CONTROL OF PULSED BEAM PARAMETERS AT THE EXIT CHANNEL OF THE HIGH-INTENSITY LINAC

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Control of beam parameters is important for maintenance of linac operating conditions, as well as, for securing a high-speed protection of exit channel components against the beam damage. For this purpose the beam current, beam center position and ellipse cross-section (10 MeV, 10 kW, 1 A/pulse, 300 Hz, 3.5 μs) are measured at the output part of linac. Two similar current sensors, position sensor and water-cooled copper collimator in the gap between the current sensors were used. All the sensors of a magnetic induction type have windings on ferrite coils placed in vacuum. The system is described and the component calibration results are reported. The coefficient of beam losses during the transit through the collimator is calculated with the use of a special microprocessor placed in the ADC module which receives the signal from two current sensors. An algorithm of signal digitization eliminates the failures under the action of pulse interference. When the set threshold of beam losses is exceeded, the signal from the electron source blocking enters into the linac synchronization unit. Control of position sensor signals is carried out without beam chopping by the on-line comparison between the four position sensor signals and the current sensor signal being placed in the same case. The data on the beam parameters are displayed on the PC screen. The system is successfully used during several years.

PACS: 29.20.Ej; 29.27.-a

INTRODUCTION

Development of nondestructive transit methods for beam diagnostics is an urgent problem for research accelerators and high-power industrial electron accelerators. The most important parameters of the beam are its current value and spatial characteristics: coordinates of beam centroid and beam ellipse cross-section distribution (the first and the second cross-sectional moments).

In reference [1] a device which operates on the principle of measuring the "image" currents in the walls by means of 16 discrete sensors is described The above beam parameters can be obtained using the approximate Fourier analysis of sensor signals. The device is designed for a nanosecond duration range.

In reference [2] a system of 8 air-core coils uniformly distributed around the sensor perimeter is applied. The signal processing is the same as in [1]. The sensor operates with beams of ≅50 ns duration.

In reference [3] one uses a sensor of four electrostatic plates which are impact-excited by the field of subnanosecond electron bunch.

For measurements at the linear electron accelerators with current pulse duration of ≅1.5…4 μs it is advisable to apply magnetic induction sensors with ferrite ring windings having a high μ to image the beam pulse shape with insignificant distortions.

A possibility in principle of measuring the beam parameters by the magnetic induction method is under consideration in [4]. In this paper it is shown to which requirements should answer the sensor for measurements of beam current spatial characteristics.

The distribution of the beam-current pulsed magnetic field in the ferrite-filled induction sensor differs markedly from that of the atmospheric one. Therefore, investigations of the four-coil sensor designed for measurements of the first and second cross-section moments were commenced.

1. SENSORS OF HIGH-INTENSITY LINACS

In the Science and Research Establishment "Accelerator" of the National Science Center "Kharkov Institute of Physics and Technology" the high-intensity linacs are operating over a long period of time. The linac LU-10 current pulse duration is of about 4 μs, pulse current from 0.4 to 1 A, pulse repetition rate 150…300 Hz, electron energy near 10 MeV. Schematic representation of the exit channel of this linac is shown in Fig. 1.

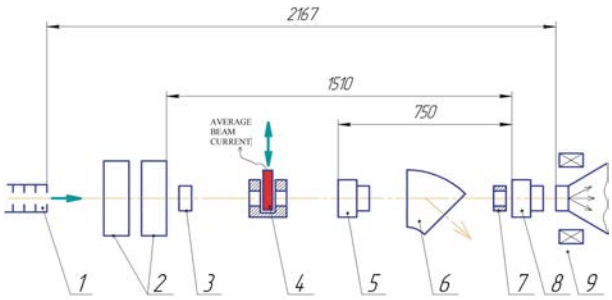

Fig. 1. Schematic representation of the exit channel of the accelerator LU-10:
1 – accelerating section output; 2 – doublet of quadrupoles; 3 – corrector magnet; 4 – Faraday cylinder with a movable cap; 5 – beam current sensor; 6 – spectrometer; 7 – cooled collimator; 8 – beam position and current sensor; 9 – scanning magnet

To provide a safe beam transfer, there were manufactured four-coil magnetic induction sensors designed for measuring the beam position centre relatively to the accelerator axis with an error ±0.5 mm at the input and output of the accelerating section [5].

Before placing in the linac the sensors each have passed calibration tests on the special stand. The stand comprises a beam current simulator, meter head permitting to move the sensor along two coordinates with a setting accuracy of 0.01 mm and automatic measuring channel.

ISSN 1562-6016. ВАНТ. 2014. №3(91)

Schematic representation of measuring channels is shown in Fig. 2. In order to increase the signal-to-noise ratio, the signals from sensors go to the matching pulse transformer by symmetric cables. After amplification up to 2 volts, the signals go to linac control room for processing. Analog Device AD8041 high speed amplifiers are used in unit (160 V/µs slew rate). To avoid the radiation damage, measuring unit is situated outside the linac vault.

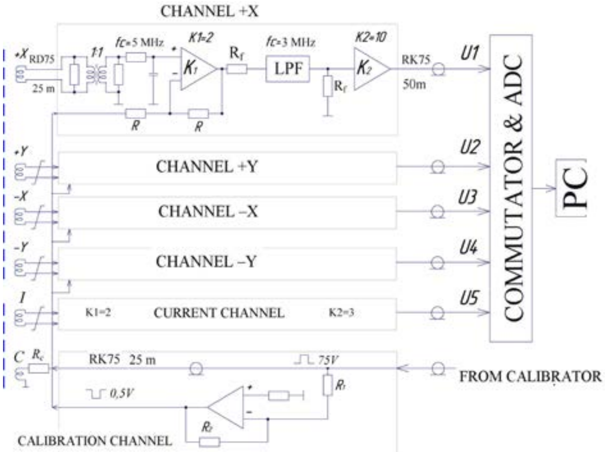

Fig. 2. Schematic representation of measuring channels

For the electron beam simulation we used one or two current-carrying strings with a cross-section diameter of 0.1 mm stretched perpendicularly to the sensor plane. Rectangular current pulses of 4 µs duration with amplitude from 300 to 800 mA were transmitted through the strings. As a result, induced signal were observed on the opposite sensor windings.

Calibration function of X-channel is shown in Fig. 3. The similar function for reduced Y coordinate is $V=(U_2-U_4)/(U_2+U_4)$. Coordinates of beam centroid are $\bar{x}=(1/S_x)H$; $\bar{y}=(1/S_y)V$; where $S_x=S_y=3.1$%/mm are calibration factors (see Fig. 2)

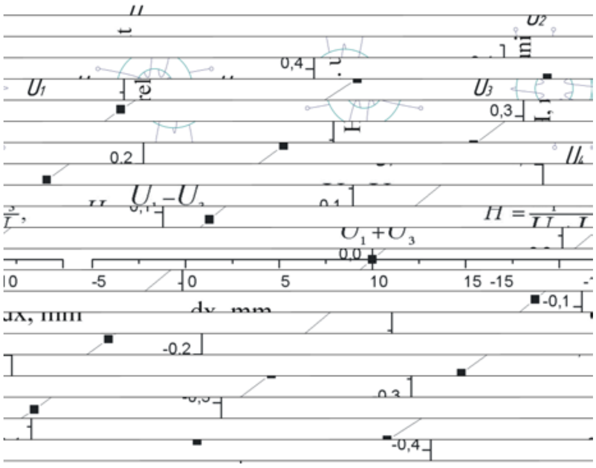

Fig. 3. Reduced coordinate H versus the beam simulator shift dx

Reduced parameter of the second moment D versus the distance between the calibration strings is shown in Fig. 4. Two strings are equivalent of thin stripe shaped beam placed horizontally or vertically (1st and 3rd quadrant in Fig. 4). Beam ellipticity is equal to $Q=\sigma_x^2-\sigma_y^2=(1/S_\sigma)D-(\bar{x}^2-\bar{y}^2)$; where σ_x,σ_y are effective dimensions of beam along X, Y axes; $S_\sigma=0.067\%/\text{mm}^2$ (see Fig. 4)

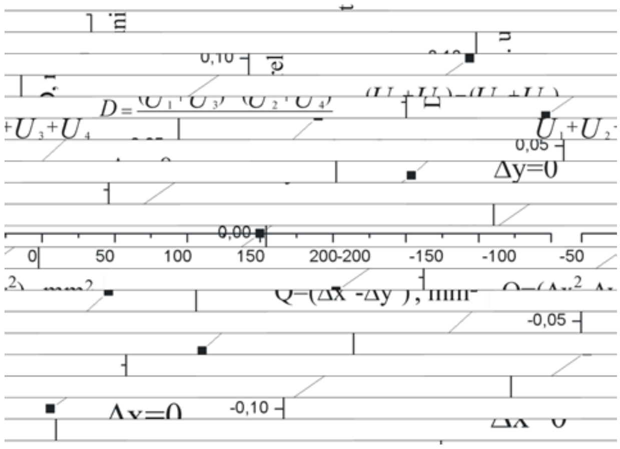

Fig. 4. Reduced parameter of the second moment D versus the distance between the calibration strings, 1st and 3rd quadrant – strings are moved apart along X and Y axes, respectively

When the high-intensity linacs are operating, the measuring channels are under influence of external noises. The latter are high-frequency noises, which modulate the beam current pulse top, and low-frequency pulses, mainly from the power system, which change the amplitude of signals from pulse to pulse. It should be noted that besides the HF noises the space-time beam structure exerts influence on the current pulse top shape.

To decrease the noise effect the values of the beam center coordinates $\bar{x},\bar{y}$ and the second moment Q are estimated by the selection of 32 (not less) current pulses and subsequent averaging of results. The appearance of the collimator unit and transit sensor at the exit of accelerator LU-10 is shown in Fig. 5.

Fig. 5. Appearance of the protective collimator unit (on the left) and transit sensor (in the centre) at the exit of the accelerator LU-10

2. UPGRADING OF SYSTEMS

In recent years the control and steering systems of the high-intensity linear accelerator LU-10 were upgraded in order to increase the accuracy of beam parameter measurement data processing, to improve the operation speed and to provide the protection against the inadmissible electron beam losses in the case of emergency situation.

The automatic control and steering system (ACSS) provides the control of current, energy, electron beam distribution, beam position steering by changing the current value in the power supply to magnetic elements [6]. ACSS is a hardware-software complex comprising the following units:

- personal computer (PC) of IBM PC type;
- control cabinet;
- power frame of accelerator magnetic components;
- software.

An external sync pulse enters into the synchronization input of ADC-02 and produces the interrupt of the IRQ2 signaling processor. The interrupt processing routine triggers the measurement process by the program-controlled delay time.

After the interrupt is terminated the main program of the signaling processor transfers the data into the PC main memory via the PCI bus. The measurement process is repeated with the next sync pulse arrival.

The system includes a bi-directional bus for controlling the external analog switching unit.

The appearance of the ADC (ADC-02 type) is represented in Fig. 6.

Information on the operating condition of accelerator systems and electron beam parameters is displayed on the color graphic terminal. Monitoring of the accelerator operation is performed by the operator with the aid of the PC keyboard. Program modules can provide a single and multiple monitoring of accelerator systems and to issue control commands. Information on the accelerator beam parameters is transmitted to the file server of the computer network of the Science and Research Establishment "Accelerator".

Fig. 6. Appearance of the ADC (ADC-02 type)

For measurements of the beam amplitude and beam pulse current shape the accelerator is equipped with two magnetic induction sensors mounted at the input and output of the water cooled collimator [7, 8].

The sensor signals are used in the control system for estimation of the amplitude and average values of the current.

Calibration of sensors is carried out systematically with the use of test pulse trains from the special current generator [9, 10]. At the output part of linac, besides transit sensors, a four-coil position sensor is placed which permits to determine the beam center position and beam ellipse cross-section with an accuracy of below 0.5 mm. The system is operating during three years.

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Article received 25.03.2014

КОНТРОЛЬ ПАРАМЕТРОВ ИМПУЛЬСНОГО ПУЧКА НА ВЫХОДНОМ ТРАКТЕ СИЛЬНОТОЧНОГО ЛУЭ

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Контроль параметров пучка важен как для поддержания режима работы ЛУЭ, так и для организации быстрой защиты от поражения элементов выходного тракта пучком. Для этого на тракте вывода пучка (10 МэВ, 10 кВт, 1 А/имп., 300 Гц, 3,5 мкс) измеряются ток пучка, положение его центра и эллиптичность поперечного сечения. Использованы два идентичных датчика тока, датчик положения и водоохлаждаемый медный коллиматор в промежутке между датчиками тока. Все датчики магнитоиндукционного типа с обмотками на ферритовых кольцах, помещенных в вакуум. Описана конструкция и приведены результаты калибровки всех элементов. Коэффициент потерь пучка при пролёте коллиматора рассчитывается специальным микропроцессором, размещённым в модуле АЦП, на который поступают сигналы от двух датчиков тока. Алгоритм оцифровки сигналов устраняет сбои при воздействии импульсной помехи. При превышении установленного порога потерь пучка в блок синхронизации ЛУЭ поступает сигнал блокировки источника электронов. Контроль сигналов с датчика положения без прерывания пучка проводится путём оперативного сравнения суммы четырёх сигналов датчика положения с сигналом датчика тока, размещённых в одном корпусе. Данные о параметрах пучка выведены на дисплей ЭВМ. Система успешно используется в течение нескольких лет.

КОНТРОЛЬ ПАРАМЕТРІВ ІМПУЛЬСНОГО ПУЧКА НА ВИХІДНОМУ ТРАКТІ СИЛЬНОСТРУМОВОГО ЛПЕ

В.М. Борискін, В.М. Верещака, А.М. Довбня, Р.М. Дронов, Л.К. Мякушко, Л.В. Репрінцев, О.М. Савченко, О.А. Сарвілов, В.І. Татанов, В.А. Шевченко, В.А. Шендрик

Контроль параметрів пучка важливий як для підтримки режиму роботи ЛПЕ, так і для організації швидкого захисту від поразки елементів вихідного тракту пучком. Для цього на тракті виводу пучка (10 МеВ, 10 кВт, 1 А/імп., 300 Гц, 3,5 мкс) вимірюються струм пучка, положення його центра та еліптичність поперечного перерізу. Були використані два ідентичних датчика струму, датчик положення та водоохолоджуваний мідний коліматор проміж датчиками струму. Всі датчики магнітоіндукційного типу з обмотками на феритових кільцях, які знаходяться у вакуумі. Описана конструкція та приведені результати калібровки усіх елементів. Коефіцієнт витрат пучка при прольоті коліматора розраховується спеціальним мікропроцесором, який знаходиться у модулі АЦП, на який приходять сигнали від двох датчиків струму. Алгоритм оцифровки сигналів зменшує вплив імпульсної перешкоди. При перевищенні встановленого порогу втрат пучка в блок синхронізації ЛПЕ подається сигнал блокування джерела електронів. Контроль сигналів з датчика положення без переривання пучка здійснюється шляхом оперативного порівняння суми чотирьох сигналів датчика положення з сигналом датчика струму, які розміщені в одному корпусі. Параметри пучка виводяться на дисплей комп’ютера. Система успішно використовується на протязі декількох років.