DEVELOPMENT OF A PULSED MODULATOR FOR AN S-BAND KLYSTRON

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Abstract

We are developing a pulsed power supply (Modulator) to power a 10 MW Klystron [Model 2KHY-111B of TORIY, Russia]. The power supply is required to deliver a 69 kV, 355 A pulse of 10 μs duration at a repetition rate of 40 Hz. We discuss here the design of the pulsed modulator, and the various schemes being employed to develop its various sub-systems.

1 INTRODUCTION

The Klystron to power the Plane Wave Transformer linac being developed at CAT has an efficiency of 40%, which translates to an electrical power requirement of 25 MW to extract the rated 10 MW RF power out of it. The electrical power required is in the form of 10 μs pulses of 69kV and 355A, and the klystron can be operated with a maximum repetition rate of 40 Hz.

The shape of the RF pulse obtained from the klystron depends upon the input voltage pulse applied to it. Ideally, since the klystron is an amplifier, the input RF pulse to the klystron can be made to fit within the applied voltage pulse so as to obtain amplification of the RF in the flat-top region of the voltage pulse. However, if the voltage pulse has slow rise and fall times, it reduces the energy efficiency of the Modulator. Hence, it is desirable to have fast rise and fall times of the pulse, such that it could be directly used to amplify the input RF signal for the complete duration of the voltage pulse (ideally, rectangular pulses are the best).

A modulator for such applications typically employs a direct current (dc) source to charge a pulse-forming network (PFN), which discharges into the matched load through a high voltage switch and a pulse transformer, which steps-up the pulsed voltage to the required level and also matches the impedance of the klystron to the PFN impedance. The pulse characteristics are critically dependent upon the design of the PFN, which typically consists of cascaded low pass LC filters. The choice of the values of inductance and capacitors, and the number of sections in the PFN determines its pulse characteristics [1]. The pulse transformer only steps-up the voltage pulse applied to it while matching the impedance of the PFN to that of the klystron giving maximum energy transfer to the klystron. Hence, a good pulse transformer should perform a faithful stepping-up of the voltage pulse applied to it without causing any deterioration of the characteristics of the pulse.

In the next Section, we discuss the design considerations and the basic schematic of our modulator, which is followed by a discussion of the tests performed on the modulator and its sub-systems in Section 3. We conclude with a discussion of results in section 4.modulator design

From the rise time, fall time, and flat top requirement of the voltage pulse for the klystron, the values of the inductance and capacitance used in the PFN are obtained by solving the standard equations of conventional filter theory [1]. From our requirement of rise time, fall time, and flat top of 0.6 μs, 1 μs, and 8.4 μs respectively, the optimum values of inductance and capacitance turns out to be 2 μH and 55 nF respectively for a PFN with 15 sections, and the optimum coupling coefficient ‘k’ is 0.21. It is assumed here that a pulse transformer is going to be used to match the impedances. PFNs employing lumped inductances have large fall time due to non-linear phase characteristics of the network, while those using distributed inductance, which gives high coupling coefficient due to the high mutual inductance between neighbouring sections, produce better approximations to a rectangular pulse.

For the values of L and C chosen, the characteristic impedance of the PFN turns out to be 6Ω, which has to be matched to the impedance of the klystron for maximum energy transfer. The klystron has an impedance of 194 Ω at the rated voltage of 69kV, and this impedance changes with the operational voltage. The modulator has been designed to match the impedance of the PFN with that of the klystron at the rated voltage of 69 kV, for which a pulse transformer with a turn ratio of 1:5.4 is required. From this turns ratio, the requirement of 69 kV for the klystron translates to a voltage of 11.5 kV at the primary of the pulse transformer. Since this voltage pulse is obtained from the PFN, the capacitors of the PFN have to be charged to twice this value considering perfect matching of impedances. With a tolerance of about 30%, the voltage rating of PFN capacitors is fixed at 30 kV. We have used a continuous air-core solenoid, which is tapped at definite intervals giving individual sectional inductance of 2 ± 0.1 μH, and a coupling coefficient of 0.18. Fifteen capacitors of 55 ± 2 nF were connected at the tapping points on the solenoid. A schematic of the PFN used is shown in Figure1.

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[*] Presently with Oxford Instruments, Oxford, UK.

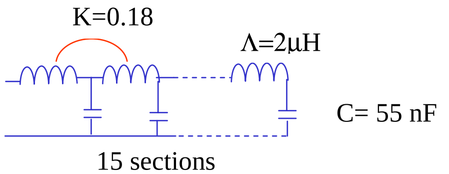

Fig.1 Schematic of the pulse forming network

From the 6Ω characteristic impedance of the PFN and that of the klystron referred to the primary of the pulse transformer, the switching current at 30 kV turns out to be 2.5 kA, for which we use a pseudospark switch [Mod. TD-50K/45 of PLAZMA].

Considering charging of the PFN through a charging choke of 30 H, which charges the capacitors in the PFN to twice the voltage applied to it, the dc charging power supply for the PFN has a voltage rating of 15 kV and a current rating of 1 A, which is just the charging current of the PFN. A schematic of the charging power supply is shown as Figure 2. To achieve a flat-top voltage ripple around 1% from the modulator, the charging of the capacitors of the PFN also has to be done with the same regulation, which is achieved by using three phase input through a motorised variac and a high voltage transformer with one primary and two secondaries connected in Δ / Δ,Y configuration along with two six-pulse rectifiers in series with a filter. Output voltage regulation of the dc power supply is done by a feedback circuit that generates an error signal to drive the motorised variac in case of deviation of output voltage from the set value.

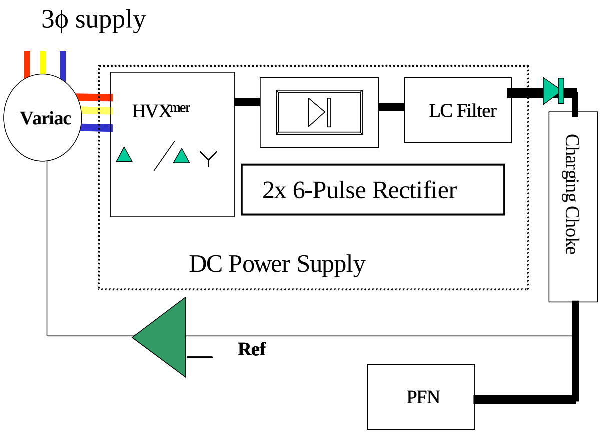

Fig.2 Schematic of the dc charging power supply

The pulse transformer with a turn ratio of 1:5.4 was made using four stacks of 0.05 mm thick laminated cold rolled grain oriented (CRGO) core. Ideally, it is desirable for a pulse transformer to have the same impedance as that of the PFN. Hence, the parasitic capacitance and leakage inductance values should match the values of the capacitance and inductance of the PFN. To achieve this, two primaries have been used to minimize leakage inductance and the secondaries have been wound on tapered bobbins to minimize the leakage inductance[2]. Two secondaries have been used to supply the heating current to the filament of the klystron. These two secondaries, along with suitable capacitors connected at the low and high voltage sides, form a low pass LC filter isolating the high voltage pulse from the filament heating power supply. A schematic of this circuit is shown as Figure 3.

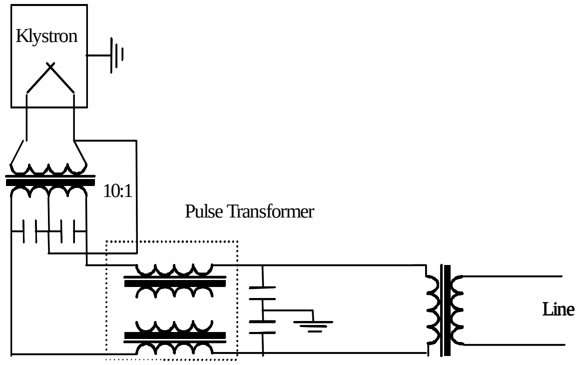

Fig.3 Schematic of connections for filament heating

In order to achieve a low voltage droop, the time constant (L/R) of the pulse transformer should be very high as compared to the pulse width. As the pulse voltage increases, the core of the pulse transformer can move towards saturation resulting in lower values of shunt inductance 'L' causing an increase in the droop. This can be overcome by magnetizing the core in the opposite direction to that of the magnetization due to primary current, for which we have provided 10 turns on the core.

3 TESTING OF THE MODULATOR

Before integrating the various components of the modulator, major sub-systems like the dc charging power supply, PFN, and the pulse transformer were individually tested for their rated performance.

The dc charging power supply was tested to its rated voltage and current under open circuit condition, and with a dummy load. Voltage regulation of better than 1% has been achieved.

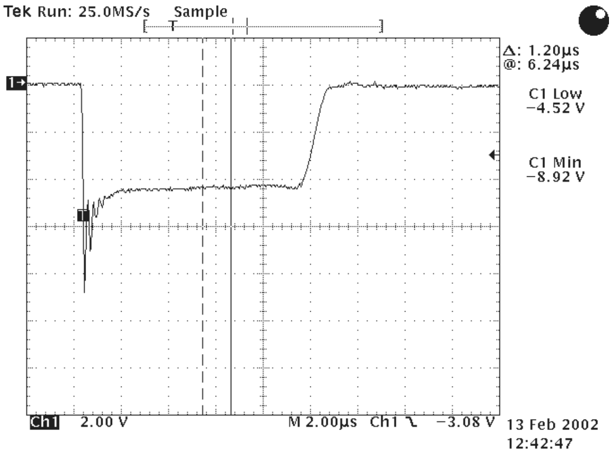

Figure 4. Typical pulse shape from the PFN with a dummy load.

The PFN was tested using the dc charging power supply to its rated voltage with a matched load of 6Ω. A typical pulse obtained from the PFN is shown in Figure 4. Rise and fall times of about 0.4 μs and 0.9 μs respectively have been measured. A non-inductive film type resistor was used as the dummy load to test the PFN, and the observed ringing in the pulse shape points to the fact that the load is not completely non-inductive.

The pulse transformer was tested with the klystron as a load. Figure 5 shows a typical pulse shape at 40 kV obtained from the pulse transformer. The measured rise and fall times, and voltage droop of the pulse are *** μs, *** μs, and *** V respectively. While designing the pulse transformer, it was decided to opt for a lower droop at the cost of increased rise time for the pulse. The pulse transformer was designed for a high magnetizing inductance by increasing the number of turns in the primary, which resulted in the low voltage droop. This, causes and increase in the leakage inductance resulting in an increase in the rise time. The values of leakage inductance, shunt capacitance, and magnetizing inductance of the pulse transformer, measured using an LCR meter (Kingsley, Mod.), are 6.2 μH, 1 nF, and 6.3 mH respectively. This translates to a theoretical voltage droop of 2.1%, which agrees well with the measured pulse.

Since the pulse transformer is designed for operation at 69kV, at which the impedance of the klystron is 194 Ω, the best performance in terms of pulse shapes is expected at this voltage. At lower voltages, the characteristic impedance of the pulse transformer had to be tuned to match that of the klystron at that voltage by adding external shunt capacitors. This results in a slight increase in the rise time of the pulse.

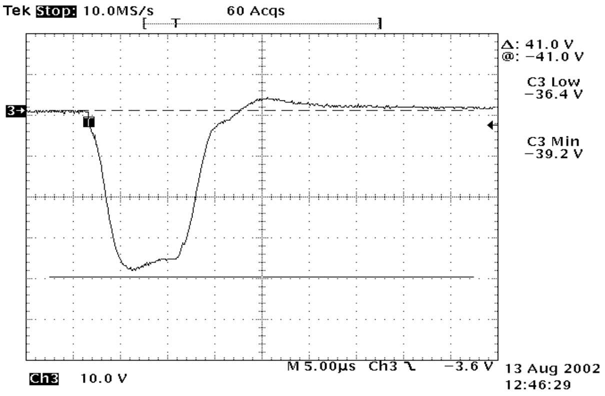

Figure 5 Typical pulse shape from the pulse transformer

4 CONCLUSIONS

We have designed, fabricated, and tested a 25 MW pulsed modulator to power a 10 MW klystron. The modulator has been tested at 40 kV with the klystron, and about 3 MW of microwave power has been measured in the high power microwave test line assembled for the commissioning trials. The microwave line has been designed to operate at the rated 10 MW with SF_6 pressure of greater than 3 bar. Since we do not yet have an SF_6 handling system, the commissioning trials are being done with N_2 at a pressure of greater than 4 bar. Even at this pressure, arcing is observed in the line at power levels close to 3 MW, which causes a restriction of the modulator voltage to less than 40 kV. Efforts are currently underway to improve the pulse shape by biasing the core.

5 REFERENCES

[1] G.N. Glasoe, .J.V. Levacqz, “Pulse Generators”, McGraw Hill, New York, 1948.

[2] M.A. Nadkarni, S. Ramesh Bhat, “Pulse Transformers”, Tata McGraw Hill, New Delhi, 1985.