OBSERVATION OF MODE RESONANCE STRUCTURE IN SYNCHROTRON MAGNET STRING

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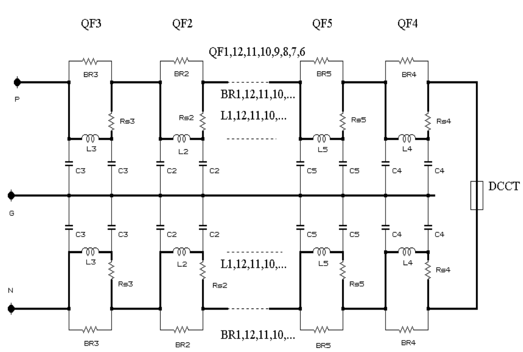
Abstract

Synchrotron magnet system consist of a number of magnets and can be regarded as a ladder circuit the unit circuit should be described by three input and three output circuit. The relevant parameter in this circuit can be decomposed into two separate orthogonal mode of common and normal mode circuit. The combination of the spike and the resonant property of the ladder circuit could enhance a magnetic distortion an may deteriorate a circulating beam property. In this article, we report the measured frequency characteristics and spatial distribution of the resonant structure of the normal and the common mode magnetic field along magnetic string under high power excitation of a routine operation condition. The observation and the theory are compared .

1 INTRODUCTION

In a synchrotron, accelerated beam is utilized either after being extracted with a time scale of revolution period(fast extraction) or being extracted with a time scale of around a second(slow extraction). Or sometimes beams are collided inside the synchrotron and are utilized by hitting an internal target in it. For the case of slow extraction, the



beam is extracted resonantly by kicking out a beam outside a septum by making use of a finite size turn separation of the circulating beam. The turn separation of this process is sensitive to a fluctuation of magnetic field of the synchrotron as the process involves betatron resonance.

Power level of synchrotron extends from hundreds of kilowatt to tens of Megawatt. In this power range, thyristor has been known to be best the power elements. On the other hand, the thyristor's spike noise has been notorious.

HIMAC heavy ion synchrotron is a synchrotron that this spike noise as well as low frequency ripple was removed much below ppm level[2]. This accelerator is a dedicated machine to cancer therapy and has been operated for a couple of years. Roughly 400 patients was treated by a carbon beam.

In HIMAC, the resonant property of the load synchrotron magnet is made to be suppressed by bridge resistor which is connected in parallel to the excitation coil. In previous report the resonant property of the load was measured at a small signal level[1]. That resonance was characterized by a frequency dependence of an admittance or impedance of the magnet string. Fig.1 shows a spectrum of an output voltage signal of a search coil inside a dipole magnet gap and shows a resonant property of the magnet string. Fig.2 shows the model circuit of the magnet string. For detecting resonance the bridge resistors are removed in taking the spectrum of Fig.1.This circuit provides several special features such as six-terminal circuit, separated coils etc.

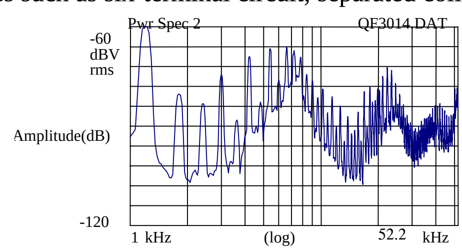


Fig.1 Output of the search coil without bridge resistor

Analytical expression of in the coil of the magnet derived in reference [2];

$$i_{mc}(n) = 2\frac{u_c(N)}{Z_{mc}}\frac{\sinh\left[(n-\frac{1}{2})\varsigma_{mc}\right]\sinh\left[\frac{1}{2}\varsigma_{mc}\right]}{\cosh(N\varsigma_{mc})}$$

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Fig.2 Ladder circuit of the magnet string

Here subscript m shows the current in magnet and n denotes the mode(•=n for normal mode and•=c for the common mode) and n in parenthesis denotes the location of unit cell of the magnet in the string.

This equation tells us that the magnet current is a function of the location and also frequency. It may be resonant or non-resonant depending on a magnitude of the resistance of the bridge resistor.

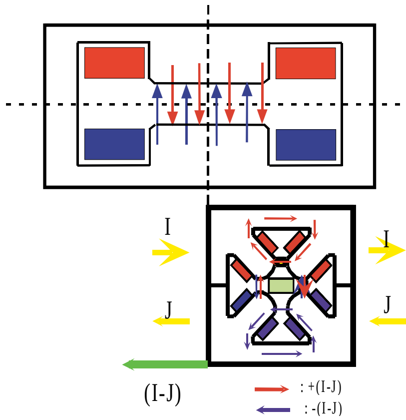


Fig. 3 Canceling of the common mode flux

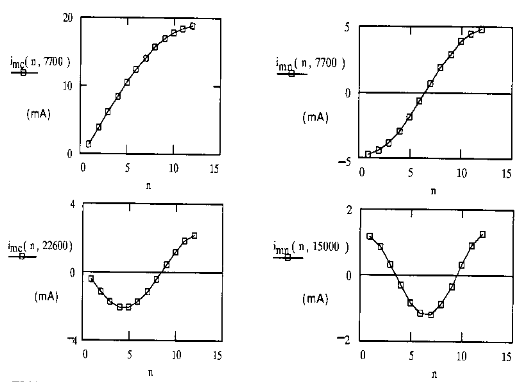


Fig.4 Current distribution

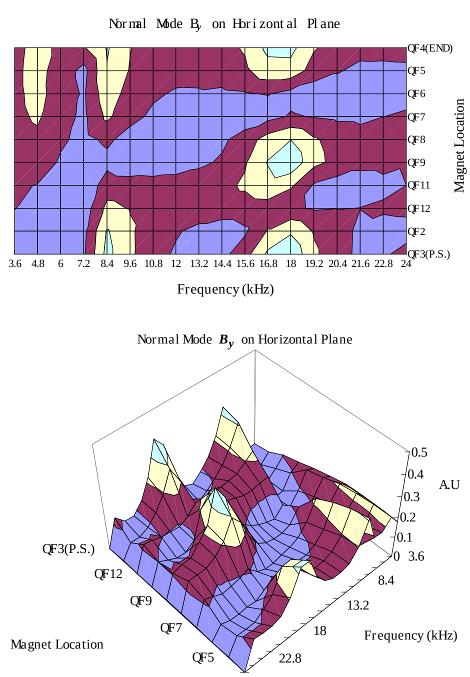


Fig.5 Normal mode B_y on the horizontal plane(a)

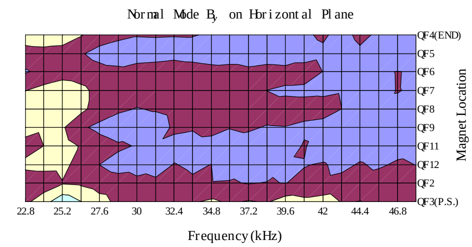


Fig.6 Normal mode B_y on the horizontal plane(b)

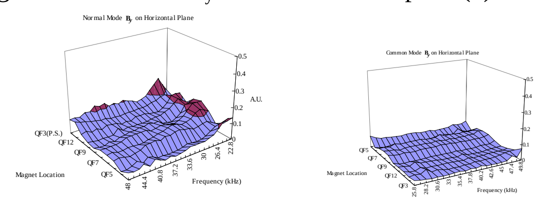
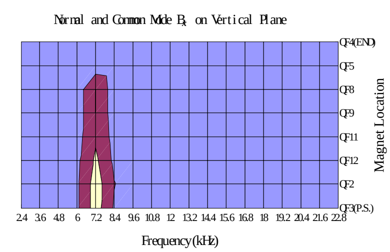


Fig.8and• Normal mode B_y on the horizontal plane(c),(d)



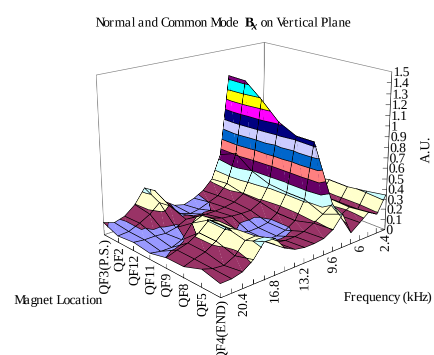


Fig.10 Normal & common mode B_y on the horizontal plane(a)- Multiples of 1.2 kHz

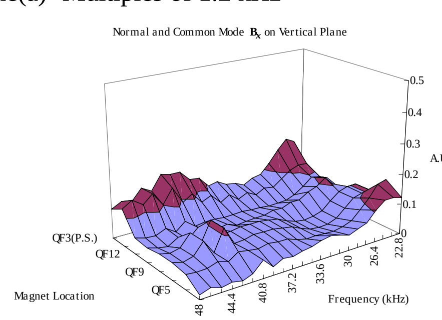


Fig.11 Normal & common mode B_y on the horizontal plane(b)- Multiples of 0.6kHz

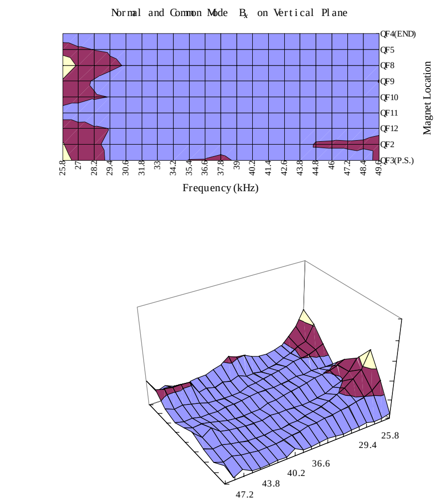


Fig. 12 Normal & common mode B_y on the horizontal plane(c)- Multiples of 1.2 kHz

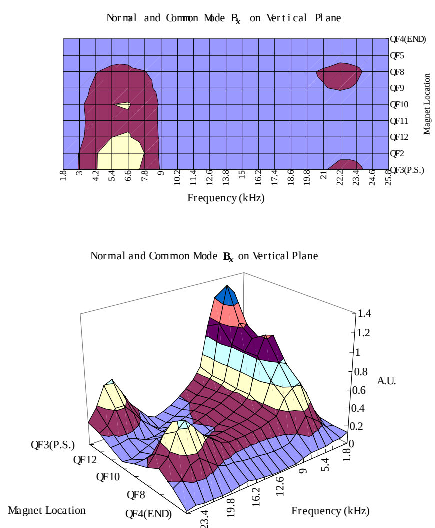


Fig.13 Normal & common mode B_y on the horizontal plane(d)- Multiples of 0.6kHz

We point out that the magnitude of the magnetic field is not the one calculated from the ordinal normal mode current. This depend on how one choose cabling method of the coil. In HIMAC, upper coils and lower coils are grouped separately. This results in difference in common mode magnetic field. In our way of connection, the common mode ripple is canceled out for dipole magnetic field. For the Quadrupole magnet the common mode ripple cancels out only on horizontal plane but not on vertical plane. This is shown schematically in Fig.3.

2 OBSERVATION AND THEORY

The magnetic field along the magnet string are measured by the search coils inside of a Quadrupole magnet like in Fig.3 where two search coils are positioned orthogonally. The effective area of the coil was 0.3315 m2 .The impedance of the coil was flat within 1.5 % below 50 kHz. HewletPachard HP35670A four channel FFT analyzer was used for spectrum analysis.

For the comparison between the theory and the observation, the calculated current distribution in the magnet are shown from Fig.4 . They show typical distribution of current noise in the excitation coil along the magnet string calculated from the equation.

From a quarter wavelength to one wavelength are shown. On a horizontal plane, the common mode currents in the upper coil and the lower coil are canceled each other as a common mode magnetic field but on the vertical plane they are not and magnetic fields of both mode appear.

The calculated field distribution of these mode can be clearly observed in Fig.5 from Fig.13 as a 2D contour mapping and 3D contour mapping.

Table • Resonance Mode and Freq.•Normal Mode•

Resonance Mode	theory(kHz)	measured (kHz)
λ/4	5	4.8
λ/2	7.7	8.4
3λ/4	12	14.4
λ	15	18.0

Table • Resonance Mode and Freq.•Common Mode•

Resonance Mode	theory(kHz)	measured (kHz)
λ/4	7.7	5.4
λ/2	12	16.2
3λ/4	22.6	22.2
λ	-	30.6

4 DISCUSSION

In this simple ladder circuit model, the parameter of the elements are assumed to be independent of frequency. However, frequency above 10 kHz or so, the inductance is decreased and the resistance is increased and the validity of the assumption is violated. We need more accurate model of those elements for more accurate modeling.

5 CONCLUSIONS

The magnetic field distribution along a synchrotron magnet string at a high power operating condition was observed first time. The normal mode and the common mode distribution roughly agrees with simple theory of ladder circuit of six-terminal model.

6 ACKNOWLEDGEMENT

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