Design and test of the power supply for a fast kicker magnet
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Abstract
To perform fast beam switch during spot scanning and energy modulation procedures, a fast kicker magnet system is adopted in HUST-PTEF (Huazhong University of Science and Technology Pteron Test Facility). The rising/falling time is expected to be less than 100 μs, and the maximum repetition rate should be up to 500 Hz. To meet the dynamic performance of the power supply, a solution with two separate DC link schemes is proposed in this paper. Since the Kicker is closed to other sensitive equipment, an output filter is installed to prevent electromagnetic disturbances from propagating along the cables. The optimized design of out-filter and comparison measurement results of the power supply are introduced as well. Here, a trade-off between the voltage oscillation, dynamic performance and engineering implementation has been made.

INTRODUCTION
A proton therapy facility based on spot scanning technique is under development at HUST. For HUST-PTEF, a fast kicker magnet system is placed upstream from the degrade to perform fast beam ON/OFF switching during beam spots and the energy modulation procedures. And it can also work in DC mode to provide a function of fast beam stop in case of emergency with safety interlocks.

The schematic design of the power supply was completed in October 2018, the optimized design of output filter and the test of the power模块 were completed in May 2019.

REQUIREMENTS

Fig.2 shows the waveform requirements of the Kicker. For the Kick ON state, the proton beam is deflected to the beam stop (a Faraday cup). The field accuracy at Kick ON state is relaxed, 10% overshoot at rise time and 2% stability at flat-top time can be accepted. For the Kick OFF state, the output current should be less 2% of normalized current within 200 μs to reduce the disturbance of the downstream beamline.

The design difficulty of the kicker converter is to meet the EMC requirements, especially in such a medical application. Special care should be taken to avoid the high frequency voltage oscillation and by that EMC noise. There, an output filter is adopted to reduce Electromagnetic Interference (EMI).

Fig.2 The requirements for dynamic response and accuracy of the kicker.

TOPOLOGY OF THE POWER SUPPLY

Table 1: Design parameters of the fast kicker magnet.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Design Parameters</th>
<th>Kicker Output</th>
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<tbody>
<tr>
<td>Inductive energy (MxV)</td>
<td>250</td>
<td></td>
</tr>
<tr>
<td>Deflection angle (rad)</td>
<td>70.3</td>
<td></td>
</tr>
<tr>
<td>Max. magnetic field (T)</td>
<td>22</td>
<td></td>
</tr>
<tr>
<td>Output power (W)</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Output current (A)</td>
<td>250</td>
<td></td>
</tr>
<tr>
<td>Transformer ratio</td>
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<td></td>
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<tr>
<td>Ring width (mm)</td>
<td>300</td>
<td></td>
</tr>
<tr>
<td>Winding (tw)</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>Winding (tw)</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Wire size (mm)</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>DIA (mm)</td>
<td>356</td>
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</tbody>
</table>

Fig.3 shows the block diagram of the power supply and the timing sequence diagram of the control signals.
To meet the dynamic performance of the kicker magnet, the DC link voltage should increase or decrease the load current rapidly, the low DC link voltage should keep the output current with low ripple.

WAVEWAYS WITH OPTIMIZED FILTER

Fig.4: Block diagram of the power supply. (a) Timing sequence diagram of control signals.

It is crucial in selecting the value of the resistance R1, R2, the capacitance C1, C2 and the inductance L. The value of L is required to be less than one tenth of the kicker inductance to ensure the current change rate. The output filter capacitors should be minimized to reduce the power consumed in the resistances. A trade-off between the voltage oscillation, dynamic performance and engineering implementation should be made.

Fig.5. (a) shows the waveform of the Kicker on state. The output waveform exceeds the reference value (13V) within 100 μs.

WAVEWAYS WITHOUT OUTPUT FILTER

The optimized design of output filter and test of the power supply for kicker magnet in HUST-PTEF has been completed. The features of output filter and control topology were verified on the test bench with two DC regulated power supply for DC link voltage. With output filter, the current rise rate is reduced, the output filter causes the load voltage to overshoot by approx. 50%.

Fig.6 shows the waveform of the steady state. The output voltage oscillation of approx. 22 V in Fig.4 (c) is reduced to approx. 2.5 V in Fig.6 (c). The output waveform of the Kick OFF state, high-frequency voltage oscillations disappear and there is a 5% current undershoot. It takes about 50 μs to eliminate the current resonance.

However, the requirements given in Fig.2 can also be exceeded.

CONCLUSIONS

Fig.5 shows the waveforms of the Kick ON state. With additional output filter, the current rising rate is reduced. It takes about 70 μs to reach the reference value (13V). The output filter causes the load voltage to overshoot by approx. 50%.

For the Kick OFF state, high-frequency voltage oscillations disappear and there is a 5% current undershoot. It takes about 50 μs to eliminate the current resonance.

The drive current of the kicker magnet is 50 A and the high DC link voltage will be up to 480V. The assembly and commissioning of the kicker converter is expected to be completed in this year.

REFERENCES