DESIGN AND PROTOTYPE DEVELOPMENT OF SOLID STATE MODULATOR FOR PULSED ELECTRON GUN OF THE 10MeV LINAC AND RELATED STUDIES OF PULSE TRANSFORMER

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Abstract

The paper describes the design and development of an IGBT-based pulse modulator rated for 85-100 kV, 4 A, 10µs, 250pps. The paper discusses the design considerations, pulse transformer design and analysis of two different pulse transformer cores with and without Core Biasing. The cores analysed are iron based 2605SA1 Amorphous Cut C Cores, and Cobalt based 30KCP Torroidal cores. The effect of the gun and stray capacitance of the filament transformer on the rise time has also been highlighted. The paper also describes the design of a compensating circuit to eliminate the excessive ringing in the output due to high impedance load. The paper concludes with the results of the testing of the prototype modulator on electron Gun load and future scope of work.

INTRODUCTION

The electron gun of the 30MeV linac is rated for a nominal operating peak voltage of 85kV(negative), peak current of 500mA at a pulse width of 10 µs and Pulse Repetition Frequency (PRF) of 250 pps[1]. The desired rise time is less than 1 µs. Hence the useful pulse power is 42.5kW. The useful energy per pulse is 425mJ, and the useful average beam power (at 250 pps) is 106W.

The estimated Capacitance of the Gun is 30pF. Hence, the energy stored in the gun capacitance ($0.5CV^{2)}$ is 0.11J/ pulse. This indicates that the energy stored in the Gun capacitance is ~ 25% of the useful energy. The effect of the gun capacitance is more prominent to increase the rise time of the pulse and decrease the effective characteristic impedance of the Pulse Transformer equivalent. Energy lost in the rise time and the fall time is negligible as compared to useful pulse energy and hence need not be considered in our estimate.

Minimum Gun resistance is 170k Ω. The gun resistance can be very high as compared to the resistance at full rated beam current when the filament is not heated. Hence, unlike standard case, where the pulse V-I is more or less fixed within small band of variations around the operating point, the pulse transformer will see a wide variation in the load impedance. Thus, a pulse modulator designed for optimum operation at full peak power, will result in excessive ringing and overshoot when the gun filament is OFF. To overcome this problem, the gun is loaded with externally connected resistance such that the impedance variations seen by the pulse transformer (No load to full load case) does not significantly affect the pulse characteristics. The pulse modulator is designed for ~3.4A loading at 85kV, i.e. the pulse transformer is loaded by 25 kΩ resistor. Hence the effective variation in the current with and without beam is from 3.4A to 3.9A. The pulse modulator is designed for optimum pulse shape at 3.6A. In this case, however it has to be noted that the energy loss per pulse in 25 kΩ resistance at 85 kV is 2.9 J, which is 5.5 times the energy delivered to the electron gun

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TOPOLOGY

Among the various topologies used for Solid –State Pulse Generators [2], PULSE TRANSFORMER Switching Topology has been used for the required Pulse Generation, wherein a 1kV DC is switched and a pulse transformer is used to step up the primary voltage to the necessary level (85 kV). The choice of 1kV Switching voltage is based on the availability of IGBT rated at 1.7kV/590A with rise times less than 100ns. Table 1 summarizes the design parameters of the modulator.

. Table 1: Design parameters of Pulse modulator

Secondary Pulse Voltage (V_{SEC})	85kV(negative)
Secondary Pulse current (I_{SEC})	3.4A – 3.9A
Rise time (t_r)	<1 µs
Pulse Flat Top (τ)	10 µs
Pulse Repetition Frequency (PRF)	250 Hz
RMS Secondary Current (I_{RMSsec})	200 mA
Maximum Primary Voltage (V_{PRI})	1 kV
Primary Pulse current (I_M)	332 A
Rise Time in primary	100nsec
RMS Primary current(I_{RMSpri})	17 A
Turns ratio (n)	1:85

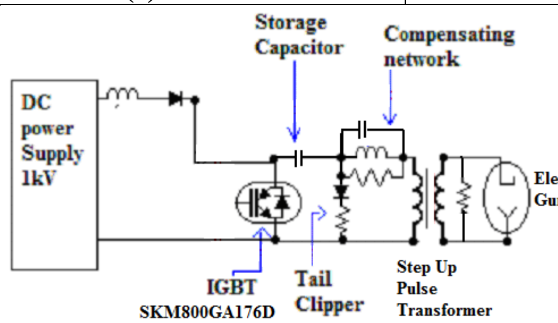

Fig1: Basic Schematic of Pulse modulator

As shown in Fig.1, the storage capacitor (47 µF) is charged to ~1kV DC, and switched by a Semikron make IGBT (SKM800GA176D). The IGBT gate is driven by a Semikron make IGBT Driver (SKHI 10/17), with inherent V_{ce} monitoring and Short circuit protection. The RCD snubber ensures that the Turn-off overshot across the IGBT is within 1.3kV.The main part of the development effort is on the design and development of 1:85 step-up pulse transformer.

METGLAS® make Fe-based Amorphous Cut-C cores (2605SA1), having maximum effective core cross-section area of 23 sq cm and magnetic path length of 427mm (AMCC1000) are locally available and were found to be suitable for the above application. These are made of 25 micron width ribbon of metglas alloy 2605SA1 (Iron based). They are designed specifically for low loss High Frequency chokes and transformers. These cores have a pulse permeability of ~1,500 for a flux swing of ~ 1.4T (unidirectional). The pulse permeability of these cores was confirmed at various flux swings, with and without core biasing.

The 10MeV Linac at Electron Beam Centre uses a 60kV/1A, 10 µs, 400pps Electron Gun. A prototype 1:57 Pulse transformer was constructed for max 60 kV, 10µs pulse output across a load of 25k Ω at 200 pps. The transformer consists of 5 turns primary (Foil type with 70mm winding length) and 280 turns secondary (SWG36). The secondary has a tapered winding geometry with ~20mm spacing between the primary and the secondary on the HV side, and negligible spacing at the low voltage side. Two major effects have to be considered when the pulse transformer drives a high impedance load.

One effect is that the magnetizing current of the pulse transformer is limited by the pulse permeability of the core, and is comparable to (if not more) than the load current. This extra penalty has to be considered while considering the power requirements of the supply, and this also affects the reversal (back-swing). There is a limit set on how much the back-swing can be reduced. The only way to increase the magnetizing inductance for a given core, is to increase the number of turns, but this adversely affect the rise time. Square loop Co based torriodal uncut cores having pulse permeability order of magnitude more than the iron based cores can be used for the same application. The Co based 30KCP cores showed a pulse permeability of ~22,000 for a flux swing of 2.2T.

The second and a more serious effect of the high impedance, is on the transient response. The impedance seen by the pulse transformer is larger than the characteristic impedance of the transformer. This results in excessive ringing and overshoot. It becomes worst when the load capacitance is also considered in the design, as the characteristic impedance of the pulse transformer will be even smaller, so much so in many cases the load capacitance dominates and is more comparable to the distributed capacitance. Hence, an RLC compensation circuit has been designed and is connected in series with the pulse transformer primary. The effect is clearly shown in Fig 4a where there is a 24 kV overshoot in a pulse voltage of 45.6kV, and the ringing on the flattop is also not acceptable. Fig 4b shows the effect of compensation circuit at a pulse voltage of 50kV. The probe used for measurement is a Iwatsu make 2000:1 probe (HVP-60). The load capacitance is attributed to the capacitance introduced due to the inherent geometry of the gun anode-cathode and is unavoidable. The electron gun is a thermionic gun and requires Filament heating. This is conventionally fed to the filament through a HV isolation step down transformer (50 Hz). This has a very large capacitance to ground (unless special care is taken during fabrication). In this case, the transformer has 80pF capacitance to ground and the Gun capacitance is 30pF.

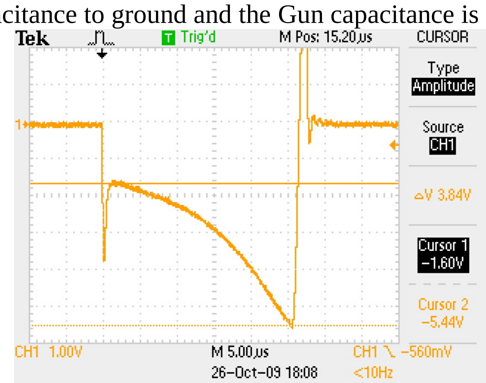

Fig. 3: Typical Primary Current in case of High Impedance Load

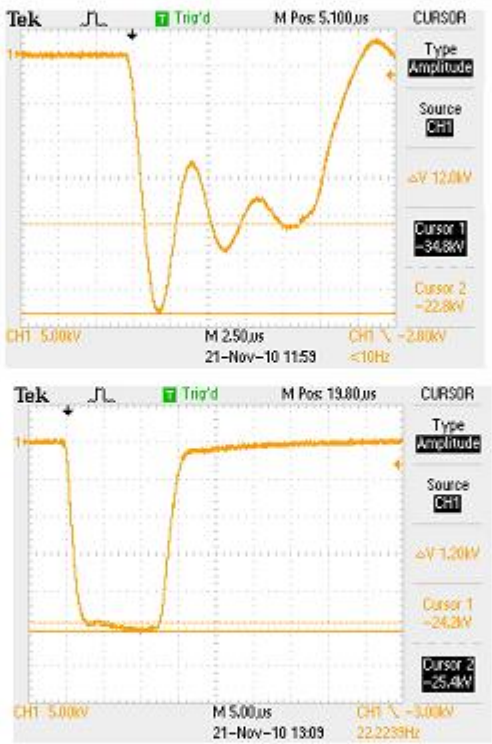

Fig4a &4b: Modulator output without and with compensation circuit

CONCLUSION

The design, development and testing of the prototype on a resistive load (25 kΩ) at PRF of 200pps and 55kV output & electron gun load has been successfully demonstrated. Further testing of the system up to 85 kV is in progress.

REFERENCES

[1] 30MeV Electron Linac, V.T.Nimje et.al. APAC07

[2]Solid State Pulse Power Systems. Stephen Roche.