Development of a Multi-Network for Resonant Excitation of the JHF 3GeV Booster Magnets

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Abstract

In order to investigate the possibility of a resonant excitation of the magnets of the JHF 3GeV Booster using a multi-network, two model networks were constructed. A model network comprises a dummy magnet, a resonant capacitor and a pulse power supply. It is a main subject to synchronize two resonant circuits that are oscillating individually. So far, stable operation within a phase fluctuation of 0.3mrad has been obtained by reducing the ripple of a rectifier of the pulse power supply.

1 Introduction

The Japan Hadron Facility (JHF) is a project aimed at a kaon factory. The JHF accelerator complex consists the 200MeV Linac, the 3GeV Booster synchrotron and the 50GeV Main synchrotron. The 3GeV Booster supplies a proton beam to the facility, which utilizes the meson and neutron beams produced by a 3GeV proton beam for the research of condensed matter, as well as to the 50GeV Main ring. In order to obtain a high-intensity secondary beam, the repetition of the Booster was determined to be 25Hz at first and 50Hz in future.

In such a rapid-cycling synchrotron, magnets are excited using the White circuit or the resonant network[1][2]. So far, the tune could not be controlled, since a combined-type magnet was used in this kind of the synchrotron. In a modern synchrotron aimed at high intensity, a space-charge effect and instabilities are so hard that the tune will play an essential role to cure such effects. Therefore, in the JHF Booster, the bending magnets and quadrupole magnets are excited separately using individual resonant networks, so as to control the tune.

When bending and quadrupole magnets are operated separately, the amplitude and a phase of each magnetic field must be controlled so as to minimize the c.o.d and tune difference from the design value. According to experience at the KEK PS-Booster, the field value at injection can be stabilized within 4×10^{-4}. On the other hand, there has been no experience concerning the synchronous operation of multi-network. Therefore, two resonant circuits and power supplies were constructed as a model of a multi-network, and are now being investigated.

In the following sections, the results obtained so far are described and the possibility of resonant excitation of the magnets of the JHF 3GeV Booster using the multi-network is discussed.

2 Model circuits

The multi-network is simulated by two resonant circuits and pulse power supplies. Each resonant circuit comprises a dummy magnet of 10mH and a resonant capacitor of 1mH. Hence, the circuit resonates with a frequency of about 50Hz. The resonant frequency was determined while speculating on frequency upgrade in the future, since the phase stabilization becomes more difficult with increasing the frequency. The resonant frequency and quality factor of each circuit were measured. The results are listed in Table 1.

Table 1
Resonant Frequency and Quality Factor

Circuit	Resonant Frequency (Hz)	Quality Factor
No. 1	48.88	78
No. 2	48.76	73

Fig. 1 shows a photograph of the model circuits. Here, two dummy magnets and pulse power supplies can be seen.

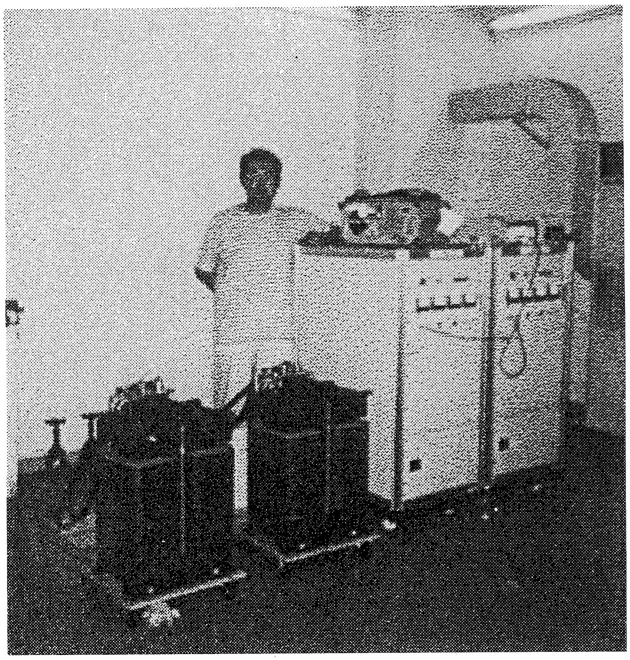

Fig. 1 Photograph of the model circuits.

Pulse power supply comprises an energy storage capacitor (C_f), a charging circuit, and a discharging circuit, as shown in Fig. 2. The rectifier (V_s) charges C_f through the filter choke (L_f). Then, the thyristor (SCR) is triggered to discharge C_f through the pulse choke L_p, so that a half-sine-like current pulse (i_p)is generated.

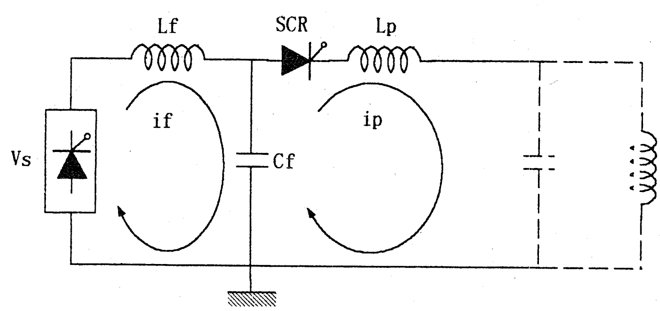

Fig. 2 Basic construction of the pulse power supply.

Fig. 3 shows typical waveforms of the back-leg signal and pulse current (i_p).

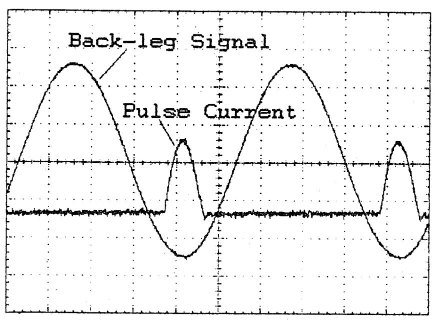

Fig. 3 Waveforms of the back-leg signal and pulse current.

3 Phase Measurement

Fig. 4 shows a block diagram of the feedback system for the model network.

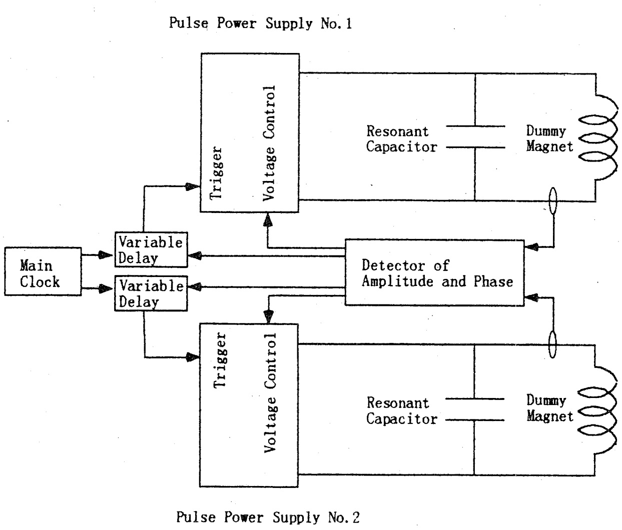

Fig. 4 Block diagram of the feedback system.

A trigger pulse for firing the thyristor is fed to each pulse power supply through a variable delay, which compensates for a proper phase shift due to the proper resonant frequency and quality factor of each resonant circuit. Such a phase shift is given by

$$\delta = \tan^{-1}\left(\frac{\omega \cdot \omega_0}{Q \cdot (\omega_0^2 - \omega^2)}\right), \qquad (1)$$

where δ is the phase shift, ω_0 the proper resonant frequency, ω the frequency of the trigger pulse and Q the quality factor.

The amplitude of the magnet current is monitored by a current transformer (CT). The zero-crossing timing is measured by a back-leg winding. Then, the amplitude is fed back to the voltage source of the pulse power supply. The zero-crossing timing, i.e. the phase, is fed back to the variable delay.

The synchronous operation of the multi-network is the main subject in this experiment. At first, a fluctuation of the zero-crossing timing with respect to the trigger timing was measured. The fluctuation was measured to 7μs in full width. Since the operation frequency was 48.82Hz, the corresponding phase shift amounted to 2.1×10^{-3}rad in full width. This large value was due to a large ripple of the rectifier. Fig. 5 shows the envelope of the back-leg signal. Here, the signal is expanded around the upper envelope and Vpp is 4.5V. The amplitude is modulated by 1.3×10^{-3} with a frequency of 6Hz.

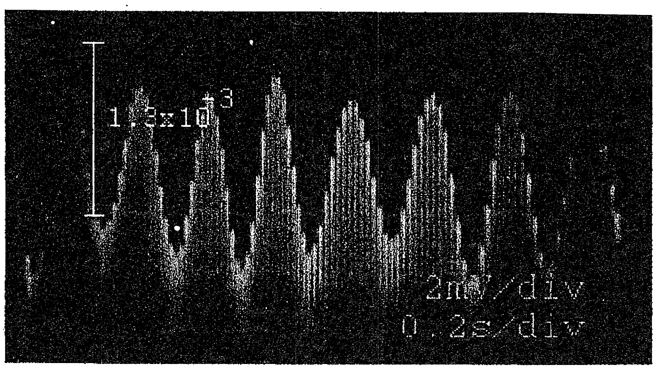

Fig. 5 Upper envelope of the back-leg signal.

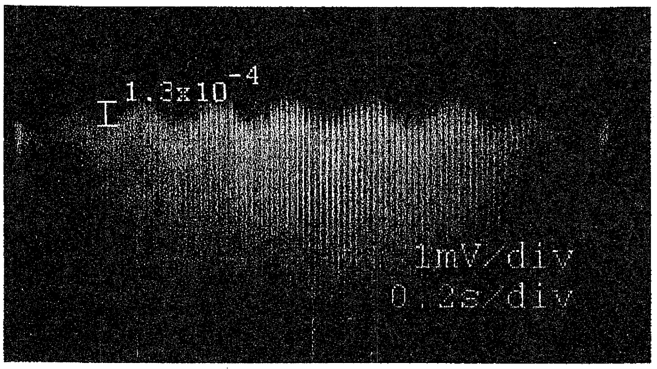

Fig. 6 Upper envelope of the back-leg signal after replacing the rectifier.

On the other hand, the amplitude fluctuation was reduced to 1.3×10^{-4} by replacing the 3-phase rectifier with a regulated-voltage source (TAKASAGO GP0600), as shown in Fig. 6. Here, Vpp is 4.2V. The timing fluctuation was 2μs in full width, which corresponds to a phase fluctuation of 6.1×10^{-4} rad.

The amplitude fluctuation in the case of a different resonant frequency was also measured by tuning up the frequency to 34.47 Hz. The results are listed in Table 2.

Table 2
Amplitude fluctuation of the Back-leg Signal

Operation Frequency (Hz)	3-phase Rectifier	GP0600
48.82	1.3×10^{-3}	1.3×10^{-4}
34.47	4.8×10^{-4}	2.1×10^{-5}

The relative phase difference between two resonant circuits was measured when the individual phase fluctuation was 2μs with respect to the trigger timing. Fig. 7 shows back-leg signals near to the zero-crossing timing where the operation frequency was 48.86Hz. There is a natural phase difference of about 1ms due to differences of the resonant frequency and the quality factor. A consistent value of 1.15ms was obtained in terms of eqs. (1) and Table 1. Such a phase difference was compensated by delaying the trigger timing of the pulse power supply for the circuit with the earlier phase.

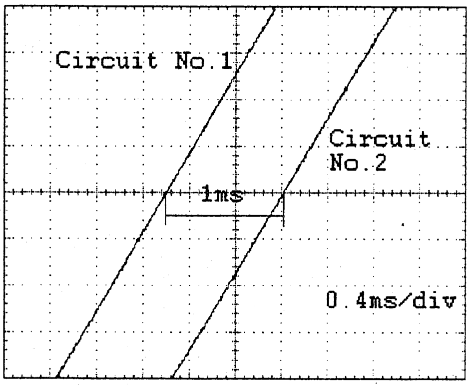

Fig. 7 Phase difference between two back-leg signals.

The fluctuation of the relative phase was measured to be less than 1μs, which was smaller than expected if the pulse power supply fluctuates randomly. It implies that the main origin of the phase fluctuation is an a.c. power line, since two pulse power supplies were connected to the same breaker.

4 Discussion

So far, the following items were found:

(1) In order to reduce the phase fluctuation, the amplitude modulation of the resonating current must be reduced. This means that the ripple of the rectifier of the pulse power supply must be reduced.

(2) The amplitude modulation becomes larger as the operation frequency becomes closer to the line frequency. A similar result was obtained elsewhere, and such a behavior was analyzed in detail[3].

(3)The relative phase difference can be detected within a fluctuation of less than 1μs.

A focussing error occurs due to a phase difference between the quadrupole field and the bending field, even if the amplitudes of both quadrupole and bending fields are exactly controlled.

In the JHF Booster, the tune must be stabilized around the design value within 0.01. The corresponding phase difference is 7.9×10^{-4}rad, i.e. 2.5μs for 50Hz operation or 5μs for 25Hz operation. Therefore, at least in the JHF Booster, a synchronous operation of the multi-network was found to be possible.

Since the phase shift depends on the resonant frequency (ω_0), it may vary due to a drift of the inductance and the capacitance in the resonant circuit. Such a drift, however, is expected to be sufficiently slow to be compensated by the phase feedback.

5 Concluding Remarks

In order to investigate the possibility of a resonant excitation of magnets of the JHF 3GeV Booster using multi-network, model circuits were constructed. It was found so far that the phase fluctuation occurs due to mainly a ripple of the power supply, and becomes larger at an operation frequency close to the line frequency. As a result, the phase fluctuation was reduced to 0.3mrad, i.e. 1μs for 50Hz operation, so that synchronous operation of the multi-network is expected to be possible in the JHF Booster.

Now, long-term operation is being prepared in order to establish a phase feedback scheme.

Acknowledgment

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