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1 GeV LINAC DESIGN NOTE

題目 (TITLE) Design and Construction of a Pulse Transformer for a Long Pulse Klystron

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概要 (ABSTRACT)

A pulse transformer which is used to be linked with the 15 MW linetype modulator was designed and constructed for an L-band high power rf source of 1-GeV proton linac of the Japanese Hadron Project (JHP). This pulse transformer steps up an output pulse voltage from the modulator to 140 kV with a 600 μsec pulse width at 50 pps. The pulse transformer and its associated circuit components were installed in an oil tank, and operated at 400 μsec of pulse width for a klystron load.

KEY WORDS:

Ion source, RFQ, DTL, CCL, Magnet, Monitor, Beam Dynamics,
Transport, Vacuum, Cooling
Klystron, Low level rf, High power rf, Modulator
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DESIGN AND CONSTRUCTION OF A PULSE TRANSFORMER FOR A LONG PULSE KLYSTRON

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Abstract A pulse transformer which is used to be linked with the 15 MW line-type modulator was designed and constructed for an L-band high power rf source of 1-GeV proton linac of the Japanese Hadron Project (JHP). This pulse transformer steps up an output pulse voltage from the modulator to 140 kV with a 600 μsec pulse width at 50 pps. The pulse transformer and its associated circuit components were installed in an oil tank, and operated at 400 μsec of pulse width for a klystron load.

INTRODUCTION

The modulator for the power source of the 1-GeV proton linac for the JHP[1,2] consists of the high voltage DC power supply, charging circuit, PFN and thyratron switching devices which contain main and crowbar thyratrons. The PFN consists of 34 cells of inductor and capacitor network at present and can produce the pulse with 20 kV height and 400 μsec duration. Near future 50 cells will be installed to generate 600 μsec pulse duration. More detail discussions will be made and the parameters will be described in other manuscripts.[3,4] The output pulse of the modulator is supplied to the L-band klystron (1.296 GHz) through the step-up pulse transformer. The performance of the modulator influences the stable operation of the rf-system. The peak power of the output pulse is 15 MW, and the peak power of the klystron used is 6 MW.

The pulse transformer for this purpose was designed and manufactured by the company. It was a first experience for KEK to develop such a pulse transformer with high power, high duty and long pulse duration. Its size is very large and the weight of the core itself is about 3 tons. In the operation it has been installed in the oil-tank to increase the voltage tolerance. The pulse current and voltage monitors, the heater transformer assembly for the klystron, and the bypass diode connected with the resister serially have been assembled in the tank.

PULSE TRANSFORMER

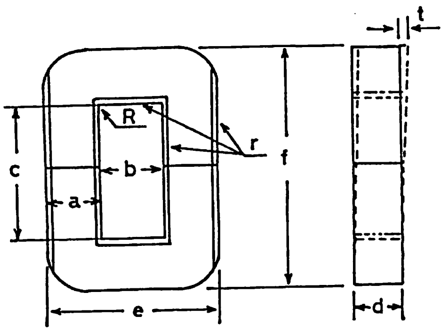
The pulse transformer was designed under the concept described above. The final specifications of it are as follows.

primary pulse voltage	20	kV
secondary pulse voltage	140	kV
primary pulse current	740	A
secondary pulse current	105	A
set-up ratio	1 : 7	
pulse width	600	μsec
repetition ratio	50	pps
sag	< 3	%

The input pulse from the modulator will be transferred to the klystron through the step-up pulse transformer by satisfying these specifications. The wave form of the output pulse will be varied in accordance with the design parameters and influences the performance of the system. Thus the most appropriate parameters must be adopted for the pulse transformer. For this purpose at the first it is very important to decide what type of the iron core we have to use and secondly we have to investigate the winding method. The characteristics of the designed pulse transformer have to be estimated lastly. These three points are closely connected with each other, hence it is necessary all these points are examined at the same time. Here, the designed process and the results will be described.

The frequency range of the long pulse comes up to DC to a few ten kHz, so it is necessary to use the iron core material having good performance, namely having high μ. This is also profitable for reducing the core size. As a result thin silicon annealed iron sheet of 40 mm width, 0.23 mm thickness and effective μ, about 1500 has been used in this case. The core is cut core style in general in order to be able to been inserted the assembled coil frames, and the cutting plane is the center of the core. The geometrical size of the cut core is shown in Figure 1. The weight of the pair is about 120 kg. 25 pairs of these were assembled in one block and the whole size is 500 mm w x 1024 mm l x 900 mm h including core space 1 mm and the weight comes up to 3 tons.

The winding method of the primary and secondary coils are described in Figure 2. The coil winding method and voltage insulation length had to be considered carefully to prevent from the voltage breaking down, accordingly many experiences and know how had to be taken into account. As in Figure 2 the coils are wound with auto transformer winding. When the step-up ratio is not so high this configuration is often adopted. The wire size and number were fixed corresponding to the average pulse current. The two secondary coils in two parallel windings mainly came from the reason the wire size had to be same as the primary coils, and are also possible to be used for supplying the heater power of the klystron in the next place.



a	200 mm
b	135 mm
c	500 mm
d	40 mm
e	535 mm
f	900 mm
R	4 mm (outside only)
r	8 mm (outside), 3mm (inside)
t	1 mm max.

FIGURE 1 Core Size Parameters

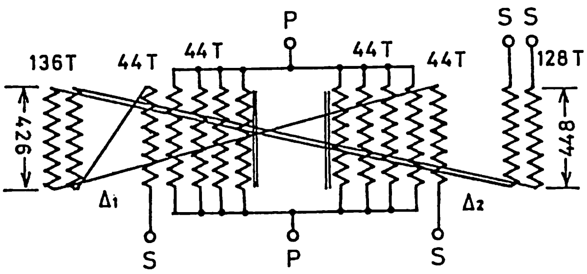


FIGURE 2 Autotransformer Winding

From the geometrical size of the core, the coils, and the gaps between core and coils, and between primary and secondary coils the various parameters were estimated. Here the typical wave form of the output pulse from the pulse transformer is shown in Figure 3. The parameters in the figure will be estimated by the simple equivalent circuit [5,6] given in Figure 4. R_G, Z_L, L_P, L_L, C_D, and R_E describe the impedance of the modulator output, load impedance, primary inductance, leakage inductance, total stray capacity including the the assumed stray capacity, 60 pF of the klystron, and the sum of

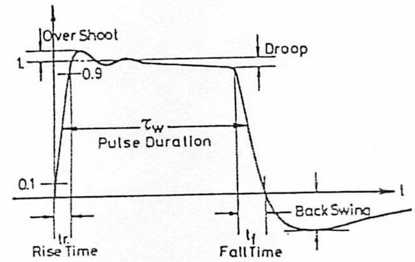


FIGURE 3 Output Pulse of the Pulse Transformer

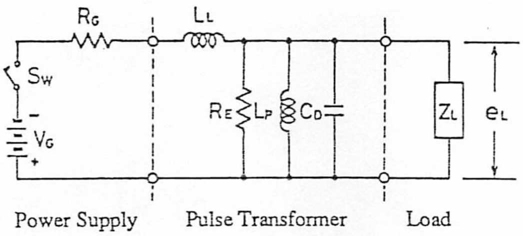


FIGURE 4 The Equivalent Circuit for the Pulse Transformer

the eddy current, hysteresis and copper loss, respectively. Here R_G and Z_L are both 27 Ω. Other parameters are calculated according to the formula in Reference 5, 6. L_P, L_L and C_D are estimated as 0.36 Henry, 189 μ Henry and 0.023 μF. From these data the rise time and fall time are estimated as 6.5 μsec and 7 μsec. It is expected no overshoot will appear in this case. These values are sufficient for our purpose. The sag or droop in Figure 3 is also one of the most important parameter for the pulse transformer and restricts the reducing of the core size. The core size was determined by assuming the maximum magnetic flux becomes 1.4 W/m for the 140 kV pulse height and 600 μsec pulse duration.

The heating from the eddy current loss (W_E), hysteresis loss (W_H), and copper loss (W_I) were also taken into consideration. W_E, W_H and W_I are estimated as 380 W, 2110 W and 3470 W respectively for the maximum core flux to be 1.4 W/m and are 1300 W, 9800 W and 3470 w respectively for the maximum core flux to be 1.7 W/m. Total power losses become about 6 kW for the former case and about 15 kW for the latter case. This is the one reason why we adopted former case. Still more, the power loss are related with the thickness of the core material. The power loss becomes large in accordance with increasing the core thickness. Thus we decided to use the most available core material whose thickness is 0.23 mm. After the design the pulse transformer were manufactured by the company and Figure 5 shows the assembled pulse transformer. The measured stray capacitance is 0.020 μF assuming the 60 pF for the klystron. This is reasonable in comparison with the designed value.

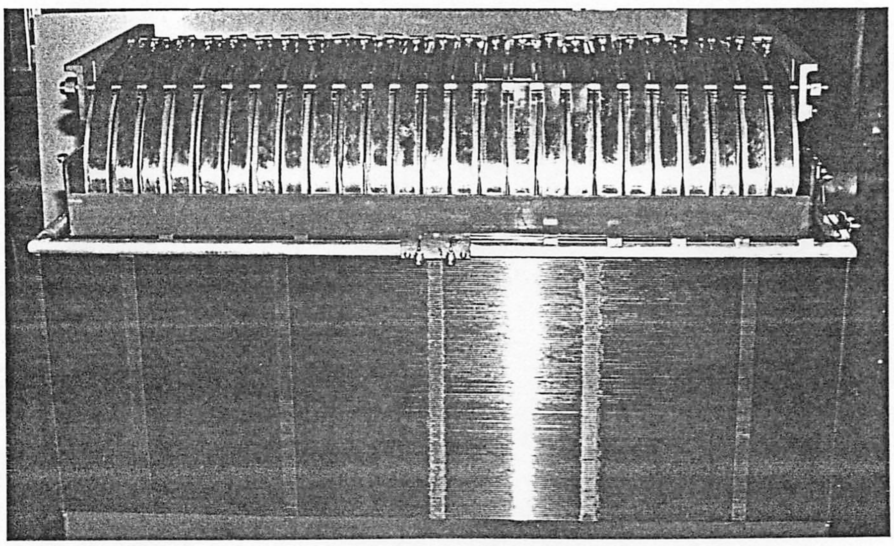


FIGURE 5 Manufactured and assembled Pulse Transformer

The biased pulse transformer was investigated for reducing the core size for the alternative selection. But it turned out that the blocking choke would be very big, 0.8 ton, even if the size of the pulse transformer would be reduced.

ASSEMBLING OF THE PULSE TRANSFORMER IN THE KLYSTRON TANK

Figure 6 shows the schematic diagram inside the tank. The bypass diode in the Figure is used in order to flow the charging current at the time of PFN charging to prevent the charging voltage from becoming unstable, since the potential of the minus side of the PFN will be fluctuated by the large inductance of the primary inductance of the pulse transformer. That is, the inductance of the pulse transformer and the charging choke are 0.36 Henry and 2 Henry respectively and the voltage ratio is 0.18 if the bypass diode were not used. This cannot be negligible. The resistor serially connected with the diode has a role of balancing the charging currents in pulse transformer and diode, and of resetting the core flux. The charging peak current is 53 A for the 600 µsec pulse duration. The value of the resistance was fixed from the computer simulation including the PFN. Figure 7 shows the examples of the simulation for the 200 µsec pulse duration with respect to the primary current. As can be seen, in case of 25 Ω the exciting current is near to zero after PFN charging. The power loss by this resistor is estimated as 6.2 kW for 400 µsec pulse width and 30 pps repetition rate. But the power loss amounts to 26 kW at the full rating operation. In this case the bypass diode and the resistor will be installed probably in other water cooled oil tank.

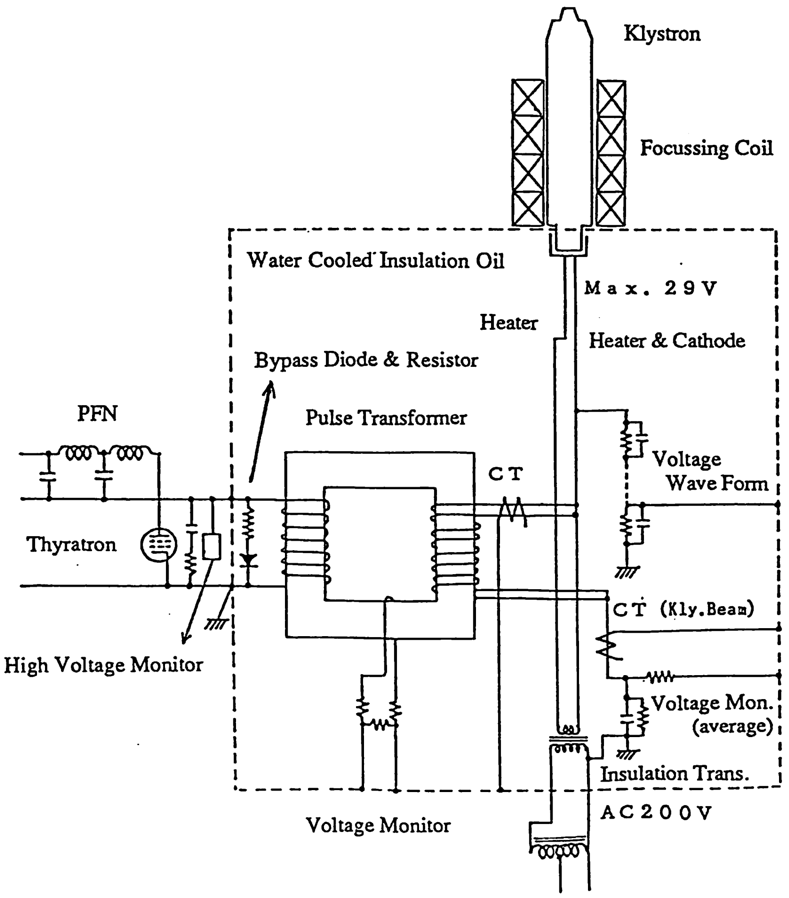
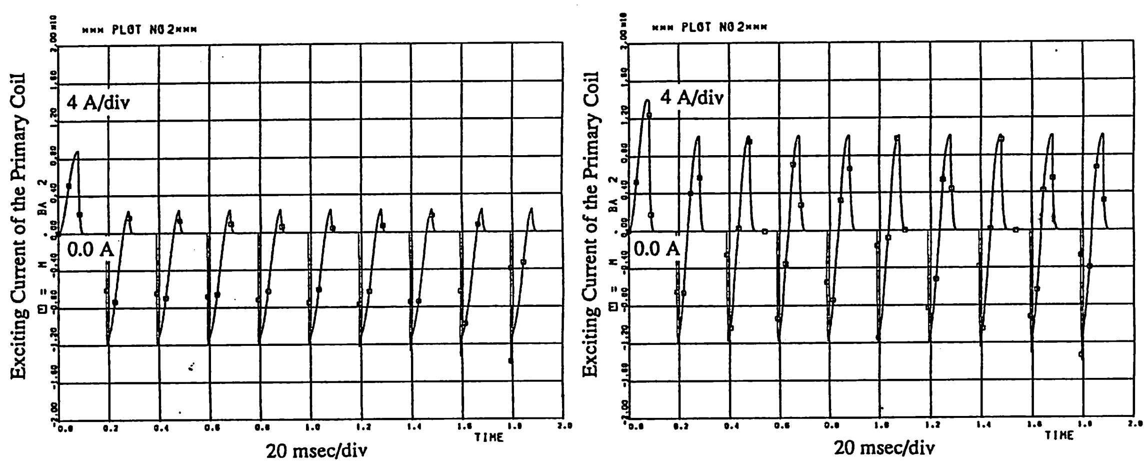


FIGURE 6 Schematic Diagram inside the Oil Tank

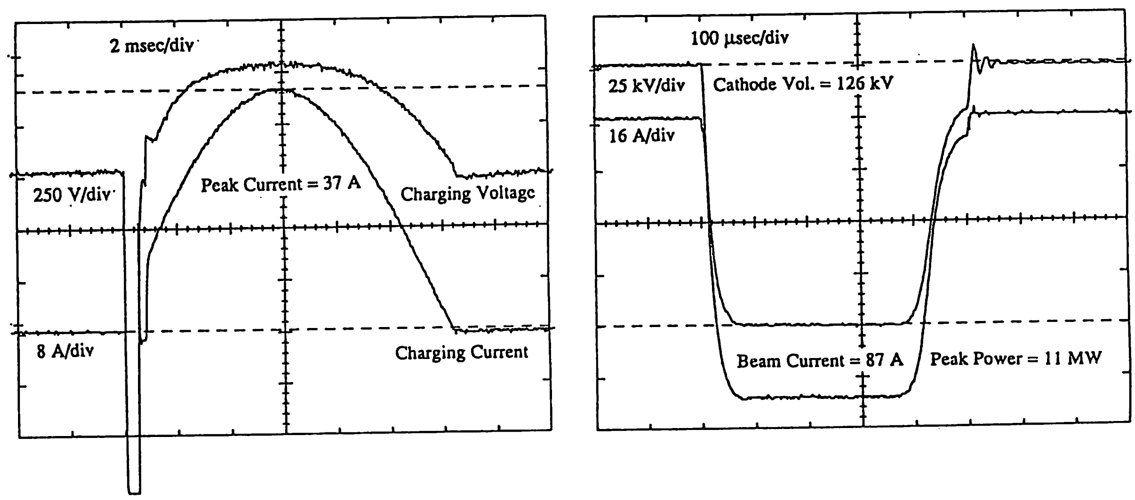
The heater transformer assembled in klystron socket is used in the short pulse modulator generally. The heater power is supplied through the two parallel windings windings of the pulse transformer and the AC voltage will be stepped down by the heater transformer. But in this case there remains a little anxiety about the heater transformer, because the pulse duration is very long and the bypass capacitor between the secondary two parallel windings coils must be large enough to transmit the secondary long pulse. On the other hand the AC heater power will be consumed as a reactive power by this mean. Thus the insulation transformer for supplying directly the heater power is installed beforehand the high power test for the sake of the spare. Figure 6 shows the situation which it is already used.

The size and total weight of the oil tank which has been assembled the pulse transformer and other miscellaneous parts are 1425 mm w x 1740 mm l x 1250 mm h and 9.5 tons including the klystron and the insulation oil, 2200 l.



a) In case of 25 Ω b) In case of 50 Ω

FIGURE 7 Simulation with respect to the Bypass Resistance



a) Charging Voltage and Current b) Secondary Voltage and Current

FIGURE 8 Measured Wave Forms before and after the Pulse Transformer

HIGH POWER TEST

After installing the pulse transformer and the klystron we started high power test. The output rf power is transmitted to the water cooled dummy load through the wave guide and absorbed. The first test with 200 μsec pulse duration was carried out in this Spring. At the first stage the heater power of the klystron was supplied through the two parallel windings coil of the pulse transformer, but as expected at the beginning it became clear that the heater current was fluctuated by the effect of the repeating pulse current from the modulator. As a result the already prepared insulation transformer is used for supplying the heater power. The wave form of the output pulse has not been deformed by the stray capacity of it. The pulse transformer itself worked well and no trouble happened yet. After the extra 17 cells of the PFN was reinforced the high power test with 400 μsec pulse duration was carried out again.

Up to now the high power test was done with peak cathode voltage, 130 kV, and with beam current, 100 A with 30 pps. Peak power of 5 MW and average power of 160 kW were detected by the monitors. Figure 8 describes the measured output pulse wave forms. In a) it can be seen the behavior of the charging current, and the peak values, 37 A. The rise time and the sag are estimated as 30 μsec and < 3 %, respectively in b). The rise time is about 4 times larger than the designed value. The sag and the fluctuation on the flat top will be improved in the range of adjustable PFN inductors. The temperature rise of the water cooled insulation oil is about 10 degrees at present.

CONCLUSION

The R&D rf power source system for the JHP has been installed and works well at present. But as a next step we have to reinforce or improve the system by solving a few problems. The modulator must be reinforced to get 600 μsec output pulse. The main thyratron becomes unstable in accordance with the long pulse and high duty operation. The 1-GeV proton linac for the JHP needs 36 L-band klystrons, namely 36 modulators. Thus to achieve a stable operation of the linac more and more stable thyratron or switching devices have to be developed or introduced. The oil tank of the bypass diode and the resistor suitable for the full power operation has to be prepared. Most important problem is to improve the pulse transformer. There is a possibility to make the pulse transformer smaller than existing system by reducing the power to 340 kW in stead of 450 kW, since the klystron power of the real system requires 4.5 MW. There is a room also to decrease the pulse width, because the pulse beam width is to be 400 μsec. By this way it will be possible to improve or make a new pulse transformer which has more compact size and good performance.

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