International Journal of Soft Computing 10 (5): 326-331, 2015
ISSN: 1816-9503

Microprocessor Control System of Sapphire Crystal's Growth Temperature Regime

Vasiliy Grigorievich Rubanov,
Aleksandr Stepanovich Kizhuk and Yuriy Aleksandrovich Gol'tsov
Belgorod State Technological University Named after V.G. Shukhov,
Kostyukova Street 46, 308012 Belgorod, Russia

Abstract: By analyzing of temperature control system of unit for sapphire crystal growing, applied in production are revealed significant disadvantages, affecting both the quality of the process and energy consumption in manufacturing. Here is proposed a structure of microprocessor automatic control system and software of its functioning, eliminating revealed lacks, associated with phase imbalance of supply voltage and appearance of higher harmonics, negatively affecting industrial voltage supply quality. Providing technological modes of heating installation carried out using the power supply circuit of two groups of field-effect transistors, operating in dynamic mode with minimum drain-source resistance at the time of switching which required the development of control system on a monostable multivibrator. To implement regulating laws are used modern microcontroller tools and technological programming languages, recommended by the IEC. Usage of visualization tools enables graphical representation of current information, operational control and corrective parameters as well as notification of emergency modes. Also, here is shown efficiency of system operation using PID control law with width modulation and proposed specific technological solutions.

Key words: Crystals growing, crucible, heater, temperature, control, thyristor regulator, field effect transistor, structure, program, control law, algorithm

INTRODUCTION

Synthetic sapphire growing is tied to the execution of the temperature regime control technological process, wherein the temperature in a crucible varies between 25°C and 2050°C with a fixed degree of its increasing and decreasing that is ensured by implementing a control system with the ability of programmatically temperature change preset in a crucible with a set accuracy (Dobrovinskaya *et al*., 2004). In existing installations used by "Techsapphire" Ltd. control is performed on the primary winding of the power transformer,connected to an industrial voltage of 380 V wherein to create the appropriate power capacity, emitted by the secondary winding, a thyristor regulator TYA110 is used. There is in the system a 50-60 kW step-down transformer used as a heating element power supply. Thyristor regulator TYA110 (TR) controls the power capacity, emitted by the secondary winding of a step-down transformer by thethyristorscouple in the primary winding of the power Transformer (T1). Operating principle of such regulator is based on converting the continuous voltage on input into a sequence of phase impulses that control the thyristors. Apart from TR in the system are used industrial controllers with help of which the input voltage on the regulatoris changed programmatically depending on the defined temperature curve in the crucible (Bagdasarov and Goryainov, 2007).

There are two operation modes of the thyristor regulator used. Phase angle control mode with a "soft start" and acurrent limit and "burst firing" for resistive and transformative loads. In the first mode, power capacity is controlled by changing the phase value. In "burst firing" mode, it is controlled by changing the amount of "full waves" in supply voltage, applied to the heater during each "control" period. This method is used for purely resistive loads which have a "cold" (original) resistance commensurable with its "hot". This operation mode provides very small electromagnetic interference. At transfor merloads thyristor regulator works in "burst firing" mode with back cutoff of phase angle for the first half-wave. After the "soft start" regulator automatically switches into "burst firing" mode if the "given preset" is greater than the minimal setting value +10% of preset's range.

Corresponding Author: Vasiliy Grigorievich Rubanov, Belgorod State Technological University Named after V.G. Shukhov, Kostyukova Street 46, 308012 Belgorod, Russia

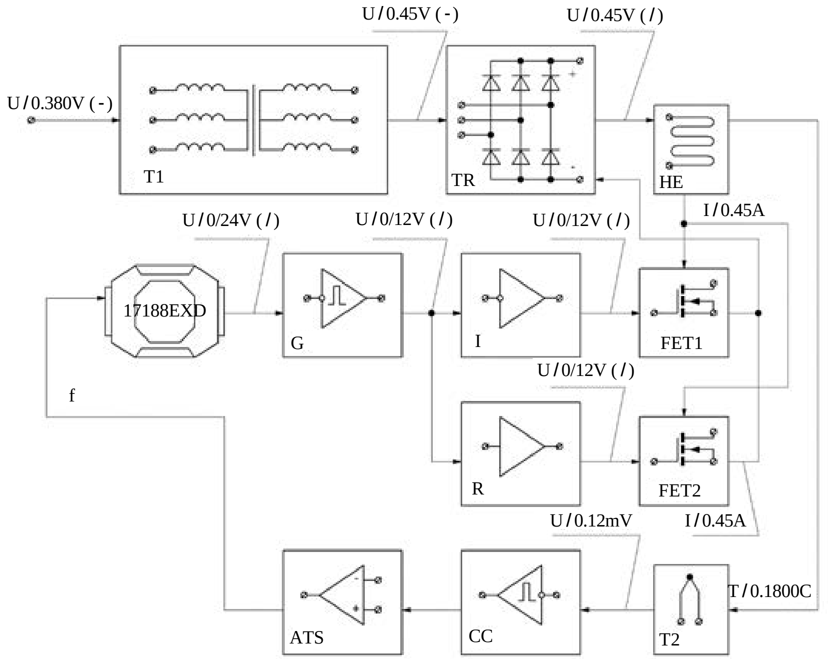

Fig. 1: Temperature regime microprocessor control system flowchart where; T1: Transformer; TR: Thyristor Regulator; HE: Heating element; G: Generator; I: Inverter; R: Repeater; ATS: Amplifier of Thermocouple Signal; CC: Compensation Circuit; T2: Thermocouple

Thorough, analysis of the thyristor regulator working modes allows noting such disadvantages in control as:

- In the industrial electric network taking into account view of using a powerful transformer to supply the heating element due to uneven loadarises phase imbalance which could lead to significant changes in phase voltages
- During “soft start” and loadconnecting, when the “sinusoid is cut”, higher-order harmonics arise in the second winding which leads to noises in the industrial power supply network
- In TR’s “burst firing” mode uneven distribution of sinusoidal voltage periods occur which also lead to harmonics arising in the second winding
- Connecting a power transformer to the industrial 380V power supply leads to the necessity of solving the load balancing problem for the industrial power network during the launch of all crystal growing facilities on the plant

Main part; structure of high-power heater micro-processor control system: To eliminate the aforementioned disadvantages researchers suggest a temperature regime control system for sapphire crystal growing, structure of which is shown on Fig. 1 (Rubanov *et al*., 2013; Porkhalo *et al*., 2013).

Efficiency of the developed system rises due to introduction of the following changes:

- Control is concentrated in the secondary winding of the used three-phase transformer instead of one-phase which eliminates the problem of phase imbalance and reduces the amount of noise in the industrial power supply network
- Now control is carried out at a constant voltage, received from the result of three-phase voltage rectifying on the transformer’s output with the help of a three-phase diode rectifier which leads to elimination of the noise
- Heater power supply produces through controlled switches (Nabokov *et al*., 2013) in place of which are used powerful field-effect transistors, working in impulse mode
- To form an interface device of IRF3205 thereis used FET’s control system on timer IC NE555

Since, control is performed by the second winding with a constant voltage of 12-20V to which the crucible heater is connected, then the current I flows through the heater and reaches 2 kA since:

$$k \times P = I^2 \times R$$

Where:

k = Efficiency factor of the transformer
R = Heater resistance
P = First transformer windingpower capacity
k×P = Second transformer winding power capacity) this value occurs for k = 0.53, R≈0.008 Ohm, P = 60 kWt

To ensure the commutation of such current there are appropriate FETs needed. Reduction of losses on drain-source transitions according to technical characteristics can be achieved by using a short time interval in which the drain-source resistance is reduced in 2-3 times to the initial. In the heater control system researchers recommend the aforementioned FET operation mode.

As noted, to let the currentof about 2 kA flow there was chosen an IRF3205 FET with current-voltage characteristics as shown on Fig. 2. The feature of FET's work in impulse mode is in its reduction of drain-source resistance. Since FET is connected in series with the transformer's load, then the dissipated power capacity on the transition will be less and most of it will be emitted on the load. To make a FET work in impulse mode there is correct tuning of control impulse duration,supplied to the gate, required. For IRF3025 FET according to source current and source-drain voltage relation and the control impulse duration,supplied to the FET's gate, there should be chosen a commutation time of 10...100 msec which can provide the flow of current with a value of 200...400 A.

On the 10 msec interval of FET's opening and for source-drain voltages of 12-20 V currents let through by the transistor in this interval will lie within the range of 400 A; lets take the middle value of 200 A, then the amount of transistors needed to let the current of 2 kA through the load will be equal to 10 units. Since the current through the load must flow continuously and the transistor must work for 10 msec, then to provide a continuous current there areneeded two groups of transistors which will work alternately and provide the impulse work mode of FET's.

Since modules 70XX are used in communication with remote control objects, then in this case a SMH2G PLC can be used with a MC module. Because this controller cannot commute10 msec FET control impulses there is arise a problem of creating a converter of control impulses coming from the SMH2G's digital output unto the short control impulses of IRF2035 FET.

To this end with the help of NE555 IC lets construct a monostable multivibrator with 20 msec output of "meander" type square-wave impulses (Fig. 3).

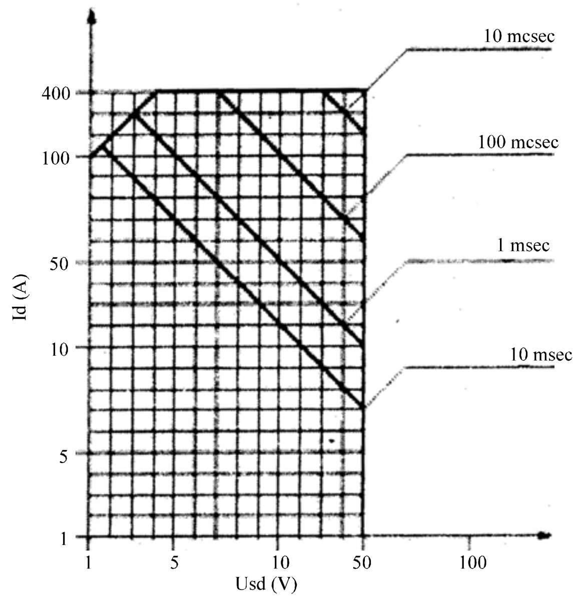

Fig. 2: Source current and source-drain relation and control impulse duration fed to the FET's gate

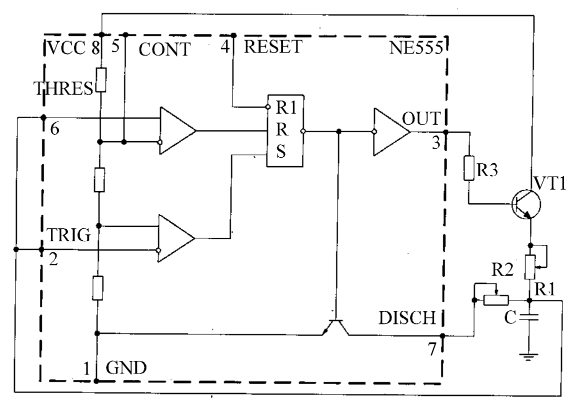

Fig. 3: Monostable multivibrator on NE555 IC

Monostable multivibrator control carries out from SMH2G's digital output and generated signal produces in the form of a PWM signal with pulse width control for the selected control law. To provide the commutation of FETs the timer's output applies to the circuit of obtaining the direct and inverse signal, supplying to the first and second FET group, incorporated into the load current control circuit. To set the required signal period on the timer's output a time-setting circuit is introduced. When supplying a high-level voltage to RESET input (pin 4) NE555 IC will go into "start timer" mode. In this mode on IC's OUT output (pin 3), a high-level voltage will be set which will open transistor VT1, connected to VCC via collector and to time-setting circuit R1C via emitter, through which the charging current of the capacitor C will flow. When capacitor C, connected to THRES (pin 6) and TRIG (pin 2), reaches two thirds of VCC's voltage timer's trigger reset will be achieved and simultaneously will be opened the internal transistor of the IC, through which will begin the cycle of capacitor discharge when it's voltage will reach two thirds of VCC's voltage the signal will be inverted. Thus, on the timer's output will be formed a "meander" type signal in the case of equality of R1 and R2 is provided.

Since, the developed generator will control groups of FETs, connected into the heater's load circuit and will be started by a square-wave signal from the controller's output then as a result in the load in the appropriate points of the coupling circuit will be formed signals, diagrams of which are shown on Fig. 4.

Control system for temperature regime of sapphire monocrystal growingfacility is developed on the researchers patent's basis (Kizhuk *et al*., 2014). Control circuit uses SMH2G PLC which circuit scheme is shown on Fig. 5. SMH2G PLC uses an expansion module MC. To synchronize the time intervals during heater control a period of supply voltage is used received by the controller through the counter input DI8 of circuit VD7, VD8, R1, R2, VT1 (Fig. 5). Measurement of the current object's temperature is provided by a microprocessor temperature converter METRAN 2700 from which the signal is received by the MC expansion module through AI0. Scheme, ensuring the temperature regime in the controlled object, is represented by T1, VT7…VT26, DD1, R3…R9, VT2…VT6, Rн.

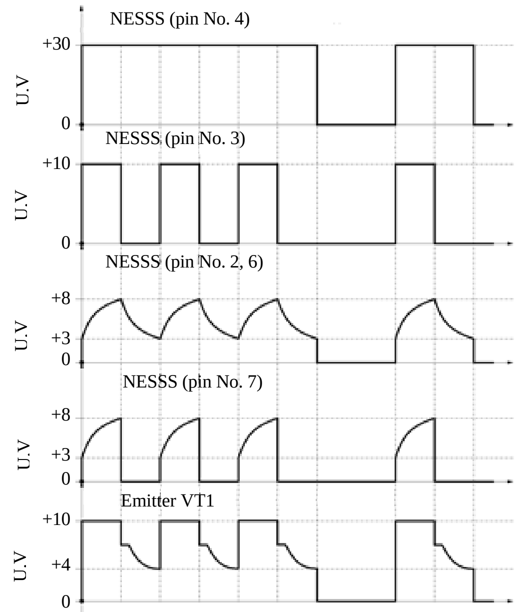

Fig. 4: Diagrams of IC NE555 output signals

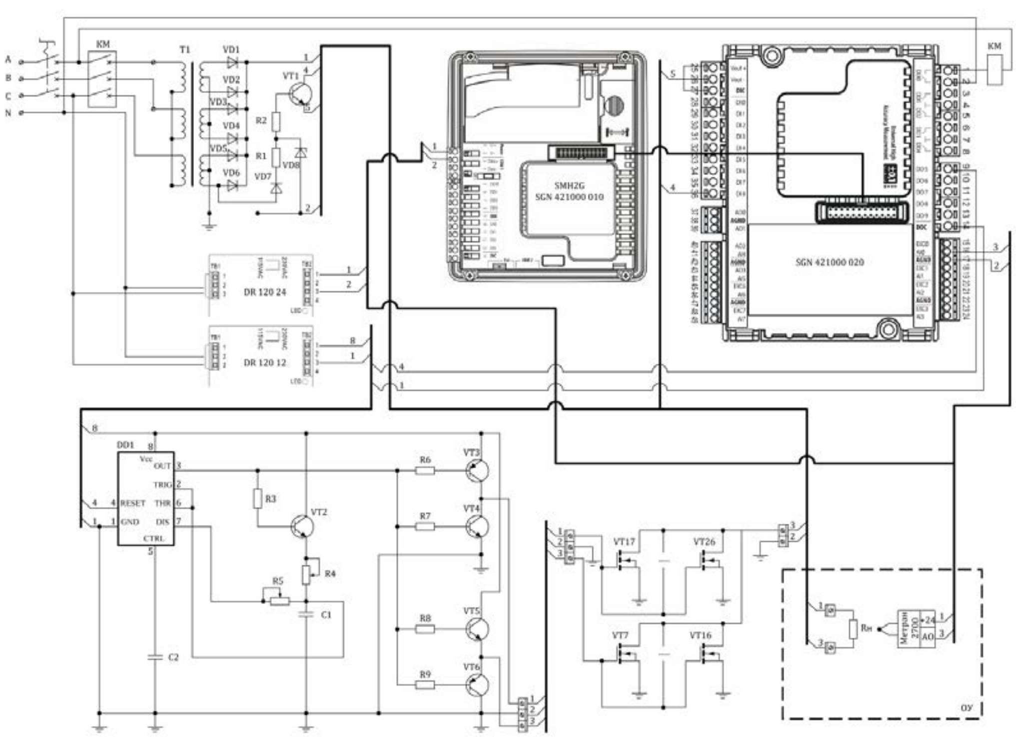

Fig. 5: Heater control circuit scheme

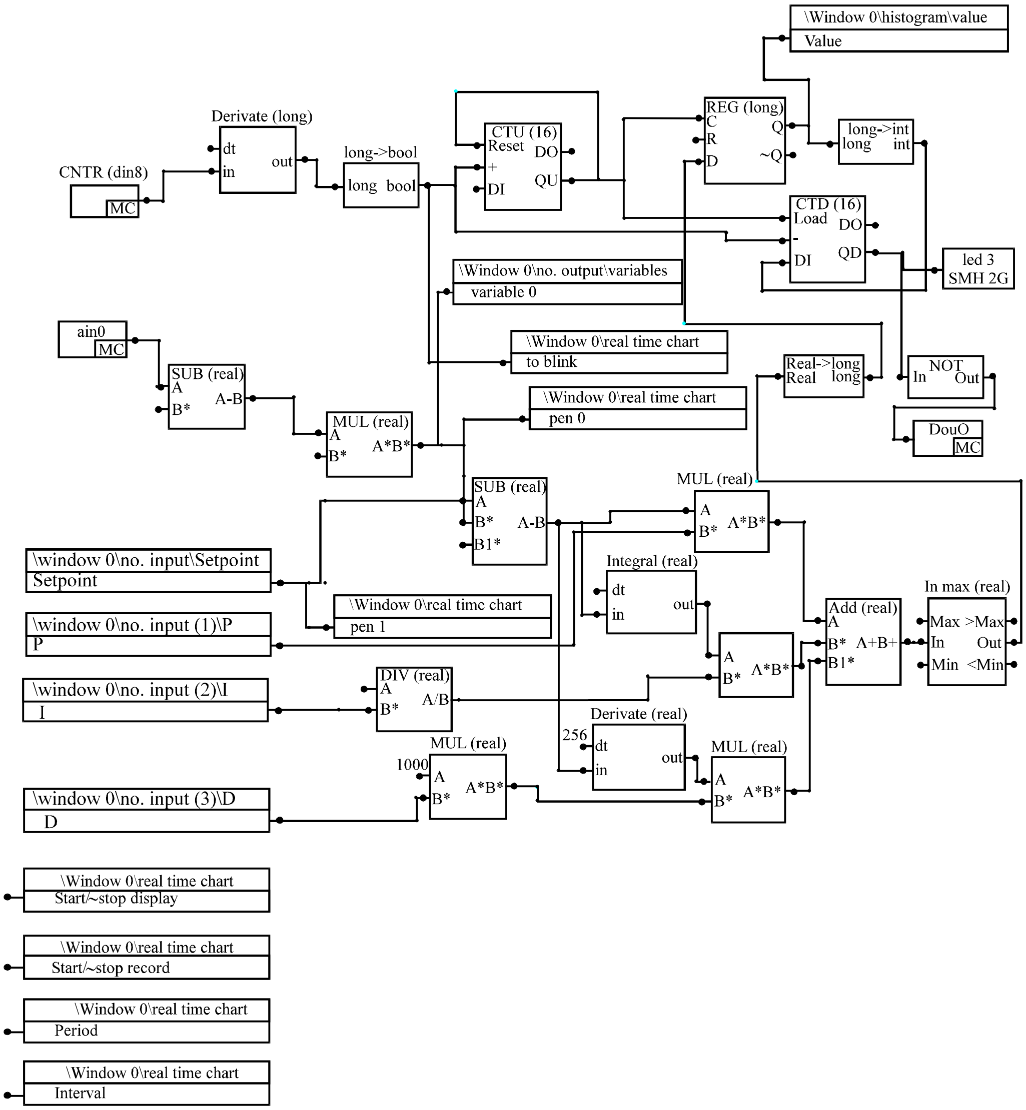

Fig. 6: Object's temperature control system program realization

The software of the heater control system operation: For the control law realization SMLogic programming system is used in the software of which was developed object's temperature regulation algorithm (Fig. 6) (Mishunin and Rubanov, 2003). At startup of the algorithm from the counter input "CNTR (din 8)" controller counts the current amount of supply voltage periods which is converted by differentiation block "Derivate (long)" into "log. 0" (positive half-wave)/ "log.1" (negative half-wave). Further on counter block "CTU (16)" releases 256 supply voltage periods (control periodicity interval) which periodically resets. Reset signal from the "QU" output is supplied to the strobe input "C" of "REG (long)" register; onto the "D" input will come proportional to the current object's temperature control, i.e., a number in the range 0…256, produced by a PID-regulator. As a result, the current control for the periodicity interval will be fixed in the register (Grigorevich, 2013). This value will also be written to the down counter "CTD (16)", onto the "minus" input of which will be supplied the impulses, equal to the supply voltage period and on the output of the given block will be formed a PWM signal, proportional to the control action.

The "CTD (16)" counter's output "QD" is connected with an indication block "led3 SMH2G" on the front panel of the SMH2G controller and with block "duo0" (digital output DO0) of the MC expansion module which controls the monostable multivibrator on the DD1 (NE555) IC (Fig. 3-5).

Current temperature is received and converted by "ain0", "SUB (real)", "MUL (real)" blocks and onwards is supplied to the blocks forming PID-regulator. “SUB” block performs the substraction of the current temperature on input “B*” from the setpoint on input “A” which is set from the front panel of SMH2G. “MUL” block performs the proportional control law, “Integral (real)” block performs the integral control law and the “Derivate (real)” block performs the differential one. For visualising the control process is used program SMART in the SMLogic environment which allows to access the screen and keypanel of the SMH2G controller. Blocks “\Screen\Value input (1..3)\P|I|D\”, “\Screen\Value input\Setpoint” blocks are used for visualisation.

SMH2G’s control panel is used as a local control pad for the sapphire growing facility on the screen of which in different windows the operator may observe the current temperature inside the object, set date, select required control law coefficients using the keypad and adjust the setpoint as apropriate.

SUMMARY

Further, improvement of the microprocessor sapphire growing technological process control system can be achieved by introducing extra circuits of cooling control, rarefication, etc., furthermore these subsystems can be realized on same SMH2G controller since its remaining resources are more than enough for these objectives.

CONCLUSION

The developed microprocessor temperature regime control system for the heating facility, implementing the technological process of sapphire crystal growing has a significant advantage incomparison with the existing systems since it eliminates phase imbalance from uneven load resulting from simultaneous start of several facilities which was achieved due the usage of a three-phase transformer with control in the second winding; avoid the appearing of harmonics which result in noise in the industrial power supply network during “soft start”. Moreover, using a PID-law for control over PWM there is increased the quality of the system while the usage of FET properties allows significantly increase permissible current in the short-time impulse mode which led to the realization of a flexible control over high loads.

ACKNOWLEDGEMENT

This research was made under support of the RFBR grant #14-41-08009.

REFERENCES

Bagdasarov, K.S. and L.A. Goryainov, 2007. Heat-and Mass Transfer in Single Crystals growing by Oriented Crystallization. Publishing House, Moscow, Pages: 224.

Dobrovinskaya, Y.R., L.A. Litvinov and V.V. Pishchik, 2004. Encyclopedia of the Sapphire. Publishing House, Kharkov, Pages: 508.

Grigorevich, R.V., 2013. Disaggregation of control system synthesis for mobile vehicle with survivability property. Middle-East J. Sci. Res., 15: 1666-1674.

Kizhuk, A.S., V.G. Rubanov and A.V. Chuyev, 2014. Control system of electric heating temperature. Patent Application RU 2515129.

Mishunin, V.V. and V.G. Rubanov, 2003. Thermal object control unit by usage of the fractional type control law. Priborostroenie, 11: 30-34.

Nabokov, R.A., V.G. Rubanov and A.S. Kizhuk, 2013. The analysis of the dynamics of the voltage regulator with an electronic relay element with hysteresis. World Applied Sci. J., 24: 1686-1690.

Porkhalo, V.A., V.G. Rubanov and V.G. Shaptala, 2013. Automation of clinker burning kiln based on cascade and multiply connected control systems. Bull. BSTU, 2: 69-72.

Rubanov, V.G., E.N. Korobkova and E.P. Dobrinskiy, 2013. Application of decomposition method to cyclic finite state machine synthesis with reconfigurable time parameters of output signals. World Applied Sci. J., 25: 69-77.