Distributed Control System for Crystal Growth

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Keywords: Crystal Growth Control System, LBO Crystal, Controller, Load-commutator, Thermal Field Symmetry.

Abstract: Distributed system for control over the crystal growth process is presented. The main advantages of the system are its low cost, ability to recover after power failure, an application of standard ISaGRAF software environment and available low-power PC-Controller. One of the option of the system is an ability to control symmetry and dynamics of the heat filed. This option is the key factor for the progress in growth of nonlinear optical LBO crystal.

1 INTRODUCTION

Crystal growth systems with various control loops (rotating, pulling, weighting of the crystal etc.) have been developed for industry since the middle of last century. Now there are a lot of commercially available growth stations with modern control systems (CS). Our approach in elaboration of CS is based on ability to nonuniformly heat the crystallization domain and therefore to apply nonsymmetric stationary or dynamic heat field. This provides additional parameters to control over heat-mass transfer processes which are always have been considered as a key factor in the growth of high quality crystal.

The base of our CS is a PC-controller I-7188 and remote input-output modules of I-7000 series (produced by ICP DAS Company). The use of the modules of I-7000 series provides quite cost-effective reliability. They are not unique. A lot of similar modules are produced by other companies, for instance by Advantech. Also we have designed home-made modules with controllers of crystal rotation and pulling, as well as load-commutator for control of the heat field.

2 HARDWARE

Here we consider one example of operating CS for the growth of nonlinear crystal LBO (LiB_3O_5). Fig. 1 presents the scheme of the growth station which consists of three-zone heating furnace, balance sensor, pulling and rotation drives, contact-meter and main controller I-7188EG. Temperature control is realized by three-zone Eurotherm reglator through the separated RS-485 bus. For that reason additional serial ports for I-7188EG were added by introducing mezzanine board X511. A main feature of the CS is the presence of the load-commutators which may switch segments of the heating zones through solid state relays according to the program. The feedback signal for thermoregulator is provided by four parallely connected thermocouples placed around heating zone. This was found to be enough for stable regulation of temperature in the wide range of periods of switching (1 sec - 20 min).

3 SOFTWARE

Each growth station with individual IP-address has its own controller with onboard DOS-compatible “Mini OS7”. In that way any standard programming language may be used to realize a project. In our case we were concentrated on the logic of crystal growth process, so the I-7188EG controller with built-in ISaGRAF 3.xx system was used. ISaGRAF system implements the following functions: data reading signal preprocessing, realization of control algorithms, communication between modules and HOST computer.

A program loaded in the controller is performed with cycle 0.2 sec. Crystal growth parameters are slow and have a very wide dynamic range. For instance, the growth speed may vary from 0.001 to hundreds of grams/hour.

While a parameter is low-rate changing, the controller specifies some time interval and calculates

E. Kokh A., A. Vlezko V. and A. Kokh K..
Distributed Control System for Crystal Growth.
DOI: 10.5220/0004033902020205
In *Proceedings of the 9th International Conference on Informatics in Control, Automation and Robotics* (ICINCO-2012), pages 202-205
ISBN: 978-989-8565-21-1

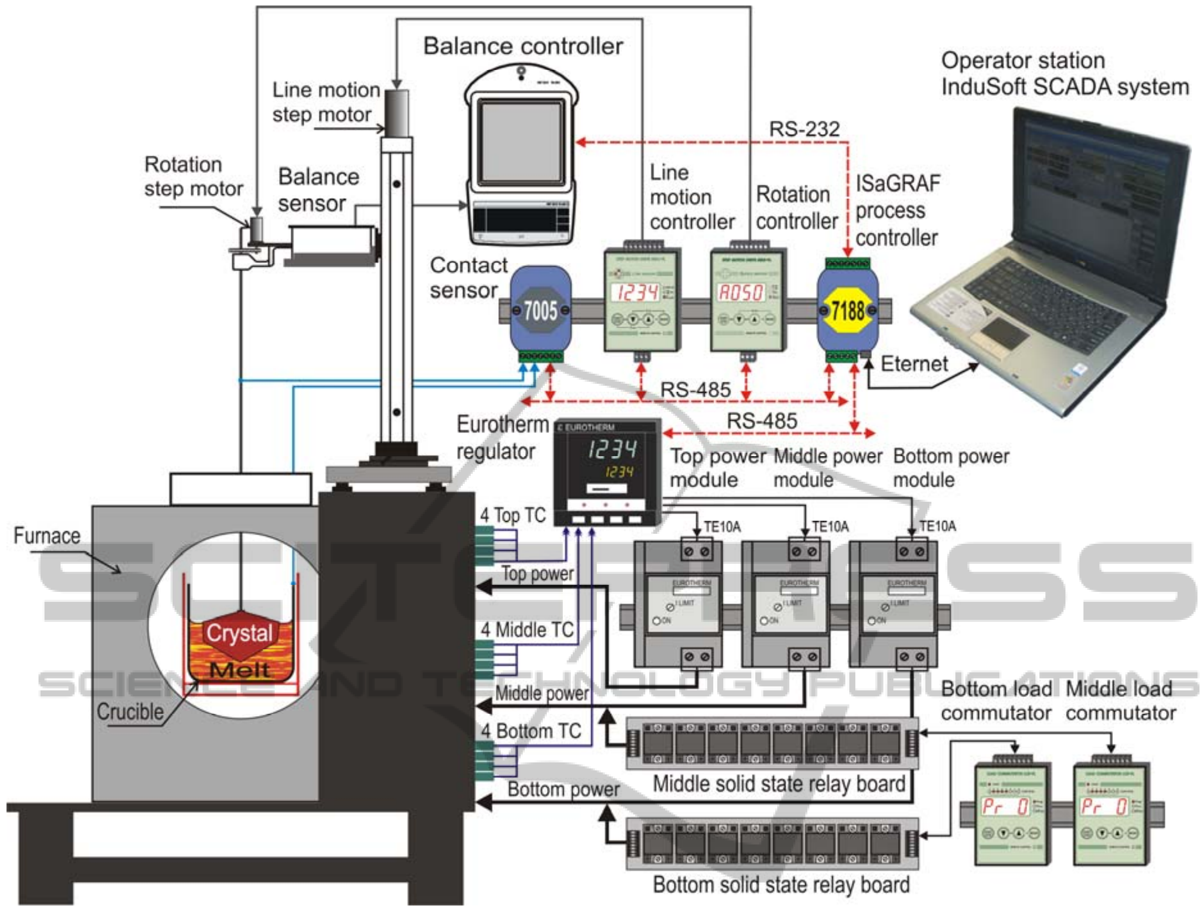

Figure 1: LBO growth station with ISaGRAF process controller and SCADA system.

the value. And on the contrary, if parameter changes very fast, the controller defines how often it will change the value.

Fig. 2 shows a fragment of FBD program of process parameters calculation. Output value of every parameter is the function of crystal length. So the first part of the algorithm consists in calculation of length increment as a function of growth speed. After that other growth parameters are specified as a function of the increment. In that way limitation of input/output numbers (not more than 32) for each block of FBD scheme is avoided.

Crystal growth process may take place up to several months. During this time there may be some imperfection in electrical supply while UPS blocks do not totally protect the system. Or sometimes it is necessary to reconfigure or even replace some blocks of the CS. In that view survivability and reliability of the system is very important. In other words the controller should contain some algorithms to restore values of all critical parameters and to recover the CS after a power failure. It is done with the current values saved in a nonvolatile RAM while setpoints and other seldom changing parameters are saved into EEPROM and are read from there in the case of system reload with the symptom of breakdown. The same concept of parameters restore after breakdown or power off was realized for our periphery modules like step motor drive MD1-VL which may be used offline.

A SCADA program InduSoft Web Studio is used as the program of upper level because of low price and the presence of Modbus driver for direct communication between ISaGRAF project and SCADA. The last reason is also important since many programs use various OPC-servers which slow down the system.

A main purpose of SCADA-program is to interface with operator and visualization of parameters and trends. The program has 1500 variables which is quite enough for CS of one growth station. On the other hand, all calculation function, storage and initialization of variables, and restore of data after breakdown are implemented in the main controller.

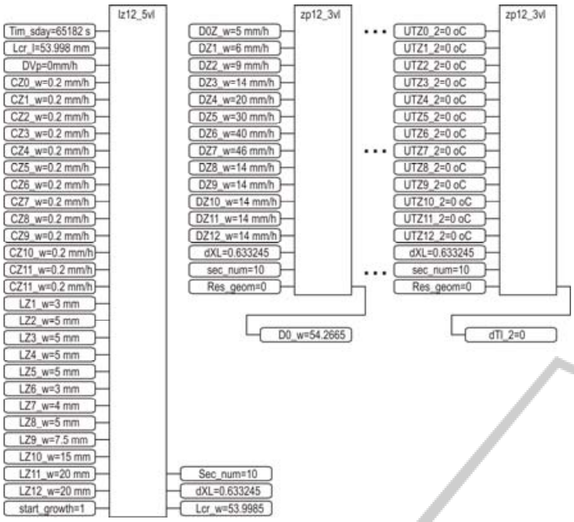

Figure 2: Block diagram of the piecewise-linear crystal geometry master.

4 USE OF THE CONTROL SYSTEM. EXAMPLE OF LBO CRYSTALS GROWTH BY KYROPOULOS METHOD

Kiropoulos method consists in the growth on seed crystal slightly dipped in the melt (or the melt-solution). The growth proceeds towards the melt by a smooth decrease in temperature at small temperature gradients, which makes it possible to grow high quality crystals. This method is widely used for production of large sapphire crystals of any crystallographic orientation, with an extremely low dislocation density of less than 1000 cm^{-2}.

LBO single crystal is a well-known material used in nonlinear optics (NLO) for the last 20 years. Due to good operating performance and relatively high nonlinear coefficients LBO crystals are widely used for frequency conversion in the visible and near UV regions. These crystals are of special interest now since they may be used in the laser systems of extremal intensity (http://www.extreme-light-infrastructure.eu/). Growth from molybdenum oxide fluxes has brought a considerable progress in LBO growth technology but the crystals with large high quality parts were still unavailable until recent time.

LBO growth furnace has 3 heating zones. The bottom and middle zones are composed of 8 heating elements. Their connection is realized through two separate load commutators governed by the control system. Each one allows to simultaneously switch on any of the heating elements in any sequence and for any time period (Kokh et al., 2009).

First advantage of such a system is the possibility of intensive but noncontact mixing. It is very important since homogeneity of badly-miscible LBO and the flux seems to be a key factor to large size and high-quality crystal growth. The melt homogenization procedure is realized by prolonged period between switchings (more than 15 minutes). In this case, extremely high radial temperature gradient produces intensified thermogravitational convection. A convective pattern at the surface of the melt (Fig. 3) clearly indicates a direction of the prevalent flow which will be turned relative to the crucible after next switching of the heaters.

Figure 3: Convective flows on the top of the melt-solution during homogenization procedure.

In order to grow larger crystals the direct scale up of the setup faces some serious problems. For example, for large crucibles (>100 mm in diameter) it is difficult to maintain axissymmetric heating and hence to fix a coldest point on the melt surface at the geometric center of the crucible. Otherwise distorted heat field can lead to highly asymmetric crystal growth which results in the formation of defects.

The CS allows to set the corrections to switching time for any group of the heaters. Seeding process is carried out in quazi – stable heat field when period of switching is ~3 sec. In that case no temperature oscillations are observed in the melt. Usually our furnaces need delay corrections less than 0.5 sec for some heaters to adjust surface temperature distribution to axissymmetric one. This process is controlled by observing the movement of small pieces of LBO (~ 1-2 mm) thrown onto the melt surface at a temperature of 10-15 degrees higher than crystallization temperature (Kokh et al., 2010). Step-by-step adjusting of time for each pair of heaters is done until a crystal piece stops to move and dissolves right in the crucible center.

Large period of switching may result in the considerable temperature oscillations (~10˚C) in crystallization region. Until recently such conditions were considered as unfavorable for crystallization process. However our results have proved this opinion to be incorrect (Kokh et al., 2012). The progress of LBO growth under nonstable temperature regime has resulted in the crystals (Fig. 4) suitable for fabrication of world largest 65 mm in diameter optical elements for high energy laser applications (Mennerat et al., 2011).

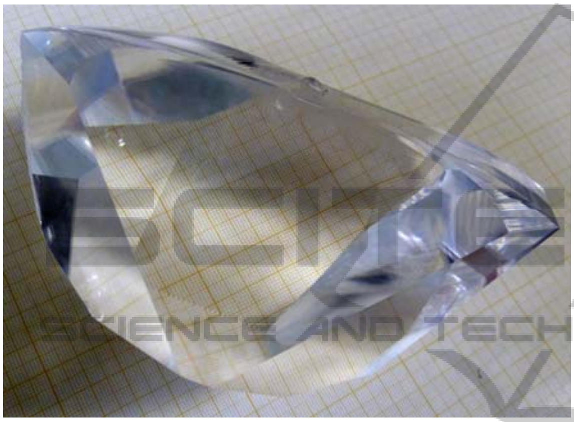

Figure 4: LBO crystal suitable for production of Ø65mm nonlinear optical element; weight: 1290 g, dimensions: 149x131x83 mm.

5 CONCLUSIONS

Elaborated distributed control system provides reliable growth process. One of the options of the system is an ability to control symmetry and dynamics of the heat field. By the example of LBO crystals, this option was shown to contribute in the progress of growth technology.

ACKNOWLEDGEMENTS

Financial support form grants RFBR 11-02-12156-ofi_m and 11-02-12164-ofi_m is highly acknowledged.

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