NEW INJECTION KICKER MODULATORS FOR HLS RING*

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Abstract

This paper describes the new injection kicker modulators for HLS ring. In the new injection system, each kicker drives two kicker magnets in a parallel mode. The modulators can deliver a half-sine wave current with a bottom width of 3.5 μs, a peak current of 10kA at the max repetition rate of 2 Hz. The 27 kV capacitor-charging circuit is based on constant-current, series-resonant, switching techniques. Simulated and measured waveforms of charging circuit are given. Basic formulae of designing a switching-mode series-resonant charging circuit are provided. Local control of the modulators is based on PLCs. Ladder Relay Logic program and performance of PLC controlling is described too.

1 INTRODUCTION

Hefei Light Source (HLS) is a dedicated synchrotron radiation light source and was opened to users from 1991. The Phase Two Project to upgrade this machine began construction in 1997 and scheduled to be finished in end of 2001 [1]. New thyratron modulators for the injection system have been fabricated and put into operation since June, 2000. The modulators performed well for almost one year without EMI problem or circuit failures. In the first step, the loads are old air-core kicker magnets. After the installation of ceramic chambers, the loads will be changed to ferrite kicker magnets. Each kicker will drive two magnets in parallel mode. Table 1 gives the specifications of these modulators.

Table 1: Specifications of new kicker modulators

Thyratron	EEV CX1174
Total capacitor	0.66 μF
Damping R	1Ω
Peak current	10kA
Maximum charging voltage	27kV
Waveform	Half-sine wave with bottom width of 3.5μs
Repetition rate	0.5-2Hz

2 PFN AND LOADS CONNECTION

PFN is a simple RLC resonant discharging circuit as shown in the right part of Fig.1. The thyratron, damping R and the high voltage capacitor are placed inside a coaxial copper structure to reduce the stray inductance. The total inductance of two magnets in parallel and their connections is about 1 μH while the inductance of the coaxial structure is only about 0.5 μH. Suitable damping R reduces the reversal voltage and noise. An attenuated wave caused by the damping R also meets the requirement of multi-turn injection physical design.[2]

Because each modulator drive two magnets in parallel mode. Much attention is paid to the evenness of the current feeding to each magnet. A carefully designed, T-shaped coaxial connection is applied between the magnets and the modulator to guarantee the balance of the current. The measured difference of peak current between two magnets is less than 0.1%. This connection structure also enables the small adjustment of inductance possible.

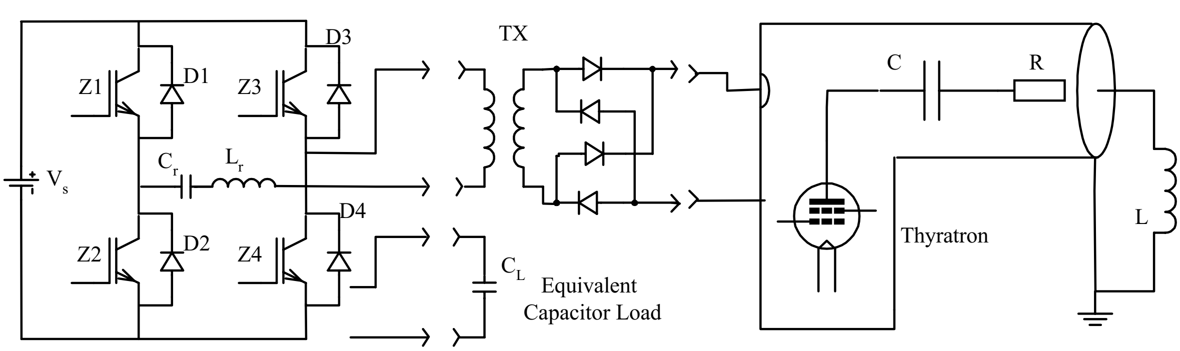

Fig.1 HV charging power and PFN circuit

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3 HIGH VOLTAGE CHARGING POWER

The 27kV HV charging power employs a series-resonant, switching-mode circuit which take the advantages of zero-current switching, constant-current charging and inherent short-circuit protection. It works at the frequency of 12.5 kHz and has a charging ability of 2kJ/s.

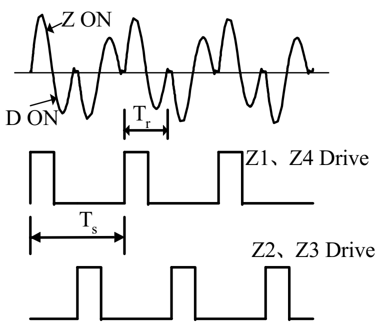


Fig.2 driving signals of IGBT and resonant current

Figure2 shows the driving signals of IGBTs and the resonant current in switching devices. The characteristic impedance of the resonant circuit is $Z = \sqrt{L_r / C_r}$, and $T_r = 2\pi\sqrt{L_r C_r}$.

C_L is the equivalent load capacitor seen from the primary winding of the HV transformer (refer to Fig.1), the capacitance of C_r and C_L in series almost equal to C_r because C_L is much larger than C_r.

The voltage gain of C_L in each switching period (two resonant period) is:

$$\Delta V = \frac{V_S C_r}{C_L}(2 - \frac{4C_r}{C_L}) \qquad 3\text{-}1$$

And the positive peak current is

$$i_L = \frac{1}{Z}(\frac{V_S}{2} + \frac{2(N-1)V_S C_r}{C_L}) \qquad 3\text{-}2$$

V_S denotes the input DC voltage source, N is the number of resonant periods. The reverse peak current is:

$$i_L = \frac{1}{Z}(\frac{V_S}{2} - \frac{2NV_S C_r}{C_L}) \cdot \qquad 3\text{-}3$$

Simulated charging voltage and resonant current envelope in one charging cycle is plotted in Figure 3. It can be seen that there is a transition time t_1 and before t_1 the charging is linear. Linear charging ends. when reverse current reduces to zero and from equation (3-3) t_1 can be derived as:

$$t_1 = 2NT_s = \frac{C'}{2C} T_S \qquad 3\text{-}4$$

It is better for the HV converter to be shut down before t_1 to obtain a linear charging. Because the C_L is quite large and the charging time is long (-40ms), ΔV is small and high repeatability of charging voltage can be achieved in this case.

The parameters in simulated circuit are selected as following:

$V_s = 500V$, $C_r = 1.6uF$, $L_r = 30uH$, $T_s = 100us$, n=1:40

Please note these parameters are not the real adopted ones. They are selected so as to get a shorter charging time and therefore be easier for plotting.

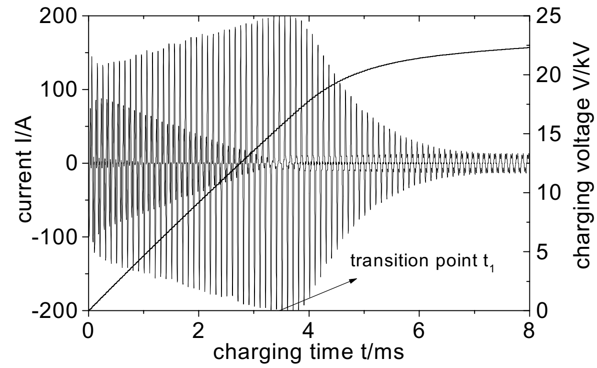


Fig.3 Simulated charging voltage and resonant current envelope in one charging cycle

Figure 4 gives the real measured PFN discharging waveform, charging voltage waveform, measured and simulated resonant current in the charging circuit of the kicker modulator.

4 CONTROL

The new control system of NSRL is built upon EPICS and following the standard model. The injection system control is a subsystem as shown in Figure 5. In each modulator, a OMRON PLC C200HE is employed as the local device controller. Command control, status-monitor, safety interlock and real-time communication with the IOC are achieved by the PLC. Several modules are adopted in each PLC including a 16-point Digital Input (DI) module, a 16-point Digital Output (DO), a 8-channel AD/DA module and a communication module. All the digital in/out signals are optical insulated. Strong electromagnetic interference, which was caused by the large pulse current in the modulator, was restrained. The program is written in the form of Relay Logic Ladder. Some special functions are realised by the RLL program, for example,

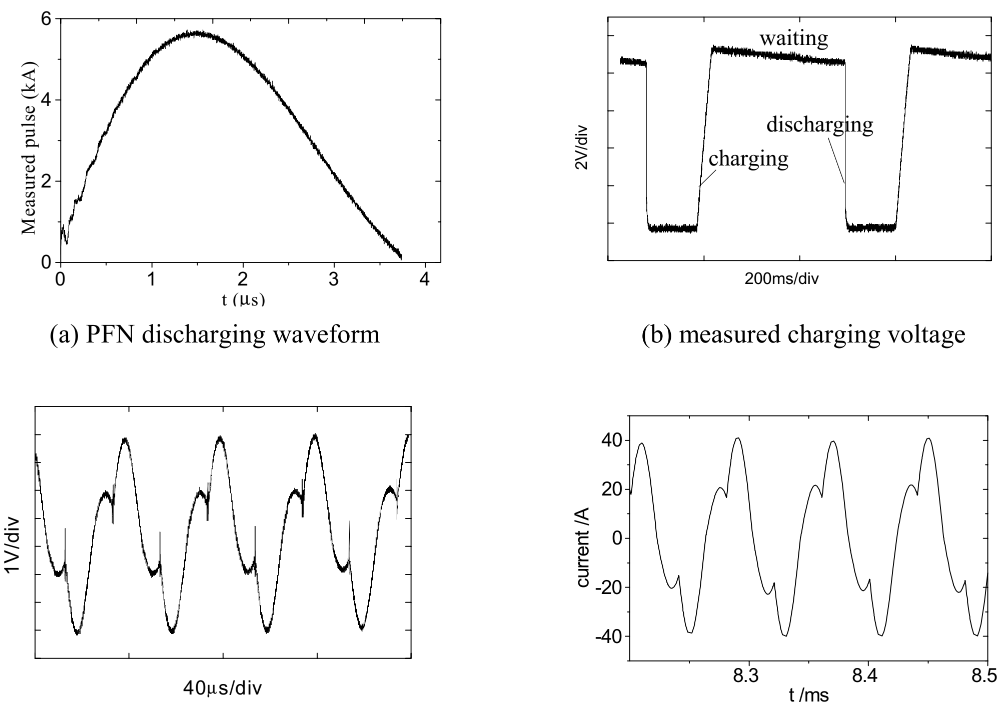
- the counter function which can record the number of discharging and help determine the lifetime of a thyratron,
- the soft-start function which increase the input voltage slowly to avoid surge current when the modulator power is switched on.

PLC makes the operation of the modulator more stable and reliable..

5 REFERENCES

[1] Initial Design Report of Phase Two Project of NSRL,1997.

[2] L. Shang, et al, “Tracking study of the new injection bump system of the HLS ring”, Nucl. Ins. & Meth. In Phys. Res. 406(2), 1998. 171~181.



(a) PFN discharging waveform

(b) measured charging voltage

(c)measured resonant current

(d)simulated resonant current

Fig.4 Measured and simulated waveforms of PFN and charging power

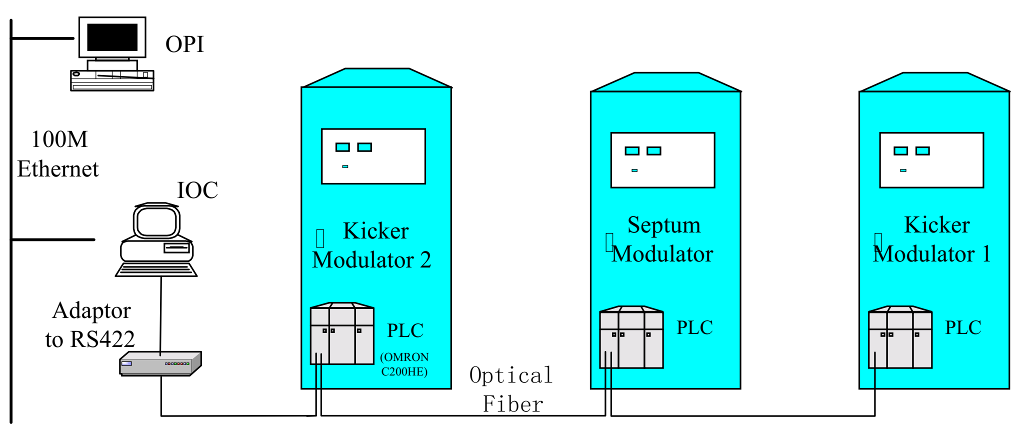


Fig.5 Kicker modulator control structure