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SYSTEM OF CONTROLLING TEMPERATURE CONDITIONS OF DRUM-TYPE ROTARY FURNACE IN OBTAINING URANIUM OXIDES

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Application of symistor control stations for current throttling through heating chamber elements of drum-type rotary furnace in obtaining uranium oxides is suggested. Functional scheme of automatic control system by electric heating elements is presented. By means of it one can control furnace temperature conditions optimally. Imitation model and some results of investigation are given.

1. Introduction

At present one of the main industrial techniques of producing uranium oxides, being the important intermediate compounds in conversion of natural uranium, spent fuel and weapon uranium into nuclear fuel of power reactors, uranium fluorides and metallic uranium, is the technique of chemical denitration of uranylnitrate through ammonium polyuranates. In this connection, the investigation of thermal decomposition process of ammonium polyuranates is of a great theoretical and practical importance [1–3]. Thermal decomposition process of ammonium tetrauranate to uranium oxides occurs in a drum-type rotary furnace (DRF).

DRF is a cylinder with diameter 0,6 m and length 8,8 m installed in a heating chamber with trizonal indirect resistance heating. The furnace has a 2° slope to the horizon and constant angular frequency of revolution 3,33 rev/min. The degree of furnace drum fullness is 3,0...3,5 %. The response time accounts about 20 min. Irreversible endothermic reaction of ammonium terauranate thermal decomposition occurs in the apparatus at temperature 723...923 K:

$$9(NH_4)_2U_4O_{13} \rightarrow 12U_3O_8 + 10NH_3 + 21H_2O + 4N_2.$$

Preliminary heated nitrogen, which consumption makes from 6 to 20 m^3/h is yielded into the furnace.

It is necessary to control temperature condition in a heating chamber along the length of the furnace for qualitative technological process. The heating chamber with resistance heating is intended for necessary temperature formation in the furnace drum. Walls of the chamber are laid with chamotte and diatomite brick. The outside brickwork is proofed with metal frame and encased with ceramic tile. On top heating chamber is covered with heat-insulating blocks. According to the connection circuit heating chamber is divided into three independent heating zones. Inside the chamber there are heating elements (HE) for its heating. Nichrome spiral with «star» connection is applied as an HE. In the first two zones there are three stars of such kind and at the third there are two ones. Temperatures in the heating zones are controlled by thermometers of Tomsk Chemical Combinate.

Circuit of heating elements connection to the power system is presented in fig. 1.

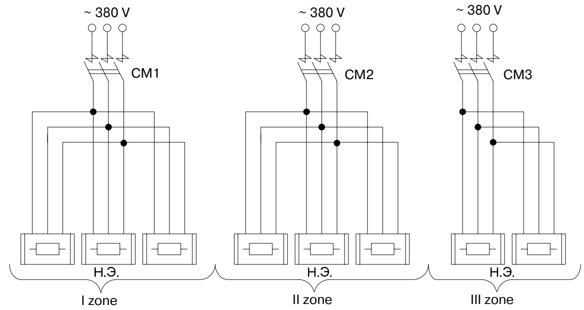

Fig. 1. *Connection circuit of heating elements*

Traditionally, HE controlling of DRF heating chambers is realized by means of contactor-relay circuits. Relay-contactor control does not secure high reliability of HE operation, as power supplying on a cold HE results in its burnout owing to the power, released at HE at the moment of turning on at full capacity, several times higher than nominal one. Besides, instant release of significant thermal energy in small volume promotes thermotension occurrence in structural elements [4]. High values of switched circuit currents (up to 150 A) also results in sharp reduction of contactor endurance.

In this case, existing relay-contactor system of automatic temperature monitoring and control in zones of furnace heating chamber does not allow stable supporting temperature optimal values, determined by the schedule of technological process without additional electric energy consumption, excessive wear of HE and power contacts commutating feeding HE circuits.

Contactors application does not also allow supporting temperature value with high accuracy, as control method assumes contactor switching-off at achieving preset temperature upper bound and its switching-on at achieving lower one. Switching frequency of HE feed circuit is restricted by cutoff frequency of contactor commutation.

Listed disadvantages may be eliminated by means of change of relay contactors, commutating feed circuits, to power semiconductor keys, which realization is possible by using thyristors and symistors. Semiconductor keys application for controlling enables us to develop a system of automatic control of DTRF heating chamber temperature conditions, optimize the process of uranium oxides production and support rise of productivity, reliability and power efficiency of the whole technological process.

In the given paper to apply symistors control stations (CS) instead of contactors is proposed. They are developed by the authors to control smoothly current through the heating chamber HE of drum-type rotary furnace at uranium oxides obtaining. In fig. 2 the scheme of contactor (CM) changing for the power symistor station (PSS) is presented.

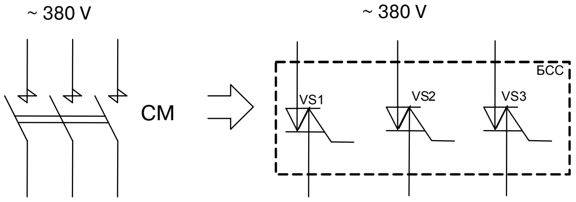

Fig. 2. *Scheme of contactors (CM), commutating HE feed circuits, changing for power symistor station (PSS)*

DRF temperature conditions control. In fig. 3 circuits of HE control system of DRF heating chamber are presented. HE are evenly distributed along DRF axis in heating chambers and «star» connected with zero.

The given circuit of DRF heating control allows us to regulate working zones temperature of heating chamber along the furnace axis with required accuracy to 5 %, which is determined, in general, by temperature sensor (thermocouples) accuracy and amount of heating chamber zones.

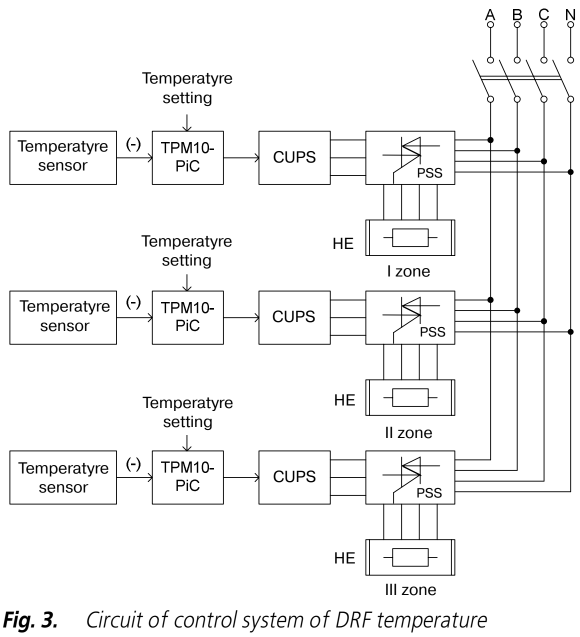

Fig. 3. *Circuit of control system of DRF temperature*

In control system of furnace temperature conditions specialized control units of production association «OVEN» (Moscow) are used. Control unit of power symistor commutating (CUPS) in consistence with commands, generated by temperature controller, produces control pulses of power symistors commutating. The unit serves for transforming commands 0...20 mA into symistors commands, commutating feed circuits of HE. By means of CUPS smooth yield of HE to the given power level is performed. Input signal locking is stipulated in the unit. The unit allows current controlling in the load and voltage transition through zero. Control device of current in the load provides load protecting cutout at fixed value increasing [5]. The unit allow three-phase load to be controlled in two ways:

- phase method;
- by half-periods amount.

Phase control method allows changing symistor opening angle in wide range and provides smooth control of power in the load. In this case, the moment of control signal injection determines the phase of symistor opening. However, when symistors working with non-nil control angles high level of higher harmonic occurs. Particularly this level is high at resistive load. These harmonics are the most dangerous for automatic measuring devices of alternating current.

Control method by half-periods amount provides higher accuracy of power control in the load at minimal level of high-frequency noises. In this case, control signal determines the number of transmitted entire voltage half-periods into the load and symistors commutation occurs at the moment of voltage transition through zero. The given control method is chosen as the main one and applied successfully at symistors control stations, developed by the authors for control of DTRF heating chamber temperature.

Microprocessor programmed meter-regulator, which has an input for sensing devices (transducers) connection, data processing unit, consisting of physical quantities meter, digital filter, PID controller and comparator, connected with proper output devices is used as temperature regulator in the system of control of DTRF temperature conditions.

Meter-regulator, simultaneously with outlet temperature sensor, serves for monitoring and controlling heating technological process and maintains preset temperature with high accuracy. It has several input varieties, permitting connection of:

- resistive temperature transducer;
- thermocouples;
- current or stress sensors.

In closed systems of temperature automatic regulation control action (total power of heating elements) depends on value and sign of output signal of temperature regulator and determines the value of input power into furnace heating chamber, necessary for elimination of disagreement occurred in the system. In the suggested system of temperature automatic regulation, changing of power, supplying to furnace heating chamber is realized by changing of heating elements supply voltage by means of symistor control stations (CS). Power extracted in the heating elements of furnace heating chamber is a nonlinear function of input voltage and determined according to the expression:

$$P_{ГК} = \frac{(U_У K_{СУ})^2}{R_{НЭ}}, \quad (1)$$

where $R_{НЭ}$ is the equivalent resistance of heating elements; $U_У$, $K_{СУ}$ is the input command and magnification constant of symistor control station.

It is obvious that to support linear dependence between an output signal of temperature regulator U_{PT} and power $P_{ГК}$ of furnace supplied to heating chamber, CS has an input nonlinear block with further transfer function:

$$U_У = \text{sign}(\Delta\theta) U_{PT} \sqrt{K_{CУ}}, \quad (2)$$

where sign($\Delta\theta$) is the disagreement signal at input temperature regulator.

It follows from the expressions (1) and (2) that linear dependence of power supplied to the furnace heating chamber on input signal of temperature regulator is provided at such block presence:

$$P_{ГК} = \frac{U_{PT}^2 K_{CУ}^3}{R_{НЭ}}. \quad (3)$$

Taking into account expression (3) transfer function of temperature control open circuit in furnace heating chamber in one-loop system of continuous action with equivalent transfer function, for example, one-capacity chain [6]

$$W_{ГК}(p) = \frac{K_{ГК}}{T_{ГК} p + 1},$$

may be presented in the form:

$$W_{PAЗ.}(p) = \frac{K_{CУ}^3}{R_{НЭ}} \cdot \frac{K_{ГК}}{T_{ГК} p + 1} \cdot \frac{K_{ДТ}}{T_{ДТ} p + 1},$$

where $K_{ГК}$, $T_{ГК}$ are the transmission coefficient and equivalent time constant of furnace heating chamber; $K_{ДТ}$, $T_{ДТ}$ are the transmission coefficient and time constant of temperature sensor.

If $T_{ДТ}$ is taken as fast noncompensible time constant, then at adjustment of temperature-control loop to modular optimum, transfer function of temperature regulator will be obtained:

$$W_{PT}(p) = K_{PT} \frac{T_{PT} p + 1}{T_{PT} p}, \quad (4)$$

where K_{PT}, T_{PT} are the amplification coefficient and time constant of temperature regulator. Here

$$K_{PT} = \frac{R_{НЭ} T_{PT}}{a_{PT} T_{ДТ} K_{CУ}^3 K_{ГК} K_{ДТ}}, T_{PT} = T_{ГК},$$

where a_{PT} is the parameter of temperature regulator adjustment.

Experimental investigations and structured modeling at the program MATLAB package SIMULINK show that at temperature regulator with the transfer function (4) in the one-loop system with a_{PT}=2 and $T_{ГК}$=3$T_{ДТ}$, standard reaction of control loop relative to output signal of inverse feedback (σ=4,3 %) is supported.

Curves of transients of heating chamber temperature changes in three independent zones of furnace heating are presented in fig. 6. They were obtained at simulation model of closed-loop control of furnace temperature, realized with the help of mathematical program MATLAB and its package of dynamic systems analysis SIMULINK. In this system temperature control loop is tuned to modular optimal.

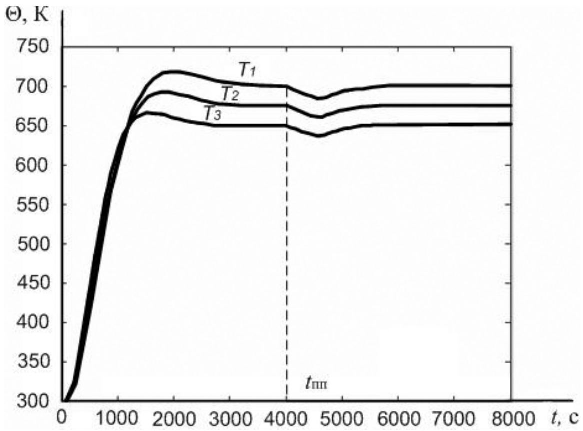

Fig. 6. *Transients of temperature change of DRF heating chamber*

As it is seen from the results of the modeling at selected parameters of temperature regulator adjustment the system of automatic control provides continuous control of heating power and works off perturbation action. However, the curves of temperature change transients of furnace heating chamber in three heating zones (T_1, T_2, T_3) are characterized by rather large overcontrol. To decrease temperature overcontrol of furnace heating chamber to standard value and obtain the transient of temperature change with the minimal degree of overcontrol it is necessary to install compensating device, which transfer function is equal, in our case, to the direct component of feedback $1/(T_{ДТ}p+1)$ at the input of the control system.

Simulation model with control by half-periods amount. The simulation model of symistor station with the control by half-periods amount for temperature automatic control of furnace heating chamber is presented in fig. 7.

The given model consists of six main blocks:

- block «Command» is the device of command setting;
- blocks «3-phase source 1», «3-phase source 2» are three-phase power sources with nominal industrial parameters;
- subblock «System controller» presents three blocks, in each of which the circuit is set up. With it help three-phase signal is generated by control system with frequency 20 times lower than frequency of the circuit for 10 half-wave pulse packets forming;
- subblock «Module» is a block of power symistors, connected by the circuit presented in fig. 2;
- block «3-phase R1» is a three-phase heating element (connection «star» with zero) being resistive load.

The diagram of current at HE according to signal assignment, obtained at simulation model is presented in fig. 8.

It is seen from the given diagram that at decrease of signal assignment level reduction of transmitted half-periods occurs. Besides, symistors commutation at the given control mode occurs at the moment when current at HE is insignificant or equals to zero. It excludes the mode of voltage impact application to HE at symistors commuta-

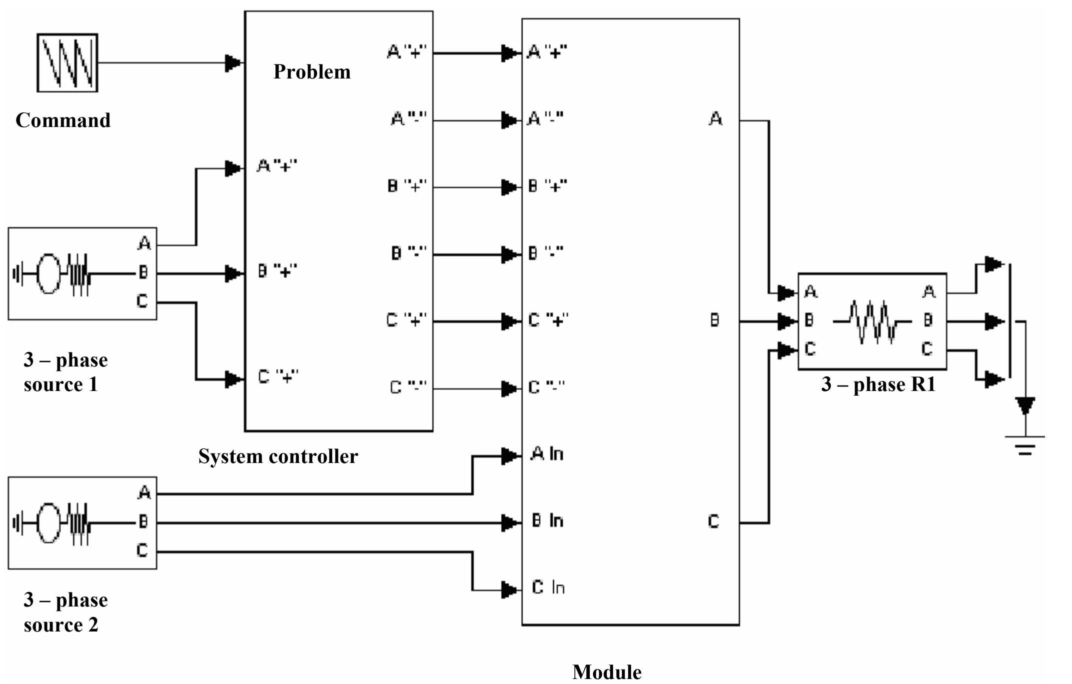

Fig. 7. Simulation model of symistor station with control by half-periods amount

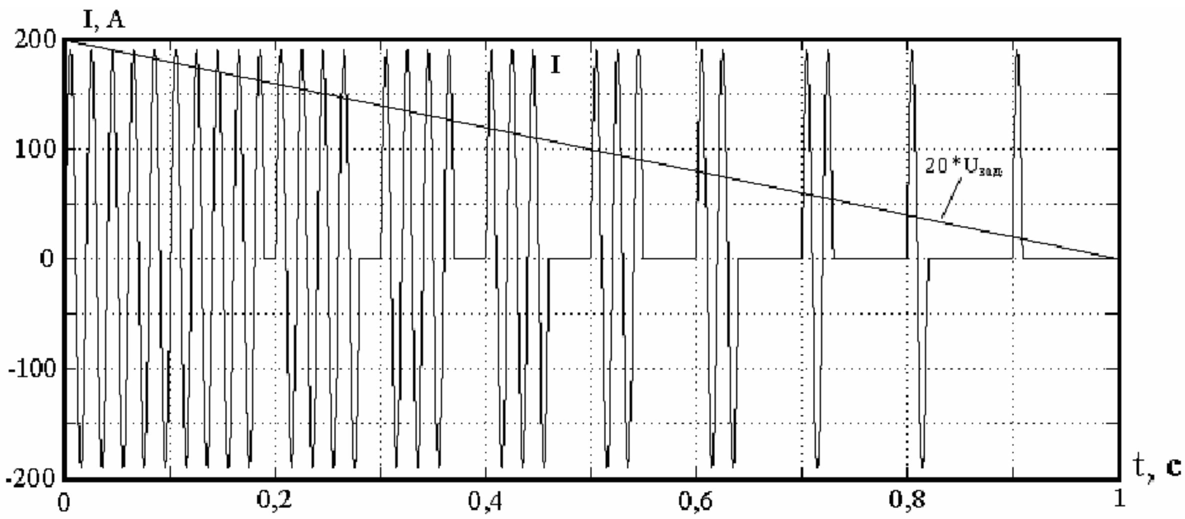

Fig. 8. Diagram of current dependence on signal assignment

tion, that significantly increases their service life, improves working capacity and reliability of the system of temperature automatic regulation of DRF heating chamber.

The above confirms once more that at CS working to powerful active load it is reasonable to use the control mode by half-periods amount instead of phase mode of symistors control.

4. Conclusion

Application of symistor control stations instead of contactors for smooth control of current through heating elements of drum-type rotary furnace heating chamber at uranium oxides production allows:

- using in the system of automatic control of heating chamber temperature conditions industrial controller, owing to which it is possible to optimize the process of uranium oxides production;
- applying power symistors control according to the number of half-periods, that excludes voltage regime percussive enclosure to heating elements at commutation, that increases significantly equipment service life, working capacity, reliability and interrepair time.

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PULSE-CODE TECHNIQUE OF CONTROLLING PROCESS VARIABLE OF FREQUENCY CONVERTER IN INDUCTION HEATING DEVICE

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The technique of pulse-code control of frequency converter process variable to install induction heating is suggested. The basic analytical relationships for calculation of control characteristics of the technique suggested at constant resistance of converter load are presented. Using the given method both loss power at switching power interconnecting device and mass-size parameters are shown to decrease significantly, whereas frequency converter efficiency increases.

Induction heating by high-frequency currents is the most modern and high-technology way of carrying out many working operations (element heating for pressing, hardening, crucible melting etc.) [1].

When designing processing equipment the wide range of powers, extracted at various elements, for providing required rate of their heating is necessary [2. C. 19]. Aforesaid, undoubtedly, requires application of controlling energy flux transmitted to the load in the devices of induction heating.

In up-to-date induction heating devices frequency converters (FC) with different control modes of process variable (current, voltage, power) are applied. One of the main disadvantages of known modes is a significant dynamic loss in key elements, occurring at controlling, that results, in its turn, in overheating and probable failing. This problem is solved by applying damping chain in this case FC circuit technology becomes more complex and their mass-size parameters become worth [3]. Therefore, at present, one of the main tasks of FC design is a choice of effective control mode, providing high efficiency and improving mass-size parameters of the developed device.

1. Systems with pulse-code controlling

Pulse-code systems [4], where forming of control action in a form of pulses set occur, are applied in control engineering. Systems with pulse-code modulation (PCM) have found wide application for power control in blast melting furnaces in the condition of average power leveling [5]. In SS P 51317.3.2-99 this method is determined as control of current alternation, i.e. the process of changing in relative of half-times of current flowing to the number of half-times, when there is no current.

Modification of this method is suggested to be used also in systems of induction heating, as at high values of Q factor of oscillatory circuit typical for these systems it allows controlling inductor continuous current with low pulses in wide range. For high-frequency systems of induction heating symmetric components of low-order consumed current, occurring in this case, meet the demands of SS P 51317.3.2-99, where it is noticed, that harmonic frequency should not be less than 40 harmonics of system voltage frequency (50 Hz), namely $f_{har.}$>2 кHz.

According to the conversion technique of control signal to control action [6] pulse-code controlling modes of FC are divided into main groups (fig. 1): with forward conversion analog-code, with programmed equilibrium and with following two-position conversion.

If at FC realization, the converter «analog-code» is selected as a controller, so sequence of control pulses (pulse-code combination), determined by the program beforehand, is assigned each value of control signal. Forward conversion allows obtaining high control rate.