RF POWER SUPPLY SYSTEM OF INDUSTRY IRRADIATION FACILITY

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Irradiation facility is designed for fruit disinfestations by means of two-side 9 MeV electron beam irradiation. Throughput of the facility is 30 T/h at a minimum dose of 150 Gy. The system includes a master generator, preamplifier, 2856 MHz klystron, waveguide bridge, two directional couplers, two automatic frequency adjustment units, water control unit connected to two feed back loops for RF frequency control, guaranteeing a designed acceleration regime in two the same standing wave linacs.

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1. INPUT DATA

Usually, two-side irradiation is used for medical sterilization and food irradiation. Two technical solutions are possible: a) alternate irradiation of the first and second side and b) two-beam irradiation. In the second solution usually two identical linacs are used. The most expensive parts of the industry linac are the modulator and the klystron. The use of one klystron for RF power feeding of two linacs and one modulator allows us to decrease the cost of facility. Each linac includes a 1 m standing wave accelerating structure. Designed electron energy is up to 10 MeV (9 MeV nominal). Average RF power of klystron is up to 45 kW (18…30 kW nominal). Changing the RF power of the klystron and the injected beam current we can control the electron energy in the needed range.

2. MAIN SCHEME

Main scheme of RF power supply system is shown in Fig.1.

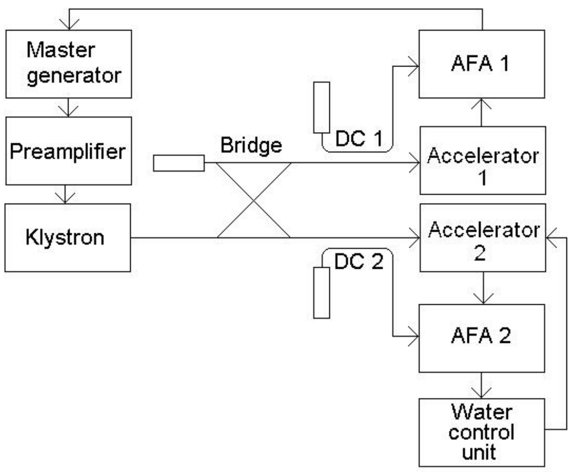

Fig.1.Schematic diagram of the RF power supply

The high- frequency stability master generator gives 2856 MHz RF signal to the input of preamplifier. Master generator can operate in the amplitude modulation mode. The pulse width is 10…20 μsec. Preamplifier increases the RF peak power up to 200 W. This power is enough for klystron operation. Klystron gives up to 5 MW (10 MW for the modified klystron) RF peak power. This power is divided by the waveguide bridge. The dividing ratio is 3 dB. The RF power from the bridge goes to the Accelerator 1 and Accelerator 2.

There are two Directional Couplers (DC 1 and DC 2) at the input of accelerators. These are the waveguide-coaxial 70 dB directional couplers with a strip-line inside. The RF signal is proportionate to the travelling wave power at the input of each accelerator and RF signals from accelerators go to the corresponding Automatic Frequency Adjustment units (AFA 1 and AFA 2).

AFA 1 controls the frequency of the master generator. AFA 2 controls the temperature water and therefore the resonant frequency of Accelerator 2.

3. FAST FEED BACK LOOP

RF signals form DC 1 (from the generator) and Accelerator 1 are analysed in AFA 1. The signal at the AFA 1 output is proportional to the phase difference of these signals and therefore to the difference of generating frequency and resonant frequency of Accelerator 1. Master generator, preamplifier, klystron, bridge, DC 1, Accelerator 1 and AFA 1 form the first feed back loop. If the resonant frequency of Accelerator 1 changes due to heating, AFA 1 changes the frequency generated by the master generator so that the generated frequency is equal to the resonant frequency of Accelerator 1. Use of this feed back loop allows us to keep the equality of generated frequency and resonant frequency of Accelerator 1. The reaction of the electronically controlled master generator is much faster then the thermal frequency changing of Accelerator 1. Therefore this feed back loop is called as a fast loop.

4. SLOW FEED BACK LOOP

If the resonant frequency of Accelerator 2 changes due to heating, AFA 2 changes the temperature of water supplied by the Water Cooling unit for cooling Accelerator 2 so that the resonant frequency of Accelerator 2 is equal to the frequency of the master generator. The reaction of Water Cooling unit is slower

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then the reaction of the master generator. Therefore this second feed back loop formed by Accelerator 2 (with DC 2), AFA 2 and Water Cooling unit is called as a slow loop. The water temperature changing is realized by means of changing the power of electric water heater. The thermal capacity of this heater is minimized and it is located at the water inlet to Accelerator 2 directly to minimize the reaction time delay.

5. WAVEGUIDE ELEMENTS

The 3 dB waveguide directional coupler (waveguide bridge), 70 dB waveguide-coaxial directional coupler, waveguide load were calculated. Calculation results are:

Waveguide bridge:

- power dividing ratio S_{12}=-3.0 dB,
- reflection S_{11}=-34.6 dB,
- isolation S_{14}=-32.3 dB;

Waveguide-coaxial directional coupler:

- power dividing ratio S_{12}=-70.0 dB,
- reflection S_{11}=-34.6 dB,
- isolation S_{14}=-32.3 dB;

Waveguide load:

- reflection S_{11}=-34.6 dB,
  overvoltage 20%.

6. THERMO-FREUENCY TRANSIENT CONDITION IN THE LINAC

The thermo-frequency transient condition in the linac was calculated using a special calculation program. The main results are:

- Accelerator frequency stopway depends linearly on the average RF power switched on stepwise and reaches 1.7 MHz at a maximum RF power loss 11 kW and equal to 0.5…1.25 MHz at 3.1…8.3 kW in nominal regime.
- Time dependence of the accelerator frequency after RF power switching on or water temperature changing stepwise is not exponential. Two exponents can interpolate it. Time constant at the start of the process is equal to 15…18 sec.
- Time constant of the water heater is 7 s.

7. AUTOMATIC FREQUENCY ADJUSTMENT UNIT

The system includes two the same Automatic Frequency Adjustment units. Each AFA unit includes electronically controlled attenuators and phase shifters at both inputs, phase discriminator, detector modules, pulse amplifiers designed in strip-lines and mounted on one printed circuit board, located in the RF unit. The prototype of this board was made on the special RF dielectric plate with low dielectric loss. It is shown in Fig.2.

RF unit includes 4 RF detection channels for monitoring of signals in the accelerator, the travelling and reflected power at the accelerator and at the generator output. Really each DC is double and is provided with two the same directional couplers located on both sides of the waveguide. They allow us to measure the travelling and reflected power in the waveguide. The same Directional Coupler is installed at the klystron output to measure the generated power and reflected power at the klystron output. Second parts of DC 1 and DC 2 and Directional Coupler at klystron output are not shown in Fig.1.

The RF unit is shown in Fig.3.

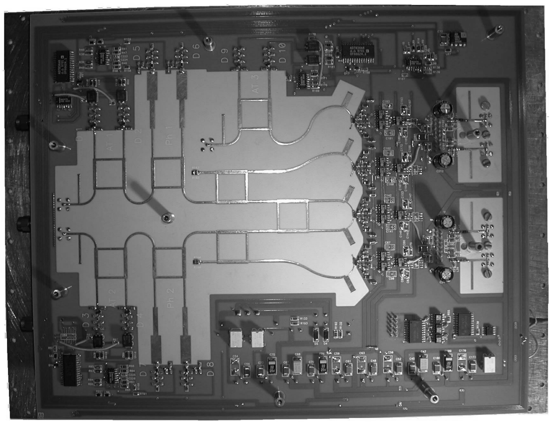

Fig.2. AFA prototype board

Fig.3. RF unit with AFA prototype board

The prototype of AFA unit was made in the 19” Rack mounted crate (see Fig.4.).

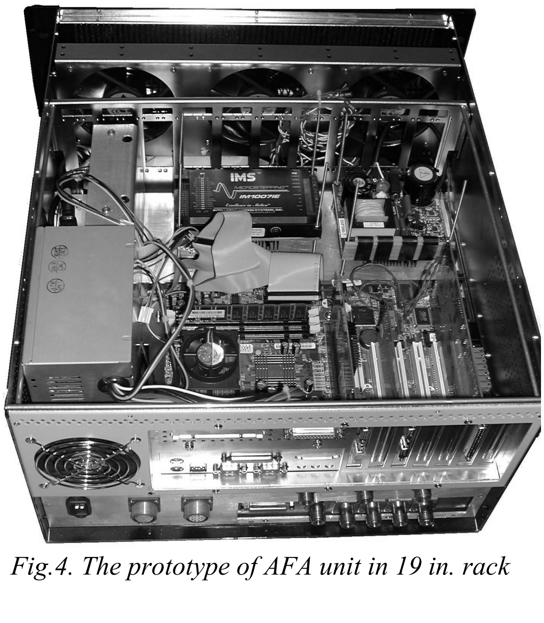

Fig.4. The prototype of AFA unit in 19 in. rack

The prototype of AFA unit was tested in the operating linac. The linac had one accelerating structure. Therefore there was only one feed back loop in this linac. Measured oscillograms of detected signals from the accelerator, signal of travelling wave at accelerator input and signal at phase discriminator output are shown in Fig.5. All measures have been taken to decrease the electromagnetic noise influence. One can see that measured signals are noiseless.

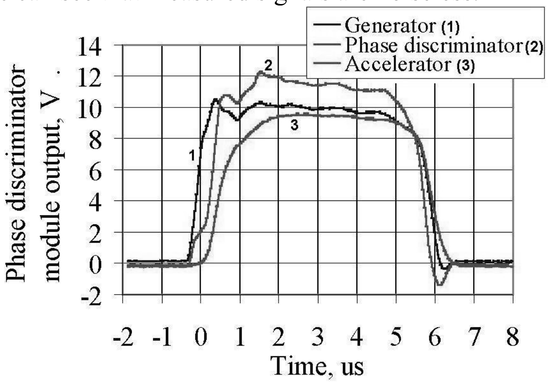

Fig.5. Signals from accelerator, waveguide directional coupler (generator) and phase discriminator

The measurements have been done using the digital oscilloscope with electronic memory. AFA prototype was connected to the computer analysing the signals and forming commands for the frequency control unit.

The phase difference depends on the amplitude and phase of signals at the both inputs of the phase discriminator. The phase value is calculated using measurement of signals at the phase discriminator inputs and output. The calculated signal of measured phase is shown in Fig.6.

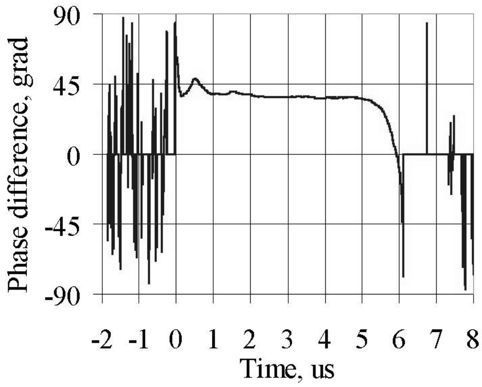

Fig.6. Calculated signal of measured phase

8. FREQUENCY CONTROL STEADINESS

The scheme of the frequency control is shown in Fig.7. This scheme was used to analyse the frequency control stability and to choose the operation range of facility parameters. The Laplace transform operational method was used for this analysis.

P_0 is the klystron power. 0.5 is the ratio of dividing the klystron power. U(S) is the transient condition function of step RF power changing. P_{ST1} and P_{ST2} are the start RF power of accelerators 1 and 2. W(S) is the transient condition function of the step cooling water temperature changing. f_{R1} and f_{R1} are the resonant frequencies of accelerators at a temperature T_0=200C. k_T=df/dT is the temperature coefficient of the accelerator frequency. k_P=df/dP is the power coefficient of the accelerator frequency (frequency shift because of temperature gradient in the accelerator). k_{pd} is the phase discriminator gain. k_c is the control unit gain. k_g is the master generator gain. k_H is the water heater gain. T_H is the typical water heater reaction time. S is the Laplace transform argument.

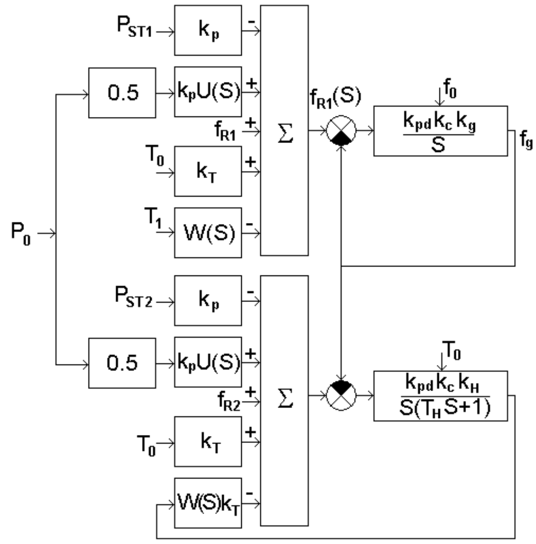

Fig.7. Frequency control schematic diagram

The analysis shows that the typical settling time is 10 sec for the fast loop and 200 sec for the slow loop at 95% of steady-state.

9. CONCLUSION

Main results of this work are:

- The scheme of RF power supply of two-side irradiation facility with one klystron and one modulator allows us to save a lot of money.
- AFA unit prototype shows the possibility of building of the system with a very low level of electromagnetic noise.
- Scheme of RF power supply with two fast and slow feed back loops guarantees steadiness of frequency control.
- Fast feed back loop will tune the frequency of the master generator to the frequency of Accelerator 1. The slow feed back loop will tune the frequency of Accelerator 2 to the frequency of Accelerator 1.

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СИСТЕМА СВЧ-ПИТАНИЯ ПРОМЫШЛЕННОЙ РАДИАЦИОННОЙ УСТАНОВКИ

В.Т. Гавич, А.А. Завадцев, Д.А. Завадцев, А.А. Краснов, Н.П. Собенин, О.С. Колосов

Радиационная установка предназначена для дезинсекции фруктов с помощью облучения двумя электронными пучками с энергией 9 МэВ. Производительность установки равна 30 Т/ч при глубинной дозе 150 Гр. Радиационная установка, базируется на двух идентичных линейных ускорителях электронов со стоячей волной, питаемых от одного клистрона с частотой 2856 МГц. Система СВЧ-питания включает задающий генератор, предварительный усилитель, клистрон, волноводный мост, три направленных ответвителя на 70 дБ, два блока автоматической подстройки частоты (АПЧ) с фазовыми детекторами и систему водяного обеспечения, объединенные для управления частотой в два независимых контура обратной связи.

СИСТЕМА НВЧ-ЖИВЛЕННЯ ПРОМИСЛОВОЇ РАДІАЦІЙНОЇ УСТАНОВКИ

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Радіаційна установка призначена для дезинсекції фруктів за допомогою опромінення двома електронними пучками з енергією 9 МеВ. Продуктивність установки дорівнює 30 Т/годину при глибинній дозі 150 Гр. Радіаційна установка базується на двох ідентичних лінійних прискорювачах електронів зі стоячою хвилею, що живляться від одного клістрона з частотою 2856 МГц. Система НВЧ-живлення включає задавальний генератор, попередній підсилювач, клістрон, хвилевідний міст, три спрямованих відгалуджувача на 70 дБ, два блоки автоматичного підстроювання частоти (АПЧ) з фазовими детекторами і систему водяного забезпечення, об'єднані для керування частотою у два незалежних контури зворотного зв'язку.