DESIGN, DEVELOPMENT AND OPERATION OF A SCANNING POWER SUPPLY FOR AN RF LINAC

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Abstract

A compact power supply, based on closed loop scheme, for the scanning magnet of a 10 MeV RF Electron Linear Accelerator was designed, developed and operated. The supply can generate bipolar triangular current waveform of 0-6 A peak current at 1-10 Hz frequency through the magnetizing coil to cover 1 meter scanning length. The load is connected to an unregulated DC power supply through an IGBT bridge. The reference triangular waveform is generated by the DAC (Digital to Analog Converter) of a microcontroller. The voltage across a current-sensing feed-back resistor connected in series with the magnet coil is compared with the reference waveform. The IGBTs are switched appropriately to increase or decrease the current through the load depending on the nature of the feed-back. In our earlier designs, square-wave voltage waveform was fed to the coil through an IGBT bridge to obtain triangular waveform if L/R (ratio of inductance of coil to effective series resistance) was much larger compared to the time-period of the scanning current waveform. For the coil used by us, this condition is not met at lower frequencies but the introduction of the closed-loop scheme overcomes this problem.

The peak scanning current and scan frequency can be entered from a user-friendly Touch Screen Panel. Dosimetric measurements below the exit foil shows that the desired uniformity for irradiation jobs over 1m scan length can be achieved.

INTRODUCTION

A 10 MeV RF Linac is currently operational at Electron Beam Centre, Kharghar, Navi Mumbai to demonstrate various industrial applications like medical sterilization, food irradiation, polymerization and cross-linking etc. The 100 mA, 10 µs current pulses repeating at 300 Hz are scanned over the job by employing an electromagnet which provides time-varying magnetic field. The 10 mm diameter beam is scanned over 100 cm length of a Titanium foil. The scanning frequency is in 1-10 Hz regime to ensure overlap of beam-spots so that desired uniformity of radiation can be realized.

DESIGN OF THE SCANNING SUPPLY

Ideally, the magnet coil should be an inductive load but this is not so due to the resistance of the copper windings and connecting leads. A triangular current waveform with sufficient linearity can be realized by applying a square wave input to the load provided $L/R >> \iota/2$ where ι is the time-period of the wave form, L and R being the inductance and resistance of the coil respectively. In our case, L = 200 mH and R = 1 ohm and therefore, in the low frequency regime of 1-5 Hz , the above condition is not satisfied leading to nonlinearity in the current-waveform. Earlier we used to connect a heavy inductor with negligible resistance to boost the L/R ratio to tackle this problem [1].

In order to get over this problem, a closed loop approach can be followed [2]. The circuit diagram is shown in Fig.1. A reference waveform was generated with Digital to Analog Converter (DAC) of a microcontroller (Model 8051F120, Silicon Lab make). A feed-back resistor was connected in series with the load. The current waveform was compared with the reference wave-form using a comparator LM339. If the current is less than the desired one, one comparator generates a pulse signal to drive the IGBT Q5 and Q4 which connect the load to the power supply in such a manner that the current increases. The current will rise and then overshoot the desired current after sometime when the comparator senses it and IGBT Q3 and Q6 will connect the load to power supply in the opposite direction to reduce the current. These corrections will go on around the reference waveform in the form of many small saw-tooth cycles. One has to remember that one has to use a power supply at some threshold voltage to obtain proper correction.

For rise of peak current from $-I_0$ to $+ I_0$ in time $\iota/2$, the slope of the waveform is $4I_0/\iota$.. This is the slope of the reference waveform and one has to exceed this slope sufficiently by choosing a proper supply voltage so that corrections can be made. For example, for our load operating in 1-5 Hz at 6A peak current, a DC voltage of 75 V is good enough.

To introduce the dead band in the full bridge of the IGBTs , an RC circuit is used . AD 202KY is used as an isolation amplifier in the feed –back circuit. Two IR-2110 chips are used as the IGBT driver ICs and draw their power from a 15 V supply. An inverter is used to ensure that when IGBT Q5 and Q4 are on Q3 and Q6 are off and vice-versa. A typical signal recorded with an oscilloscope is presented in Fig.2.

FAST TRIP INTERLOCK CIRCUIT

When the scanning system fails the Titanium foil may rupture due to beam incidence at a particular location. Therefore, the electron beam is to be tripped within 100ms to prevent such an occurrence.

The drive to IGBT gate is a pulsed signal which is present all the time if the scan system is working satisfactorily. This continuous pulse stream is fed to a monostable multi-vibrator using IC555. The time duration is set to 25ms. Repeated pulse input to the vibrator keeps the output high. Unavailability of such a stream of pulses corresponding to the failure of the scan system will make the output of the multi-vibrator low, thus generating a trip. It has been tested that the trip action takes place within 40ms.

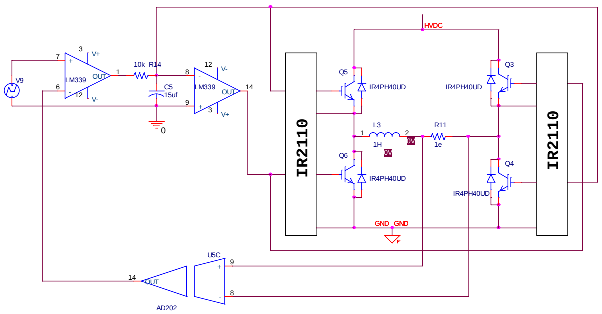

Figure1: Electrical Circuit of the Power Supply.

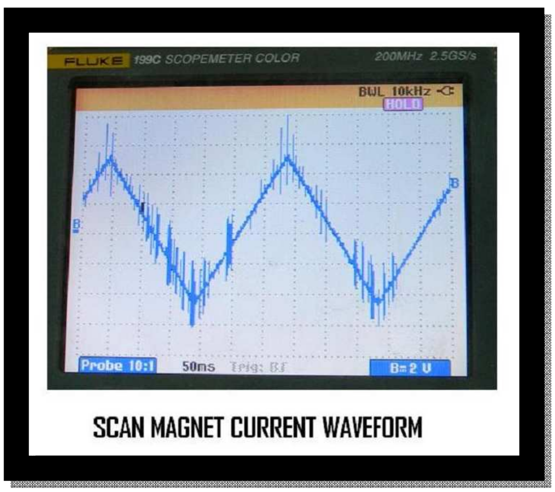

Figure 2: Current Waveform.

USER INTERFACE

A color Touch Screen shown in Fig.3 (diagonal dimension 5.7”, model V606eC, resolution 320*240 pixels) forms the user interface. Readymade attractive icons like On/OFF, Increment/Decrement switches and alarms are available in HMI programming software. The user can enter the values of amplitude and frequency of the wave form from the touch panel. Button pressing is acknowledged with a beep. It interacts with the microcontroller through MODBUS protocol. BNCs are provided in the panel for viewing the reference and real signals with an oscilloscope. The power supply can also operate from a PC panel by RS-485 communication.

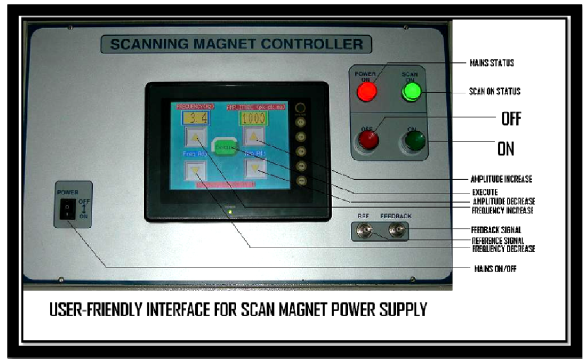

Figure 3: Touch Screen Panel

DOSIMETRIC EXPERIMENTS

Dosimetric measurements were carried out using radio-chromic B3 films by placing a matrix of 10 mm x 10 mm films below the Titanium window. The dose rate along the scanning direction is shown in Fig.4. The variation in dose over 80 cm. length is within ± 10%. The power supply has been reliably working for the last three years in strong EMI environment without any problem.

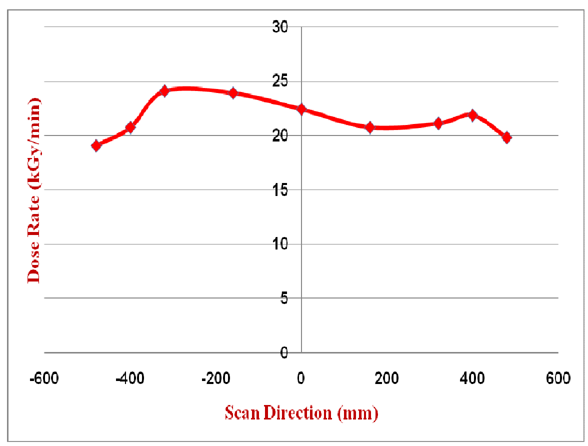

Figure 4: Dosimetric Profile of Electron Beam

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[1] “Development Of Scanning Systems For 3 MeV DC and 10 MeV Rf Industrial Electron Accelerators”, S. Acharya et al, Proc. InPAC-2005, Kolkata, March 1-5, 2005

[2] Scanning Magnet Power Supply for 10 MeV RF Linac, R. Banwari et al, Proc. InPAC, 2005, Kolkata.