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A crowbarless power supply for klystrons

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A new crowbarless power supply is to be installed at the New SUBARU storage ring. A high-power switching inverter unit eliminates the need for expensive and unstable crowbar circuits for the klystron power supply. It also realizes a very small voltage ripple in the low-frequency region. This is an important characteristic, especially in a quasi-isochronous storage ring such as New SUBARU.

Keywords: klystrons; crowbars; inverters.

1. Introduction

New SUBARU is a synchrotron radiation facility constructed in Harima Science Garden City, Hyogo Prefecture, Japan. The facility includes a 1.5 GeV storage ring (Ando *et al.*, 1998), several beamlines and a 15 MeV FEL dedicated linac. The storage ring has a circumference of 119 m. The linac of SPring-8 is used as an injector of the storage ring. This facility, which is a supplement to the 8 GeV storage ring of SPring-8, covers from synchrotron radiation VUV to the soft X-ray region.

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

The klystron power supply should have two important characteristics. One is low ripple voltage and the other is protection from arcs when the klystron faults. Regarding arc protection, a conventional power supply uses a crowbar circuit that quenches a klystron arc in less than 6 µs and results in a discharge of stored energy. However, the crowbar circuit has false-firing problems caused by electrical noise. With regard to the crowbarless power supply, a starpoint controller is adopted in the storage ring of SPring-8 (Kumagai *et al.*, 1995). However, at New SUBARU another kind of crowbarless power supply using inverters will be introduced, because here the synchrotron oscillation frequency is changeable in the region below 5.2 kHz. This means the voltage ripple has to be kept at a low level below 5.2 kHz to prevent resonance with synchrotron oscillation frequency. The power supply with inverters is suitable for keeping the voltage ripple low in a wide range.

This paper describes an outline of the crowbarless power supply with inverters.

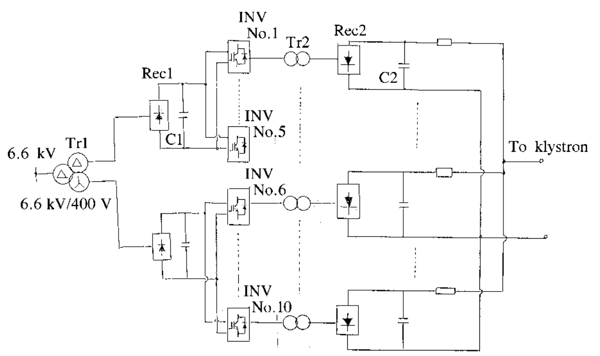

Figure 1
Configuration of a crowbarless power supply.

2. Ratings

The ratings of the crowbarless power supply with inverters for the klystron are as follows: (i) maximum voltage, −45 kV; (ii) maximum current, 9 A; (iii) voltage control range, −22.5 to −45 kV; (iv) AC line frequency, 60 Hz; (v) inverter frequency, 20 kHz; (vi) voltage ripple, ±0.2% (at 1–10 kHz); (vii) klystron, E3774 (Toshiba) (frequency, 500 MHz; radio frequency power, 180 kW).

3. Characteristics of the crowbarless power supply

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

The transformer Tr1 steps down the AC voltage from 6.6 kV to 400 V because inverters, which consist of IGBTs, are suitable for low voltage. After a conversion to DC voltage by the rectifier Rec1, the DC voltage is inverted to AC 20 kHz. The AC voltage is stepped up by the transformer Tr2 and is converted to DC by the rectifier Rec2. 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 360 Hz ripple, which is contained in the DC output from Rec1, is reduced by C1, and is 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 has a problem, the parallel connection enables us to continue an operation by using other high-voltage units.

The output voltage phases of high-voltage parts are not shifted, though the shifted phases raise the ripple frequency because the inverter frequency, 20 kHz, is high enough at New SUBARU.

C2 can be very small because the ripple frequency is very high. C2 is so small that the crowbar circuit is not required.

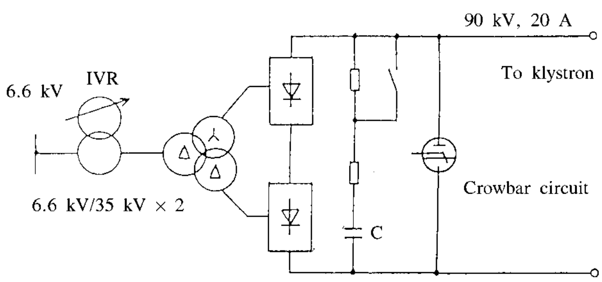

Figure 2
Configuration of a conventional power supply.

Table 1
Comparison between two types of power supplies.

	Crowbarless power supply with converters	Conventional power supply
Voltage control method	PWM with inverters	Mechanical control with IVR
Ripples	Higher than 20 kHz	720 Hz and its multiples
Voltage ripple reduction method	By low capacitance	By large capacitance
Protection method when klystron fails	By IGBT off	By firing the crowbar and switching off a VCB
Features	Low capacitance and no crowbar circuit, so there is no problem of false firing of crowbar circuit; fast response	False firing of the crowbar circuit, so it decreases the running efficiency of the storage ring

4. Comparison between the crowbarless power supply with inverters and the conventional power supply

Fig. 2 shows the configuration of the conventional power supply.

The ripple voltage of a klystron power supply is required to be low. Protection against arcs is also indispensable in case the klystron should have a fault.

The voltage ripple causes phase oscillation of RF power from the klystron. If the frequency of the phase oscillation corresponds to that of the synchrotron oscillation frequency, it causes harmful resonance to an electron beam. In order to prevent the resonance, not only must the ripple voltage be reduced but also the output voltage frequency must avoid the synchrotron oscillation frequency.

The conventional power supply shown in Fig. 2 has a large capacitor bank to reduce the voltage ripple, which is 720 Hz and its multiples. Even if the large capacitor reduces the above ripples, 720 Hz and its multiple ripples still exist to some degree. This means that the conventional power supply is not suitable for New SUBARU because the synchrotron oscillation frequency at New SUBARU ranges from 0 to 5.2 kHz continuously. The ripple frequency of the crowbarless power supply shown in Fig. 1 is higher than 20 kHz, so this power supply is available to New SUBARU.

When the klystron fails, the conventional power supply uses a crowbar circuit that quenches a klystron arc in less than 6 μs to suppress the inflow energy to less than 24 J (Kumagai *et al.*, 1995) and results in a discharge of stored energy in the large capacitor bank. This crowbar circuit has false-firing problems caused by the electrical noise. The problems decrease the running efficiency of the storage ring. At New SUBARU, since the ripple frequency is very high, we can reduce the capacitance so that the crowbar circuit can be omitted.

A comparison between the crowbarless power supply with inverters and the conventional power supply is shown in Table 1.

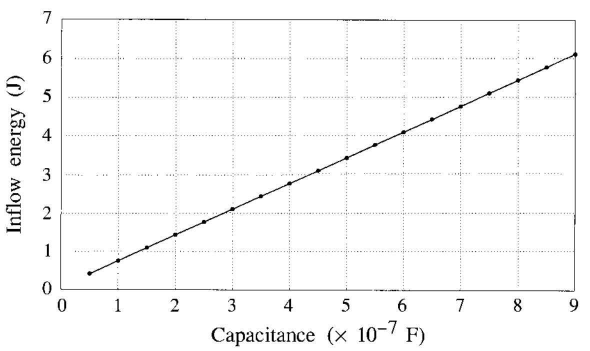

Figure 3
Inflow energy into the klystron when the klystron faults.

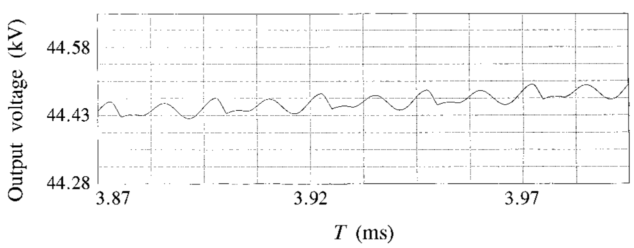

Figure 4
Voltage ripple of crowbarless power supply with inverters.

5. Estimation

Fig. 3 shows the result of the calculation of inflow energy into the klystron when the klystron faults. We estimated the inflow energy by calculating the integral of the product of a breakdown current by an arc voltage inside the klystron. Since we intend to choose a capacitance of 0.02 μF, the inflow energy is about 0.3 J. This value is much smaller than 24 J, which means that the power supply can protect the klystron when the klystron faults.

The estimated ripple is about 0.1% peak-to-peak as shown in Fig. 4 (the voltage is rising gradually in Fig. 4 because the data are extracted before reaching −45 kV). This means the ripple voltage is well reduced.

The ripple in Fig. 4 shows the frequency of 40 kHz that corresponds to the frequency of full-wave rectification. This means that the output voltage frequency avoids the synchrotron oscillation frequency (0–5.2 kHz).

Consequently the power supply is available to the klystron E3774 and New SUBARU.

6. Conclusions

We have estimated the feasibility of a crowbarless power supply with inverter. This power supply will be installed and tested at New SUBARU by the beginning of 1998.

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