EMI NOISE SUPPRESSION IN THE KLYSTRON PULSE POWER SUPPLY FOR XFEL/SPring-8
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Abstract
Klystron modulator power supply of XFEL/SPring-8 is required low electro-magnetic interference (EMI), in order to realize a high stable beam by a feedback loops of high-precision beam monitors. We suppressed the EM noise of the modulator by the enclosure of the steel tank, eliminating a DC core bias circuit, and inserting pair noise filters into heater power lines. To estimate the effect of the noise filter, we measured the conducting noise on the heater power line. The amplitude of the noise was suppressed to less than 10 V peak-to-peak. In the prior operation test, we confirmed that the modulator noise hardly affects the low-level rf devices.

INTRODUCTION
In XFEL/SPring-8 project, we need a high stability of an electron beam in order to get a stable X-ray Free Electron Laser (XFEL) light. The stability is realized by an accurate feedback from beam monitors to the rf sources. Therefore, the monitors should be operated in the low noise environment.

The EM noise radiated from the modulator power supply is a problem for a long time [1]. When the modulator is triggered the PFN capacitor, the large EM noise is emitted and interferes surrounding electrical instruments [2]. The noise suppression of the modulator is one of the most important issues for the stable FEL light source.

We have developed a low-noise modulator power supply which is used for a 50 MW C-band klystron (TOSHIBA E37202). The typical specification is written in Table 1 [3]. The characteristic features of this modulator are all-in-one type and compact; it is contained a PFN unit, a thyatron, a pulse transformer, and other components in a thick steel tank filled with insulation oil. The dimension of modulator is L1.7 m × W1 m × H1.1 m.

In this report, we explain the EM noise prevention of the modulator power supply, and report the effects.

EM NOISE FORM KLYSTRON-MODULATOR POWER SUPPLY
When the thyatron is triggered, the anode voltage droops 50 kV max, and the large current pulse flows from PFN capacitor to the pulse transformer and the klystron. At that moment, the EM noise is generated by two mechanisms.

One mechanism is the thyatron switching. When the thyatron is triggered, the plasma is created in the thyatron, and the plasma oscillation radiates the EM noise. The frequency range of the noise is about 10 – 100 MHz. The amplitude of the thyatron noise is large which causes the problem at the control devices, frequently.

The other noise is the inductive field by the loop-current from PFN to klystron. The frequency of this noise depends on the rise time of the PFN discharge. In our case, the frequency is about 1 MHz.

These noises transmit by two ways, travelling in the space and conducting on the wires. Therefore, the key points of the suppression of EM noise are the shielding the travelling noise, and the filtering the conducting noise.

NOISE REDUCTION DESIGN FOR NEW MODULATOR

Completely Enclosed Metallic Shield
The modulator tank is monocoque structure, which frame itself supports the load of the tank and the klystron. Because the inner support is not necessary, the structure can take the large internal space. As the result, the high power components can be housed within the tank. By this all-in-one system, the pulse current loop is confined to the
tank. In addition, the loop dimension can be minimized, 
and the inductive filed noise is suppressed.

The aperture area of the frame is closed by stainless-
steel panels to seal the insulation oil. Therefore, these 
noise sources are completely enclosed by thick metallic 
plates, and then the radiated noise cannot leak to outside.

The face of the tank is plated with electroless nickel. 
This coating not only prevents the rust but also takes a 
good conductivity for the adopters connecting to the 
frame ground.

**Pair Noise Filter**

The EM noise can also transmit to the outside of the 
tank by conducting the metallic lines connecting to 
external cables: the heater power lines, the thyratron 
trigger lines, and the monitor signal lines. Especially, the 
heater lines of the thyratron must conducts the thyratron 
noise because it directly connects to the thyratron cathode.

To reduce the conducting noises on the heater lines, it is 
effective to insert noise filters into the lines. The noise 
filter is required to seal the tank filled with the insulation 
oil, and to pass the electrical heater power at 60 Hz.

We have developed the low-pass noise filters satisfying 
the above requirements. The figure 2 shows the view and 
the equivalent circuit of the pair noise filter. The filter has 
a pair line for the ac power, line A and B. The common 
mode noise is blocked by the common-mode choke 
inductor, and the capacitors connecting to the frame 
ground. The differential-mode noise is blocked by the 
capacitors connecting between the power lines. To sealing 
the tank, the filter is moulded by epoxy, and equips an O-
ring on the contact surface with the tank. This filter is 
made by RISHO KOGYO Co., Ltd.

![Figure 2: View of the pair noise filter and the equivalent circuit.](image)

The pair noise filters have been inserted into the three 
heater lines: thyratron cathode heater, thyratron reservoir 
heater, and klystron cathode heater.

**Removal Bias Choke Circuit**

Conventional transformer had a DC bias circuit in order 
to avoid the magnetic flux saturation of the transformer 
core by supplying the DC current to the core. This circuit 
is designed to cut the high frequency pulse by a LC low-
pass filter. But the pulse noise practically leaks to the 
outside [4]. Moreover, the current returns to the DC 
supply through the various ground lines, and generates the 
inductive field.

In the pulse transformer of the modulator, the core of 
transformer is made of the high-silicon steel which has 
low magnetostriction properties [5]. As the result, the 
core has a large air gap and avoids the flux saturation. We 
eliminate the DC bias circuit.

![Figure 3: Top figure is the inside of connector panel in the 
bad case. The bottom figure is the waveforms of the 
thyratron noise transmitting the monitor signal.](image)

**Assembly of Connector**

When the receptacle adopters had been used for the 
panel connection of the thyratron trigger lines, the thyratron noise conducting the trigger lines transmitted to 
the other monitor signal lines, as shown figure 3. The 
coupling was caused at the end of cable where the centre 
core and the shield of the co-axial cable were divided.

To prevent the noise coupling, we used the jack to jack 
co-axial panel adapters. As the result, the thyratron noise 
disappeared from the monitor signals.
MEASURING EMI

Conducting Thyatron Noise

We measured the effect of the twist pair noise filter for the conducting noise on the thyatron cathode heater line. Figure 4 shows the typical waveforms of the thyatron cathode heater voltage at the moment of the thyatron trigger. The wave 1 and 2 are the voltage between the heater line A and ground, and that between the line B and ground, respectively. These waves represent the mixing of the common-mode and the differential-mode noise. That is, the same pattern of the two waves indicates the common-mode noise components, and the different pattern indicates the differential components. The wave 3 represents the voltage between the line A and the line B, which indicates the differential-mode noise.

These heater voltage waves spike just before the rising edge of the klystron cathode voltage which is indicated as wave 4. It means these noises are generated around the thyatron. These waveforms indicate as below. Without the noise filter, the common-mode components of the conducting thyatron noise have mainly about 300 V peak-to-peak at 30 MHz, and the differential-mode components is about 150 V peak-to-peak. By inserting the noise filter, the noise amplitude is decreased to about 10 V peak-to-peak for common mode, and to about 7 V peak-to-peak at differential mode. We confirmed the filter decreased the common and differential mode noises.

Prior Operation Test

The modulators have been installed since July 2009. In February 2010, the prior operation test of the modulator and controller devices has been hold. In order to investigate the influence of the noise of modulator, we measured the noise level of the low-level rf system in the case of in operation and non-operation of modulator. As the result, there was no difference between these operational statuses.

SUMMARY

For XFEL/Spring-8 project, we developed the low noise modulator power supply; the noise sources are confined the completely enclosed metallic tank, the pair noise filters are inserted into the heater line, the DC core bias circuit is eliminated, and the coupling noise between the cables is suppressed. We measured the conducting noise on the thyatron cathode heater, and confirmed the noise filter decreased the noise to sufficiently small. In the prior operation test, we investigated the influence to the other devices, and confirmed that the interference was negligibly small.

ACNOKLEGEMENT

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REFERENCES

[4] T. Inagaki, internal information