Power Supply System for the TRIUMF KAON Factory

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Abstract

The TRIUMF KAON Factory consists of 5 rings, 3 of which are dc powered and 2 synchrotrons running at 50 Hz and 10 Hz, respectively. This paper deals with the power supply system envisaged for the accelerator as well as the experimental results obtained using dc-biased single and dual frequency resonant magnet excitation for the booster and driver synchrotrons.

I. Dc Rings

A, C & E ring dipoles and quadrupoles are designed for 1000 A, with 0.001% current regulation required for E ring dipoles. This regulation requirement almost precludes the use of SCR supplies. Our study showed that large switching supplies were feasible and economically competitive with active filtered 12 or 24 pulse SCR equipment. Power supply ratings of 450 Vdc, 1000 A, current regulated to 0.001%, meet requirements for most of the dc magnet strings. One unit powers all A ring dipoles. With series voltage sources, power is provided to the C and E ring dipoles. The same unit is used for quadrupoles. A full power prototype was built which met design criteria.

II. Acceleration Rings

Booster and Driver ring magnets require dc biased ac excitation with repetition rates of 50 Hz and 10 Hz respectively. Typical current waveforms are shown in Fig. 1.

To minimize ac line disturbances, resonant magnet excitation was selected as proposed by J.A. Fox [1]. D ring dual frequency operation is as proposed by Praeg [2] . The 3 to 1 rise to fall ratio results from switching out of 8/9 of the resonant capacitance during the reset period. This mode of operation was verified using NINA magnets in our magnet test stand.

Dc bias is provided by a 12 pulse SCR unit delivering 650 Vdc @ 3000 A acting in series with a number of voltage sources. Dc bias is inserted in a modified resonant cell where the bias supply is not subject to the alternating current component. Ac makeup power flows through the bypass capacitor which is in parallel with the supply. An 80 Vdc 3000 A supply was used as the bias supply in the magnet test stand.

A. Ac Makeup Power

Ac makeup power which serves to excite and control the resonant response, is coupled via primary windings on the dc bypass chokes. Booster makeup power may be sinusoidal. The Driver, however, which has dual frequency components, requires distributed pulse forming networks which provide a power makeup pulse during the acceleration interval. This method was verified experimentally on the magnet for both Booster and Driver applications.

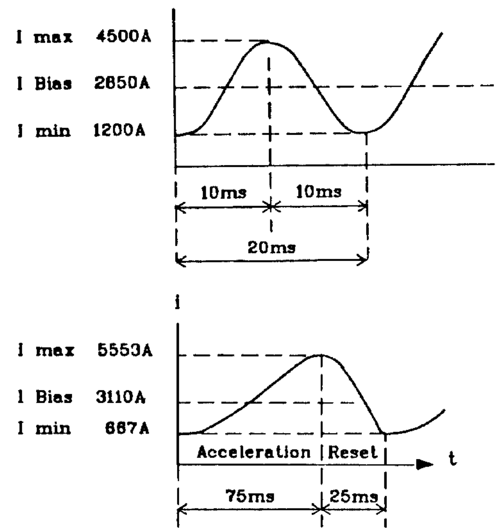

Figure 1: a) Booster dipole current cycle (50 Hz). b) Driver dipole current cycle (10 Hz).

B. Dc Bypass Chokes

Various competing designs were developed and yet need to be refined for the final configuration.

C. Quadrupoles

F and D quadrupole resonant networks are slaved to the dipole circuit. Straight section quadrupoles, sextupoles and COD magnets are driven by programmable supplies.

D. Control

All magnet power supplies have their own controllers which communicate to the central control system via coaxial cable. The controller contains digital, analog and ADC circuitry required for either local or remote operation of the power supply. These units are based on existing G-64 format controllers currently in use at CERN.

III. Experimental Work

A test facility was set up to investigate resonant circuit parameters at intermediate and full operating power levels.

Preliminary tests were carried out using NINA magnets to investigate dual frequency resonance as it would apply to the Driver ring. Tests were conducted at 50 Hz nominal

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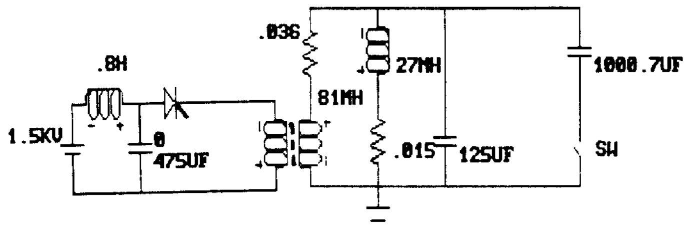

Figure 2: Dual frequency test circuit.

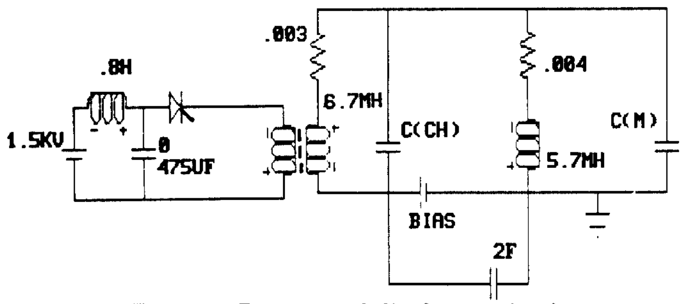

Figure 3: Booster and dipole test circuit.

repetition rates with 33.3 Hz rise and 100 Hz fall components. The results of this investigation were a first step in choosing appropriate parameters for the full system design as they would apply to the Booster and Driver synchrotrons [3–6]. Test circuit shown in Fig. 2.

A Booster dipole prototype was constructed and the test facility was reconfigured to excite the magnet to full operating level at 50 Hz with dc bias, for magnet measurement purposes (Fig. 3). Various tests were carried out at 50 and 33 Hz to establish circuit performance. The results of these tests with regards to the shift in the natural resonant frequency as a function of excitation and the implications on ac makeup power requirements help to define system requirements as well as giving a good basis for the development of the various control loops [6].

IV. Test Results

The following graph (Fig. 4) presents results obtained while maintaining a constant voltage from the high voltage ac makeup supply with a starting magnet current of 500 A rms. The frequency of the makeup pulse was then varied from optimum to see the resulting changes in power requirement from the source. This test simulates a change of natural resonant frequency from the nominal operating point. Plotted are source current, peak pulse current, and magnet rms current vs. frequency.

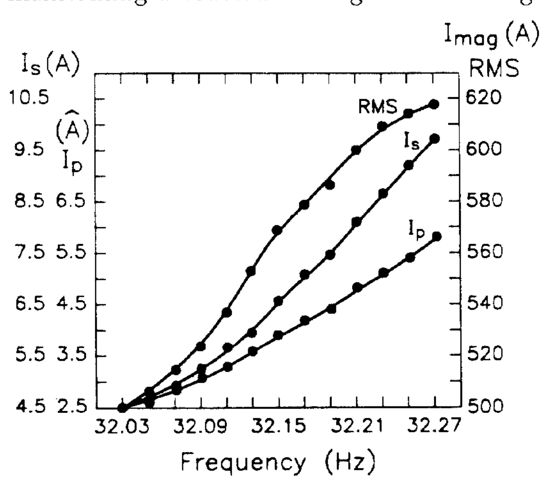

Figure 4: Ac makeup source current, pulse peak current and rms magnet current as a function of driving frequency with v_{source} constant.

Figure 5 shows the variation of the system natural resonant frequency as a function of ac excitation and dc bias level variation (32 Hz case).

Figure 6 shows the variation of ac makeup power as a function rms magnet current and dc bias level (32 Hz case). The frequency characteristics are as presented in Fig. 5.

Figure 7 shows the variation of the system natural resonant frequency as a function of ac excitation and dc bias level variation (50 Hz case).

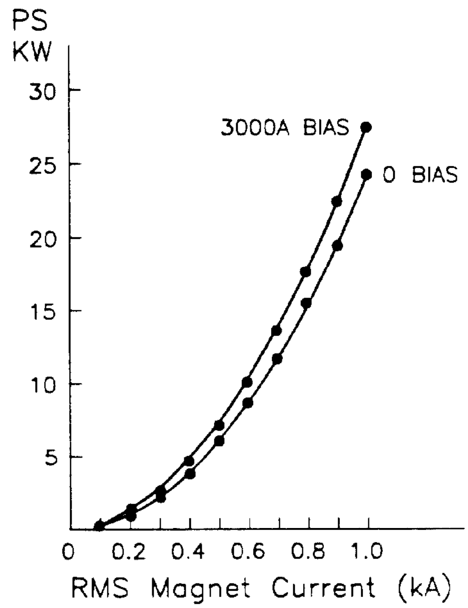

Figure 5: Ac makeup power as a function of excitation (32 Hz case).

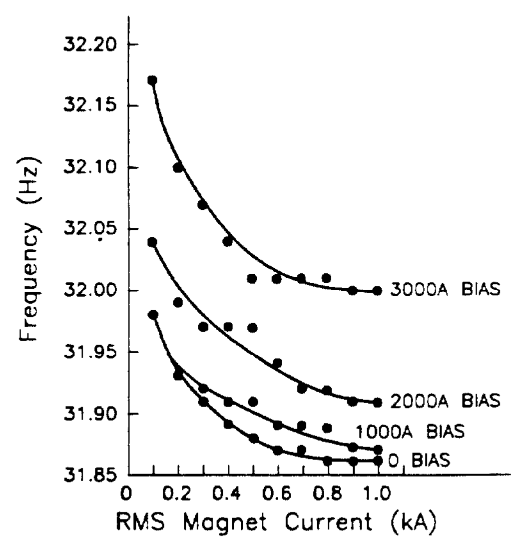

Figure 6: Shift in natural resonant frequency as a function of excitation (32 Hz case).

Figure 8 shows the variation of ac makeup power as a function rms magnet current and dc bias level (50 Hz case). The frequency characteristics are as presented in Fig. 7.

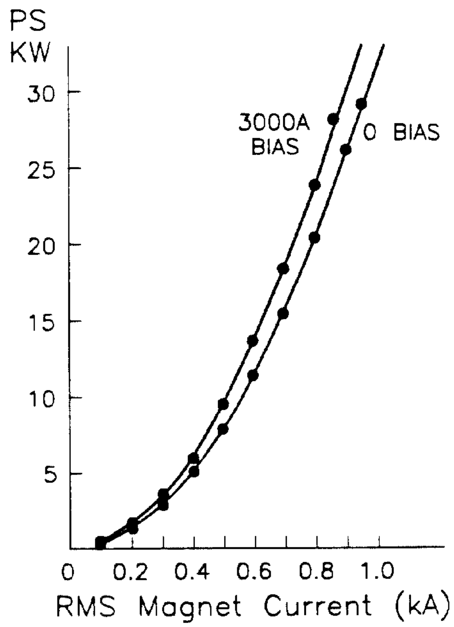

Figure 7: Ac makeup power as a function of excitation (50 Hz case).

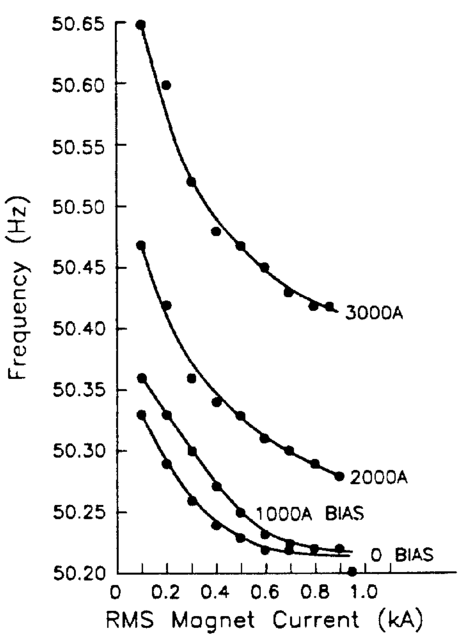

Figure 8: Shift in natural resonant frequency as a function of excitation. 50 hz case.

V. Conclusions

To obtain stable system operation, it is advantageous to excite the resonant circuit slightly off the natural resonant frequency, which will drift as a function of temperature and other parameters. This results in a fixed operating frequency. The power required from the ac energy makeup varies depending on the difference between the operating point and the natural resonant frequency. System detuning from optimum can be monitored by observing the variations in power delivered by the ac makeup supply. Dynamic tuning correction by the adjustment of the resonant capacitance, allows the system to operate at optimum power efficiency. These adjustments should be relatively infrequent and are only necessary when the normal dynamic operating range is exceeded.

Components for the ac power makeup portion of the driven slaved quadrupole resonant system must be overrated by some factor of 30 to 50% from nominal to allow for sufficient dynamic operating range to track the dipoles, as well as to have sufficient capacity to deal with natural resonant frequency shifts.

Test results show that due to the high Q of the circuits, a relatively small mismatch effectively doubles the current requirement from the power supply feeding the pulse forming network. This implies that the nominal rating of the supply must be significantly higher than required for optimum tune. The average current rating of the pulse forming network charging inductor must be conservative. The mismatch also results in significantly higher peak currents through the PFN switch and discharge inductor which must be appropriately rated. The discharge inductor must stay out of saturation since its inductance directly effects the width of the power makeup pulse which should stay constant, otherwise the result will be system instability.

VI. References

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[6] KAON Factory Study, 1990.