Specialized x-ray machine for neonatology

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Introduction

The usage of X-ray radiation in modern neonatology makes a significant contribution to the quality of medical care for newborns with pathologies. High-quality image of the baby allows to quickly diagnose the problem or to prevent future possible complications.

The method of contact diagnostics (see fig.1) gives satisfactory results, however, to obtain informative images should take into account the following restrictions:

1. *A large distance between the radiation source and the object of study*. This condition is dictated by the need to distance the radiation source to reduce the blurring of the edges. It is necessary to use sufficiently powerful sources to work around the dynamic range of the receiver (which leads to the maximum contrast of the image). Increased tube current causes an increase of the focal spot. Its size directly affects the degree of outer edges blur on the image, which is unacceptable in the case of medical diagnosis. Compensation for this phenomenon is increasing the distance between source and receiver. This can lead to unwanted additional exposure of medical staff and others patients.

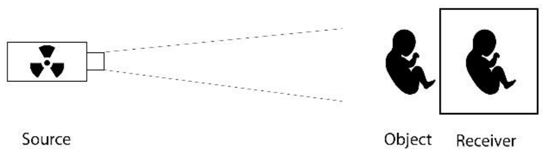

Figure 1: Contact X-ray diagnostics of newborns

2. *High resolution X-ray detector*. Upon contact of an object and a radiation receiver, the image quality depends on resolution of the receiver. However, increasing resolution naturally reduces sensitivity of pixels (by reducing their geometry sizes). This eventually leads to the necessity of increasing power of the radiation source.

3. *High power X-ray radiation*. Increased distance source-object and high resolution of the receiver lead to significant increase in power of X-ray diagnostic machine. Traditionally, the radiological diagnosis in neonatology and pediatrics using radiation sources with power up to 5 kW, which is directly related to their size and weight. From the point of view of stationary use it's not a big deal. However, for portable options, which work in conditions of constant transportation, this factor is essential.

Thus, of use of X-ray machines in non-specialized conditions, for example when you need to do diagnostic immediately after the procedure of childbirth is in the room of the maternity ward, the use of classical X-ray machines, described above, is not optimal. The basic idea, which is based on an alternative approach to the diagnosis of newborns is the use of smaller power sources with reduced size of the focal spot of the radiation source. The decrease in its value up to 0.3 mm or below will allow to diagnose newborns under appropriate conditions with scaling method (see fig. 2). Decrease focal spot is achieved with a small current of the tube and using additional focusing electrodes. The lack of dose is compensated by minor (20 – 30%) increasing of operating voltage and decreasing of shooting distance. As a result, while maintaining the quality of the image this approach provides the following benefits:

- Resolution of the receiver can be reduced. This leads to the best sensitivity.
- Source-object distance is reduced, which minimizes exposure of staff and others, and also reduces requirements on the output power.
- Relatively low power (360 – 500 W) of radiation source reduces weight and size of the device, which greatly simplifies its use in unsteady conditions [1].

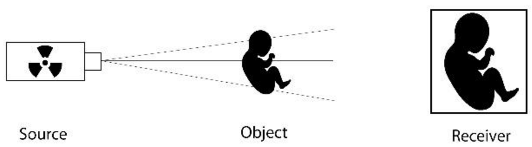

Figure 2: X-ray diagnostics of newborns with scaling

In this paper, the circuit and structural features of low-power portable apparatus for neonatology, its internal structure and organization of electronic modules are introduced.

Materials and Methods

Interconnection of electronic modules built on the centralized control principle (see fig.3). For the implementation of sensing functions and heat supplying, the subsidiary module is used. The high-voltage part comprises a generator and a voltage multiplier.

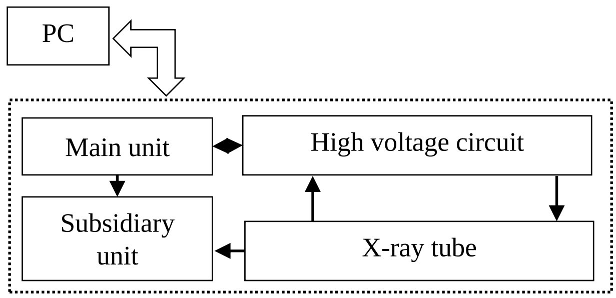

Figure 3: The generalized structure of electronic modules

Fig. 4 represents the organization of the main control module. Its basic functions are:

- control of X-ray tube supply power generator;
- management of data flow between PC and device;
- monitoring of the central module: the temperature of the inductive element, the average temperature of the power transistors, the average power consumption;
- X-ray dose control.

The Central MCU communicates with the Ethernet controller that have hardware support for the TCP/IP protocol. All data transmission is handling through specialized Ethernet PHY controller by SPI interface. The use of specialized chip simplifies the interaction of the microcontroller with a PC and partially offloads the core and the peripheral modules, however, the cost of such solution is considerably higher than MII/RMII chip. The power supply is controlled by 16-bit timer with push-pull signal with a pulse width modulation (PWM) [2]. The module is located on the outside of the case and is not in contact with an insulating filler (transformer oil). Inside casing the subsidiary module, all high voltage components (transformer, multiplier and divider, the X-ray tube) are located. From the Central unit to the internal elements a power line (the transmission of energy to the transformer) and two differential signal lines are routed. To ensure independent transmission in both directions of the communication channel a full duplex is implemented.

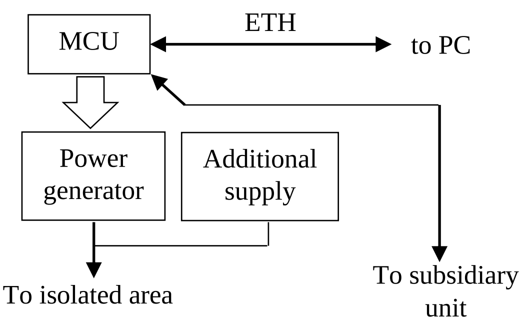

Figure 4: Structural diagram of control board

A subsidiary module (a structural diagram is represented in fig. 5) is placed inside the case in the vicinity of high-voltage circuits. The unit performs following functions:

- control of filament current;
- measurement of electrical parameters of the X-ray tube, such as voltage, tube current, filament current;
- calibration of measurement data and control of electrical parameters of the X-ray tube searching in a given workspace;
- control of ambient temperature (temperature of transformer oil);
- flexible converting input analog signals.

The main module node is the MCU, which controls the filament current and measures circuit parameters using the 4-channel 12-bit internal ADC. The temperature of the environment is controlled by sensor, which integrated into MCU package. Communication with the control board is realized via the RS-485 interface. This solution provides the most optimal ratio of communication speed to noise immunity.

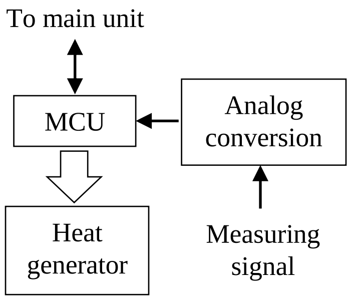

Figure 5: Structural diagram of the subsidiary module

When controlling the filament current is important to consider that the resistance of the filament is substantially depends of temperature. Standard approach uses the pulse-width modulation; full voltage amplitude is applied to the filament. In the case of low temperature (it happens at first turn on) initial current intensity may be significant (exceed the maximum to 1.5 times). This eventually may lead to its thermal destruction. A solution to this problem is the combination of pulse-width modulation and frequency control [3]. Fig. 6 represents a simplified circuit of the filament supply. The pins of the X-ray tube cathode form a parasitic inductance which at high frequency limits start current equal to:

$$I_{start} = \frac{U_s}{R_{heat} + Z_{leak}}, \qquad (1)$$

where U_s is the amplitude of the voltage of the filament supply, V; R_{heat} – the resistance of the filament in Ohms; Z_{leak} – impedance of the parasitic inductance of pins on the current frequency, Ohms.

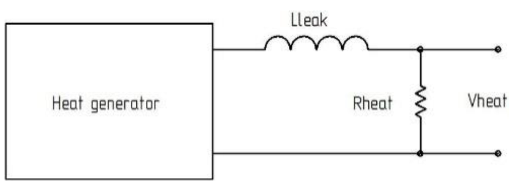

Figure 6: The equivalent circuit of circuit the heated filament

Thus, the combination of a gradual increase of duty cycle and frequency can be used to achieve amplitude modulation of the heat voltage that will provide a smooth increase of operating current and significantly extend the service life of the machine.

The machine construction design (see fig. 7) is based on several ribs formation of the carrier frame. This is done by perpendicularly arranged walls that provide a rigid positioning of the device in space relative to the outer aluminum case. This aspect is especially important because of the strict requirements for maintaining a minimum displacement of the apparatus. The change in the position in the process of exploitation can lead to the risk of voltage breakdown. Therefore, special attention was paid to make the structure as rigid as possible [4].

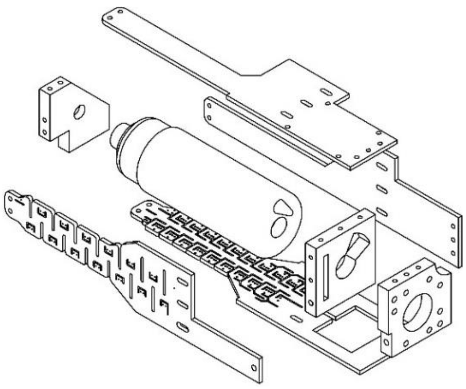

Figure 7: Sketch of the internal nodes construction of X-ray machine

Load-bearing walls are made of FR4. The products made of this material is technologically advanced and has a stable surface breakdown voltage of about 1.5 kV/mm (assuming storage material is isolated from dirt and moisture). The transverse plate is made of PTFE and in addition to quality insulation provide rigid fixation of all structural elements.

Results

Eventually, fully functioning layout portable, low power apparatus for neonatology with the ability to control from PC or control panel, were designed and constructed. Main characteristics are introduced below:

- operating voltage: 120 kV;
- operating voltage ripple: < 3%;
- maximum power: 360 W;
- efficiency: > 75%;
- output raise time: < 20 ms;
- weight: 5 kg;
- controlled by PC or portable console;
- size: 380 × 130 × 180 mm.

The present design provides a quick assembly, which increases the manufacturability of serial production. A modular approach to the design of electric circuits allows to make fast replacement of units and perform a local update of specific parts of the scheme. Testing the model sample of the device was carried out in laboratory conditions.

The closest analog is portable X-ray machine EcoRay 9020HF. Comparison (see tab. 1) demonstrates, that new design uses tube with lower focal spot, which allows to decrease power of machine and its weight. Lower power is compensated by higher voltage (120 kV against 90 kV) and decreased distance (0.35 m).

Table 1: Characteristics of apparatus in comparison with nearest analog on the market

Item	**Introduced machine**	**Analog**
Focal spot size, mm	0.4 × 0.4	1.2 × 1.2
Power, W	360	1200
Operating voltage, kV	120	90
Shooting distance, m	0.35	0.66
Weight, kg	5	7

Discussion and Conclusions

Modern medical X-ray machines allow to obtain high-quality images for accurate diagnosis of patients. However, medical staff are always at risk of extra exposure. This is especially true for portable applications, when medical worker holds the apparatus or stands near it. Introduced machine greatly reduces extra radiation in comparison with similar ones having large focal spot. Small focal spot allows to decrease power of the apparatus and distance between source and receiver. Dimensions and weight are also decreased, portability is improved. Moreover, X-ray diagnostic complex based on microfocus tube can perform images with higher quality than classic apparatus does. Implementing local net between machine, PC and receiver allows to expand possibilities of constructing specialized X-ray complexes. Several sources and receivers could be combined under single or distributed control.

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Acknowledgements

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