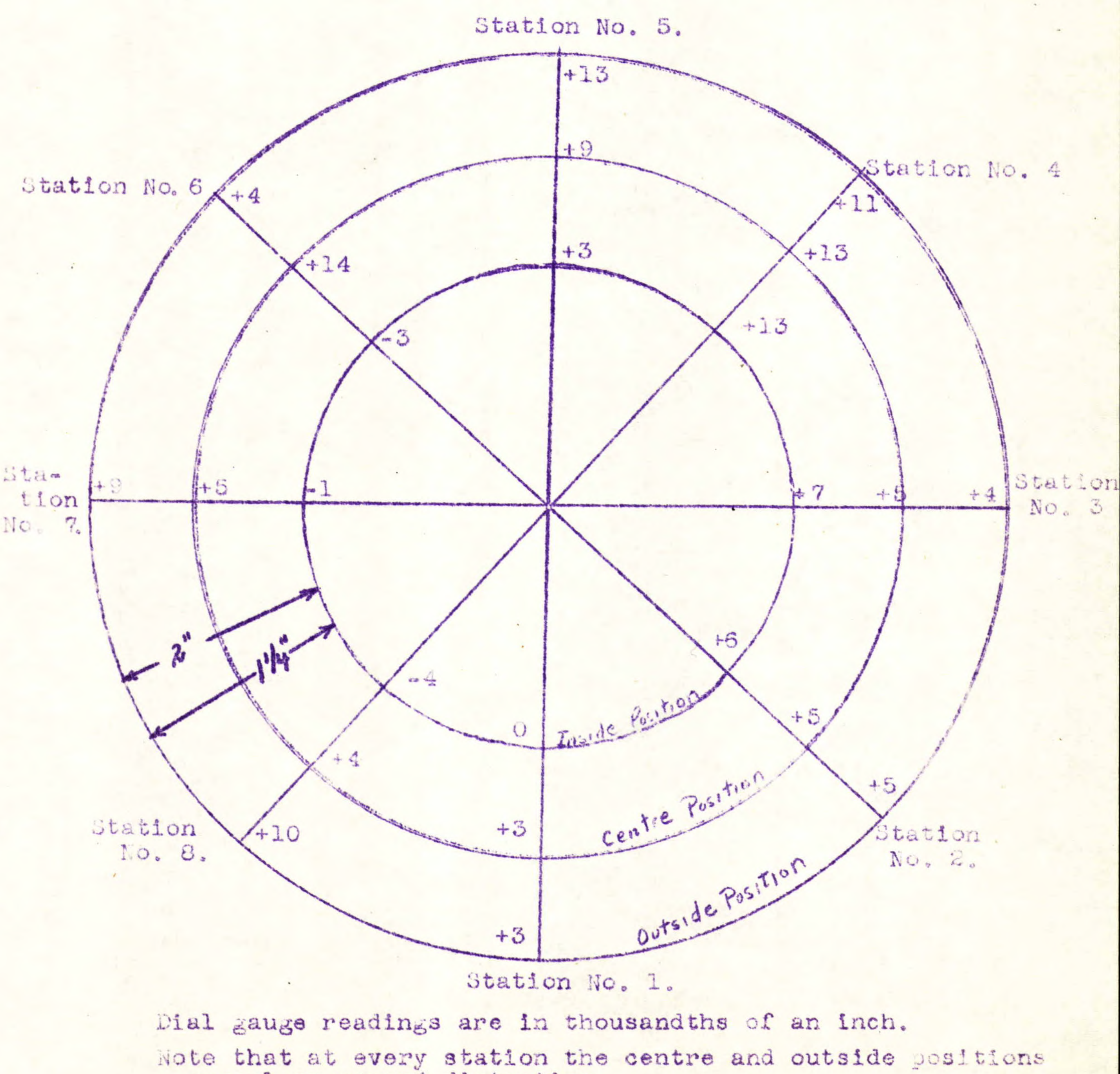
Station No.	"A" - Upward distortion at Rim. (Inches)	
1	0.051	
2	0.050	
3	0.046	
4	0.056	Average 0.053
5	0.043	
6	0.058	
7	0.065	
8	0.055	

In addition, measurements were made to check the distortion of the race surface. The following is the method reported to have been used. A dial gauge was mounted on fixed vertical and transverse arms and these attached to a surface block. Adjustments were made so that the dial gauge finger part touched the race surface. The entire arrangement could be moved around the recer plate by sliding on the surface plate. By inserting accurately machined spacer blocks

Procedure, cont'd) -

between the dial surface block and the outer, machined rim of the racer plate the same distance from surface block to rim could be reproduced at any station. By using various widths of spacer blocks the dial finger could be positioned accurately on the inside, centre and outside positions at any distance. Using this method at Station No. 1 the dial gauge was set to zero at the inside position and the readings at the same position at all other stations noted. Then, without changing the original zero setting readings were taken at the centre and outside positions of all stations. The sketch (No. 2 below and the table shows the results secured.

Sketch No. 2.



Dial gauge readings are in thousandths of an inch.

Note that at every station the centre and outside positions reveal an upward distortion.

(Procedure, cont'd) -

TABLE NO. VI.

Station No.	Race Surface Position Inside	Centre	Outside	Maximum Transverse Difference	Difference from 0 position
1	0.000	+0.003	+0.003	0.003	0.003
2	+0.006	+0.005	+0.005	0.001	0.006
3	+0.007	+0.005	+0.004	0.003	0.007
4	+0.005	+0.013	+0.011	0.008	0.013
5	+0.003	+0.009	+0.013	0.010	0.013
6	-0.003	+0.004	+0.004	0.007	0.007
7	-0.001	+0.005	+0.009	0.010	0.010
8	-0.004	+0.004	+0.010	0.014	0.014

(11). The above plate was drawn at 500° F. for 2 hours and cooled to room temperature in 4 hours while still in the furnace. This heat treatment was done at Hull Iron and Steel Foundries Limited, Hull, Quebec, and then returned to Canadian Arsenals Limited, for a second series of distortion measurements.

Here again, the measurements were made by Mr. Hinchcliffe by the method outlined in Section 10 of this report. The following table lists the results secured and should be compared with Table V.

Station No.		"A" - Upward Distortion at Rim. (Inches)	
1	-	0.035	
2	-	0.028	
3	-	0.029	
4	-	0.028	Average 0.031
5	-	0.030	
6	-	0.035	
7	-	0.032	
8	-	0.032	

Race face measurements, by the method previously described, are stated to have produced the results reported below in Sketch No. 3 and Table No. VIII.

(Sketch No. 3 follows,)
(on next page.)

(Procedure, cont'd) -

Sketch No. 3.

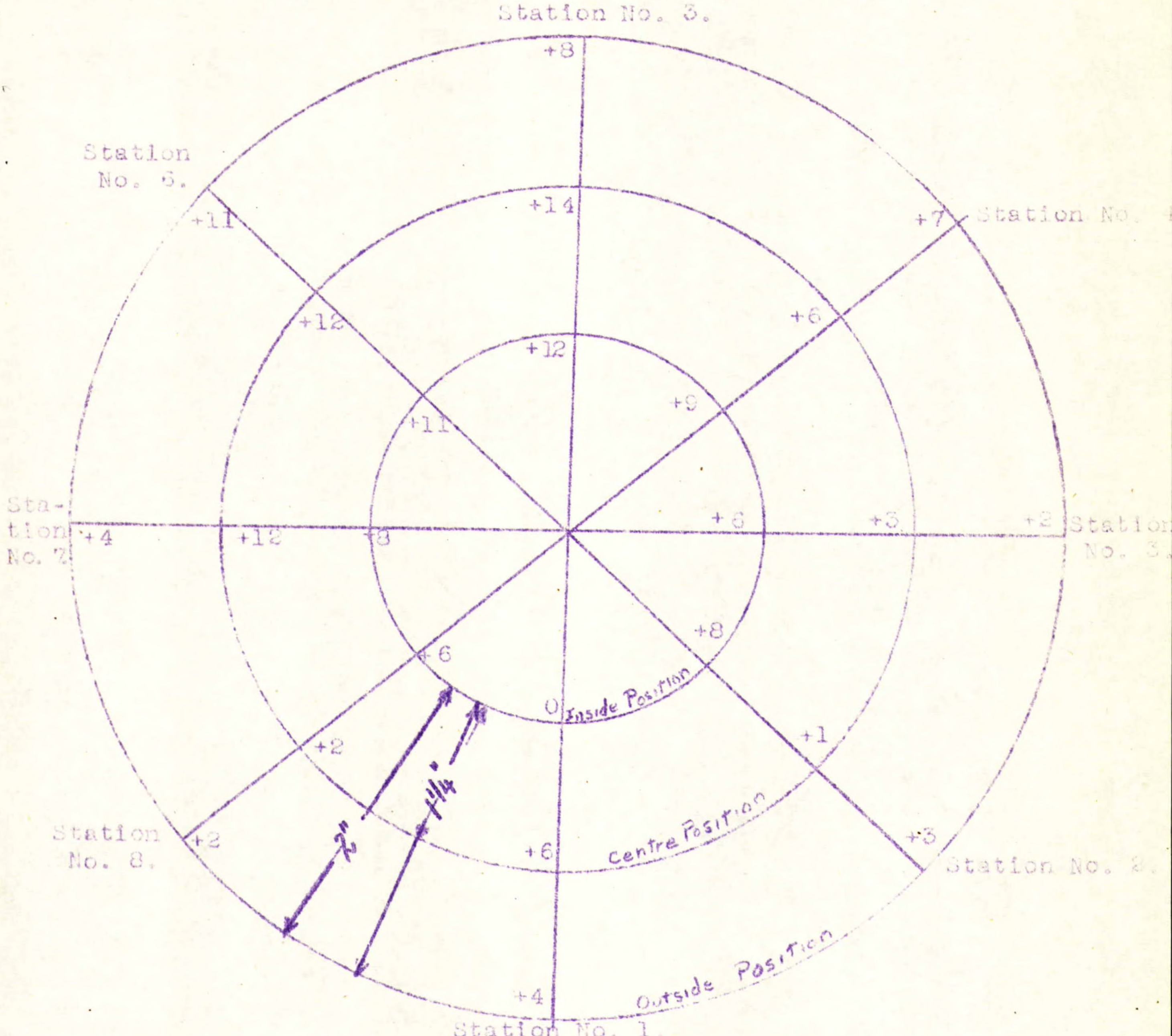


TABLE NO. VIII.

Station No.	Race Surface Position			Maximum Transverse Difference	Differenc from O Positi
	Inside	Centre	Outside		
1	0.000	+0.006	+0.004	0.006	0.006
2	0.003	+0.001	-0.003	0.011	0.008
3	0.006	+0.003	+0.002	0.004	0.006
4	0.009	+0.006	+0.007	0.003	0.009
5	0.012	+0.014	+0.008	0.006	0.014
6	0.011	+0.012	+0.011	0.001	0.012
7	0.008	+0.012	+0.004	0.008	0.012
8	0.006	+0.002	+0.002	0.004	0.006

DISCUSSION:

The four plates, on which work has been done to date, exhibit a wide range of hardenability as calculated from chemical composition. It is generally accepted that carbon and manganese are the most potent elements with regard to hardenability and rather than consider their separate effects the concept of "carbon equivalents" are now widely used. There the total effects of these two elements are considered as that attributable to carbon content alone if one sixth of the manganese content is added to the carbon content of the steel. In other words, carbon equivalent $= \%C + \frac{\%Mn}{6}$. Using the concept the four plates compare as follows:

Plate No.	1	2	3	4
Carbon Equivalent	0.449	0.368	0.345	0.456

Obviously, as the carbon equivalent declines the hardenability fulls off; that is, the steel is less responsive to rapid cooling from above the upper critical. It is, then, apparent that under such conditions standardization of flame hardening procedures is impossible.

Plate No. 3 -

The check of the level of the plate before hardening showed a maximum difference in level of 0.005 inch. The readings shown in Table II show a maximum difference in level between the inside and outside of the race of 0.012 inch, part of which would be due to the taper on the race surface. This table also shows a maximum difference in level on the outside of the race of 0.026 inch and on the inside of 0.018 inch. Part of this difference in readings would be offset by the 0.005 inch difference in level. It must be borne in mind that the rough machined race surface and the measurement method used make it difficult to make accurate measurements in the order of thousandths of an inch and also exaggerate any minor

(Discussion, cont'd) -

differences in level. It is believed, however, that the measurements do indicate that there are no gross variations of the surface level of the race surface.

The technique of flame hardening was selected from those used with Plate No. 2 (see Investigation No. 1960) with a slight reduction in speed of travel to ensure reaching the necessarily higher austenitizing temperature of the lower hardenability material. The subsequent increase in speed, used because of surface melting from one jet, is still within that range usable for a plate of this composition. The unfortunate impression created by marring the surface of the race in this manner should not be taken too seriously at this stage of experimentation. It does, however, indicate the need for accurate positioning of the flame head above the surface of the race and also the necessity for rigid maintenance of the jets themselves.

As reported above, rough measurements showed an upward bulge in the centre of the race in the order of 0.025 inch. This distortion was far greater than had been anticipated and far greater than that correctable by grinding. It is believed that distortion is the result of two factors; (1) lower yield strength of the race at the austenitizing temperature and (2) the outward expansion of the heavy flange which throws a strong bending moment on the race. The outward expansion of the flange is the result of heating by the back flare of the flames from the torch head. The bending moment applied to the hot race is resisted at the centre of the race by a thin cross-section which has a low yield strength and results in an upward bulge at the centre of the race.

The first factor might be corrected as follows. Since the centre of the race has the thinnest cross section, at low speeds of travel the heat can readily penetrate this

(Discussion, cont'd) -

area. It is undesirable to have this centre section at a high temperature due to the reduction in yield strength as the temperature increases and also because it renders a drastic surface quenching action more difficult. Forced cooling of the underside of this thin section by means of a water jet should result in less distortion of the race face. This idea was put into action with Plate No. 4.

Plate No. 4 -

A check of the level of the plate before hardening showed a maximum difference in level of 0.0035 inch. Since this plate was in the finished ground condition all measurements were much easier and more reliable than was the case with Plate No. 3.

The readings shown in Table III, have no direct relationship one position to another, since for each position the dial gauge was set to zero at Station 1. This method was adopted to offset the effect of the taper on the race surface. The uniformity of these readings transverse to the race surface are noteworthy and indicate that the race surface while reasonably straight across the surface is not consistently in the same horizontal plane. This deviation from a true horizontal plane varies from 0.0085 inch to 0.010 inch.

The technique of flame hardening was similar to that used with Plate No. 1 with a slight reduction of speed from the desired 6 to 5.4 in. per minute necessitated by limitations of settings available with the dividing head of the milling machine. The marring of the race surface during hardening by one jet, in spite of a prior check for proper orifice size, indicates the necessity for establishing a minimum end-of-cone-to-race-surface-distance and also constant maintenance of the flame head jets. Once again it should be stressed that the

(Discussion, cont'd) -

development of a new operation cannot reasonably be expected to be completed in one or two trials. Industrial experience has shown that the "ironing out" of such difficulties takes a little time before a process can be standardized completely.

The measurements of the hub-to-flange distances on the completion of the hardening operation showed that the flange had expanded outward 1/16 inch at each of the four points measured. This distortion is the result of heating by back flare of the flames from the flame head and throws a severe strain on the thin section of the race. When cold the flange returned to its former position or as close to the original position as could be measured by the method used.

The reported system of measurements of the race surface and centre rim using a surface plate was far superior to the method used in prior measurements. The upward distortion at the rim is surprising in view of the outward expansion of the flange. One would logically expect that the flange expansion would result in a downward distortion at the rim since the plate was not supported during hardening at any point farther out than the inside of the race. It is stated that prior to hardening the rim and the hub are all in the same horizontal plane and therefore the distortion is due to the hardening operation. This information is not conclusive as this point was not checked prior to hardening. However, since the training rack could not be inserted after hardening it is apparent that the distortion encountered renders the rear plate useless from the point of view of service. But since the training rack is fitted to the race plate by a final hand scraping operation very little distortion would make insertion impossible.

It will be noted from Sketch No. 2 and Table VI that there is an upward distortion of the race surface towards the

(Discussion, cont'd) -

outside edge. This confirms the general trend of the readings of Table V. Table VI also reveals that there is a considerable variation in the level of the race surface in a transverse direction at the various stations, ranging from 0.001 to 0.014 inch. It would appear that this distortion is approximately one half that of Plate No. 3 but of a different nature, in that Plate No. 3 exhibited an upward bulge in the centre of the race. No explanation of this difference can be advanced. Table III also reveals a variation in level of 0.009 inch, 0.0085 inch and 0.010 inch respectively of the inside, centre and outside positions before hardening. Whether these differences at the various stations should be subtracted from the readings at the same station in Table VI is a matter of conjecture due to the entirely different system of measurements used. However, the fact that differences in level were detected prior to hardening is difficult to ignore.

With regard to the race surface alone it would appear that the simple addition of the underneath water jet has brought about an appreciable reduction in distortion. There is every reason to believe that still further reduction could be brought about by additional refinements of procedure as follows. (1) Shielding flange from the back flare of the flames and thereby preventing its heating and outward expansion. (2) Fastening down the outer rim to a level plate to resist upward distortion. (3) Flooding the entire plate with water to a level just slightly above the race surface.

The reported results of measurements after the drawing at 500° F. are somewhat obscure. They apparently show that at the rim there has been a consistent tendency to correct the upward distortion noted after flame hardening. One would logically expect that this would be accompanied by a similar, even if smaller, change in the measurements of the race surface. However, a comparison of Tables VI and VIII reveals that there

(Discussion, cont'd) -

is no such consistent change. This might be explained on the basis of a twisting action during drawing but it is difficult to see how such an action could take place against the restraint of heavy sections such as the flange and the spokes. It is believed, however, that it has been demonstrated that some correction of distortion may be expected from drawing but that this procedure will not eliminate it entirely.

General -

It is only logical to expect that, the slower speeds of travel necessary to secure the high austenitizing temperature of the lower hardenability plates, would be associated with greater distortion. This tendency, as with all hardenabilities, can be partially corrected by cooling the bottom surface of the race where the section is the thinnest. The effectiveness of this has been demonstrated but that of other suggested methods remains to be proven. Should further plates be available further experiments are warranted.

It is admitted that the design of the plate is such as to render flame hardening of the race more difficult than might be expected at first glance. The elimination of the reduction of the race cross section at its centre, for example, would considerably facilitate the operation. It is the opinion of the writer that, even with the present design, a flame hardening procedure on the higher hardenability plates could be worked out using methods referred to above to control distortion. It must be admitted however, that others concerned with this problem, do not concurr in this opinion. It should be borne in mind that only two plates have been hardened, one without attempt to control distortion, and one with only one corrective step. The results of these two experiments, while not all that was hoped for, serve only

(General, cont'd) -

to emphasize the necessity of taking all possible precautions and do not warrant outright rejection of the process. It is also believed that the method of distortion measurements is susceptible to further refinement in the interests of accuracy.

CONCLUSIONS:

1. The wide variations of hardenabilities of the plates used to-date, render impossible the standardization of flame hardening procedures.

2. Rough machined surfaces make accurate measurement of distortion, in the order of thousandths of an inch, difficult if not impossible.

3. Straight forward flame hardening of plates without precautions against distortion results in upward distortion of the race centre. This distortion is too great for correction by grinding.

4. Cooling the thin centre section of the race during flame hardening reduces distortion. However, the distortion encountered is still too great for correction by grinding. The upward distortion at the rim alone is sufficient to warrant rejection of the process.

5. Drawing for 2 hours at 500° F. reduces the upward distortion of the rim but does not produce a similar desirable effect on the race surface distortion.

Recommendations:

1. If plates are available additional experiments should be undertaken using the knowledge gained in these investigations.

2. The possibilities of control of distortion as outlined above are worth a trial.

Acknowledgments:

It is a pleasure to acknowledge the continued co-operation of the Dominion Oxygen Co. Limited. This company made available the services of Messrs W. W. Graham and S. Johnston for these experiments. Our thanks are also due to Mr. S. L. Gertsman, Development Engineer, Hull Iron and Steel Foundries Limited, Hull, Quebec, who kindly arranged the drawing of Plate No. 4.

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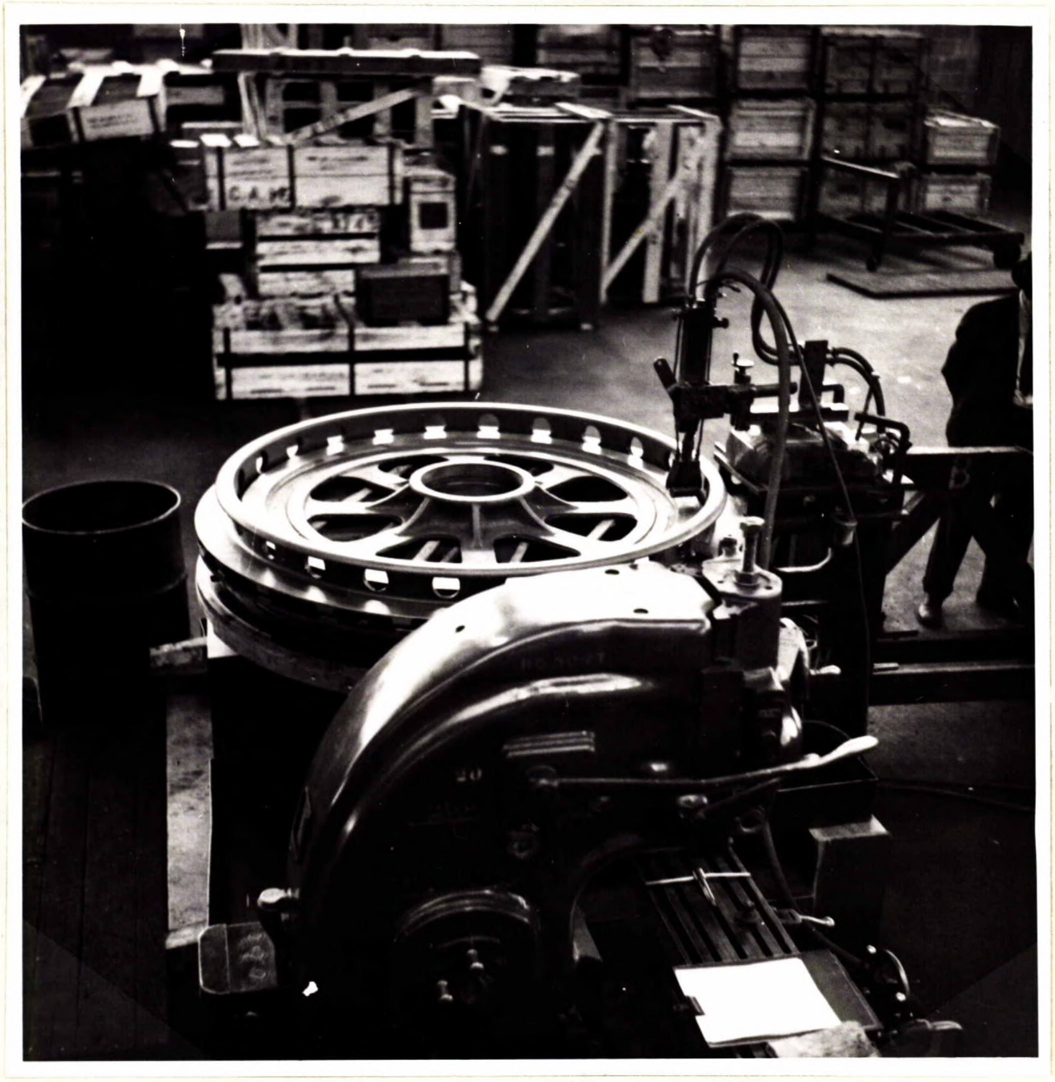
(Figures 1 and 2 follow,)
(on Pages 22 and 23.   )

Figure 1.



ARRANGEMENT OF RACER PLATE AND FLAME-HARDENING EQUIPMENT FOR FLAME HARDENING.

In foreground is the milling machine which provided the power to rotate the plate through a dividing head.

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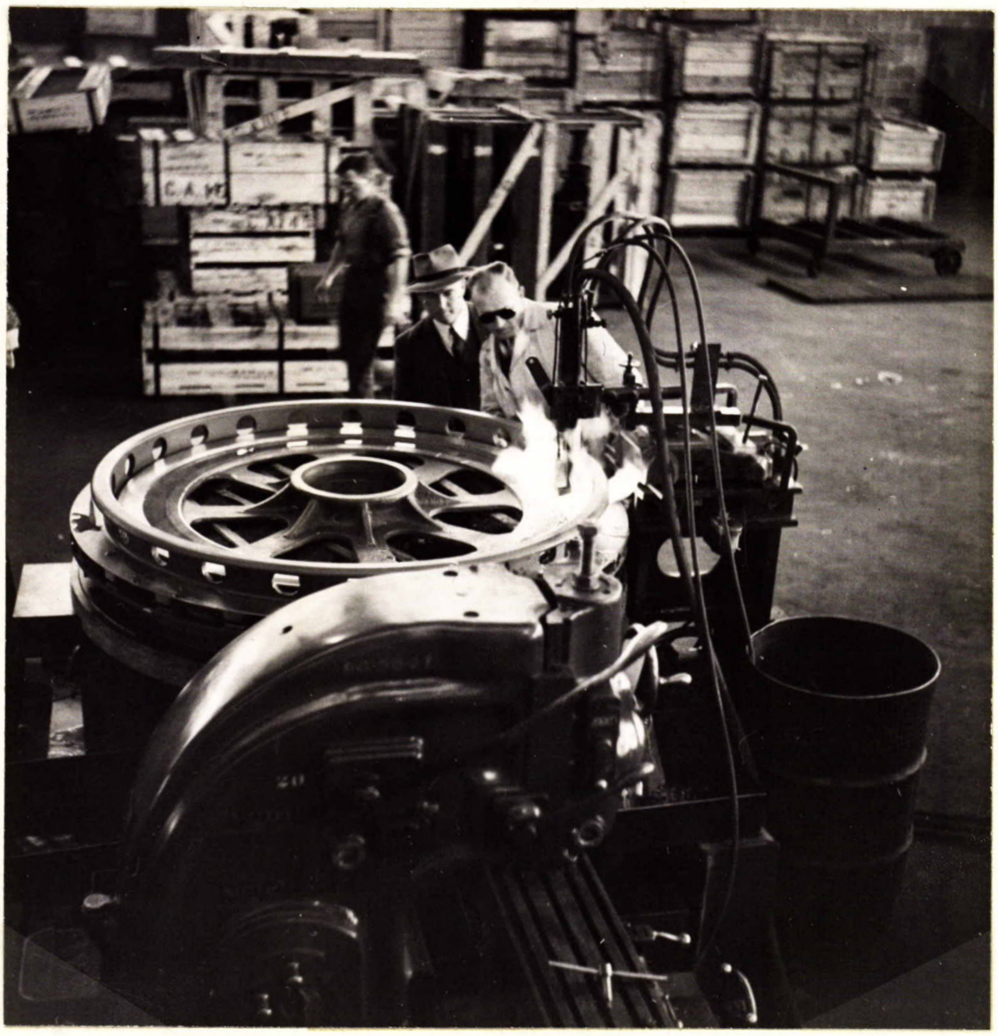
Figure 2.

USE AS FILE COPY



FLAME HARDENING OPERATION IN PROGRESS.

Note back flare of flame playing on the flange.

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HJN:LB.