

# The Design of Platinum-wound Electric Resistance Furnaces

By J. E. Priddis, A.M.I.E.E.

*Platinum and its alloys are particularly suitable for the construction of electric resistance heating elements for furnaces with working temperatures in the range from 1200 to 1700°C. The principal factors governing the design of these furnaces are discussed in this article.*

The introduction of high temperature sintering and refining techniques in the electronic industry, the extension of the use of combustion analysis in the control of steel-making, as well as the requirements of metallurgical and ceramic research, all contribute to the demand for an accurately controllable source of high temperature heat. This demand has been largely met by the platinum-wound furnace, which possesses a combination of properties unique in the high temperature field. It is compact, simple in construction and operation, easy to control and widely adaptable. It can be used at temperatures up to 1700°C without the need for a protective atmosphere.

Of the available types, the horizontal tubular models are the most widely used, and these alone will be considered in detail here.

Before the last war, it was in the laboratory itself that most of the platinum-wound furnaces were constructed. At that time, little fundamental data existed and it was therefore not surprising that these furnaces met with a widely varying degree of success. Failures which subsequent experience has shown were largely due to faulty methods of construction were frequently attributed to defective resistor material or to impure refractories. It is only in comparatively recent years that a thorough investigation of constructional methods has been made and it is now apparent that, in a furnace of sound design, not only must great care be taken in

the construction of the element but at least as much attention must be paid to the general furnace design.

## Element Design

The important properties of platinum and its alloys in furnace construction are high mechanical strength and resistance to oxidation at very high temperatures. Although superior in this combination to any of the heat-resisting base metal alloys, the advantages of platinum are relative, and elements must be designed to minimise the mechanical stress on the winding and to protect the resistor from erosion by oxide volatilisation. To achieve these objectives the platinum resistor must be carried in a refractory body that will not slump or sag, which must be sufficiently dense to exclude air from contact with the winding, and which will withstand repeated heating without cracking.

The basis of all elements embodying a platinum resistor must be a highly refractory material. Almost all the physical characteristics of the material are important, and each has to be considered. It is necessary that the material be free from contaminants, resistant to thermal shock, and of low electrical conductivity at all temperatures. Besides these essential qualities, it is desirable that it is a good heat conductor, has a low firing shrinkage, a coefficient of expansion similar to that of platinum, and can readily be formed into the required shape. Not unnaturally, no

single material or combination of materials adequately meets these requirements and to some extent a compromise has to be made.

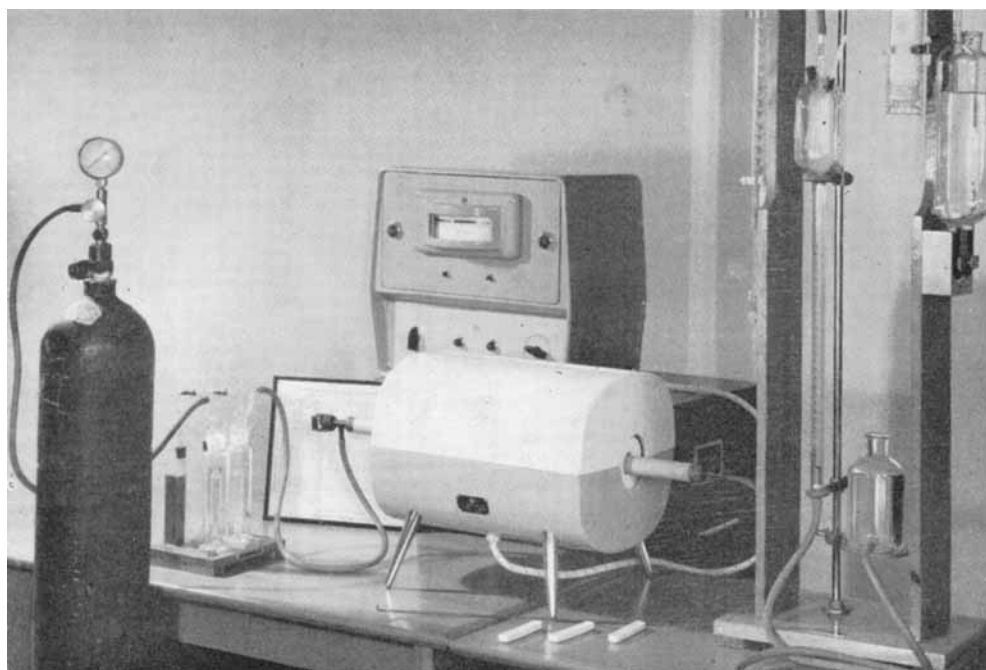
Were it merely a matter of procuring a highly refractory former upon which to wind a resistor little difficulty would be experienced, but this will inevitably lead to failure. In order to obtain a satisfactory life from a platinum-wound element, the resistor must be firmly and completely embedded in the refractory material, since any cavities which form around the resistor will bring about local volatilisation with consequent failure. In muffle furnaces, therefore, it is necessary that the resistor be embedded in a homogeneous refractory material which will as far as possible remain free from cracking under the arduous conditions likely to prevail.

Alumina fulfils the required conditions better than any other material but, like all oxides, it lacks both plasticity and strength in the "green" or unfired state. The addition of a small proportion of china clay will make good both these deficiencies at the expense

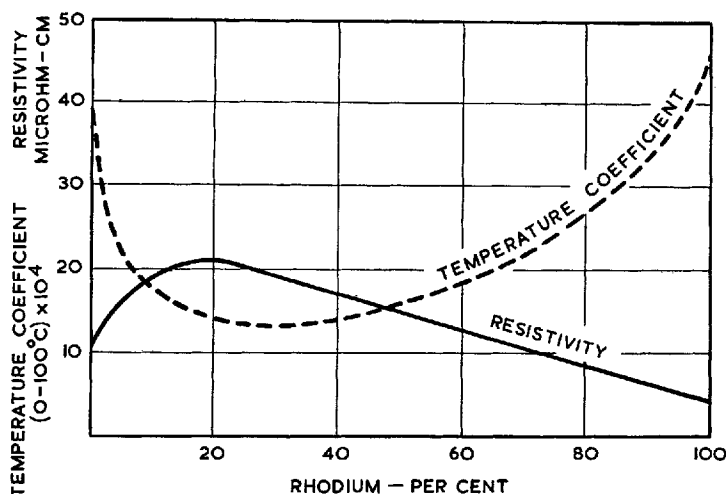
of a slight reduction in the refractoriness of the resultant material. Generally, the improved working characteristics of the material justify this reduction, but a solid supporting bed must be provided for the element. If this is not practicable, or if the operating temperature is above 1500°C, purer alumina must be used in spite of its limited workability.

## Selection of Resistor Material

The first step in the application of platinum to furnace construction is to choose the most suitable alloy. Both pure platinum and pure rhodium have been employed, but neither is entirely suitable. Platinum has too low a melting point (1769°C) and insufficient hot strength. Rhodium, although having a higher melting point, 1966°C, is too brittle. Both have a comparatively low specific resistance at room temperature, and a high temperature coefficient, so that the starting currents are very large in relation to the loading when hot.



*A platinum-wound laboratory furnace and control unit set up with Stroklein apparatus for the determination of carbon in steel*



*Electrical resistivity and temperature coefficient of rhodium-platinum alloys*

Alloys of rhodium and platinum, which form a continuous series of solid solutions, are much more suitable. It can be seen from the graph shown above that the region between 10 and 40 per cent rhodium-platinum provides the best electrical properties. The 10 per cent rhodium-platinum alloy, with a melting point of 1850°C, is ductile and workable, with excellent mechanical properties at the working temperature, and is used in nearly all general purpose furnaces, although there is no reason why 15 or 20 per cent rhodium-platinum cannot equally well be employed. Because of its higher melting point (1950°C) the 40 per cent alloy is chosen for elements working at temperatures above 1550°C. The melting point of pure rhodium is a little higher, but this advantage is more than offset by its inferior ductility.

In furnaces having radiating elements, the resistor section is usually governed by the surface power loading of the resistor material, with the result that a flat strip of large surface area is frequently selected. In platinum-wound muffle furnaces where the heat is conducted from the resistor by the surrounding refractory material, the need for large surface area does not arise. Indeed, such a shape would prove detrimental because a resistor of large area would break up the "key" of the refractory and cracking would inevitably result. With fine gauge resistors,

any section other than circular would have insufficient mechanical strength to be practicable. Since both platinum and rhodium are volatile at high temperature, a circular section conductor will assist in restricting to a minimum any loss by this means. It is for these reasons that round wires are invariably employed.

## Power Rating

Because tubular furnaces are put to a variety of uses, it is good practice to rate all sizes up to about 2½ inches bore diameter so that they will attain their working temperature with both ends open. Under these conditions, the end losses will be severe even in a well-designed furnace, with the result that for a given bore diameter the power losses will remain substantially constant for any furnace up to 24 inches in length. Accurate calculation of the heat losses can only be made with the aid of very comprehensive data, and not only is this rarely available, but for furnaces of this size the possibility of error will always remain considerable. Reference to tables based upon experience is, therefore, the simplest and most practical method of arriving at the required input.

The graph shown opposite indicates the heat losses from tubular furnaces of varying bore and with open ends after a state of equi-

brium has been reached. Although these curves have been based on furnaces of the type of construction described here, they will be found to be substantially correct for any well-insulated furnace of comparable size. In arriving at an appropriate rating, due allowance must be made for any variation in supply voltage, and bearing in mind that the furnace input is proportional to the square of the voltage, an addition of 25 per cent in power input is advisable. Further allowance should also be made of about 10 per cent to cater for any variation between the designed input and the actual input, and to allow for depreciation during life. The input thus arrived at will usually prove satisfactory for average conditions and should enable the furnace to reach its working temperature in a reasonable time. Naturally, variations must be made to suit individual circumstances. In laboratory furnaces, the heat demand of the charge and its associated apparatus is usually insignificant, but this is not necessarily always so, and in some instances additions to the rating may have to be made on this account.

### Electrical Considerations

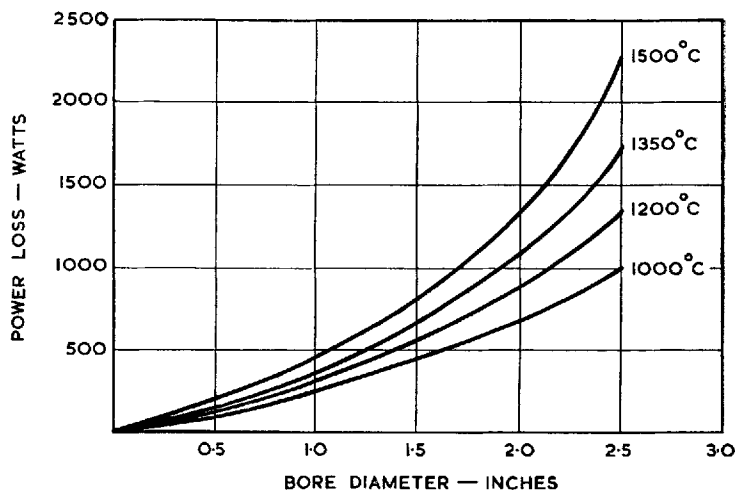
When a suitable alloy has been selected, the conductor cross-section, the operating voltage and the current can be correctly inter-related. Which of these is chosen first is a

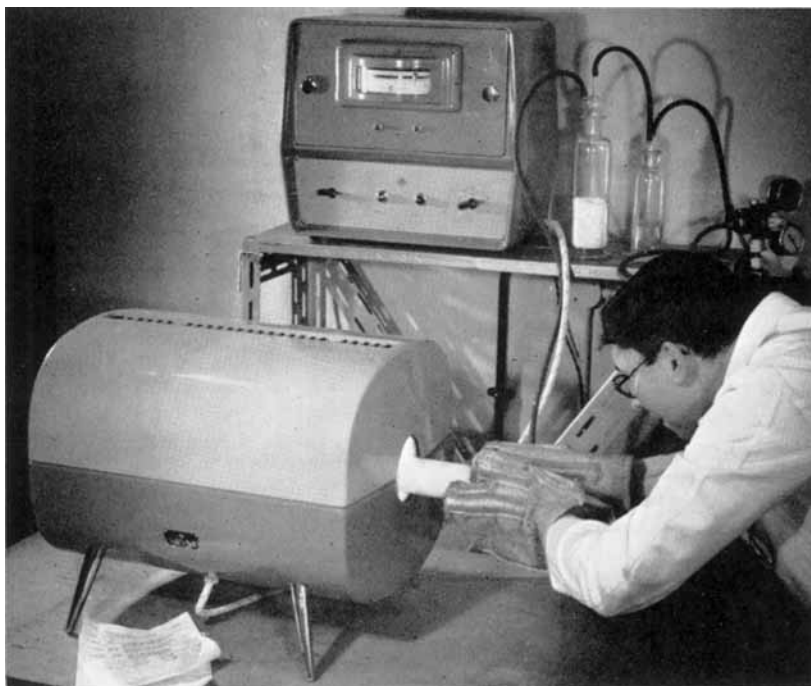
matter of individual design approach, the important factor being an appreciation of the effect upon life and operation that these may have. For a given metal weight and power rating the life of the element will, apart from minor considerations, be unaffected by the operating voltage. The factors which this will affect, however, are the mechanical strength of the element, the turns spacing of the winding, and the likelihood of electric shock.

Considering first the mechanical properties of an element, refractory formers inevitably shrink as a result of prolonged heating at high temperature and in so doing tend to compress the resistor wire. Also during heating the resistor expands faster than the refractory, this again setting up stresses between the two materials. If the wire is coiled into a helix before being wound around the former, a degree of resilience is imparted and the element is better able to withstand these internal stresses. Even so, a resistor of this formation can still be sufficiently rigid to cause the refractory to crack if the wire diameter is too large. Generally, it is inadvisable to employ wire gauges in excess of 0.050 inch, while sizes below 0.036 inch are to be preferred.

While too stout a wire can bring about a crack in the refractory, too fine a wire, on

*The heat losses from tubular muffle furnaces, 10 to 24 inches long, with open ends*





*A high temperature platinum-wound furnace fitted with an impervious combustion tube for work in special atmospheres*

the other hand, may itself fracture. Further, very fine wires are more liable to become weakened, either through straining in the winding process, or as a result of grain growth after prolonged heating. Such troubles are more likely to occur in wires below 0.01 inch diameter and in general it is preferable to employ a gauge in excess of 0.012 inch diameter.

The total length of the resistor wire is proportional to the voltage applied, and this must be suitably chosen to permit a satisfactory turns coverage. The maximum permissible distance between turns can vary within quite wide limits according to the particular construction employed, but generally this should not exceed  $\frac{3}{4}$  inch, while, on the other hand, the turns/space factor should be limited to a maximum of 50 per cent.

The possibility of electric shock must not be overlooked. Although alumina has a high resistivity at room temperatures, this decreases very sharply with increasing temperature and the material becomes a poor

electrical insulator in the range 1500 to 1700°C. Consequently, the limitation of the element potential to earth can only be regarded as a wise precaution and in the writer's experience it is prudent to restrict this to a value not exceeding 150 volts.

It will generally be found that all the above electrical conditions will be satisfied if a value of current between 5 and 12 amp. is selected.

The laboratory furnace user often requires as great a length of the element as possible at constant temperature with a sharp fall-off at each end. At the temperatures under consideration, the axial heat radiation is high and a very sharp fall-off at the ends is therefore not practicable. Indeed, it is as well not to aim at too sharp a temperature change at this point, as such an achievement will only result in undue thermal stresses. With the type of furnace design under discussion here, a reasonably fast rate of fall will be obtained at the ends, while a flat heating zone gradient is possible for about 60 to 70 per cent of the

element length. The actual spacing of the turns in order to obtain this flat zone will vary with diameter and length, but generally about 20 per cent of the total power is allotted to the centre third of the element, with the balance distributed equally between the two remaining thirds.

## Element Life

The matter of element life is one which the user cannot afford to ignore. Before installing a furnace, he may fairly ask what life he is to expect from a single element, and it may appear unreasonable that no positive answer can be given. The constancy of use of a furnace, its method of control, the variation of supply voltage, the shape and nature of the charge, varying temperatures of use and the rate of heating and cooling are only some of the operational factors which determine the life of an element. Clearly, therefore, it would be quite impossible for an estimate of life to be given which would hold good under such diverse conditions of use.

Manufacturers will design their furnaces to withstand, as far as possible, the usage likely to be encountered and will make tests to determine the resistance of their furnaces to this. Nevertheless, operating techniques vary so widely that it would be quite impossible to establish any "standard operating conditions" for test purposes, and consequently representative life tests can only be conducted if the conditions of test running are carefully controlled. These usually consist of running furnaces continuously at one fixed temperature until failure.

Within certain limits, the life of an element is directly proportional to the weight of platinum alloy embodied in it, and is therefore within the designer's control. It is of course necessary to hold a proper balance between the capital cost of the noble metal and the economic working life of the element. While the user will naturally be concerned with the life of the furnace in his laboratory rather than on the test bed of the manufacturer, it will nevertheless be appreciated that

it is upon the "test life" that the hours of useful work ultimately depend. The degree by which a furnace in use will fall short of this life will clearly, therefore, depend upon the conditions of use. Experience has shown that modern furnaces are much better able to withstand severe service conditions than their counterparts of ten years ago, with the result that operational lives of 60 per cent of the maximum expectation are commonly encountered, while lives approaching 100 per cent have been achieved in many instances where the furnaces are employed under favourable conditions. The platinum furnace is thus able to provide reliable service under severe conditions but, like any other tool, the kinder the treatment it receives the more useful work will it perform.

## The Furnace Case

The element will of course only achieve its full designed life and temperature rating if it is properly supported in an insulating housing so that it cannot sag, and is at as nearly as possible the same temperature throughout its length.

To provide adequate support, solid insulating material should be used which must be highly refractory and free from contaminants. The lightest possible insulating materials having sufficient refractoriness should be employed in order to reduce the furnace heating time and heat losses. It is important that this material be given a prolonged firing at high temperature if subsequent shrinkage is to be avoided.

Because the more refractory materials are of high density and relatively high thermal conductivity, it will be necessary to use at least three grades of furnace insulation, each successive layer being of greater thermal resistivity. For furnaces designed to operate in excess of 1500°C four or even five grades are sometimes necessary.

Efficient lagging is necessary as, for a given alloy, the weight of noble metal forming the resistor will be directly proportional to the power rating of the furnace. On the other



*The interior of a Johnson Matthey high temperature furnace, with the insulating cartridge partly dismantled. The cast aluminium case is fully ventilated and continuously air-cooled during use*

hand, it must be remembered that laboratory furnaces are generally used intermittently and care must be taken not to over-insulate the furnace, otherwise the heat mass of the insulating material will unduly prolong the heating time. For this reason, it is preferable to employ lighter insulation and a higher case temperature than would normally be employed on a larger industrial type furnace, while selecting the best possible insulants available. One very satisfactory arrangement is to provide a light and compact insulation to permit rapid heating and to surround this with a separate case with an air cooling stream between the insulation and the outer case. Escaping heat is thus convected upwards and the operator is not subjected to constant heat radiation from the furnace case.

To ensure that all parts of the furnace element are maintained as nearly as possible at the same temperature, the heat losses should be balanced in all directions so that excessive local loss due to either conduction or radiation is prevented. With tubular elements it is not always convenient for the user to operate the furnace with plugged ends,

and allowance for this must be made in design. In such cases, the element should be considerably shorter than the overall length of the insulation if end radiation is to be appreciably restricted. This end insulation may sometimes be a hindrance in use but can generally be tolerated to some extent, and it is desirable that an unheated, insulated length equivalent to about three times the furnace bore be incorporated wherever possible.

The furnace shown above is an example of the application of the factors outlined in this article. The wound element length is less than one-half of the overall length; the element is surrounded by three layers of graded solid insulation which is split radially to allow easy access to it. The element inside its insulation forms a cartridge, which is borne on transverse ribs forming part of the two light alloy castings that make up the ventilated outer case.

This design has proved so successful that the test life of elements in the prototype models has been about three times as great as that of former standard types.