THE USE OF THE PROGRAM MODERTL IN CONTROL SYSTEM OF INDUSTRIAL ELECTRON ACCELERATOR

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Abstract

Authors have designed and integrated the software ModeRTL (Modeling of Radiation-Technological Line) into the control system of the RTL incorporating an industrial linear electron accelerator with a scanner of electron beam and a conveyor. An operation of the control system is based on monitoring of electron beam and radiation facilities parameters, calculations of the absorbed dose distribution in an irradiated materials, and elaboration of control signals on value of deviation between calculated and calibration data for the specific radiation–technological process. A summary of integrating of the software ModeRTL in control system of the RTL will be discussed in the paper.

1 INTRODUCTION

One of the most important characteristics for all radiation-technological processes is the absorbed dose of electrons in an irradiated materials. For each product to be treated in the irradiation facility, there will usually be a minimum dose limit $D_{min\text{-}lim}$ to obtain the desired effect and a maximum dose limit $D_{max\text{-}lim}$ to avoid product degradation. Monitoring and control of an absorbed dose within irradiated materials practically are a little used. Such situation is determined by absence of direct express measurement methods of an absorbed dose within irradiated product in real-time mode. The additional technical problems arise at measurement of an absorbed dose from scanning electron beams.

The modern industrial electron accelerators are equipped with control systems for electron beam and radiation facility parameters. In these control systems the independent stabilization and support of an optimal value of each controlled parameter, for example, electron energy, current of an electron beam, conveyor speed etc. are carried out The criterion of adjustment for each parameter is worked out from a condition, that all others parameters in this moment are in the range of valid values.

More flexible and more reliable control system of the radiation-technological process can be carried out by monitoring all parameters of the radiation facility, which determine an absorbed dose in irradiated materials, so-called critical parameters, and stabilization of the process to realize by physical criterion - on a dose and a dose non-uniformity. Such control system allows simultaneously to regulate several controlled parameters for stabilization of an absorbed dose in the irradiated product in given range, that expands functionalities of a management system of the radiation process and decreases a restoring time of the optimum modes of operation of the radiation facility.

For realization of such approach the software ModeRTL was designed for simulation of radiation processes and calculation of the absorbed dose, charge and temperature distribution within products irradiated by a scanning electron beam with electron energy range from 0.1 to 20 MeV on industrial RTL. This software was integrated into the control system of the RTL.

2 CONTROL SYSTEM CONSIDERATION

For RTL with fixed layout of the main components of radiation facility there are the set of critical process parameters to ensure the required level of absorbed dose within irradiated products. These parameters are the following: the electron energy, electron energy spectrum, electron beam current, beam current distribution on the target surface, a form and amplitude of beam current in magnet of scanning system, and conveyor speed. In radiation technological process while irradiated products are stationary in the irradiated zone, irradiation time governs the absorbed dose in the product when other operation parameters are held constant.

In accordance with International Standard a monitoring and control of critical process parameters are required to ensure that the irradiated materials has been treated with an acceptable range of absorbed doses [1].

In some radiation-technological processes the overheat of a material, which is determined by an absorbed dose and/or by radiation-induced exothermic reactions, results in a degradation of an irradiated material. In these technological processes an additional critical parameter, which is necessary for inspecting, is a temperature limit $T_{max\text{-}lim}$ of an irradiated product [2].

The control system based on the monitoring of critical process parameters, measurement and calculation of the absorbed dose and temperature distribution within irradiated materials was designed.

The control system of radiation technological line (CSRTL) incorporates an electron accelerator control subsystem (ACS), a beam monitor subsystem (BMS), a scanner control subsystem (SCS), a conveyor line subsystem (CLS), and PC with corresponding software [3]. As a source of the scanning electron beams, a linear

accelerator of the type "Electronica - U003" is used with the following characteristics: electron energy 5-8 MeV; electron beam current up to 0.5 mA; mean beam power up to 5 kW; pulse duration 1-4 mcs; pulse frequency 1-250 Hz; scanning frequency of electromagnetic scanner 1-8 Hz.

The control system uses the thermoacoustic emission, generated by the pulsed electron beam in radiation-acoustic dosimeter, as a source of primary information about the current status of characteristics of each electron pulse of scanning electron beam [3, 7].

3 SOFTWARE ARCHITECTURE

The software ModeRTL is a complex of physical and mathematical methods included in an uniform program shell [4,5,6]. ModeRTL performs Monte Carlo simulation of electron transport in arbitrary materials and complex geometries. A mixed procedure is used for the simulation of electron interactions (elastic scattering, inelastic scattering and bremsstrahlung emission), in which 'hard' events are simulated in a detailed way, while 'soft' interactions are calculated from multiple scattering approaches. Non-conventional Monte Carlo methods is used for statistic estimation of the 2-dimensional dose distribution in spatially inhomogeneous objects [5,6].

The analytical calculations are carried out on specially designed semiempirical model for 2-dimensional dose distribution in objects irradiated by a scanning electron beam. This model is generalization of empirical relationships for calculation of the depth-dose distribution of plane-parallel electron beams mainly in the energy region from 0.1 to 20 MeV in semi-infinite media.

The main function of the software ModeRTL in control system are the following: optimization of operation parameters of radiation facility for specific radiation process; processing of the acoustic response amplitude from radiation-acoustic dosimeter and restoration of the critical process parameters; calculation of the absorbed dose, charge and temperature distribution in an irradiated materials on the base of the critical parameters; comparison of the calculated absorbed dose and temperature with the measured calibration data that are stored in the data base; preparation and verification of control commands for operator of radiation facility; preparation of documentation for radiation process and irradiated product.

The software ModeRTL is a program shell containing the following functional modules:

The Analytics module - implements semiempirical models for calculation of a spatial distribution of a dose and integral characteristics of action of scanning electron beam on irradiated objects.

The Monte Carlo module - implements methods of statistic trials for calculation of a spatial dose distribution and integrated characteristics of action of scanning electron beam on irradiated objects.

The Comparison module - implements methods of mathematical physics for handling and comparative analysis of calculation results obtained in modules Analytics and MC. This module ensures procedure of a choice of optimum modes of irradiation and estimation of reliability of the accepted solutions on the basis of comparison of calculation data.

The Calorimetry module - implements numerical methods of evaluation of spatial distribution of radiation-induced temperature and analytical estimations of integral characteristics of a heat transmission for process of cooling of the irradiated objects in a thermostable environment.

The Dosimetry module - implements methods of mathematical physics for entering, processing and comparative analysis of experimental dosimetry data with calculation results, and with the world-wide data base.

The Radiation-acoustic module is intended for processing of the acoustic response amplitude from radiation-acoustic dosimeter and restoration of the critical parameters of scanning electron beam.

The ModeRTL program shell ensures parallel operation of the basic functional modules, that enables essentially to reduce a latency period of results gained by a MC method during a choice of optimum modes of an irradiation and estimation of reliability of the accepted solutions. The software ModeRTL is connected in on-line regime with BMS, SCS, CLS subsystems, and the processing technologies database.

4 DATABASE DESCRIPTION

The processing technologies database consists of a user guide, an archive database, and a dynamic database.

The user guide contains the detailed description, the rules and instruction for users - "how to get results", which allows them successfully to work with all modulus of the software.

The archive database stores geometrical and operational characteristics of radiation facilities; detailed description and characteristics of the current radiation-technological process; the optimum parameters of electron beam; the calibration data for monitoring equipment; the parameters of irradiated materials; the material and size of the package for irradiated product; the table data for comparison of a calculated absorbed dose data with the world-wide data base [4, 8].

The dynamic database stores input files with monitoring data from BMS, SCS, and CLS subsystems; output files with reconstructed data of critical process parameters; data with permissible level of uncertainties and deviations between operation and limited values of absorbed dose for irradiated product.

5 CONTROL SYSTEM OPERATION

An operation of the control system is based on monitoring of the critical process parameters, that affect the dose distribution in the irradiated product, calculations of the absorbed dose distribution within an

irradiated materials, and elaboration of control signals on value of deviation between calculated and measured calibration data of the absorbed dose for the specific radiation–technological process.

Monitoring of critical parameters for scanning electron beam and radiation facility is carried out by SCS, BMS, and CLS subsystems.

As a result of thermoacoustic signals reconstruction from radiation-acoustic dosimeter, the following critical parameters of scanning electron beam were determined: an electron beam intensity**,** a spatial profile of the radiation field on the surface of irradiated materials, an electron energy, and the width of scanning [3, 7]. All data for critical parameters of scanning electron beam were received, processed, and sent to the output data files of the dynamic database in real time regime.

A calculation of the absorbed dose and temperature distribution in an irradiated materials was carried out on the base of experimental monitoring and analytical restoration of the critical process parameters.

The optimum operation parameters of the irradiation facility to achieve the required absorbed doses in the irradiated product for specific radiation-technological process were calculated by the software ModeRTL with the use of the precise Monte Carlo method and were stored in the archive database.

These dose and temperature limits were determined experimentally for different irradiated product and also were stored in the archive database.

For each electron pulse the software ModeRTL calculates the absorbed dose distribution and determine the operation value of a minimum dose $D_{min\text{-}op}$ and a maximum dose $D_{max\text{-}op}$ in the irradiated product. These data compare with the value of dose limit $D_{min\text{-}lim}$ and $D_{max\text{-}lim}$. The data of deviation between a compare dose values were processed and sent to the output data files of the dynamic database.

In accordance with value of these deviations the software ModeRTL offers for operator of radiation facility which critical parameters and on what value theirs are necessary to change to ensure optimal operation regimes of radiation facility.

Time interval between moment of radiation-acoustic signals registration, processing of signals, and preparation of control commands is nearly 1 sec.

The control system was used in the following radiation processes: sterilization of medical devices and polymer composite materials formation [2,3]. In the process of medical devices sterilization the product is irradiated on the continuously moving conveyor, and conveyor speed governs the absorbed dose in the product. The use of the software Mode RTL in control system of this process has reduced a dosimetric measurements and has allowed to receive the certificates with the absorbed dose distribution for all boxes with medical devises.

In the process of polymer composite materials formation the irradiated compound are stationary in the irradiated zone, and irradiation time governs the absorbed dose in compound. The set of required dose for full radiation-induced polymerization of compound is carried out in the time interval from 1 to 20 minutes in the stationary position. Besides in this process the additional control a temperature overheat in irradiated samples was carried out. To avoid of the composite materials degradation the control system keep up the optimum regimes of dose rate which varies according to prescribed low during time of radiation treatment of compound.

6 CONCLUSION

In an offered control system the management of the radiation-technological process is carried out by criteria and physical characteristics, which characterize the process of a radiation effect on an irradiated product. Such characteristics are a dose and a dose non-uniformity in an irradiated product, and for some processes a temperature of an irradiated product is also. This approach allows simultaneous regulation of several controlled parameters of the radiation facility for fast stabilization of an absorbed dose and temperature in irradiated products in case of their deviation from an optimal value. The implementation of such approach is carried out by integration in a control system of the software ModeRTL.

PC based simulation and calculations of electron and gamma irradiation transport allows essentially to reduce the volume of routine dosimetry measurements of an absorbed dose within materials, irradiated with scanning electron beams, at stages of planning, starting-up and adjustment works of radiation facility and realization of the radiation-technological process.

The ModeRTL program is available for Windows - 95/98/NT/Me/XP PC's, has a convenient user interface which users can use intuitively, and can be easily adapted to PC-based control system for all industrial RTL with scanning electron beams.

7 REFERENCES

[1] ISO 11137, "Sterilization of Health Care Products-Requirements for Validation and Routine Control-Radiation Sterilization", 1995.

[2] A.M. Avilov, V.A. Deryuga, G.F. Popov, Proc. of the PAC'99, Vol. 4, p. 2549-2551, 1999.

[3] A.I. Kalinichenko, Yu.A.Kresnin, G.F. Popov, Proc. of the ICALEPCS'97, p. 550-554, 1997.

[4] V.M. Lazurik, T. Tabata, V.T. Lazurik, Radiation Physics and Chemistry, Vol. 60, pp. 161-162, 2001.

[5] F. Alouani Bibi, V.T. Lazurik, Yu. Rogov, Canadian Journal of Physics, Vol. 77, N. 2, pp. 127-136, 1999.

[6] V.T. Lazurik, T. Tabata, V.Moskvin. IEEE Trans. Nucl. Sci. Vol.45(3), 626-631, 1998.

[7] A.I. Kalinichenko, G.F. Popov, Radiation Physics and Chemistry. Vol. 63, Issue 3-6, p.755-758, 2002.

[8] T. Tabata, P. Andreo and R. Ito, Atomic Data and Nuclear Data Tables Vol. 56, pp. 105-131, 1994.