Computer program for setting up a medical X-ray apparatus

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Introduction

Distribution of digital equipment, including the production of medical X-ray apparatuses, allows to control various devices using a computer software. At present, this mechanism is a widespread practice.

The vast majority of power sources of medical X-ray apparatuses are built according to the scheme with amplitude or pulse-width modulation (PWM). At the same time, the resonance control scheme of the X-ray tube is also promising. In comparison with PWM control, the resonance circuit allows to obtain greater efficiency and to provide a more exact adjustment of operating parameters of the apparatus. The adjustable parameters are: resonance frequency, heating current and duty cycle. The most convenient way to establish the values of these quantities is their software setting. Thus, the aim of the work is to create graphic user interface (GUI) for setting up an X-ray apparatus.

Materials and Methods

A model sample of medical X-ray machine for neonatology was compiled on the basis of the EPU department of ETU «LETI» [1]. Due to the features of a scope of the apparatus it is necessary to provide high efficiency of his work that is achieved by applying a resonant control circuit.

Parameters of the X-ray apparatus

The parameters of the power supply (excluding the voltage multiplier), which define the mode of operation of the X-ray tube (current and voltage on the tube) include filament current, resonant frequency and duty cycle. A specific set of values for these parameters will yield the desired current and voltage of the tube.

In order to determine possible combinations of these parameters for establishment the required values of current and voltage on the X-ray tube, the characteristic curves for current and voltage were obtained experimentally. The received dependences are qualitatively reflected in figure 1, 2 and 3 (in Fig. 1, the ratio of currents is as follows $I_4 < I_3 < I_2 < I_1$; in Fig. 3, the ratio of the filament currents is as follows $I_{h4} > I_{h3} > I_{h2} > I_{h1}$).

Experiments have shown that at different currents of heat, the current of the X-ray tube is guaranteed to reach saturation at a voltage of 40 kV (V_{min}). This feature allows to receive calibration points as follows: to expose the minimum level of filling (about 5%); to shift the frequency before obtaining voltage on the tube of 40 kV; when this value is reached, record the calibration point parameters. Increasing the filling coefficient with a given step, it is possible to receive a set of calibration points. In order to set certain operating parameters, the machine takes the values of the obtained calibration points as a basis during operation and, if necessary, calculates the value at the interval between them.

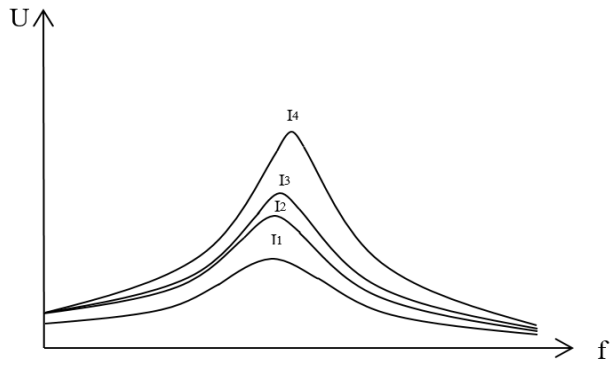

Figure 1: Dependence of the X-ray tube voltage on the generator frequency

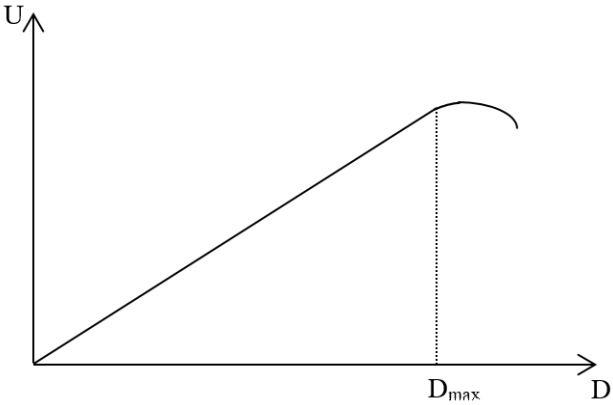

Figure 2: Dependence of the X-ray tube voltage on duty cycle

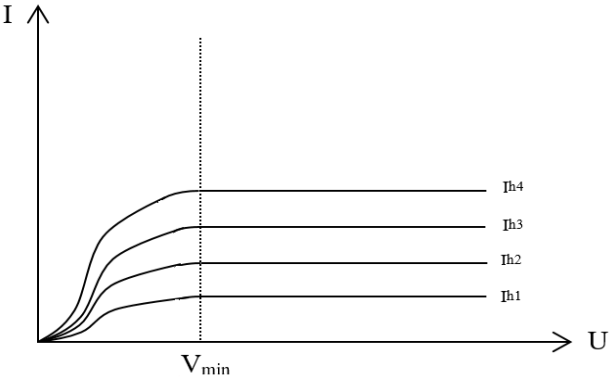

Figure 3: Volt-ampere characteristic of the X-ray tube

Features of the apparatus control and their software implementation

Due to the fact that the X-ray radiation belongs to ionizing, special attention should be given to matters of radiation safety when carrying out all types of work. If it is necessary to control the X-ray machine remotely using a computer program, first of all there is a question about the reliability of the communication line. In addition, the reliability of the received and sent data, which can affect the operation of the machine, is also an important point. At the same time all data can be sent and received only according to a certain protocol of interaction.

Reliability of the communication line: Taking into account the aforesaid, communication of the apparatus with a personal computer can be performed through the Ethernet line. There may be situations when the apparatus stops responding to commands due to the loss of physical connection between the cables. In that case, if the generation of X-ray has been started, then it will continue that is undesirable. To monitor the situation of loss of communication software implemented the constant data exchange between the personal computer and the x-ray apparatus. The need for constant monitoring of the operational parameters of the apparatus justifies the existence of such a constant connection. If necessary to send a command that differs from request parameters, corresponding to the command packet simply replaces the send queue of the request packet.

Accuracy of the data: The TCP / IP Protocol stack was selected as the top-level protocols. This ensures that the data packet is delivered to the recipient. For a possibility of management under the TCP/IP protocol a specialized chip of w5100 is used. In this chip, the use of standardized protocols is implemented by hardware, which eliminates the need to control the delivery and check the checksum (this factor is important in the X-ray t equipment as ensuring the reliability of the transmitted data will protect the machine from possible errors and emergency uncontrolled user modes).

Protocol of interaction: Any interaction between the control device and the operated device is performed according to certain rules, usually described in the so-called protocols. The first version of the protocol of interaction *XRTMP* (X-ray tube management protocol) between the x-ray apparatus and the external controller was developed to simplify the interaction of developers when writing software for the PC and for the microcontroller. In accordance with the protocol, all packets have a fixed length, which is 20 bytes. Figure 4 shows a block diagram of the interaction levels between the control device and the X-ray apparatus. The drafted protocol is responsible for the interpretation of transmitted data packets and the organization of interaction between internal nodes of the apparatus. In accordance with the communication protocol, besides control commands (these include turning the machine on and off with the set parameters), there are also special commands for apparatus settings (for example, setting generator parameters such as frequency and duty cycle, etc.).

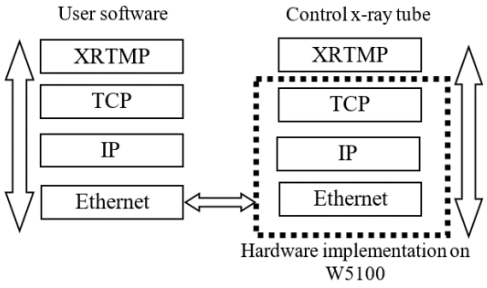

Figure 4: Organization of a protocol stack

Setup of the apparatus: Values of the operational parameters, though weakly, but vary from device to device in connection with dissimilarity of the electronic components used to build these devices. For this reason, at the first inclusion tuning of the apparatus has to be performed surely. Otherwise, the parameters stated in the documentation may not fully correspond to reality. Program and circuit control implementation provides a possibility of various calibrations types and settings:

- calibration of sensor;
- adjustment of emergency thresholds;
- setting operation modes of the tube;
- control of the working dose.

Calibration of sensors is intended for increase the accuracy and reliability of the data about current and voltage on X-ray tube, about heat current and also a radiation dose received from them. Depending on which components were used to assemble the apparatus, the emergency threshold values may vary. In order to take into account this feature, it is possible to update the threshold values. Setting of the operation modes allows to correct the current and voltage values for modes which are already written down in the machine. Special attention among the possible calibrations and settings deserves to control the working dose.

Structurally inside the apparatus there is a possibility of placement a special sensor, which is capable to register a relative dose of X-ray radiation. Under normal operating conditions, the dose level will coincide with the calibrated values (with allowance for minor fluctuations). In the case when the mode of operation of the apparatus is incorrect, the program will be able to track this by changing the working dose of radiation. All settings occur at the level of the microcontroller, which receives instructions for calibration from the host computer.

Results

To control the model of the X-ray apparatus, a program for a personal computer has been developed. As a development tool the framework Qt [2] was applied, and the program was under construction on the basis mentioned above data exchange protocol. With the help of this development environment, the interface of the control program was designed and implemented, the main window of

which is represented in the Fig. 5. The program is written on the C++ language.

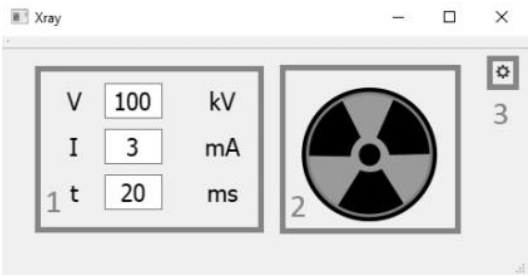

Figure 5: Main window of the program

The main window of the program can be conditionally divided into 3 parts: first block is the unit for setting exposure parameters (voltage, current and time); second block is the immediate start-up of apparatus (inclusion of X-ray radiation); third block is the configuration icon. Almost always the operator needs to use only the first two blocks. However, there are situations when it is necessary to change the machine settings (for example, to rebuild the resonant frequency). Circuitry and software implementation allow performing this action by simply changing the value in the corresponding field of the program by the operator. Despite such apparent simplicity of adjustment, all controls for calibration, advanced setting and connection of the machine are taken out into separate window, which is accessed after entering the correct password. Part of the advanced program settings window is shown in Fig. 6.



Figure 6: Part of advanced settings window

The presented part of the advanced settings allows changing the resonance frequency, duty cycle, starting and stopping the generator, and also checking the communication by the signal LED.

In general, advanced settings allow the attendants to perform the following actions:

- change IP-addresses and ports as needed to establish the connection between the personal computer and the apparatus;
- open and close the corresponding TCP connection;
- send a special request to the apparatus;
- receive and visualize response from the apparatus to corresponding request;
- start and stop pulse generator;
- change frequency and duty ratio of the generator;
- monitor the connection and operation of apparatus by means from signal LED;
- perform calibration for following parameters: voltage, tube current, filament current and temperature of tube;
- to monitor the above parameters in real time.

Indication of the current values of the main parameters of the apparatus is also contained in a separate part of the extended settings window of the apparatus. The parameter display field is shown in Fig. 7.

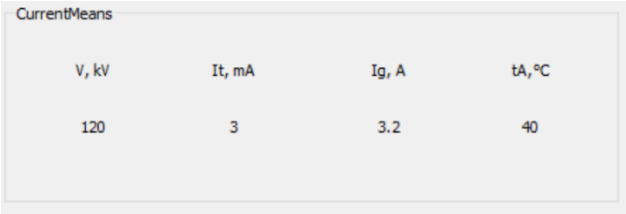

Figure 7: Indication of the current parameters of the apparatus

It should be noted that the program requires a computer with an installed operating system of the Windows family (Windows XP SP3 or higher), as well as the ability to use the computer TCP/IP connection. As for the rest, the program does not impose special requirements on the used computer.

Conclusions

The computer program created in the course of operation allows to adjust the X-ray apparatus for neonatology to improve its performance characteristics. In the future we plan to expand the ability program to control several satellites simultaneously, and also to find the optimal calibration algorithm for the apparatus and to implement it programmatically.

References

[1] V. V Klonov., I. A. Larionov, V. B. Bessonov. Modification of circuit and investigation of operating modes of the high-frequency pulse resonance converter for the X-ray tube power supply. In IV all-russian scientific and practical conference for manufacturers of X-ray technology, pages 42 – 46, nov 2017.

[2] M. Summerfield. Advanced Qt programming: creating great software with C++ and Qt 4. Courier in Westford, Massachusetts, 2010.

Acknowledgements

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