Independent Resonant System Tracking Considerations

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Abstract

The TRIUMF KAON Factory Booster and Driver rings are to be excited using a resonant topology, with independent dipole and Qf and Qd quadrupole resonant systems. Dipoles and quadrupoles for the same ring must track and the booster and driver rings must be phase locked. This paper presents some of the considerations which need to be taken into account for this system to be feasible.

I. INTRODUCTION

In the TRIUMF KAON Factory booster and driver rings the dipole and quadrupole magnets are separately excited, each having their own resonant circuits. This separated function mode of operation allows for flexibility in tuning of these elements by having independent amplitude control without having to resort to trim quadrupoles which would occupy additional space on the rings which is already at a premium.

This additional flexibility however complicates the powering of these magnets since one has at least three independent resonant systems per ring whose magnetic fields must track, in terms of frequency and phase.

II. SYSTEM DESCRIPTION

The three resonant networks are comprised of magnet inductance, dc bypass choke inductance and capacitors. The inductance and capacitance determines the nominal natural resonant frequency of the network. The natural resonant frequency varies as a function of excitation and ambient conditions. The overall circuits are of a distributed resonant cell configuration which serves to minimize the peak voltage to ground.

Since the repetition rate of the acceleration cycle is fixed, the resonant networks are excited at a fixed frequency in a driven mode, as opposed to free running. For reasons of electrical efficiency, the resonant cells are tuned to be very close to the driven frequency. The tuned response of course will vary as a result of component value drifts but this is dynamically compensated to some extent by the use of switchable trim capacitors for each system.

Figure 1 shows a typical resonant circuit configuration for the booster dipoles. Central to this circuit is found the pulse forming network which is used to establish and control the ac resonant response used to drive the magnets. The two quadrupole networks have a similar configuration, differing only in the number of resonant cells which are required.

The pulse forming network provides the energy to control the peak to peak resonant response by providing for the energy loss of the system once per oscillatory cycle. This occurs through the primary windings of the dc bypass chokes. Timing of these pulses also defines the operating frequency of the respective tuned resonant systems. A more detailed description of the energy makeup system is presented in reference [4].

Given the fixed driven response and the variations in the natural frequency tune, there exists a variable phase shift between the energy makeup waveform, which determines system timing, and the resulting magnet current. The only time these two are in phase is when the driven frequency corresponds exactly to the natural resonant frequency.

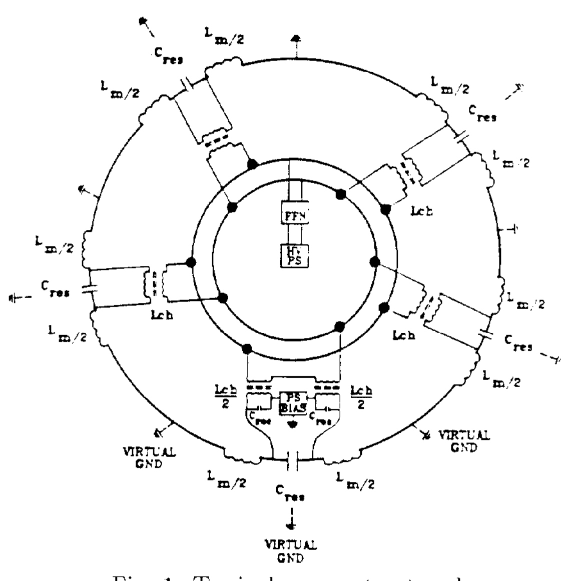

Fig. 1. Typical resonant network.

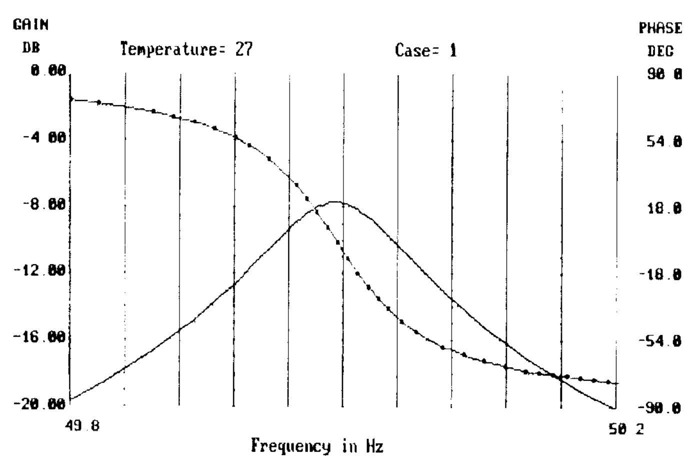

Fig. 2. Typical resonant network gain phase plot.

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Figure 2 shows a typical gain phase relationship of a single network which is representative of all three. Since one is running very close to resonance one is in a region of maximum phase transition as a function of frequency and large phase transitions are possible due to small natural resonant frequency variations [2,3].

Whether energy makeup is done with a sinusoidal forcing function or with a pulse forming network, the phase angle difference of excitation and response results in a varying time delay of the oscillatory response with respect to the master clock. Since none of the three networks stays tuned to the same natural resonant frequency, the three responses exhibit different phase angles. As all three circuits exhibit a Q of about 100 these individual phase shift variations are pronounced.

The natural resonant frequency of the three distributed magnet systems can not be perfectly matched, but will be trimmed as close as possible.

Variations of the natural resonant frequency are due to thermal variances which effect the value of capacitance and the magnet gap. The capacitors for example have a thermal coefficient of about -0.04% per degree centigrade.

The second factor which must be taken into account is the dependence of the natural resonant frequency on excitation level [1].

The dipole circuit which has the highest stored energy serves as the master reference for the two quadrupole circuits. The problem now is that of synchronizing the quadrupole circuits. If one were to use the same pulse train timing for all three circuits, there would appear phase differences of the two quadrupole currents with respect to each other as well as to the dipole current.

III. SYSTEM TIMING

The solution is to tune the quadrupole resonant frequency to have energy makeup pulses which are sufficiently time delayed with respect to those of the dipole circuit. One then uses the dipole timing as a reference, and provides the quadrupole circuit ac makeup pulses with the same repetition rate as for the dipoles but with an adjustable time delay with respect to the dipole pulses to achieve phase lock of the fundamental quadrupole currents to the fundamental dipole current.

The time delay and natural resonant frequency tuning would have to be optimized to provide sufficient dynamic range and to minimize the generation of harmonic disturbances due to the time displacement of the energy makeup pulses [3].

Driving the quadrupoles further off resonance implies a less efficient powering of the quadrupole circuits, though this is necessary to have sufficient dynamic range for the system to be feasible.

To achieve good tracking by phase locking the fundamental current components of course requires that the magnetic properties of the dipoles and the quadrupoles are carefully matched in terms of saturation characteristics etc. Since the natural response of the resonant circuits exhibit an exponential decay between energy makeup pulses, the dipole and quadrupole circuits must have an equivalent Q to match the asymmetry of the current waveforms in each circuit to achieve reasonable tracking of their magnetic fields.

The required timing correspondence between booster and driver will be handled in a similar manner where the booster dipole again will be used as the master timing reference for the driver dipoles and the corresponding quadrupoles will be slaved to the driver dipoles.

IV. CONCLUSIONS

Tracking of independent resonant networks is feasible based on experimental work done at TRIUMF for purposes of magnet measurements of the booster dipole prototype. An appropriate phase sensing network needs to be developed which functions in the presence of the tunable dc bias. As well a detailed analysis of the phase control loop which copes with the severe phase transitions encountered in the three systems needs to be done.

Though I have not had the opportunity of setting up independent networks the experience gained in running the existing resonant configuration at full power leads me to believe that the methodology contemplated will be successful.

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V. REFERENCES

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