THE TUNING STUDY OF THE COUPLED CAVITIES FOR THE RF CHOPPER SYSTEM OF J-PARC

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Abstract

A 3-MeV medium-energy beam transport line (MEBT) is located between the RFQ and the DTL in the linac of the Japan Proton Accelerator Research Complex (J-PARC). The MEBT accomplishes beam matching and chopping. An rf deflector (RFD) was adopted as a chopper in the J-PARC linac. A coupled RFD system was proposed in the design of chopper system for saving the cost of rf power source. The tuning of the coupled RFD system was successfully performed. The longer rise time of the second RFD and the delay of the second RFD excitation were found during the tuning of the coupled RFD system, and these phenomena were further analyzed and investigated. Both in the high power and beam tests, the chopper worked well without any discharge under 36 kW peak driving power.

INTRODUCTION

A Medium-Energy Beam-Transport line (MEBT) of Japan Proton Accelerator Research Complex (J-PARC) was installed in KEK for the beam test [1]. As a key component of MEBT, an rf deflector was proposed[2] and designed[3] as a chopper, because of its merits of high deflecting field, compact structure and easy to manufacture. An rf chopper, composed of two RFD (RFD-A and RFD-B), has been successfully developed. Because of the very low loaded-Q of the RFD, a coupled RFD system was adopted in operation for decreasing the demanded rf power by half.

Some frequency deviation was found after the construction of the RFDs. Although the bandwidth of the RFD is very large (~30 MHz), the frequency deviation of about 2 MHz still induces some negative effects: additional reflection and mismatch between two RFDs. The modifications of the RFDs were made for tuning the resonant frequency to the operation frequency of 324 MHz. In a low-level rf test, the fundamental rf properties showed good agreement with those in a design simulation. In a high-power test, the chopper worked well without any discharge under 36 kW peak driving power, and the longer rise time of the second RFD and the delay of the second RFD excitation were investigated in the coupled RFD system.

THE IMPROVEMENT OF THE RFD CAVITY DISIGN

The RFD cavity consists of two parts: the cavity body and the two end plates with large coupling loops. Fig. 1 shows the deformed waveform of the first RFD (RFD-A) when a mismatch of the resonant frequencies (~2 MHz) between RFD-A and B exists in the coupled RFD system.

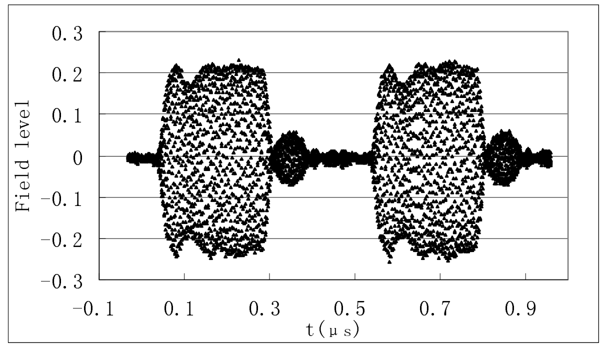

Figure1: The deformed waveform of the RFD-A of the coupled system due to mismatch (36 kW driving power).

To tune the resonant frequency back to 324 MHz, one idea is to move the large coupling loops about 3 mm towards the electrode. In practice, just about a 3mm gasket is needed between the loop and the end plate, then the resonant frequency is tuned to 324 MHz. But in this case the bandwidth of the RFD cavity is increased to 36 MHz, this means much more input power is needed than design.

To tune the resonant frequency to 324 MHz and keep the bandwidth and the other parameters unchanged, a new coupling loop was proposed, and designed by the RF simulation code HFSS.

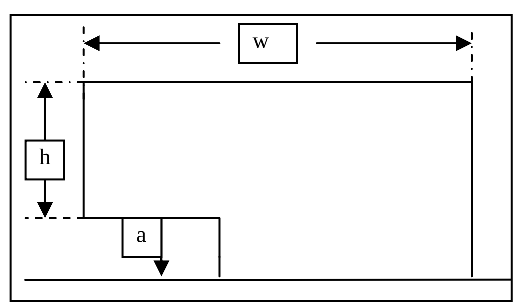

Figure 2: The shape and parameters of coupling loop.

Figure 2 shows the shape and parameters of the coupling loop. The thickness of the loop was 3mm. In design calculations by HFSS, the resonant frequencies were firstly tuned to the measured values by changing the gap distance, for RFD-A and RFD-B, respectively. In order to compensate the manufacture error of the cavities, the width w and height h of the loop of the two RFDs are

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modified to tune the resonant frequency to operating frequency of 324MHz. Tuning the resonant frequency by modifying the coupling loop has two merits: easy for fabrication and less cost. The tuner effect with 15mm insertion is included in the calculations, and the insertion of 15 mm is set as the default value.

The above designed loops were fabricated and installed in the RFD cavities. The cold model test and high power test showed the good performance of the modification. Table 1 shows the designed and measured frequencies of RFD-A and RFD-B with new coupling loops. The measured frequencies had a good agreement with design values, and the resonant frequency was changed to 324MHz for two single RFD cavities.

Table 1: The measured and designed parameters of RFDs with new and old coupling loop

	Resonant Freq. (MHz)				Bandwidth (MHz)	
	Tuner=0mm		Tuner=15mm		RFD-A	RFD-B
	RFD-A	RFD-B	RFD-A	RFD-B		
Old loop	322.30	321.90			30	30
New loop (design)	323.75	323.75	324.00	324.00	30	30
New loop (Measured)	323.81	323.88	324.00	324.15	30	30

A high-power test of the coupled RFD was performed. The RFD worked very well up to a 36 kW peak driving power. Fig. 3 depicts the waveform from the first RFD of the coupled RFD system with improved coupling loops in the high power test. It shows that there is no mismatch between two RFD cavities in the coupled RFD system, after the resonant frequency was tuned to the operating frequency.

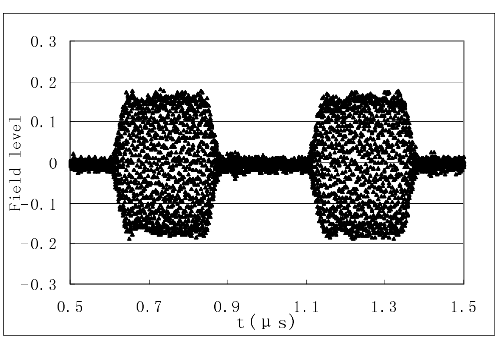

Figure 3: Waveform in the RFD-A of a coupled RFD system without mismatch (36kW driving power).

TEST OF THE COUPLED RFD SYSTEM

Setup of a Coupled RFD System

Since the loaded Q of the RFD is very low, almost all of the driving power (~99.7%) is coupled out of an RFD cavity to a matched load. If two RFD cavities are connected so that the output power from the first RFD is utilized for the second one, the total RF power demanded for the two cavities may be halved.

Two RFDs (RFD-A and RFD-B) were connected with a coaxial cable. The coupled RFD system can be regarded as a three-cavity system: two RFD cavities and a coaxial cavity. Because the distance between two gaps of the RFD cavities along the beam line is $3\beta\lambda$ (221.38 mm), the electric length between two cavities should be $n\lambda$ in order to keep the beam bunches synchronized with the rf field in the two RFD cavities. Here β is the relative velocity of a 3-MeV H^- ion, λ the free-space wavelength of RF, and n is an integer. The cable length was determined according to the results of a HFSS simulation. Taking the mechanical limitation in installation into account, the total cable length between two cavities was 942 mm. With this cable length, the measured spectrum of S_{21} in Fig. 4 shows that there are three modes, in which the second mode (324MHz) is the operating one. The measured spectrum of S_{21} gives the same feature as the simulation, in which the resonant frequency of the second mode is 323.75 MHz, with a bandwidth of 31.4 MHz and the loaded Q value of 10.4.

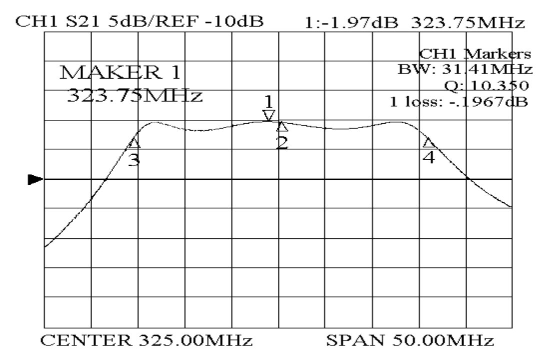

Figure 4: Measured S_{21} spectrum of the coupled RFD system.

Because the phase relations between two cavities can not be accurately checked by direct measurement, it is important to investigate the sensitivity of the deflecting effect with the phase error induced by the error of the connecting cable length. The simulation was made by using the code of TRACE3D for MEBT. The simulation showed that, within a 10° phase deviation, the influence to the deflection effect is very small.

Study on the RF Transient Behaviour

According to the measured loaded Q value (Q_L), as shown in the Fig. 4, the rise time of the cavity is $Q_L/\pi f_0$=10.6 ns, in which f_0 is the resonant frequency. The rise time of the whole RFD system is longer than that of the cavity, because of the contribution from the amplifier. The rise time of the coupled RFD system was measured by directly observing the rf response of the coupled RFD, as shown in Fig. 5, in which the dashed curve depicts the rf response from RFD-A and the solid curve the rf response from RFD-B. The rise time of the first cavity (RFD-A) is about 8 rf periods, almost the same as that of a single cavity, but it becomes 11 rf periods for the second cavity (RFD-B).

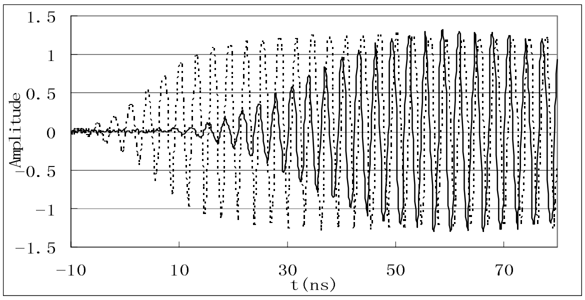

Figure 5: Measured response of the rf pulse of a coupled RFD system. The dashed curve is from the rf monitor of RFD-A, while the solid curve is from the rf monitor of RFD-B. Some delay time during transient rise time can be seen between two signals from A and B.

From Fig. 5, one can find that the delay time of the second RFD excitation was about 6 rf periods. For the $3\beta\lambda$ distance between two RFD cavities along the beam line, the 6 rf periods delay means that there were 3 micro bunches deflected by the first RFD only during the rise time; a similar case exists during the fall time.

A similar transient behaviour as that in the case of the measurement was observed in the simulation with T3 module of MAFIA, as shown in Fig. 6, in which the thin line indicates the rf signal in the gap of the RFD-A, and the dark line traces the rf signal in the gap of the RFD-B. Similar to the measurement results, the rise time of the second RFD is longer than that of the first one, and the delay time in the second RFD excitation is about 5 rf periods. The delay time obtained in the simulation is less than that in the measurement. The reason for the difference in the delay times comes from the different setups between the measurement and the simulation: in the simulation two RFDs were connected by 50 mm coaxial cable for decreasing the required computing time, while it was connected by a 942 mm cable in the measurement.

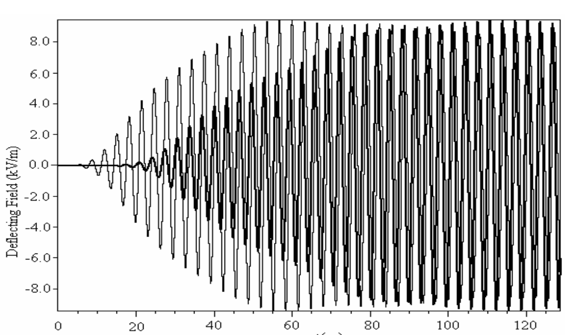

Figure 6: Simulated response of the rf pulse of the coupled RFD system made by using the T3 module of MAFIA. The thin line indicates the rf signal in the deflecting gap of the RFD-A, and the dark line traces the rf signal in the deflecting gap of the RFD-B.

It can be predicted that the two demerits, the longer rise time and the longer delay time in the second RFD will decrease the total deflection efficiency of the two RFD cavities. However, considering that the capability of the power amplifier is up to 36 kW, which is much larger than the demanded power of 22 kW in the design, these two demerits are not a problem. Fig. 7 shows the very short chopped beam signal measured by a beam position monitor in the first beam test at KEK [4]. It can be seen that both rise and fall times are about three rf periods (~10 ns), owing to the much higher deflecting field than the designed one.

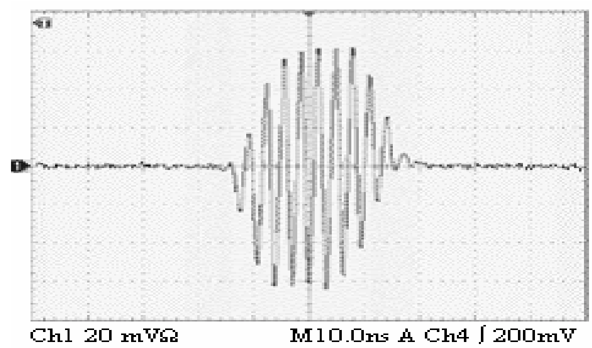

Figure 7: Signal of a chopped beam measured by the BPM. The beam current was 24 mA and driving power was 36 kW. 10 nsec/div. This is an example of a very short pulse with a fast rise/fall time after careful tuning accelerating parameters.

CONCLUSION

An rf chopper system consisting of two RFDs, has been successfully developed. A modification in the coupling loop of the chopper cavities was made for tuning the resonant frequency while keeping the bandwidth unchanged. In a high-power test, the chopper worked well without any discharge under 36 kW peak driving power. The rise time of the rf chopper system and the delay of the excitation of the second RFD in the coupled RFD system were studied by experiments and MAFIA T3 module simulations. The rise times of the chopped beam of about three rf periods (~10 ns) were obtained in the first beam test.

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