RF SYSTEM FOR HIGH-POWER INDUSTRIAL IRRADIATORS

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Abstract

The IMPELA family of industrial irradiators developed by AECL have electron beam energies ranging from 5 to 18 MeV at beam powers of 20 to 250 kW. Direct control of the rf fields during the beam pulses ensures constant output energy, independent of the beam current. These irradiators are designed for simple, push button, reliable operation. The modular rf system supports the needs of either direct electron or photon conversion irradiations. The IMPELA I-10/50 prototype has a beam energy of 10 MeV and an average power of 50 kW. The rf system features a 1300 MHz, 2 MW peak, 150 kW average, modulated anode klystron amplifier with a maximum pulse length of 1 ms. A software-based control loop tracks the accelerator structure resonant frequency while a hardware loop controls the rf amplitude during the pulse. A circulator protects the klystron from reflected power and a crowbar protects the klystron from internal arcs. This paper describes the design concepts of the system and presents results from the characterization of the I-10/50 prototype rf system.

Introduction

AECL is developing a family of industrial irradiators based on high-power electron linear accelerators to cover beam energies from 5 to 18 MeV at average beam powers from 20 to 250 kW. This family of industrial irradiators[1], called IMPELA (Industrial Materials Processing Electron Linear Accelerators), has been designed for applications where combinations of dose, penetration, and volume are high. Processing can be done in electron or in x-ray mode. Some areas of application are: the sterilization of packaged or bulk materials, the treatment of rubber and plastic to enhance performance characteristics, the elimination of pathogens in waste material and sewage, the reduction of food spoilage, destruction of insects and reduction of salmonella in food.

A schematic representation of an IMPELA irradiator is shown in Fig. 1. Major components of the irradiators include a 1300 MHz standing wave structure, a triode electron gun mounted on the structure and a scanning system that distributes the beam uniformly over up to 80 cm in width. The structure is powered with a modulating anode klystron protected from reflected power by a high-power circulator. Operation, control and monitoring is done through an industrial programmable logic controller (PLC)[2].

The rf system is designed for low peak-power levels for greater component reliability. Its main features are:

- the rf output power is directly controlled during the pulses to provide a constant energy independent of beam power,
- the rf drive frequency is determined by the structure resonant frequency,
- the beam power is varied by changing the duty factor,
- the peak beam current is constant with a beam loading coefficient of 0.65 during each pulse,
- the system is based on modulating anode klystrons with a pulse length capability up to 1.1 ms and a duty factor up to 0.075.

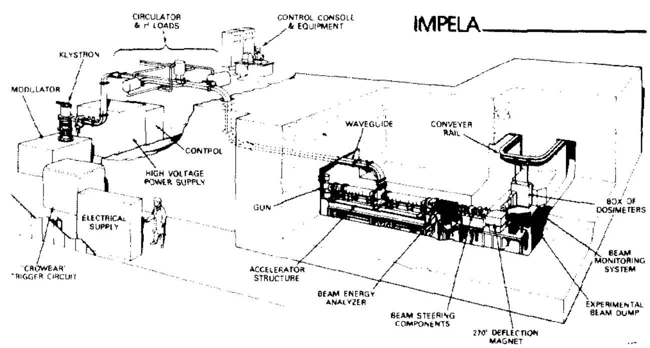

Fig. 1 IMPELA irradiator facility.

The I-10/50 prototype has an electron energy of 10 MeV, an average beam power of 50 kW. The nominal beam pulse length is 200 μs but can be adjusted from 50 to 500 μs. The rf system is based on a Thomson-CSF TH-2115, 2 MW peak, 150 kW average, modulating anode klystron. The operating voltage is modest, 82 kV. The stored energy in the rf power system is 16 kJ and the electrical energy per pulse is 900 J. The klystron is protected with a crowbar limiting dissipation during an arc to 20 J.

Control System

The I-10/50 rf system is run-up, monitored and operated through the PLC. A block diagram of the irradiator controls is shown in Fig. 2. The linear accelerator has four principal controlled variables: beam current, beam energy, repetition rate and rf drive frequency. Beam current and drive frequency are adjusted through the PLC between pulses while a hardware control loop controls the rf power during the 200 μs long pulse for a constant output energy independent of beam current.

The rf system is operated into a resonant structure which is critically coupled with beam and has a VSWR of 2.8 (overcoupled) without beam. The system run-up sequence by the PLC is:

- The structure temperature is measured and its resonant frequency is set via a look up table (the 1300 MHz structure frequency shifts by -22.5 kHz/°C).
- At low rf power, the rf drive frequency is scanned near the reference frequency until the automatic frequency control loop is locked. Transmitted phase, measured using a double balanced-mixer (DBM), is used to detect resonance.
- The amplitude control loop is closed and the peak rf power level is gradually increased at low repetition rate to the desired accelerating field level, by

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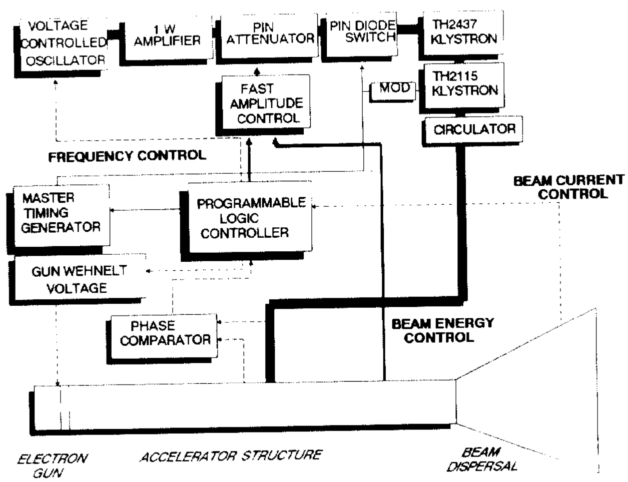

Fig. 2 IMPELA control block diagram.

changing the bias voltage on a pin attenuator in the rf drive line.

- Beam operation is started at low repetition rate and gradually ramped to full power.

The master timing generator provides the following sub-systems trigger pulses:

- the Wehnelt aperture on the electron gun is triggered first to inject a beam pulse into the structure,
- 10 μs later, the klystron modulating anode is switched to turn on the klystron beam,
- 5 μs later, the pin diode switch in the drive line is biased to provide an rf drive signal to the klystron,
- the drive pulse is turned off 200 μs later with the pin diode, the klystron modulating anode is brought to the cathode voltage and the Wehnelt aperture is biased to turn off the electron gun.

Peak rf power levels in the waveguide transmission system, the frequency error signal at a DBM and output beam current are sampled and values held between pulses. Corrections to the drive frequency and gun beam current are made between pulses. Beam energy is controlled by sensing the accelerating field in the structure and adjusting the bias on the pin attenuator in the drive line during the pulse.

RF Power System

Electrical System

The I-10/50 rf electrical system, shown in Fig. 3, consists of a 400 kVA transformer rectifier, a 2 μF capacitor bank, a modulating anode pulse modulator, a 400 W filament power supply and a 10 kW dc power supply for a TH 20277 electromagnet. The klystron beam is turned on with a rise time of 10 μs by switching the modulating anode voltage with a TH 5188 tetrode. The beam is turned off by turning the tetrode off, allowing a pull-down resistor to bring the modulating anode to the cathode voltage with a time constant of 40 μs. The klystron beam current is kept constant during the pulse by a controlled voltage droop on the modulating anode.

The oil-filled modulator tank supports the TH 2115 klystron and contains the capacitor bank, mod-anode pulse modulator and filament power supply. The modulator tank is 280 x 150 x 130 cm high and its weight with oil, klystron and electromagnet is 10 Mg.

RF Drive and Transmission System

The rf source is a voltage-controlled oscillator (VCO). The VCO output frequency is controlled through the PLC to match the structure resonant frequency. The VCO drives a 1 W solid-state amplifier operated in saturation, see Fig. 2. The drive level at the input of a TH 2437 driver klystron is adjusted with a pin attenuator driven by a hardware control loop and is pulsed with a pin diode switch driven by a master timing generator through the PLC. The TH 2115 klystron is driven through a coaxial line by the TH 2437 klystron, protected from reflected power with a circulator.

A WR 650 waveguide system pressurized with 150 kPa(a) of SF_6 is used to transmit the rf power to the structure. The klystron is protected from reflected power with a TH DHL 200 circulator.

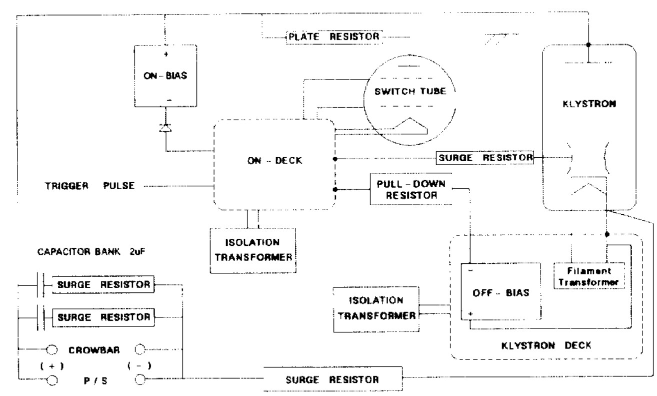

Fig. 3 I-10/50 klystron power system.

Klystron Protection System

A crowbar protects the klystron from arcs. Protection from waveguide arcs and overpower is achieved by sensing the rf power during the pulse and rapidly removing the rf drive power with a pin diode switch. While the stored energy in the electrical system is 16 kJ, the energy sustained in a klystron arc must not exceed 20 J. The Haefely crowbar, shown schematically in Fig. 4, is triggered by a toroid around the cathode high-voltage cable. When the cathode current exceeds the klystron maximum operating beam current, it triggers the spark gap. This quenches a klystron arc in less than 6 μs and results in a discharge of the stored energy in less than 100 μs. At the same time, the power supply is disabled and the mains contactor is opened. A high-speed vacuum relay in parallel with the crowbar closes in 7 ms to prevent follow-on current from re-establishing the arc.

Utilities

Total power requirement for the I-10/50 rf system is 350 kW, of which 43% is transmitted as rf power, 52% is dissipated in the klystron collector, 2.4% in the electromagnet and 2.6% in the modulator components. The total cooling flow rate required for the system is 400 L/min of deionized water.

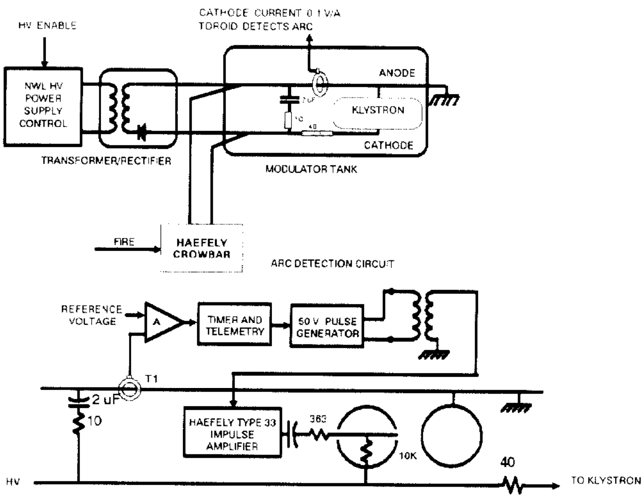

Fig. 4 I-10/50 crowbar spark gap system.

Status

Commissioning of the I-10/50 prototype is underway. First beam operation is expected early this year.

References

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