

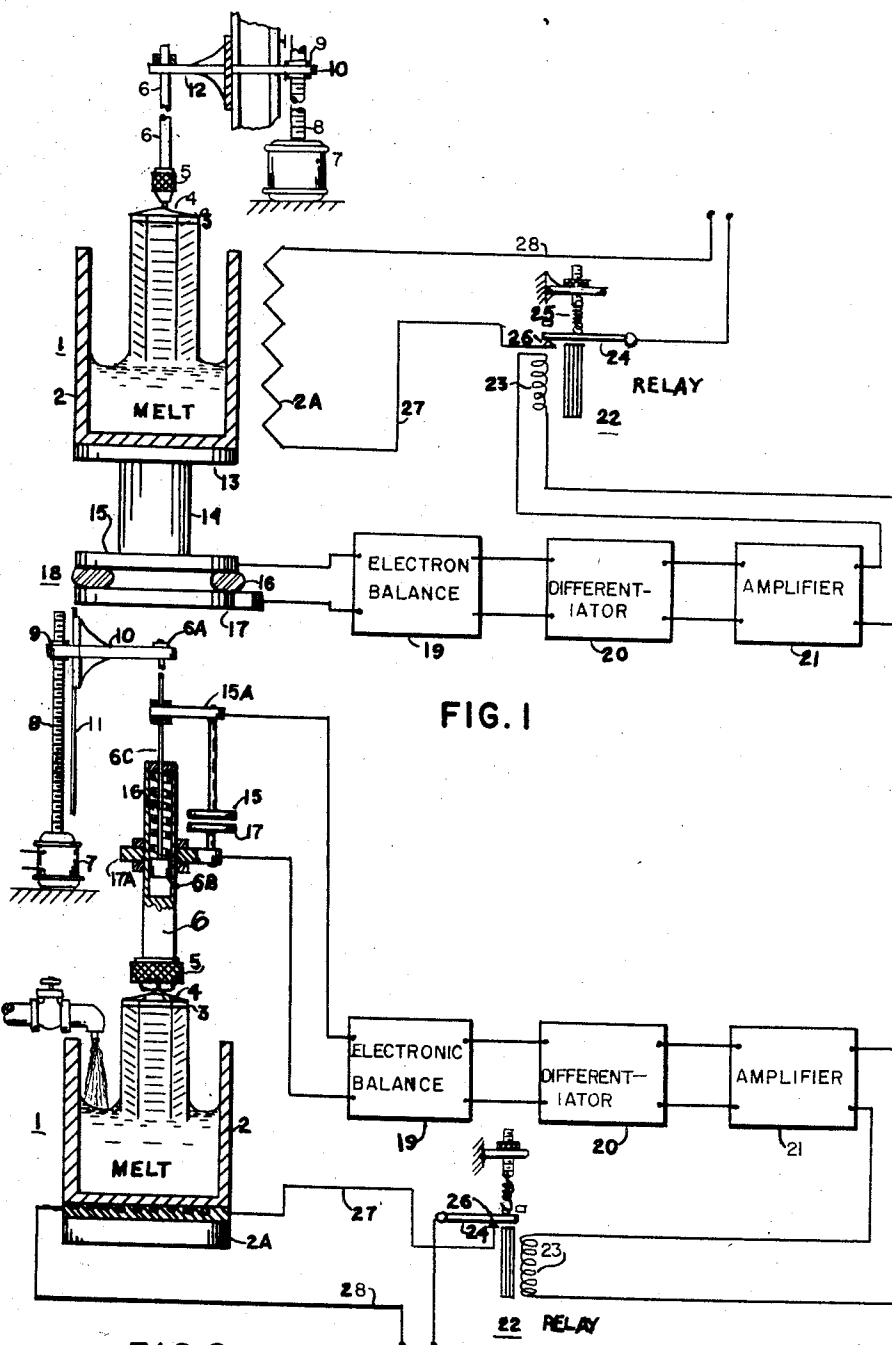
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TEMPERATURE CONTROL FOR CRYSTAL PULLING

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TEMPERATURE CONTROL FOR CRYSTAL PULLING

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The present invention pertains to a method and means for controlling the rate of growth of a crystal in a crystal pulling furnace.

The growth of a crystal in a melt of crystal forming material is a function of the temperature of the melt. The particles, such as atoms or molecules, in the melt have a higher energy state than the same particles have in the solid state. They have a higher mobility and are moving about in random direction and with momentum such that the weaker binding forces operating between the particles cannot come into play and retain them in any definite order or pattern as present in the crystal lattice. The temperature of the melt is a measure of the energy state of the particles. As the temperature of the melt is decreased or as the thermal energy of the particles becomes reduced, the binding forces between the particles begin to dominate and the particles as they move into the pattern of the crystal lattice are retained and the solid state is attained. The pattern of the crystal is characteristic of the material. Within limits, as the temperature is increased the number of particles at any given energy level decreases. Operating within these limits more and more particles will be found in a given energy level as the temperature is reduced. If the energy level be that which is favorable to the attainment of the solid state, and the temperature is reduced, there will be an increase in the rate of growth of the crystal. On the other hand, if the temperature is increased there will be a decrease in the rate of growth of the crystal. By controlling the temperature of the melt at the point where the process of crystallization is to take place, the rate of growth of the crystal can be controlled.

While temperature is an important factor in the rate of growth of a crystal, it is by no means the only factor. Impurities within the melt operate to change the binding forces as the percentage changes with stratification of the melt. This and other possible factors that influence the rate of growth make temperature unsatisfactory as the variable to determine the rate of growth of the crystal.

Heretofore the art has used temperature as the variable factor and has sought to make it constant. A means inserted in the melt responds to the temperature of the melt and produces a control effect which varies therewith. A control device inserted in a heat supply means exerts a control over the supply of heat for regulating the temperature of the melt. Between the temperature responsive means and the temperature control means a further means relates the response of the temperature responsive means and the needs of the control means operating to counteract the change in temperature. These devices and methods for controlling the growth of the crystal do not overcome the variations in growth due to factors other than temperature. The devices and the methods are attended with further difficulties due to variations in temperature gradient between the point where crystallization is to be controlled and the point where the temperature is taken.

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The present invention seeks to overcome these difficulties in a manner that is productive of a more exact control over the growth of the crystal. This makes possible the growing of crystals which are more uniform in cross section and in texture, as the rate of removal of the crystal when kept constant and the rate of growth of the crystal when kept constant determine the cross section of the crystal.

In the present invention the temperature of the melt is utilized to influence and control the rate of growth of the crystal. It is varied as it becomes necessary to counteract the changes in the rate of growth of the crystal. The rate of growth of the crystal is reflected in the rate of change of the weight of the crystal on the one hand and in certain instances in the rate of change in the weight of the melt of crystal forming material in the crucible. As the crystal increases in size its weight increases and the weight of the melt decreases. The rate of change of weight is converted into a rate of change of voltage that is differentiated to produce a voltage proportional to the rate of change. The voltage establishes a current having a value bearing a constant relation to the voltage and producing a force that is proportional to the rate of change of the weight of the crystal. The force is compared with and balanced against a constant force. As the variable force varies relative to the constant force a control over the supply of heat is effected to counteract the change in the rate of growth, and also to counteract the change in the variable force. The responsiveness of the melt to the supply of heat, the responsiveness of the means measuring the weight and the responsiveness of the intermediate links determine the percentage of regulation that may be secured. By using the change of weight of the crystal or the melt, those other factors which influence the rate of growth of the crystal are counteracted by a change of temperature and a more uniform growth of the crystal is possible.

An object of the invention is to provide a new method of growing crystals in a crystal pulling furnace.

Another object of the invention is to provide improved means for controlling the rate of growth of a crystal in a crystal pulling furnace.

Other objects of the invention will become obvious from consideration of the following specification, claims, and the accompanying drawings in which:

Fig. 1 is a view, partly diagrammatic and partly sectional, of one embodiment of the invention; and

Fig. 2 is another view, partly diagrammatic and partly sectional showing another embodiment of the invention.

There are no doubt other embodiments of the invention than those which are disclosed herein which will operate to carry out the invention, but the two embodiments of the present application will serve sufficiently well to disclose the nature of the invention.

The crystal pulling furnace 1 is diagrammatically illustrated in Fig. 1. It consists of a crucible 2 for containing a melt of crystal forming material and a heating means 2A associated therewith by which heat might be supplied to the crucible and the material therein. A seed crystal 3 is attached to a holder 4 which is held by a chuck 5. The chuck 5 is connected to the lower end of a rod 6 suspended from the arm 12. The arm 12 and an associated arm 10 are guided for movement in a direction parallel to the length of the rod 6 whereby the rod 6 may be raised and lowered relative to the melt.

For raising and lowering the rod 6, a motor 7 that may be operated at a controlled speed is connected to drive a threaded shaft 8 extending parallel to the length of the rod 6 and engaging a threaded collar 9 carried by the arm 10. Rotation of the threaded rod 8 causes the threaded collar 9 to travel along the length of the threaded rod 8 and causes a companion movement of

the arms 10 and 12 in the guide to move the rod 6 longitudinally thereof.

The crucible 2 is supported upon a table 13 mounted on a post 14 made of heat insulating material. The lower end of the post 14 rests upon and is fixed to a metallic plate 15. The plate 15 rests upon a rubber ring 16 that rests upon a metallic plate 17. The ring 16 may be any yieldable dielectrical material which is able to support the weight of the crucible, the melt and the table, and which will be compressed proportional to the weight.

The plates 15 and 17 form a capacitor 18, the capacitance of which is variable with the spacing of the plates, decreasing with the spacing and vice versa. The plates and the rubber ring also form a weighing means producing a change in capacitance with the change in weight. As the crystal forms on the seed crystal the weight of the melt is decreased, the weight compressing the rubber ring 16 becomes less and the rubber ring returns to an equal extent towards its undeformed condition causing the separation of the plates of the capacitor 18 and a corresponding reduction of the capacitance thereof.

The capacitor 18 is connected to the electronic balance 19 wherein the change of capacitance is translated into a change in voltage. The electronic balance 19 is in turn connected to a differentiator 20 and through it to the coil 23 of the relay 22. The change in capacitance of the capacitor 18 causes a change of voltage to be produced at the output of the electronic balance, the rate of change of the voltage being the same as the rate of change of the capacitance and the rate of change of the weight of the melt. In the differentiator, the rate of change of the input voltage is differentiated and a voltage is produced that causes a current in the coil 23 to be proportional to the rate of change of the voltage fed to the differentiator.

The relay 22 also comprises a core and an armature 24 pivoted adjacent the end of the core. The armature 24 operates as the movable contact cooperating with a fixed contact 26 to form a contactor. The contactor is in the circuit 27, 28 through which energy is supplied to the heating means 2A.

The armature 24 is biased by spring 25 in opposition to the force exerted by the magnetic means comprising the coil 23 and the core. The spring is connected at one end to the armature 24 and at the other end to a threaded rod. The threaded rod passes through an aperture in a fixed arm and has a knurled nut threaded thereon. The threaded rod, fixed arm and knurled nut constitute a means for adjusting the tension of the spring 25 by which standard of comparison can be selected and established. By adjusting the tension of the spring 25 a force is established in opposition to the force exerted by the magnetic means. The force exerted by the magnetic means varies with the rate of growth of the crystal. If the force exerted by the magnetic means exceeds that exerted by the spring, and the force of the spring represents the optimum rate of growth of the crystal, then it is obvious that the rate of growth of the crystal exceeds the optimum rate of growth, the contactor will be closed to supply more heat to the melt which has the effect of decreasing the rate of growth of the crystal. Vice versa, if the force exerted by the magnetic means is less than the force exerted by the spring, it is apparent that the rate of growth of the crystal is less than the optimum rate of growth. The spring force then prevails and actuates the contactor to open position to discontinue the supply of heat to the melt. The melt will cool by reason of normal radiation of heat and the rate of growth of the crystal will be increased.

Another embodiment of the invention is disclosed in Fig. 2. Certain changes of the structure shown in Fig. 1, are required to care for the installation wherein the melt is prepared elsewhere than in the crucible and is fed continuously to the crucible through a conduit. In this instance, the weight of the melt is unrelated to the growth

of the crystal. It therefore becomes necessary to obtain a continuous measurement of the weight of the crystal.

In Fig. 2 the crucible 2 is supported upon a hot plate 2A which functions merely to control the temperature of the melt during the crystallization process so as to control the rate of growth of the crystal. The heating means 2A is supplied through the circuit 27 and 28 from a suitable source of electrical energy. In the circuit is the contactor 24, 26 operable to control the supply of energy supplied to the heating means.

The crucible, as shown, is fed with a continuous supply of melt material through a conduit having a valve therein for controlling the rate of supply. A seed crystal 3 is connected to a holder 4 carried by a chuck 5 mounted on the lower end of the rod 6. In this embodiment the rod 6 is constructed with a yieldable means that permits its length to increase proportional with the increase in the weight of the crystal supported thereby. This means comprises a rod 6 having a cylindrical bore for housing a piston 6B. A rod 6C is connected to the piston 6B and extends from the cylindrical bore and is connected to the arm 10. Surrounding the rod 6C and interposed between the piston and an end wall of the cylindrical bore is a spring 16 which functions in the same capacity as the rubber ring 16 in the embodiment shown in Fig. 1.

Surrounding the rod 6 and affixed against longitudinal movement relative thereto is an arm 17A. Surrounding the rod 6C and affixed against longitudinal movement relative thereto is an arm 15A. The arms 15A and 17A preferably are made of dielectric material and serve as a means for supporting the metallic plates 15 and 17. The arms 15A and 17A are connected respectively to metallic plates 15 and 17 by metallic rods. The plates 15 and 17 operate as a capacitor 18 in the same sense as the plates in Fig. 1. As the weight of the crystal increases, the plates 15 and 17 separate because the spring 16 is compressed by the increase in weight. The separation of the plates 15 and 17 produces a decrease in capacitance.

The plates 15 and 17 are connected through the rods and conductors to the electronic balance 19 wherein the change in capacitance is translated into a change of voltage. The electronic balance 19 is connected to the differentiator 20, wherein the changing voltage is converted into a voltage that is proportional to the rate of change of the voltage at the output of the electronic balance. The differentiator 20 is connected to the coil 23 of the relay 22 wherein a current produces a force that is proportional to the rate of change of the weight of the crystal. The relay functions as in the previous embodiment, to control the supply of heat to the melt and thus controls the temperature and the rate of growth of the crystal.

The embodiments operate in the manner already disclosed. A change in the rate of growth of the crystal is converted to a change in the rate of change of a voltage. The change in a rate of change of the voltage is converted to a voltage representing the new rate of change of the voltage. The voltage produces a current in the coil to create a force that bears a fixed relation to the voltage. In the relay the variable force is balanced against a constant selected force produced by the spring. When the variable force varies and exceeds the force exerted by the spring, the heating circuit is closed. When the variable force varies and becomes less than the force of the spring then the circuit is opened. While the relay is herein utilized as a means for comparing a variable with a constant as well as a means for control, it is conceivable that other means may be provided for establishing a standard and other means may be provided for controlling the supply of heat in response to variations from the selected standard.

Having described my invention and the best mode of operating and using the same, what I consider to be my invention is set forth in the following claims:

1. Means for controlling the rate of growth of a crystal

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in a crystal pulling furnace comprising a crystal pulling furnace, heating means for said furnace, means for pulling a crystal from said furnace including a seed crystal thereon, means for yieldably supporting said furnace comprising a heat insulating table, a post connected thereto, a pair of plates separated by a yieldable means, one plate being supported by said yieldable means on the other plate and supporting said post, said plates forming a variable capacitor, an electrical circuit connected to said capacitor for producing a variable voltage which varies as the variable capacitor varies, a differentiator means connected to said electrical circuit, an amplifier connected to said differentiator and a relay connected to said amplifier said relay connected to the heater circuit for controlling the heating current to said furnace.

2. Means for controlling the growth of a crystal comprising means for growing a crystal and means for controlling the rate of growth of the crystal comprising a heating means, means for measuring the weight of the crystal as it is grown and means responsive to said last named means for controlling the supply of heat to the heating means for regulating the rate of growth of the crystal.

3. Means for controlling the rate of growth of a crystal comprising means for growing a crystal, heating means for influencing the rate of growth of the crystal, means for producing a voltage variable with the growth of the crystal, means for differentiating the voltage to establish a voltage having a value that is proportional to the rate of growth and means responsive to said voltage for controlling the amount of heat supplied to said heating means whereby the rate of growth of the crystal may be maintained substantially constant.

4. Control means for controlling a crystal pulling furnace comprising a crucible for containing a body of melted material from which the crystal is to be formed, a heating means for said crucible for maintaining the body of material at a temperature suitable for the formation of crystals, a seed crystal for initiating crystallization within said body of material, means for immersing said seed crystal within said body of melted material and for withdrawing it at a uniform rate of speed, means responsive to the weight of the melted material within the crucible for producing a voltage proportional to the weight; means responsive to said voltage to produce a current proportional to the rate of change of said voltage for producing a force proportional thereto, means for producing a constant force and means responsive to the deviation of the variable force from the constant force for controlling the amount of heat supplied to the heating means, whereby the rate of growth of the crystal is maintained substantially constant.

5. Control means for controlling a crystal pulling furnace comprising a crucible for containing a body of material from which a crystal is to be formed, a heating means for said crucible for maintaining the body of material at a temperature at which crystallization will take place, a seed crystal, means for immersing the seed crystal and for withdrawing the seed crystal from the melted material at a uniform rate, means responsive to the weight of the crystal being formed on the seed crystal for producing a voltage which varies as the weight varies, means connected to said last named means for producing a current and a force proportional to the rate at which said voltage varies, means for establishing a constant force and means responsive to the constant force and to

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the variable force and operable when said variable force deviates therefrom, for controlling the supply of heat to said heating means, whereby the rate of growth of the crystal is maintained substantially constant.

6. A method of growing crystals comprising the steps of providing a body of melted material from which a crystal is to be grown, heating said melted material to a temperature at which a crystal begins to form, inserting a seed crystal into said melted material to initiate the formation of a crystal thereon from the melted material, withdrawing the seed crystal and the crystal material forming thereon at a constant rate from the melted material, weighing the melted material to determine the rate of growth of said crystal on said seed crystal, creating a voltage proportional to the rate of decrease of the weight of the melted material and controlling the supply of heat to said melted material in proportion to said voltage, whereby the rate of growth of the crystal is maintained constant commensurate with the rate of withdrawal of said crystal from the melted material.

7. A method of growing crystals comprising the steps of providing a body of melted material from which the crystal is to be formed; heating said material to a temperature at which a crystal will form; inserting a seed crystal into said body of material to initiate the formation of a crystal thereon; withdrawing the seed crystal from the body of melted material commensurate with the rate of growth desired, measuring the weight of the crystal as it is grown; establishing a voltage proportional to the rate of growth of said crystal and controlling the rate of heat supply to said body of melted material in proportion to the voltage, whereby the rate of growth of said crystal is maintained constant.

8. An apparatus for growing crystals comprising means for heating a melted material to a temperature at which a crystal begins to form, a seed crystal to be inserted into the melted material, means for withdrawing the seed crystal from the melted material at a constant rate, means for weighing the melted material, means responsive to the weighing means for determining the rate of growth of the crystal formed on the seed crystal and means responsive to the last mentioned means for controlling the heating means.

9. An apparatus for growing crystals comprising means for heating a body of melted materials, a seed crystal to be inserted into the melted material, means for withdrawing the seed crystal from the body of melted material at a constant rate, means for weighing the crystal formed on the seed crystal, means responsive to the said weighing means for producing a voltage proportional to the rate of growth of the crystal and means responsive to the said voltage to control the heat of the said heating means whereby the rate of growth of said crystal is maintained constant.

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