MODULATOR FOR THE ELECTRON INJECTOR OF THE INDUSTRIAL ACCELERATOR ILU-10

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Abstract

Presented work describes the modulator of electron current of the industrial accelerator ILU-10. The main target of building of the unit is decreasing of energy spectrum and stabilization amplitude of the accelerated current. The base of unit is HV linear DC amplifier (up to 5000V) with power (up to 5 A) MOS-FET output stage. It allows to create feedback and stabilize either current or energy of the beam. Also this unit has mode for tuning any shape of beam current and energy. Unit has microprocessor control circuit which provides useful link with computer control system of accelerator and if needed provides the handle operation and indicates main parameters of electron beam.

THE AIM OF THE WORK

This work considers the arrangement of a new electron current modulator for the industrial accelerator ILU-10. The aim of the work was to reduce the energy spread and to stabilize the amplitude of the extracted beam.

Requirements to beam energy stability were high because of two factors at least:

- the electron energy reaching 5 MeV, the accelerator ILU-10 enters a market that is quite new for BINP, i.e. pasteurization of food products with bremsstrahlung from a tantalum converter. For the most efficient conversion of the electron beam to gamma radiation, the electron beam should have the best spectrum.
- in some applications it is necessary to “turn” the beam. Losses due to non-chromaticity of the beam can be as high as 5-10 %, which is unreasonably high at average power 50 kW, since that can result in (local) overheating of the vacuum chamber.

Since the beam in industrial accelerators is scanned along the extraction window, for the dose to be uniform, the beam current should be maintained constant during a pulse.

Accelerators of the ILU type use a cathode with an earthed control grid. The electron beam current is regulated via changing the positive locking bias voltage applied to the cathode relative to the grid. Figure 1 presents an analog electrical circuit for the electron injector.

The circuit explains the role of the voltage applied to the cathode. By the beginning of the positive half-period of RF voltage in the resonator gap (the anode of the tube), there is a direct voltage across the cathode due to the average current of the injector (smoothed by capacitor C2 and resistor R2). Varying R2 resistance in a standard injector circuit, one can regulate the bias voltage and, consequently, the average cathode current. Moreover, variation of this resistance is used to stabilize beam current inside a pulse. C2 capacitance is that of the injection cable. This cable can be 30 to 40 meters long. Consequently, the capacitance can amount to 3000 to 5000 pF. Since the injector cable is discharged by beginning of the pulse, at the first moment after the accelerator pulse arrival capacitor C2 is charged due to the beam current up to the required bias voltage. As a result, there arises uncontrolled current of the beam of electrons of low energy.

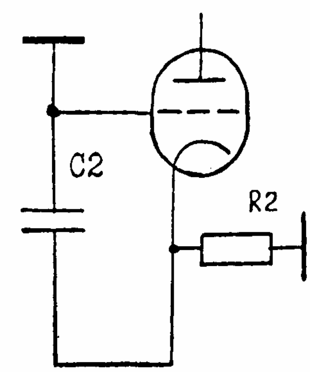

Figure 1: Analog electrical circuit for the electron injector.

Let us note that the accelerator operates in a principally pulsed mode, the pulse length being about 0.5 ms.

To achieve the best beam monochromaticity it is necessary to “lock” the accelerator modulator until the RF amplitude in the resonator reaches the nominal value. Moreover, the modulator should be “locked” slightly before the moment when the amplitude begins falling. For this purpose, the voltage across the cathode should be 2.5 to 4 kV between pulses (depending on the grid-cathode gap value in a concrete injector). The feedback is used to sustain voltage across the cathode during a pulse in such a way as to ensure stable beam current and constant electron energy or to sustain constant voltage across the cathode. Usually this voltage is 300 to 1500 V.

Both computer and manual control of the accelerator is a usual practice.

Microprocessor-Controlled Modulator

To realize the above-listed requirements, we have developed a microprocessor-controlled modulator. Its functional arrangement is shown in the Figure 2.

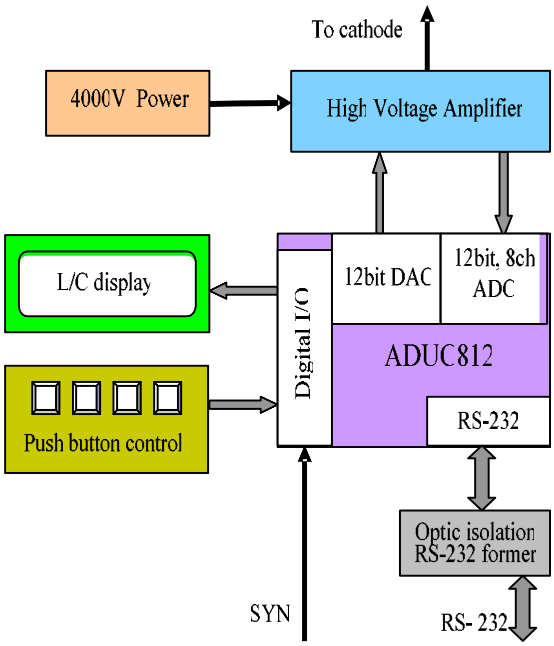

Figure 2: Functional arrangement of the modulator.

We use an ADUC812 (ADUC842) microprocessor as a microcontroller for the modulator. This microcontroller is optimal for automation of small devices since it comprises all necessary components such as:

- Program ROM, up to 64K.
- Data RAM - 2 kB.
- 12-bit ADC with a multiplexor for 8 channels.
- 12-bit DAC (2 channels).
- Embedded interface RS-232.
- Up to 24 digital I/O channels (3 8-bit ports).

The microprocessor provides both “manual” and computer control.

Manual control is realized through a keyboard with 4 buttons and LC display. The operator can specify the following parameters of modulator operation with the help of the buttons and display:

- Injection current (cathode voltage and electron energy).
- Synchronization pulse delay.
- Pulse length.

During operation, the display shows the measured (real) beam current and bias voltage (cathode voltage). If the bias voltage does not fit the specified current or a breakdown has occurred, the error message is displayed.

All these parameters can be written and read from the computer via the RS-232 channel. For the sake of safety, the RS-232 channel is equipped with an optical isolation.

The modulator has a direct voltage source to “lock” the injector. The source voltage is 2500 to 4000 V. Since bias voltage is not an in-line parameter and is constant for each modulator, we decided to leave it without external control in order to avoid an accidental error.

High-Voltage Amplifier

As noted above, voltage across the cathode should be sustained between pulses in the range of 2500 to 4000 V. During a pulse, the voltage can vary from 300 to 2500 V.

In order to provide these parameters, we have developed a high-voltage amplifier. It works in the range of 0 to 4000 V and supplies current up to 5A.

The pass band of the amplifier is up to 50 kHz. That allows connection of the electron injector control circuits in feedback and stabilization (or arbitrary control) of accelerator current or energy during a pulse. A simplified circuit of the amplifier is presented below.

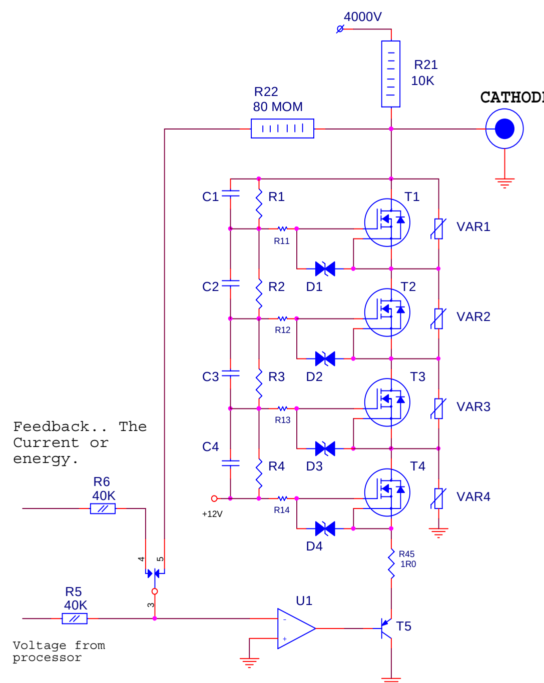

Figure 3: High-voltage accelerator.

The amplifier is made by a stage scheme. Transistor T5 is used as the current amplifier. Voltage amplification is provided by 4 field transistors (T1-T4) connected in series. The maximal voltage across each of the field transistors is 1200V. To protect the transistors against over-voltage, a 1000V varistor is connected in parallel with each transistor.

Resistors R1-R4 “distribute” voltage over the transistors. Since the field transistors have no input currents, the resistors can be rather large; in this case R1-R4 = 10MOhm. Capacitors C1-C4 provide dynamic properties of the stage, i.e. they allow fast re-charge of the field transistors.

Amplifier U1 is an error signal amplifier. A pulse from the microprocessor is input to it through resistor R5. At bias voltage stabilization the feedback signal is applied through resistor R22. At stabilization of beam current or energy, the feedback signal is applied from the corresponding external pickup through resistor R6.

The Experiments Carried

The experiments carried out confirmed efficiency of the modulator. The most obvious evidence of its correct operation is the signal from the edge beam pickups of the beam extraction device of the accelerator. The edge pickup is made by two metal lamels placed on the edges of the exit window of the accelerator, connected together and earthed through a 10 Ohm resistor. Voltage across this resistor is proportional to the beam current arriving to these lamels. Figure 4 shows a signal from the edge beam pickup at a conventional connection (without the modulator). The first (double) peak is caused just by the initial (non-controlled) current.

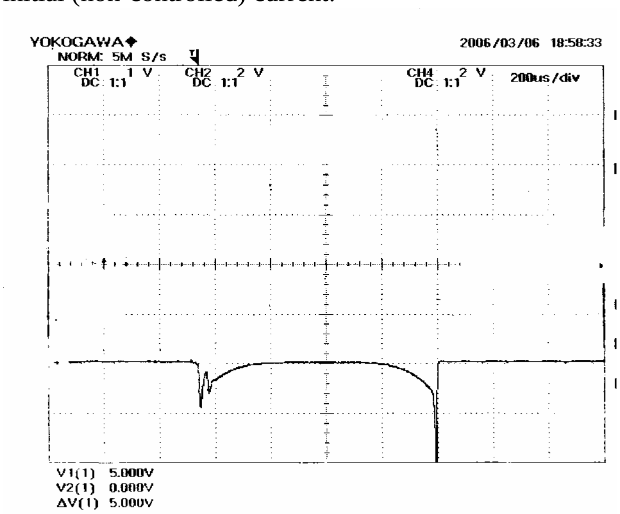

Figure 4: a signal from the edge beam without the modulator.

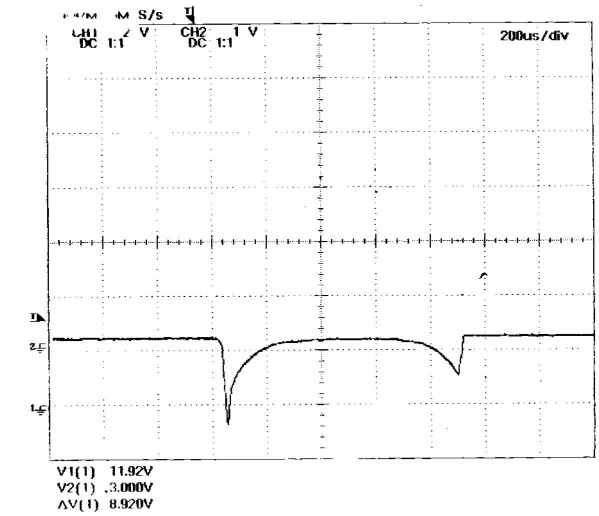

Figure 5: a signal from the edge beam with the modulator.

Figure 5 presents an oscillogram from those pickups, with the modulator. It can be seen that there is no beam current peak caused by charging of the injector cable at the pulse beginning.