Power control of the heating process in a three-phase connected electric furnace by dividing the process into intervals and controlling the average power during these intervals. The power generation in a respective phase is separately controlled and the power control can be implemented in existing and new furnaces without access to neutral wire.
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Power control for furnace

TECHNICAL FIELD

The present invention relates to a three-phase electric furnace comprising heating elements connected to each phase. More particularly, the present invention relates to a method of controlling the heating power generated by the furnace and by each heating element during a heating process. The invention also relates to three-phase electric furnaces which are specifically utilized for sintering cemented carbide blanks.

TECHNICAL BACKGROUND AND STATE OF THE ART

Cemented carbide bodies are produced by powder metallurgical technique including wet mixing of powders forming the constituents of the bodies, drying the milled mixture to a powder generally by spray drying, pressing the dried powder to bodies of desired shape and finally sintering.

Sintering is performed in large furnaces with a total volume of about 2 m³ and an effective volume of the furnace cavity of about 10% of that. The sintering temperature is 1440-1500 °C and it is very important that the sintering furnace be capable of maintaining a constant temperature between the different zones within the furnace, for example, a zone-to-zone difference that does not exceed ±5 °C. This is especially important when producing modern cemented carbide grades which often have a highly complex structure.

In prior designs, sintering furnaces employ power supplies which comprise a three-phase transformer. The primary side of the three-phase transformer is connected to a power source via a current regulator, while each of three heating elements is connected to a respective phase on the secondary side of the transformer. The tem-
perature inside the furnace cavity is measured in one place by a temperature sensor, which is, in turn, connected to the current regulator. Using the temperature information provided by the temperature sensor, the current regulator corrects the electric current in each phase using phase angle control. The current regulator is capable of making the corrections in parallel. However, sintering furnaces employing this type of temperature control scheme do not and cannot take the zone-to-zone temperature differentials, that exist between different zones in the furnace cavity, into consideration.

At the high temperatures considered graphite rods are used as heating elements. The graphite rods require a supply voltage that is lower than the voltage of the network and this is the reason why the supply from the network is made via said transformer. The graphite rods are connected in such a way that they create a star-connected load without neutral wire. This means that the furnace only has three lead-throughs into the furnace cavity for the respective phase conductors. When using heating elements that require higher supply voltages, e.g. elements of tungsten, the transformer may be omitted.

Said temperature differences may arise for several reasons, e.g. that the amount of cemented carbide blanks is different in different parts of the furnace, that the isolation of the furnace is changed during the life of the furnace and gives large heat leakages in certain places in the furnace, that the phase voltages in the network vary etc. Correcting these deviations imply possibility for individual power control of the heating elements.

The power generated by a furnace employing star-connected graphite rod heating elements is on the order of
200 kVA, the phase voltage supplied to the graphite rods is on the order of 50 V, while the phase currents through the graphite rods may reach 2,5-3 kA. The construction and location of the graphite elements in the furnace cavity are well suited for power control within three zones.

Therefore, one object of the invention is to provide a method that individually controls the power generated by each heating element in a three-phase electric furnace.

Another object of the invention is to provide a simple, cost effective power control system that can be utilized with existing furnaces and new sintering furnaces (i.e. furnaces without a neutral wire).

SHORT DESCRIPTION OF THE INVENTION

The objects are achieved by using a method in which the heating procedure is divided into cycles, which are subdivided into periods, which are further divided into control intervals, each period comprising at least one control interval for each phase, while the heating power from each heating element is controlled by on/off switching of the heating element during variable time durations of the relevant control interval in a period, said time durations being chosen in such a way that the average power during the period corresponds to the desired heating power from the heating element and that at least two phases are in a conducting state, the total power level in the furnace being controlled by using a variable number of periods in each cycle and by choosing the number of utilized periods such that the average power during the cycle corresponds to a desired, total power level.

One advantage with the method is that the on/off control can be achieved by comparatively simple
components and that the necessary control signals for
time division of the heating procedure can be generated
in a simple manner using a suitable time reference. Such
a time reference is generally available in the
computerized control units used for the control of fur-
naces of the kind considered.

According to a preferred embodiment of the method
according to the invention said periods are divided into
three control intervals of constant duration associated
with the different phases respectively. This further
simplifies the generation of control signals.

A three-phase connected electric furnace according
to the invention comprises a heating element connected
to each phase. The heat power level in the furnace dur-
ing a heating process is adjusted by controlling the
current to the heating elements. A characteristic fea-
ture of the furnace is that each phase comprises a cur-
rent switch for the control of the heating power of each
heating element by on/off switching of the phase cur-
rent, and that a control unit having features according
to the patent claims is arranged to implement the con-
trol method according to the invention.

According to a preferred embodiment of a transformer
supplied furnace according to the invention said current
switches are arranged on the secondary side of the
transformer. This embodiment is advantageous because an
existing transformer supplied sintering furnace of the
kind described above can be modified to a zone
controlled furnace according to the invention without
significant reconstruction and at a low cost, as the
existing transformer can be preserved and the power con-
trol of the heating elements can be made without access
to a neutral wire. The last feature is specially impor-
tant as the furnace also is built as a pressure vessel
implying that making another lead-through for a neutral
wire requires a new approval by the appropriate certification authority.

According to another preferred embodiment of the furnace according to the invention the actual current switches are provided by zero-transition controlled thyristor devices. It has turned out that by the use of these components less mains interferences are generated than the phase-angle controlled current regulators which are currently used.

Further preferred embodiments of the method and the furnace according to the invention are evident from the following claims.

DESCRIPTION OF DRAWINGS

The invention will be explained in detail by the following in connection with a non-limiting embodiment referring to the drawings, where:

Fig. 1 shows a block diagram of the current supply for a sintering furnace according to the state of art,

Fig. 2 shows a block diagram of the current supply for a sintering furnace according to the invention,

Fig. 3 shows examples of cycles, periods and control intervals used for the control method according to the invention, and

Fig. 4 shows an exemplifying case of power control.

Corresponding parts in the different drawings have been given the same explanatory designations.

DESCRIPTION OF EMBODIMENTS

The block diagram in Fig. 1 shows the three phase conductors L1, L2, L3 in the three-phase mains with a main voltage of 380 V and the phase voltage of 220 V. Via a current regulator SR the phase conductors are connected to a three-phase transformer T, the respective phase exits of which are connected to respective heating
elements R1, R2, R3 in the furnace. The furnace with its cavity is shown by a dash dotted line, and as implied in the drawing the heating elements are distributed in the furnace cavity OV, implying that the heating elements primarily heat different zones within the cavity.

The heating elements R1, R2, R3 are formed by graphite rods which are connected in such a way that they form a star-connected, substantially symmetric, three-phase load. The furnace has three lead-throughs for the respective phase conductors.

A temperature sensor Ω is centrally arranged inside the furnace cavity OV and it provides information about the temperature to the current regulator SR. Depending on this temperature information the current regulator controls the three phase currents I₁, I₂, I₃ in parallel, thereby furnishing the furnace with the total power desired. Existing temperature differences between different zones in the furnace can not be compensated by this control method.

In the block diagram in Fig. 2 the three phases L₁, L₂, L₃ are directly connected to the primary side of the transformer T. The three phase conductors on the secondary side of the transformer are via the current switching devices V₁, V₂, V₃ connected to respective heating elements R₁, R₂, R₃, being arranged in the furnace cavity OV in a similar manner as in Fig. 1.

The current switching devices V₁, V₂, V₃ comprise so-called zero transition controlled thyristor devices, individually switching on or off the respective phase currents I₁, I₂, I₃ at a transition zero depending on control signals which are supplied.

Associated with the heating element R₁ there is a temperature sensor Ω₁ for sensing the temperature in the corresponding zone of the furnace. The sensor Ω₁ is connected to a regulator REG₁ arranged in such a way that,
depending on the temperature information from the sensor B1, it can generate an on/off control signal at a control signal output 1, which is connected to a control input 2 on the thyristor device V1.

Similarly, heating elements R2, R3 are associated with temperature sensors B2 and B3 respectively, which are connected to the regulators REG2 and REG3 respectively, the respective control signal outputs of which (3, 5) being connected to control inputs 4, 6 of the respective thyristor devices V2, V3.

In addition, a main regulator REG10 is included with a control signal output 7 which is connected in parallel to the control inputs 2, 4, 6 of the thyristor devices V1, V2, V3. The main regulator is furnished with temperature information from all three temperature sensors B1, B2, B3 and is arranged in such a way that it generates a control signal on the control signal output 7 depending on the average of the temperature information from B1, B2, B3. In the block of the regulator REG10 this has been indicated by the average \((B1 + B2 + B3)/3\).

The set-up in Fig. 2 makes individual control of the power levels for the respective heating elements R1, R2, R3 possible and by that compensation of temperature differences between different zones in the furnace detected by the temperature sensors B1, B2, B3. The control is achieved by time controlled on/off switching of the phase currents \(I_1, I_2, I_3\) by the thyristor devices V1, V2, V3 in the way described in greater detail below in connection with Fig. 3 and Fig. 4.

The method according to the invention divides the heating process into cycles. The diagram in Fig. 3 shows at "a" a cycle t10, which in turn is divided into ten periods t123 as shown at "b". It should be noted that the dividing into ten periods only serves as an example.
Each period t123 is then subdivided into control intervals t1, t2, t3 as shown at "c", which are associated with the respective thyristor devices V1, V2, V3. In the present case the period t123 has been divided into three control intervals t1, t2, t3 of equal duration, but other selections may of course be made. Thus, as an example, the duration of the control intervals can be changed in relation to the temperature differences measured by the sensors B1, B2, B3, whereby a more rapid compensation of large temperature differences can be achieved.

The control is such that the current in a phase can be interrupted by switching off the respective thyristor device during the entire or a chosen part of the corresponding control interval. As an example, the phase current I1 can, thus, be interrupted during the entire or a selected part of the control interval t1 while the other two phases are conducting.

In a similar manner, all phase currents I1, I2, I3 can be interrupted for a select number of periods t123 of the t10 cycle by a control signal from the regulator REG10 to all thyristor devices V1, V2, V3.

By interrupting the respective phase currents during selected parts of the associated control interval for each heating element an average of the power during the period is achieved and which coincides with the desired power of the element. In a similar way a desired total power level is created as an average power during the t10 cycle by interruption of all the phase currents during an optional number of periods t123.

From this one realises that said cycle, periods and control intervals respectively must have such durations that the on/off control does not cause any temperature fluctuations.
In a practical application the control intervals may have the duration of 10 ms, which would imply a period duration of 30 ms and a cycle duration of 300 ms = 0.3 s in the previous example. As the furnace containing cemented carbide blanks has a large thermal mass and thus high thermal inertia, a cycle length of this size does not give rise to measurable temperature fluctuations. It is also possible to increase the length of the cycle by a factor of 10 or more without creating a conflict with the settled temperature limits.

Fig. 4 is a diagram showing the period t123 at 'a' and the cycle t10 at 'b' in an imagined power control case. The temperature information from the temperature sensor B2 informs that the temperature in the zone around the heating element R2 is too high and requires a decrease of the power at R2 by 20% during its control interval t2. Since control is based on average power, this means that the phase current I2 shall be switched off during 20% of t2. This condition is fulfilled in the period at 'a' in Fig. 4.

At the same time, temperature information from the sensors B1, B2, B3 may indicate that a total power consumption of 40% is needed to keep the temperature at the desired level within the furnace. Consequently, this means that the main regulator REG10 has to switch off all the phase currents during 60% of the time of the cycle, which is equivalent to six of the ten periods in t123.

The final result of the two control conditions is the cycle t10 at 'b' in Fig. 4 and containing four periods t123, the interval t2 in each of them being reduced by 20%. By this it is realised that the average power during the cycle is of course also affected by the average power during the periods involved. This is compensated during following steps, but measures may also
be taken by settling the number of periods for determination of the total power level in relation to the power averages of the periods.

The average power P₁, P₂, P₃ for each heating element R₁, R₂, R₃ respectively during a period t₁₂₃ containing the control intervals t₁, t₂, t₃ is defined by the following relationships

\[ P₁ = \frac{I₁² \times R₁ \times t₁ + I₁² \times R₁ \times t₂ + I₁² \times R₁ \times t₃}{t₁₂₃} \]
\[ P₂ = \frac{I₂² \times R₂ \times t₁ + I₂² \times R₂ \times t₂ + I₂² \times R₂ \times t₃}{t₁₂₃} \]
\[ P₃ = \frac{I₃² \times R₃ \times t₁ + I₃² \times R₃ \times t₂ + I₃² \times R₃ \times t₃}{t₁₂₃} \]

Accordingly, P₁ may be affected by varying the active portion of control interval t₁ while full power contribution is provided during the control intervals t₂ and t₃. Average power P₂ and P₃ may similarly be affected during control intervals t₂ and t₃ respectively.

By assuming that the load is resistive, symmetric and star-connected, the following calculations can be made.

When all phases are conducting the voltage drop over each heating element is equal to the phase voltage \( V_f \). The power generated in each element is then \( V_f^2 / R \), which is also equal to the maximum power generation \( P_{\text{max}} \).

When a phase is switched off the voltage drop over its element \( R \) is zero, and consequently so is the power generation. For the remaining two heating elements the voltage drop becomes equal to half the main voltage, i.e. \( V_h / 2 \), at which \( V_h = V_f \sqrt{3} \). The power generated in each of these two elements will then be

\[ (V_f \sqrt{3} / 2)^2 / R = 0.75 \times P_{\text{max}} \]
Thus, during the switch-off time the element in the interrupted phase generates no effect and the elements in the other two phases 75% of its maximum power each.

If the length of control intervals $t_1$, $t_2$, $t_3$ are the same, and heating element $R_1$ is switched off during the entire control interval $t_1$, and the elements $R_2$, $R_3$ are switched on during the entire corresponding control interval one obtains

an average power $2P_{\text{max}}/3$ for $R_1$ and

an average power $(2P_{\text{max}}+0.75*P_{\text{max}})/3 = 2.75*P_{\text{max}}/3$ for $R_2$ and $R_3$.

Thus, during the period $t_{123}$ an average power for $R_1$ is obtained which is about 27% lower than that for $R_2$, $R_3$. By allowing a variation of the durations of $t_1$, $t_2$, $t_3$ larger differences between average power may be achieved.

In Fig. 1 and Fig. 2 the regulators are shown as separate function blocks. However, this does not mean that the regulators are physically separate units in practice. Since the furnaces considered normally have a computerized control equipment these functions will preferably be implemented as computer soft-ware.
CLAIMS

1. A method for power control of a heating process for a three-phase connected electric furnace, comprising heating elements connected to each phase,
   characterized in
   - that the heating process is divided into cycles, which are divided into periods, which in turn are divided into control intervals, each period comprising at least one control interval for each phase,
   - that the heating power from each heating element is controlled by on/off switching of the heating element during optional time durations of the relevant control interval in a period, said time durations being chosen in such a way that the average power during the period corresponds to desired heating power from the heating element and that at least two phases are in a conductive state, and
   - that the total power level in the furnace is controlled by using an optional number of periods in each cycle, the number of utilized periods being chosen in such a way that the average power during the cycle corresponds to desired total power level.

2. A method according to claim 1,
   characterized in
   - that each period is divided into three control intervals of constant duration, each phase being associated with a control interval respectively.

3. A method according to claim 1,
   characterized in
   - that each of the at least two periods is divided into an optional number of control intervals wherein each of the control intervals has a variable duration.

4. A method according to any of the preceding claims for zone dependent power control of the furnace, whereby in connection with respective heating element the fur-
nace is equipped with a temperature sensor for sensing the temperature in a zone of the furnace that is heated by the heating element

characterized in

- that the on/off switching of a respective heating element is controlled in relation to the temperature information from the associated sensor during the control intervals, and

- that the total power level is controlled in relation to a balanced temperature information from the sensors.

5. A three-phase connected electric furnace comprising a heating element connected to each phase, the heat power level in the furnace during a heating process being adjusted by controlling the current to the heating elements,

characterized in

- that each phase comprises a current switching device for controlling the heating power of each heating element by on/off switching of the phase current, and

- that a control unit is arranged to control the heating power level by dividing the heating process into period divided cycles, each period comprising a control interval for each phase, and by generating control signals to said current switching device for on/off switching of the phase current to the respective heating element, each heating element generating a desired average power during such a number of periods of the respective cycle that will provide, during the cycle, an average power corresponding to the desired total heating power level.

6. A furnace according to claim 5, having voltage supply from the mains via a three-phase transformer the primary side of which is connected to the mains for step-down transformation of the voltage of the mains,
characterized in
- that said current switching device is arranged on
the secondary side of the transformer.
7. A furnace according to any of claims 5, 6, said
heating elements being arranged for heating correspond-
ing zones of the furnace,
characterized in
- that a temperature device is arranged for sensing
the temperature in a respective zone, and
- that the control unit comprises a regulator device
connected to each phase, the regulator device having an
input for receiving temperature information from an as-
sociated temperature sensor and a control signal output
which is connected to an on/off control input of said
current switching device for the supply of on/off con-
trol signals depending on the received temperature in-
formation.
8. A furnace according to claim 7,
characterized in
- that the control unit comprises a main regulator
for controlling the total power level, the main regula-
tor having a control signal output which is connected to
an on/off control input of the respective current
switching device and an input for receiving of tempera-
ture information from said sensors, the main regulator
being arranged for controlling the total heat power by
generating on/off control signals to said current
switching device during each cycle depending on the ave-
rage of the received temperature information.
9. A furnace according to any of claims 5, 6, 7, 8,
characterized in
- that each current switch device is realised by a
zero-transition controlled thyristor device.
10. A use of the method and the furnace according to
the invention for sintering cemented carbide blanks,
said furnace comprising a furnace cavity surrounded by an isolation and a pressure resistant casing, said heating elements consisting of graphite rods arranged in such a way that they form a substantially symmetric load connected to respective three-phase conductor without neutral wire, and said furnace cavity having feed throughs only for said three phase conductors.
## INTERNATIONAL SEARCH REPORT

### A. CLASSIFICATION OF SUBJECT MATTER

**IPC6**: F27D 11/02, H05B 3/62

According to International Patent Classification (IPC) or to both national classification and IPC

### B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

**IPC6**: F27D, H05B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE, DK, FI, NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WPI, CLAIMS

### C. DOCUMENTS CONSIDERED TO BE RELEVANT

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<td>US 1511050 A (E.F. COLLINS ET AL), 7 October 1924 (07.10.24), page 1, line 58 - line 79, figure 1, detail 10</td>
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<td>X</td>
<td>EP 0105770 A1 (SELA S.A.), 18 April 1984 (18.04.84), page 8, line 24 - line 28, figures 1-3, claims 1,3,6,7</td>
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Further documents are listed in the continuation of Box C. See patent family annex.

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Date of the actual completion of the international search: 20 February 1997

Date of mailing of the international search report: 25-02-1997

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