MA RF CAVITY FOR THE KEK 12 GEV PS

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Abstract

A magnetic alloy (MA) loaded cavity has been designed for the KEK 12 GeV proton synchrotron. This cavity is to be used for a dual frequency system or a fundamental frequency system. Each one of the MA ring cores is split in two and is loaded inside. By changing the distance of the air gap between each pair of cut ring core, the R/Q value of the cavity is going to be controlled, in order to cover both the fundamental (6-8MHz) and dual (12-16MHz) frequency ranges. The cavity has two accelerating gaps and provides the 40kV peak voltage. Total length is about 1.1 m. A direct digital synthesis (DDS) is adopted to generate the required rf-signals. And, the amplitude and phase of those signals have to be controlled in real time.

1 INTRODUCTION

The KEK 12-GEV proton synchrotron provides four accelerating stations, of which accelerating voltage is 90 kV in total. Considering longitudinal matching between an injected bunched beam and a longitudinal potential, the bucket height seems to be insufficient. Unexpected longitudinal blow-up or related beam loss may happen during the injection. On the other hand, increasing bunching factors of beams in a synchrotron is also essential to alleviate the transverse space charge effects.

The new MA cavity has been designed to use as a second harmonic cavity and a fundamental RF cavity for the KEK-PS. The cavity provides a mechanical structure to switch the available frequency band. This cavity will be used for versatile purposes of accelerator studies.

In order to control this cavity, the digital control system based on a direct digital synthesis has been designed.

2 CAVITY

2.1 General

Since the accelerating frequency (h=9) is 6 – 8 MHz in the 12 GeV PS, the new system must cover the frequency range of 12 – 16 MHz when operating as a second harmonic system. Considering a *LCR* parallel circuit system, an indelible capacitance; for instance, an output capacitance of tetrode, a stray capacitance and so on, limit the *R/Q* value. And, in order to satisfy resonant condition at the desired highest frequency the *R/Q* value should be below 40Ω in this case, where $R/Q = \omega L < 1/(\omega Co)$.

The shunt impedance of an MA cavity becomes high with the help of large inductance of a magnetic material, in spite of its low quality factor. Normally, the R/Q value becomes large. For actualizing such low R/Q value, therefore, the split MA ring cores are going to be loaded with the cavity.

The cavity has two acceleration gaps. A total RF voltage of 40kV is expected. Twelve pairs of the MA cores are loaded in total, and three pairs are installed into a cooling cell (Figure 1). The sizes of core are 260mm I.D., 950mm O.D. and 25mm thickness. The impedance is 1KΩ per gap at the 12 MHz regime. Total power dissipation is estimated about 200kW with 50% duty. Two 150kW tetrodes are operated in a class AB push-pull amplifier to supply the power.
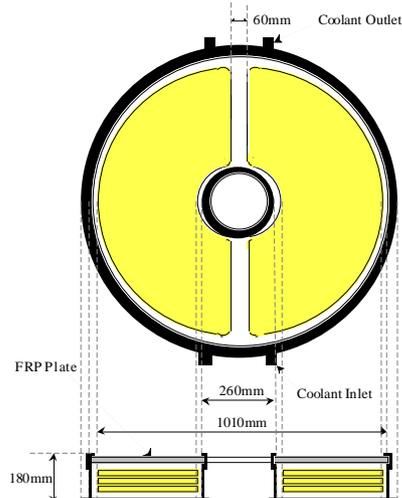

Figure 1. Topview (TOP) and cross-sectional view (BOTTOM) for one of four cooling cells; Yellow shows Magnetic Alloy core split in two.

2.2 Split Cores

Magnetic resistance of the split core increases as the air gap distance becomes large [1]. Since the impedance of the cavity is related to the total volume of the lossy materials inside the cavity, the cavity impedance stays constant even after cutting and separating the cores. In other words, the Q-value of the cavity increases and/or the cavity inductance decrease effectively by splitting. By changing the air gap distance between the split cores, it is possible to optimize the R/Q value.

2.3 Impedance

For the second harmonic cavity, the shunt impedance of the cavity is expected around 500 Ω per cooling cell, and total impedance becomes about 2000Ω. To satisfy resonant condition, the air gap distance between the split cores is to be 70 mm. And, the distance of 7 mm will be suitable for operating the cavity as the fundamental RF system.

FT950 x 3, Space bet. Cores = 10 mm
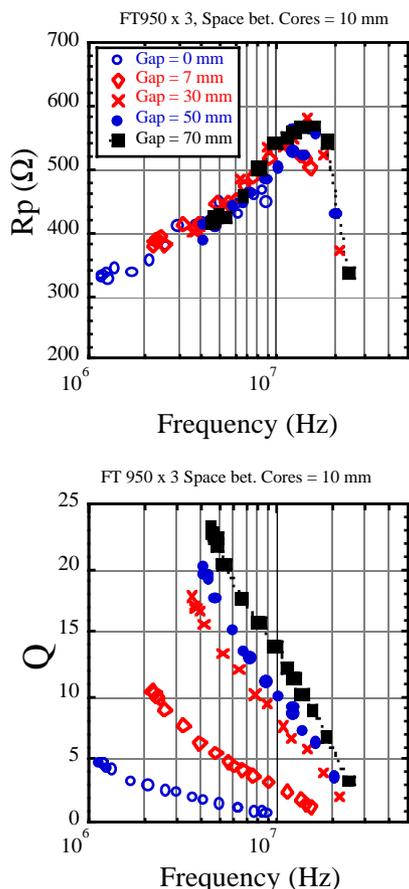

FT 950 x 3 Space bet. Cores = 10 mm

Figure 2 Frequency variation of the shunt impedances and the Q values of the unit-cooling cell; three pairs of the cut core per cell, and the air gap distance is changed as a parameter.

2.4 Cooling

Total power dissipation would be around 200 kW with a 50 % duty. About 17 kW per core has to be removed. As the air gap between the split cores gets larger, the leakage flux increases at the corner edges of the cut cores. The local heat due to eddy's loss must be avoided by smoothing the lamination profile [2].

The surface of the magnetic alloy core is not suitable for an indirect cooling method using water-cooled copper plate, because of their uncontrolled flatness. For effective heat removal, the direct cooling method is superior to others. Pure water is usually employed, because of convenience and low-cost. However, it must be taken special care that the di-electric constant of water is extremely high. When the pure water is filling up the cooling cells, the longitudinal capacitance between the core and the inner or outer cylindrical conductors and the transverse capacitance between the cores becomes 80 times larger. And, this capacitance could be coupled with the transversal resistances of the alloy cores. The magnetic alloy is electrically conductive.

The impedance measurements of a quarter wavelength cavity cell showed that when the water was filled in, the impedance dropped to about half the value before. A fully fluorinated perfluorocarbon liquid (3M, FC3283) could possibly be used as a heat transfer liquid instead of a pure water. The fluorinated carbon is thermally stable, has high dielectric strength and offers a low dielectric constant of 1.9. Since the specific heat of this material is 0.25 cal/g and the density is 1.9 g/cc, the cooling ability is about half that of water. The fully fluorinated liquid circulating system of 400 liters/min has been designed.

3 CONTROL

A significant feature of a magnetic alloy core lies in its stability against high magnetic field and temperature variation. The MA loaded cavity could be considered as a passive load. Then, the low-level rf-signal (LLRF) will be transmitted to the cavity in a predictable way. Since the system has no tuning control, a precise LLRF signal should be required.

The digital control system is the best solution to generate an exact time variable rf-signal in the place of an analog system (VCO). A direct digital synthesis (DDS) has been applied to generate the rf-signals.

The present LLRF control has been running with the analog system. As operating the MA cavity system, the present system should be also controlled by the DDS based rf-signal.

3.1 Direct Digital Synthesis(DDS)

For the second harmonic system (h = 18), the frequency sweeps from 12 – 16 MHz. The DDS master clock has to be at least 60MHz or more. The Qualcomm Q2240I-3S1 DDS chip is selected, because the chip can run with 80MHz maximum clock and is designed for an arbitrary waveform generation. The 14-bit digital output represents the internal DDS phase accumulator. The phase to sin(ϕ) transformation is done by the coordinate transformer (TMC2330). Finally, the AD9754 D/A converter is used to obtain the analog signal.

Figure 3 shows the block diagram of the DDS-System foreseen. The target frequency for the DDS chip is a 32-bit input and is calculated from the beam momentum. The
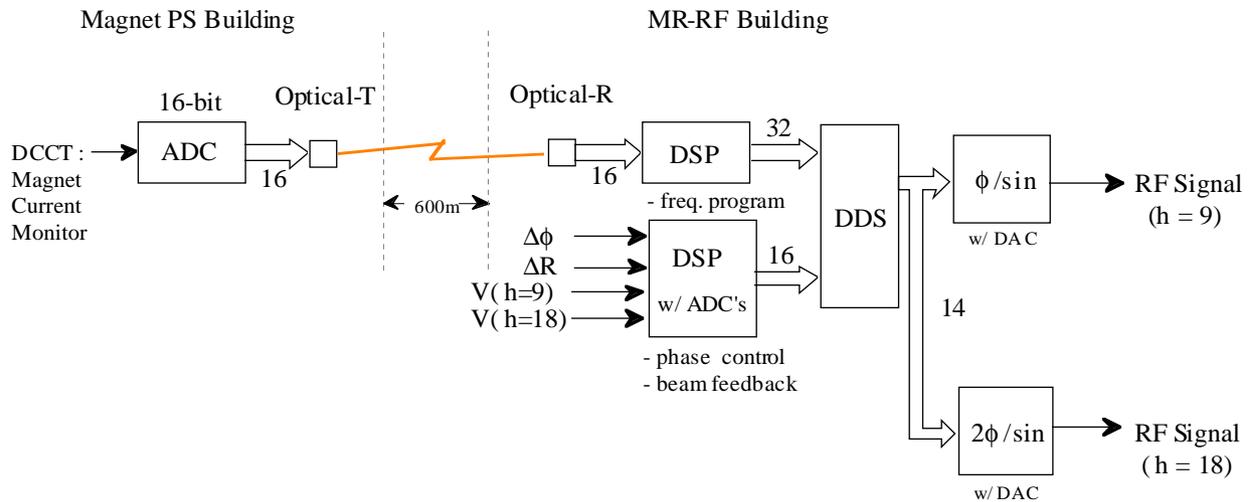
    MR-RF Building

Figure 3 Block Diagram of the digital RF signal generation. One DDS chip generates both the h=9 and h=18 RF harmonic signal. Two DSP modules running at 200MHz clock carry the frequency and phase control arithmetic.

algorism is conformed to the magnet power supply control [3]. The precise DC current transformer (TOPACCDCCT) is utilized to measure the current of the main magnet, and then the current is digitized by using a 16-bit analog-to-digital converter with a 100K sampling rate. The maximum time variation of the RF frequency is 15KHz /sec at 60msec after acceleration started. And the $\Delta B/\Delta t$ during the acceleration is 2.4 Tesla/sec at maximum. Considering an orbit error due to the frequency steps and the maximum synchrotron frequency, at least 100KHz of the sampling frequency is necessary. Since the distance between two buildings of the magnet power supply and the RF control room is approximately 600m far, the optical units with Taxi chip are employed for 16-bit data transfer, and to minimize the time delay the handshake routine in the process is minimized.

3.2 Delays

It is important to know how much the signal delays through the digital circuit. The expected time delays have been estimated during designing the control system.

1. A/D conversion time for the current transformer is 5 μsec.
2. Overall 600m data transfer delay is 3.5 μsec.
3. DSP frequency calculation is 7 μsec.
4. DDS data conversion time is 300 nsec.
5. The conversion time at the coordinate transformer is at least 22 clock cycle ; ~ 600 nsec.
6. D/A conversion time is 40 nsec.

The total delay is estimated to be less than 20 μsec. The stability requirement of a closed loop operation will limit the loop bandwidth to roughly about 10 kHz.

4 SUMMARY

The high field gradient MA cavity has been designed for the KEK-PS. This cavity will be used as the second harmonic system as well as the fundamental RF system. The frequency band of the cavity is adjustable, which is done by changing the air gap distance between the split cores installed inside the cavity. Since the system has no tuning control loop, the exact RF frequency program, corresponding to the beam momentum, should be required. The beam momentum and the corresponding target frequency will be calculated with the digital signal processor. A commercial DDS chip is employed as the basis for RF signal generation.

ACKNOWLEDGEMENT

REFERENCE

[1] Y.Mori, "A new type of RF cavity for high intensity proton synchrotron using high permeability magnetic alloy", EPAC98 (1998) p.299-301.

[2] W.Chow, a private communication

[3] T.Sueno et.al, "Software system of the main ring magnet power supply for the 12 GeV PS", Proc. 6th Symp. Accel. Sci. & Tech., (1987) p.155-157