in the cemented zones, in which the depth and the concentration of the carbon undergo great variations between one point and another.

The uniformity in temperature during the period which precedes the attainment of the constant temperature of cementation is still more perfect if, besides the solid cement, the pieces to be cemented are also first preheated to the temperature of cementation and placed in the retort at this temperature. In this case the time necessary to reach normal temperature of cementation after charging is shortened still more. Thus, by working under the same conditions as indicated above but charging the pieces of steel heated to about 800°–850° C., this time is reduced from twenty minutes to only ten minutes.

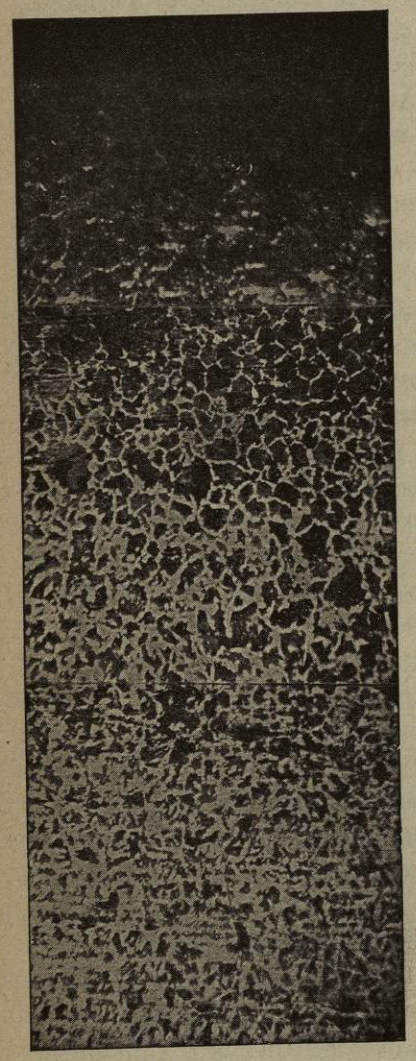

FIG. 142.

Of all the parts which I have described, the only one which must be renewed rather frequently is the horizontal frame placed within the retort. Of this, the metallic net can serve for four or five operations, but its cost is negligible. The frame can, on the contrary, serve for a far larger number of cementations. The retort not having to be removed from the furnace for the operations of charging and discharging, lasts much longer (from thirty to forty times longer, and even more) than ordinary boxes which are removed from the furnace, while for an equal capacity it costs about the same. All the other parts have a practically unlimited duration.

There follow some concrete data on the results which can be obtained with the process just described.

As regards the velocity of cementation, the concentration and distribution of the carbon, and other "local" characterististics of the cemented zones which are obtained, the observations already noted in the first part of this volume, in connection with work in vertical cementation chambers, hold unchanged.

Fig. 142 shows, enlarged 50 diameters, a microphotograph of a section of

a carburized zone, etched with picric acid in 5% alcoholic solution. This was obtained by cementing a soft steel for two hours at 1000° C. by the process described in the preceding pages. The micrograph shows clearly all the characteristics of those zones which I have called of "intermediate type," such as maximum concentration of the carbon 0.9%, the gradual decrease in this concentration, etc. These were studied and their marked practical advantages demonstrated in the first part of this volume.

The manner in which the cementation distributes itself over the whole surface of pieces of iron or steel charged into the retort is of practical importance. This distribution will be perfectly uniform, whatever may be the form of the pieces to be cemented, provided some simple conditions are realized. When these conditions are fulfilled, we may be certain *a priori* that the cementation will be perfectly uniform and that there will not be formed such non-carburized or slightly carburized or highly carburized "regions" which are so frequently formed with the ordinary solid cements, as the result of variations in the contact of the cement with various parts of the surface of the pieces.

First of all, it is obviously necessary that the temperature of the pieces should be as uniform as possible during the whole time of cementation. We have seen that this condition is easily met in the process with which we are dealing, especially when, besides charging hot carbon, the pieces to be cemented are also charged hot. In the second place, the state of the "granular" carbon used has great influence on the uniformity of the cementation. It is necessary, in fact, that the gases should be able to circulate with the same ease through all parts of the retort. This can be obtained with certainty only by using carbon in uniform sized grains. In general, for the cementation of pieces of the usual form (gear wheels of medium dimensions, drills, etc.), the best results are obtained by using ground wood charcoal and discarding the portions which pass through a sieve of 64 mesh per sq. cm. and which are retained by a sieve of 16 mesh per sq. cm.

In the third place, in order that the cemented zones may be uniform throughout their whole extent it is necessary that the gaseous mixture of carbon dioxide and monoxide should have already attained completely to chemical equilibrium with the carbon by the time that it reaches the nearest points of the objects to be cemented. This is attained by working with a sufficiently slow current of gas and by making it pass through a sufficiently thick layer of carbon before it reaches the pieces to be cemented. Experience indicates that the velocity of the gaseous current and the thickness of the layer of carbon must be regulated according to the temperature, the nature of the metal to be cemented, etc. If ordinary soft steels are to be cemented at temperatures near 1000°, under the conditions described in the preceding pages, the special data reported above apply best, both as regards the

velocity of the current of carbon dioxide and the thickness of the layer of carbon.[1]

If the velocity of the current of carbon dioxide is too high or the layer of carbon through which it must pass before reaching the pieces of steel is too thin, the cemented zone will not be uniform, showing a minimum of thickness and of concentration of carbon near to the points where the gas arrives.

For cementing with the mixed cement of carbon and carbon monoxide whenever the pieces do not specially require the use of a horizontal furnace, it is by far preferable to use furnaces with vertical muffles of the type already described (p. 294) for cementation with gaseous cements. In fact, that particular furnace was designed expressly for cementation with the mixed cement we are now considering.

Figures 130 and 131 and the accompanying description suffice for present purposes. The part of the operations constituting the cementation proper, such as the charging of the pieces, their removal for quenching, the control of the temperature and of the circulation of the gases, etc., is identical whether gaseous cement or the mixed cement is used. We will therefore give here a description of the operations of cementation carried out with mixed cement only where they begin to differ from the operations when gaseous cements are used. This is at the point when, the charging of the pieces to be cemented into the retort having been completed, the cement is introduced into the cementation chamber.

When the pieces to be cemented have been placed in the retort in the manner previously indicated (p. 296), the retort is covered; then, through the central opening of the latter, is passed the lower discharge tube of the sheet-iron receptacle *O* (see Fig. 130) full of still-hot granular carbon (in general, above 900° C.) discharged from the retort at the close of the preceding cementation.

Figure 143 shows how this operation is carried out. The receptacle *O* is easily manipulated above the muffles by suspending it with tackle to a revolving arm or to a light trolley.

The walls of the receptacles, even when filled with granular carbon at 1000°, are not heated higher than to 200°–250° C. during the time required for carrying out all the operations of charging and discharging the retorts, even when working under the most unfavorable conditions. This is easily explained by the small heat capacity and the low heat conductivity of the mass of "granular carbon," which, even if at a high temperature, can give to the walls of the receptacle which contains it but a small quantity of heat. This is easily dissipated by the simple cooling of the metallic wall by the current of air which envelops it.

[1] If the retort which is used is tall, the first layer of carbon can be made thicker without cramping the space intended for the pieces of steel; this is always convenient and desirable.

The receptacle *O* having been placed in the manner just indicated, the butterfly valve which closes its lower end *N* is gradually opened, filling in

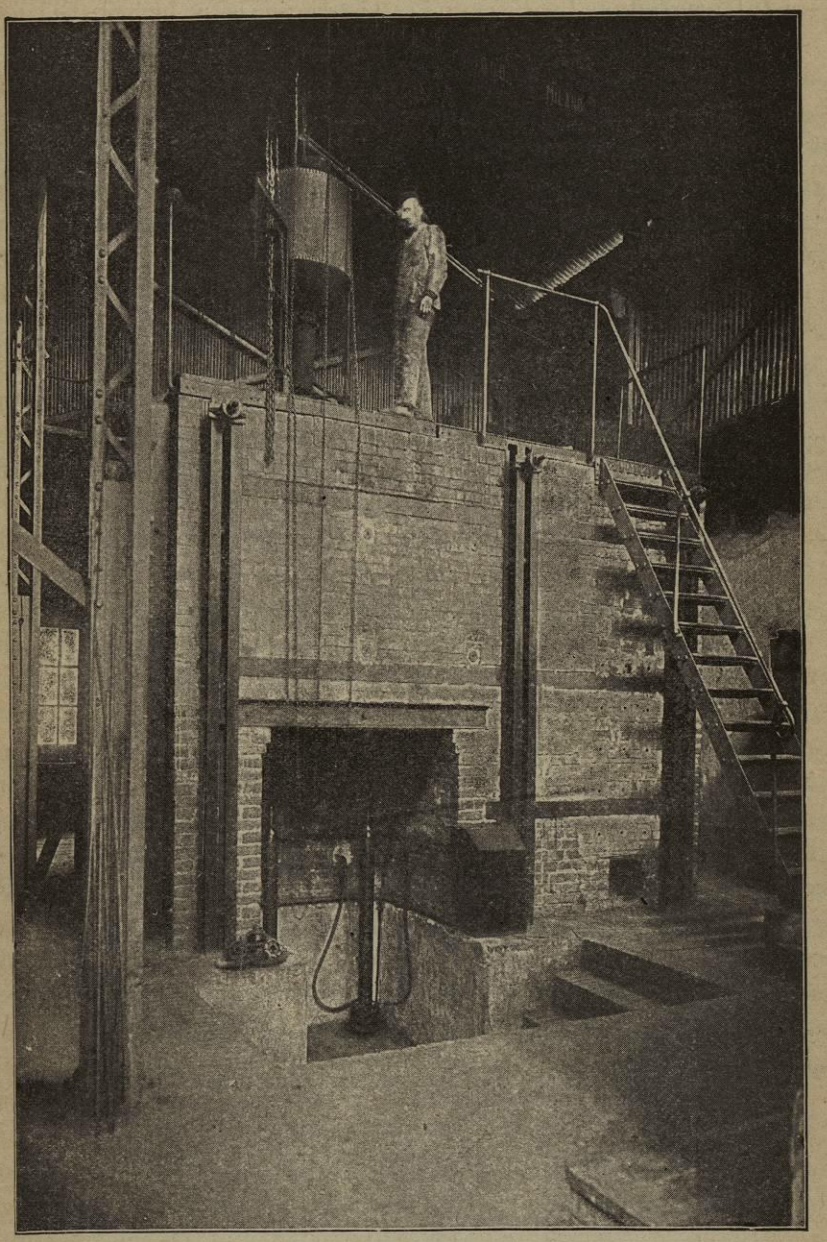

FIG. 143.

a few seconds, with the hot granular carbon, all the free spaces in the retort between the pieces charged into it.

As to the form and dimensions of the various valves, the proper working

of which is essential to the successful operation of the apparatus, they are the same as those described, with illustrations, in the case of furnaces with horizontal muffles.

The "granular" carbon used for cementation with the mixed cement possesses, especially at a high temperature, a mobility comparable to that of a liquid. This makes it capable of penetrating, by its own weight, into all the interstices between the objects to be cemented, and between them and the wall of the retort. It is also easy to assist the filling by means of iron rods introduced through holes in the cover of the retort, and manipulated by a workman who stands on the furnace.

Having introduced the granular carbon up to a level about 8 to 10 cm. lower than the upper edge of the retort, the butterfly valve of the tube *N* is closed, the receptacle *O* is raised, the central opening in the cover of the retort is closed, the plunger *L* is completely lowered, the tube *D* is screwed to the piece *C*, and through it is slowly admitted carbon monoxide or carbon dioxide, pure or mixed with air. This passes to the distributor *E* and thence to the retort.

An ordinary gas meter is used to regulate the current of carbon monoxide. This may be of the so-called "dry" type, and connected with a small anemometer, to measure the velocity of the gaseous current.

This done, the cementation proceeds at once, it being merely necessary to observe and regulate both the current of carbon monoxide and the temperature.

For observing the temperature, which is not frequently necessary with a furnace of the type described, when properly set in operation, an ordinary thermo-electric pyrometer is introduced from time to time at various parts of the granular carbon contained in the retort, by passing it through a few holes made in the retort cover. The temperature of operation must be kept perfectly constant at some definite value, chosen beforehand, usually between 900° and 1100° C. The gases which issue from the retort through the tube passing through the cover may be collected in a gasometer and used for succeeding cementations, after suitable treatment and correction of composition.

When the cementation has proceeded for a time suited to producing the desired results, which can be fixed with great precision *a priori*, the current of carbon monoxide is interrupted, the tube *D* is removed, and the discharging of the retort is begun.

When special results are not to be obtained, all of the granular carbon is directly removed from the retort by dropping it through the slide valve *Q* into the receptacle *O* placed beneath.

When, however, the specific action of the carbon monoxide must be "isolated" during the last phase of the cementation from the "direct" action of the granular carbon, in order to obtain exceptionally "gradual"

cementations, the receptacle *O* is placed in such a way that the neck of the funnel *B* enters the uncovered tube *P*; then, by gradually opening the slide valve *Q*, there is drawn from the retort[1] such a quantity of granular carbon as to leave uncovered those parts of the objects in which it is desired to "graduate" the cementation, although there still remains enough in the retort to insure the desired conditions of chemical equilibrium in the gaseous mixture.

The total removal of the carbon from the retort is effected only when the second phase of the cementation, with "isolated" carbon monoxide, has been protracted sufficiently to obtain the desired results.

In both cases, when all the granular carbon has escaped from the retort, the cover is raised. In doing this, the workman must take care to remain at a safe distance from the upper opening of the retort, for the air which enters forms with the carbon monoxide in it a mixture which ignites quickly, because of the high temperature of the retort. This rapid ignition is not dangerous, but can be avoided by completely opening the retort before withdrawing the carbon, (in which case, however, some of the granular carbon burns), or by rapidly "sweeping out" the muffle with a little carbon dioxide after having removed all the carbon. It is necessary, however, that this operation should be carried out rapidly, so as to avoid the carbon dioxide producing some superficial decarburization of the cemented pieces.

When the pieces to be cemented are supported directly by the disk *F*, as, for example, when a "column" of gear wheels has been charged, the pieces may also be raised as far as the uncovered upper opening of the muffle without first expelling the granular carbon from the retort. This procedure has the disadvantage of making it less convenient to take away the pieces for quenching, and of burning a considerable quantity of the carbon contained in the retort.

Whether or not the carbon has been removed from the retort, when the cover *R* is opened, the plunger *L* is lifted until the terminal cone *M* fits into the hollow of the piece *C*, then the hydraulic cylinder *I* is kept slowly operating so as to gradually raise the carriers *C*, *E*, *F* with the cemented pieces on them. Then the removal and the quenching is begun, in the same manner as when a gaseous cement is used.

In placing the objects to be cemented in the retort very small pieces are placed in "cages" made of frames of iron rods joined by nets of iron wire and placed on successive layers of granular carbon. Pieces of small dimensions can also be placed free on successive layers of granular carbon. This permits of easily cementing even very small objects, for which we have seen (see p. 299)

[1] The carbon contained in the retort escapes from it by first passing through a series of openings made in the base ring on which the parts *C*, *E*, *F* rest. These openings appear only in dotted lines in the accompanying drawing, owing to the way in which the section drawing was made.

that this same furnace with vertical muffles is not well suited when it is used with gaseous cements.

As regards the time necessary, the length of these operations depends on the forms and dimensions and therefore on the number of the pieces to be cemented in a charge.

To cite some concrete data, when the charge was composed of some thirty cylindrical gear wheels forming a single "column" in the retort, the times were as follows:

(*a*) Placing of the objects to be cemented on the platform, one to two minutes.

(It is clear that the length of this operation is greater the smaller and the more numerous the pieces charged, but, even for very small pieces, placed free in layers alternating with layers of carbon, the most unfavorable case, it does not exceed, in general, five minutes.)

(*b*) Placing in position the cover of the retort and the receptacle containing the granular carbon.....about one minute.

(*c*) Complete filling of the retort with the granular carbon, from one and one-half to two minutes.

(This operation also becomes somewhat longer when the pieces to be charged are very small and numerous. In general, however, even in the most unfavorable cases, it does not require more than four minutes.)

(*d*) Total lowering of the plunger of the hydraulic elevator, placing of the tube for the admission of the carbon monoxide, removal of the receptacle for the granular carbon and complete closing of the cover of the retort, in the aggregate, about one minute.

As is seen, in the case chosen as example, the aggregate duration of the operations necessary for the complete charging of the retort may vary from four and one-half to six minutes. In the other more unfavorable cases cited above, it may, on the contrary, reach ten to twelve minutes.

For the discharge the following approximate data hold:

(*a*) Removing the tube carrying the carbon monoxide, placing the receptacle for the granular carbon under the lower neck of the retort and opening of the draw valve.....in the aggregate, about one to one and one-half minutes.

(*b*) Passage of all of the granular carbon from the retort to the receptacle below, and closing of the draw valve.....from one and one-half to two minutes.

(*c*) Raising of the carrying platform and discharge of all the cemented objects.....from one to two minutes.

(If the cemented objects are very small and very numerous and especially if they are placed free in layers on the carbon, this last operation may require up to ten minutes.)

In general, it may be considered that the complete discharge of the retort lasts from three and one-half to thirteen minutes. This duration may extend in the most unfavorable cases up to thirteen or fourteen minutes.

The cementation never exceeds two hours per batch, and is often only one hour, for almost all the cases occurring in the manufacture of cemented

pieces for machine parts, in which it is seldom that cemented zones thicker than 2 mm. must be obtained. This is counting the time from when the charging of the retort is finished to when its discharging is begun, and, therefore, including the time necessary to reach the temperature of operation. The latter period is reduced to about ten minutes when the carbon and pieces are charged hot.

Under practical conditions a *complete* operation requires less than two hours and a half. The weight of the pieces which can be charged into the retorts shown in the accompanying furnace drawings varies from 100 kg. to over 500 kg. Each retort, therefore, will cement in twenty-four hours from one ton to about five tons of iron or steel objects.

Taking into account the reduced consumption of fuel which the furnace described attains, the very low cost of the cement and its being *totally* utilized without any waste, it is clearly seen that the process of cementation under consideration is highly economical.

Practice shows that this cost, when pieces of medium dimensions, from 100 grams to 10 kg., are cemented to a medium depth, is about one-fifth to one-tenth that of the same cementation carried out with Caron cement in the ordinary boxes.[1]

Aside from any consideration as to the superiorty of the product there are advantages of a technical order presented by the furnace with vertical muffles just described, when compared with the horizontal muffle furnace used for cementation with the mixed cement. These advantages consist

[1] As a concrete example, it may be desirable to summarize briefly some data relative to the industrial cost (including, that is, interest, depreciation, general costs, etc.) of the cementation of machine pieces carried out in a furnace with vertical muffles of the type and of the dimensions described in the preceding pages.

The furnace costs about 20,000 lire ($4000), including the principal accessories, and produces from 1200 to 2400 kg. of cemented pieces per day. The daily costs of working, taken from the mean of a long operation, are as follows:

1. Retorts of sheet steel.....Lire	3.60	$0.70
2. Refractory muffles.....	1.05	0.20
3. Solid cement.....	1.44	0.28
4. Gaseous cement.....	0.90	0.17
5. Labor.....	10.00	1.93
6. Fuel (including quenching).....	28.00	5.40
7. Interest and depreciation charges on furnace and accessories.....	18.00	3.48
8. General expenses (same as labor).....	10.00	1.93
Total.....Lire	72.99	$14.09

Referring this aggregate cost to the *minimum* daily production of the furnace (1200 kg) so as to obtain the *maximum cost* of the cementation, we reach a cost of 6.083 *centesimi* 1.174 *cents*) per kilogram (2.2 lb.) of pieces cemented to an average depth of 1 mm. (0.04 in.) and hardened.

essentially in the greater rapidity and simplicity of the operations, and in the greater uniformity of treatment of all the pieces constituting the charge, a uniformity which is not limited merely to the raising and maintaining of the temperatures but applies with greater force to the distribution of the carburizing gas.

In the vertical furnace, arranged as described, the "harmful spaces" which remain in the charged retort are reduced to a minimum. This does not occur in the horizontal muffle furnaces, in which these harmful spaces, representing losses of heat and of carburizing materials and greatly reducing the output of the furnace, are always present to a marked degree, especially in the "head" of the retorts.

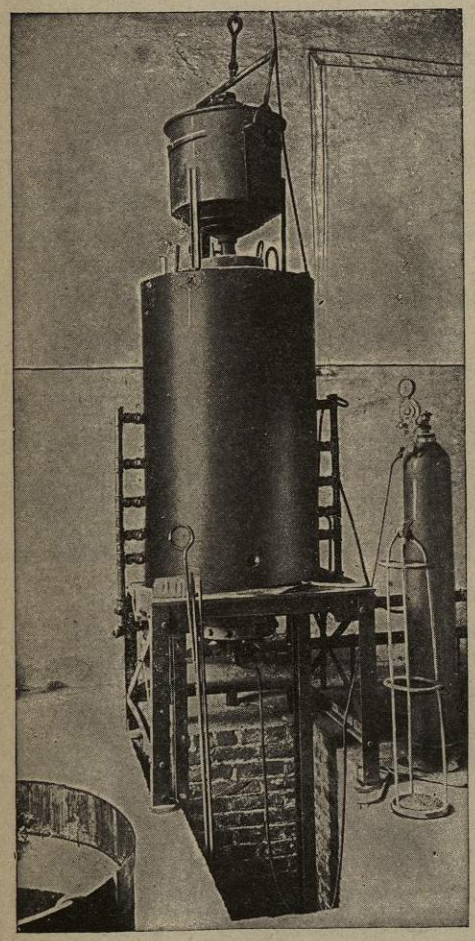

FIG. 144.

Finally, the vertical muffle furnace just described permits of carrying out with great ease, and without the addition of any new part, the cementation of the ends of pieces of very elongated form (such as connecting rods, shafts, etc.), while in ordinary cementation furnaces these results can be obtained only by adding to the furnace *special* parts, *different* from those in which the cementation of pieces of ordinary forms and dimensions are carried out.

The type of furnace described, with vertical muffles, is the best adapted to utilizing in the best way the advantages of the mixed cement, with carbon monoxide as base, either from the point of view of quality of the products, certainty of the results, or economy of production.

When only small quantities of materials are to be cemented, and especially when the operation is to intermittent, there is great advantage in using a vertical muffle furnace heated by illuminating gas, or even by heavy oil. This type has been already spoken of on p. 253 and is shown in Fig. 106.

All that has been said in the preceding pages for the gas-producer furnace

holds for this furnace, both as regards its advantages over the horizontal muffle furnaces and as regards its working and the operations of charging and discharging. Fig. 144 shows an arrangement for filling with the hot granular carbon the spaces in the retort left free by the pieces charged into it.

With a small furnace of this type, whose useful space in the retort has a diameter of 28 cm. and a height of about 1 meter, and especially for intermittent operation, the cost of the cementation is somewhat higher than with

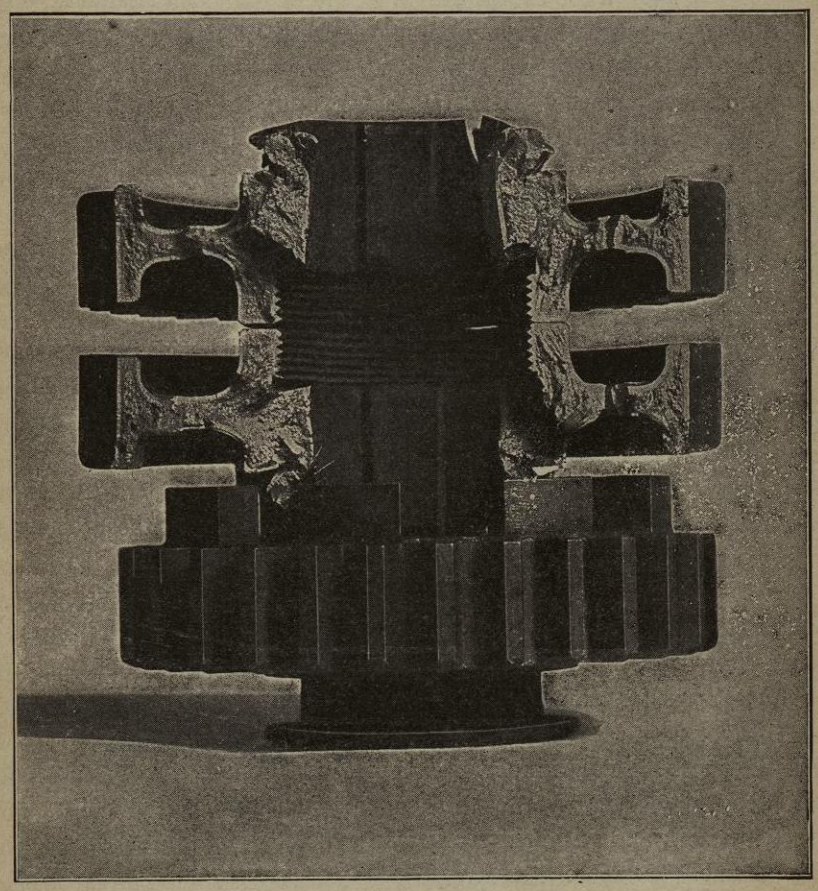

FIG. 145.

the continuous gas-producer furnace. It does not often exceed, however, 12–15 centesimi (2.4–3.0 cents) per kilogram (2.2 lb.) of cemented pieces.

The characteristics of the cemented zones which are obtained by working under various conditions with the mixed cement having carbon monoxide as base have been already amply described in the first part of this volume.

There is reproduced in the accompanying figure (Fig. 145) the surface of fracture of a gear wheel cemented in the vertical muffle furnace with the mixed cement having carbon monoxide as base, then quenched and broken. In the