5–1 Realization of High-Accuracy Orbit Control of a High-Intensity Proton Beam

— Development of a New Pulsed Power Supply for Eliminating Current Ripple —

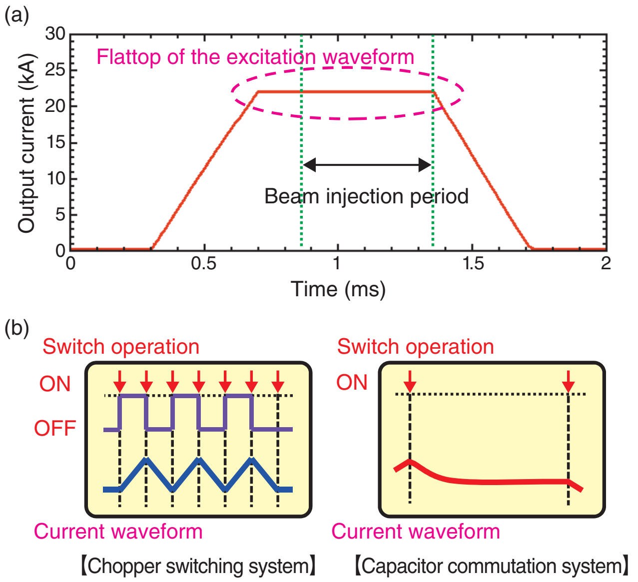

Fig.5-5 (a) Trapezoidal waveform of a pulsed power supply and (b) current waveform-formation methods using pulsed power supplies of different circuit configurations (blue: chopper-switching system, red: capacitor-commutation system)
(a) The trapezoidal waveform for exciting an electromagnet with a pulsed power supply is indicated. Ideally the waveform should be flat and without ripples during the beam-injection period to fix a beam orbit.
(b) The current ripple is caused by continuous switching in the chopper-switching system. However, the capacitor-commutation system eliminates this ripple during beam injection as the number of switch operations is limited.

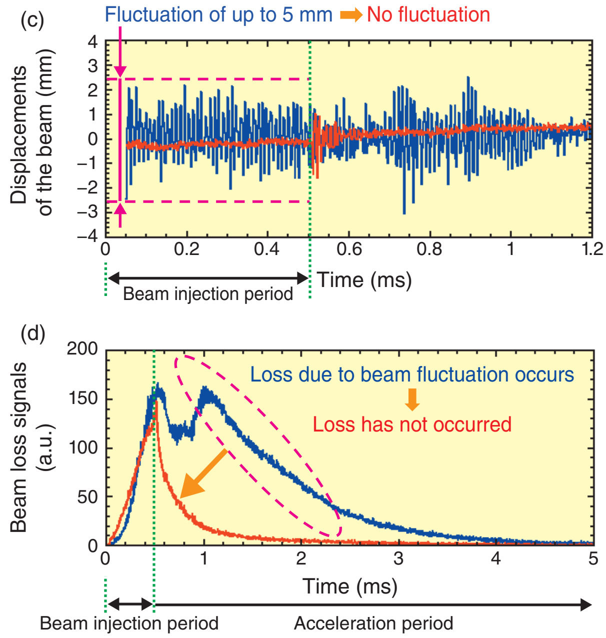

Fig.5-6 (c) Beam-orbit displacements and (d) beam-loss signals with a beam intensity of 550 kW (blue: chopper-switching system, red: capacitor-commutation system)
(c) Fluctuation of the beam orbit was at most 5 mm during a beam-injection period with the chopper system. However, in the case of the capacitor-commutation system, the displacement of the beam orbit became approximately zero and beam fluctuation did not occur.
(d) Suppression of the beam loss by the capacitor-commutation system is indicated. A fluctuation in the beam-injection period resulted in beam instability in the course of the acceleration.

Located at the Japan Proton Accelerator Research Complex (J-PARC), the 3 GeV Rapid Cycling Synchrotron (RCS) accelerates injected protons up to 3 GeV with a repletion rate of 25 Hz and is intended to output a 1-MW beam power. The injection-pulsed magnets of the RCS control the injection-beam orbit using the flat tops of the trapezoidal waveform (Fig.5-5(a)) and merge the many protons into a circulating beam.

The original pulsed power supply adopted a chopper-switching system for the main circuit, which formed the trapezoidal waveform by continuous ON/OFF-switching operation of the semiconductor switch (Fig.5-5(b): left). Thus, an arbitrary waveform change was possible and various injection parameters were produced in an acceleration-beam test. However, the continuous current ripple caused by the switching operation caused beam fluctuation (Fig.5-6(c): blue) and beam loss occurring owing to beam instability was observed during beam power ramp-up (Fig.5-6(d): blue).

We paid attention to ensure that the output current of the trapezoidal waveform of the capacitor-commutation system switched only three times per period. The power supply adopting this system is suitable for eliminating current ripple (Fig.5-5(b): right) during the beam-injection period. However, this current-waveform-formation technique is limited by the capacitance value and thus, the design of a control system is a problem that must be solved for RCS beam commissioning. In particular, distortion occurs in a flattop owing to an eddy current effect when the rise time of the waveform is changed.

To decide the basic capacitance value of the capacitor-commutation system, we constructed an equivalent circuit model by understanding the characteristic of the load exactly and analyzed it using circuit simulation. In addition, we devised a new correction circuit capable of controlling the waveform and realized high flattop flatness. Furthermore, in order to reliably reduce current ripple, we worked to reduce high-frequency noise due to the current route of the main circuit.

According to our results, various injection parameters could be produced. Thus, high-accuracy trajectory control without fluctuation has been realized (Fig.5-6(c): red) and a significant reduction of beam loss has been demonstrated (Fig.5-6(d): red). Consequently, there is a prospect of realizing stable user operation with a 1-MW high-intensity proton beam.

Reference
Takayanagi, T. et al., Comparison of the Pulsed Power Supply Systems using the PFN Switching Capacitor Method and the IGBT Chopping Method for the J-PARC 3-GeV RCS Injection System, IEEE Transactions on Applied Superconductivity, vol.24, no.3, 2014, p.3800905-1-3800905-5.