OPERATION OF CROWBARLESS POWER SUPPLY FOR KLYSTRON AT NEWSUBARU

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Abstract

A new crowbarless power supply was installed at NewSUBARU and has been operated with no serious problem since 1998. A high-power switching inverter unit eliminated the need for expensive and unstable crowbar circuits for the klystron power supply. It had a small voltage ripple in the low frequency region, which was an important characteristic especially in NewSUBARU.

1 INTRODUCTION

The synchrotron radiation (SR) facility NewSUBARU [1] is a light source in the SPring-8 site, which uses the 1.0 GeV linac as an injector. LASTI (Laboratory of Advanced Science and Technology for Industry) of Himeji Institute of Technology is in charge of the construction and operation collaborating with SPring-8. Hyogo prefecture supports the financial costs of both construction and operation of the facility. The ring covers the photon energy region from VUV to soft X-ray, and is capable of offering hard X-ray and IR using insertion devices.

One of the characteristics of the ring lattice is that its momentum compaction factor (α) is variable with invert dipoles. A vey small α would make a short electron bunch and supply a short-pulsed light, which is essential in a time resolving experiment.

The storage ring has one RF cavity powered by a 180kW/500MHz klystron. The klystron requires a high-voltage DC power supply of which the output voltage was -45kV.

The power supply should have two important characteristics. One is a low ripple voltage and the other is a protection from arcs when the klystron faults. Regarding the arc protection, a conventional power supply uses a crowbar circuit that suddenly quenches a klystron arc and results in a discharge of stored energy. However the crowbar circuit has false-firing problems caused by electric noise. With regard to the crowbarless power supply, a star point controller was adopted in the storage ring of SPring-8 [2]. The other choice to eliminate crowbar circuit is to use inverter unit.

It is known that if one of the frequency component is close to the synchrotron oscillation frequency, the ripple noise induces a coherent synchrotron oscillation. In designing the RF system, one should pay special attention to the ripple frequency of the klystron power supply. The synchrotron frequency of NewSUBARU was changeable in the region below 6kHz. This means that the voltage ripple has to be kept at a low level below 6 kHz to prevent a resonance with synchrotron oscillation. Then inverter power supply is suitable for NewSUBARU, because the inverters keep the voltage ripple low in a low frequency range.

The ratings of the crowbarless power supply with inverters for the klystron are listed in Table I.

The commissioning of the ring started in September 1998. Since then the power supply has been working stably with no serious problem or failure comes from the inverter system. We also measured and analyzed the phase ripple of the beam. The method of ripple analysis we use here was described by Hara et al.[3], who analyzed the ripple at SPring-8.

Table 1: Ratings of the crowbarless power supply

Maximum current	9A
Voltage control range	-22.5 ~ -45kV
AC line frequency	60Hz
Inverter frequency	20kHz
Voltage ripple	$\pm$0.2% at 1~10kHz
Klystron	Toshiba E3774 frequency : 500MHz rf power : 180kW

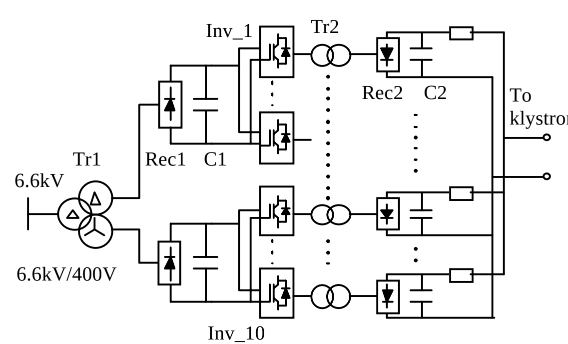

Figure 1: Configuration of a crowbarless power supply.

2 CHARACTERISTICS OF THE POWER SUPPLY

Fig.1 shows the configuration of the crowbarless power supply with inverters.

The transformer Tr1 steps down the AC voltage from 6.6kV to 440V, which is suitable for inverters consist of IGBTs. After a conversion to DC voltage by the rectifier Rec1, the DC voltage is inverted to AC 21.3kHz. The AC voltage is stepped up by the transformer Tr2. The 21.3kHz pulse is full wave rectified by Rec2. Then the main frequency component of the ripple is 42.6kHz. Finally, the DC voltage ripple is reduced by the capacitance C2.

A secondary side of Tr1, which has star connection and ring connection, leads to 12-phase rectification to reduce harmonics in the upstream AC line. A 360Hz ripple, which is contained in the DC output from Rec1 is reduced by C1, and then eliminated by the inverters.

High voltage units, which consist of Tr2, Rec2 and so on, are connected in parallel, not in series. Even if one of the high-voltage units had a problem, the parallel connection enables us to continue an operation by using other high-voltage units.

C2 can be as small as 0.01μF, because the ripple frequency is very high. We estimated the inflow energy into the klystron when it faults. We calculated the integral of the product of a breakdown current by an arc voltage inside the klystron. That was 0.2Joule. This value is so small that the crowbar circuit is not required.

3 MEASUREMENT OF RIPPLE

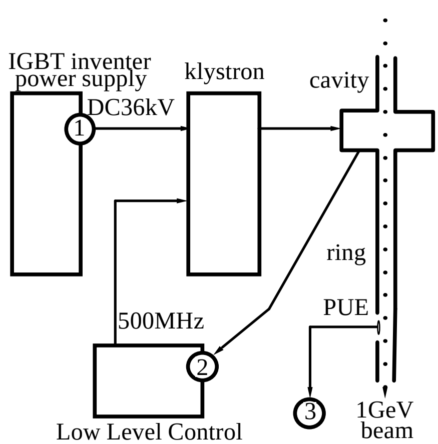

Figure 2: The ripple of DC voltage was measured at the point (1). The phase error of the 500MHz in the cavity was measured at the point (2), PLL signal of the low level control. The phase ripple of the beam is measured using the beam signal piced up from an electrode set at the beam pipe, that was the point (3).

We measured the ripples at 3 points during the beam commissioning. Fig.2 shows the points we measured the ripple. We measured the voltage ripple of the output DC, the phase ripple of the 500MHz rf and the timing fluctuation of the circulating electron beam. The measured ripple amplitudes at each point were translated to the amplitudes of phase ripple and will summarize in Table 3 for main ripple frequencies.

The measured voltage ripple is listed in Table 2. Slight changes in the cathode voltage affect the travel time of electrons in the klystron, causing a phase delay in the RF output voltage. For Toshiba E3774, the phase ripple produced by the DC power supply ($\Delta\phi_{DCPS}$) was calculated from the voltage ripple using the following equation.

$$\Delta\phi_{DCPS}\ [\text{deg.}] = 4.5\ [\text{deg./kV}] \times \delta V\ [\text{kV}]. \qquad (1)$$

The results of calculation for the main ripple frequencies are listed in Table 3.

Table 2: Ripple of the output DC voltage of the inverter power supply.

frequency	ripple (±%)	frequency	ripple (±%)	frequency	ripple (±%)
60Hz	0.035	360Hz	0.004	21.3kHz	0.0015
120Hz	0.080	600Hz	0.003	42.6kHz	0.018
180Hz	0.004	660Hz	0.002		
240Hz	0.013	720Hz	0.006		
300Hz	0.004	1.38kHz	0.0013		

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Table 3: Amplitudes of the phase ripple. The 120Hz is the twice of the AC line frequency. The 720Hz is the structure frequency of 12-phase rectification of AC line. The 5kHz is a synchrotron frequency. The 42.6kHz is the twice of the accurate inverter frequency.

ripple frequency (Hz)	point(1) $\Delta\phi_{DCPS}$	point(2) LLC	point(3) beam
120Hz	0.13 deg.	0.4 deg.	0.2 deg.
720Hz	0.01 deg.	0.1 deg.	0.03 deg.
5kHz	--	0.1 deg.	0.4 deg.
42.6kHz	0.03 deg.	0.2 deg.	--

The picked up signal from the cavity was compared with the reference signal from the synthesizer. The phase ripple was monitored at the phase detector ($\Delta\phi_{LLC}$) in the low level control. The phase lock loop of the LLC was set to work upto 100Hz.

The coherent movement of the electron bunch in the storage ring was obtained from the pick up electrode. The electrode is set at the dispersion free section, then the signal is sensitive to the timing arrival and the vertical movement. The fluctuation of timing appeared as side bands of the acceleration frequency (f_{RF}). Fig. 3 shows the side band structure. The phase ripple amplitude ($\Delta\phi_{BEAM}$), that is an amplitude of coherent oscillation in time axis, was calculated from the peak ratio of side bands of the rf frequency: f_{RF}. as

$$\Delta\phi_{BEAM}[\text{deg.}] = (360/2\pi)\ (V[f_{RF} \pm f_{RIP}]/V[f_{RF}]\ ), \quad (2)$$

here f_{RP} is an frequency of the ripple. The phase ripple of beam for the main ripple frequencies are listed in Table 3.

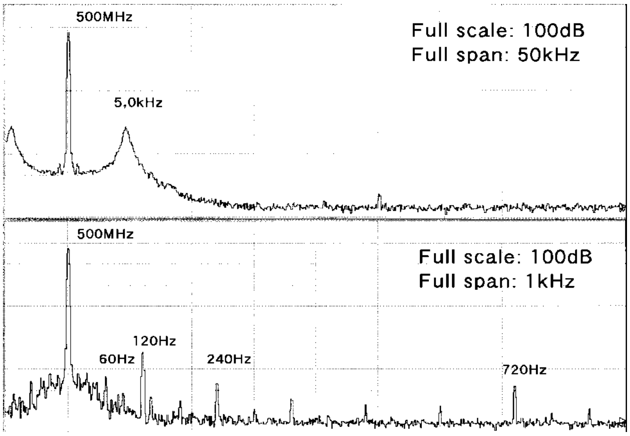

Figure 3: Side bands of the rf frequency of the beam signal, point(3) of Fig.2.

The observed broad peak corresponds to an synchrotron oscillation frequency. The phase modulation of beam produced by the phase ripple of acceleration ($\Delta\phi_{RF}$) is calculated by the equation,

$$\Delta \phi_{BEAM} = \frac{\Omega^2}{[(\Omega^2 - (2\pi f_{RIP})^2)^2 - (2\alpha_E \Omega)^2]^{1/2}} \Delta\phi_{RF} . \qquad (3)$$

Here Ω and α_E are angular frequency of the synchrotron oscillation and the damping coefficients. The shape of the broad peak agreed with the one expected from the damping time; $1/\alpha_E$=12ms. However the observed peak was not sharp like the function of Eq. (3) because of the synchrotron tune spread. The spread was calculated to be about $\pm$2ps, which was much smaller than the beam length at the present, σ>10ps. For a much low f_{RIP} than Ω the Eq. (3) is approximated to be $\Delta\phi_{BEAM} = \Delta\phi_{RF}$. For higher f_{RIP} than Ω, $\Delta\phi_{BEAM}$ is very small. In the case of f_{RIP}=42.6kHz and $\Delta\phi_{RF}$ =0.03 deg., we expect $\Delta\phi_{BEAM}$ of 0.004 deg., which was not observable.

The agreement between the measurements at three points was quantitatively in a rough level. However qualitative agreement was fine.

4 SUMMARY

The inverter DC power supply for klystron has been working well at NewSUBARU. A high frequency ripple of the inverter was not harmful. However there exist noise and ripple in the lower frequency region than 1kHz. They are not harmfull for a normal operation but could be considerable in a operation with very small momentum compaction factor, where the bunch is very short and Ω is small.

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6 REFERENCES

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