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A RESONANTLY COUPLED, FERRITE-TUNED BUNCHER-CAVITY SYSTEM FOR THE LOS ALAMOS PROTON STORAGE RING*

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Summary

Resonantly coupled buncher and ferrite-loaded tuning cavities at 503.125 MHz are separately optimized to provide fast tracking of time-dependent beam current changes in the Los Alamos Proton Storage Ring (PSR) while maximizing radio-frequency (rf) stability and efficiency.

Introduction

The PSR, now under construction at Los Alamos, is an addition to the existing Clinton P. Anderson Meson Physics Facility (LAMPF), the central feature of which is an 800-MeV proton linear accelerator (linac). The PSR is a high-current accumulator designed to convert long (100- to 750-μs) 800-MeV pulses from the linac into short high-intensity proton bunches ideally suited for driving a pulsed polyenergetic neutron source. The Ring will operate in a short-bunch high-frequency (SBHF) mode at 503.125 MHz for fast-neutron physics and a long-bunch low-frequency (LBLF) mode at 2.8 MHz for thermal neutron-scattering programs.

An important feature of the PSR is its rapid filling and extraction rate. Most storage rings have a slow fill rate and do not extract beam. Physics experiments are usually performed using the circulating beam in the ring itself. The Los Alamos PSR, in contrast, is a beam-manipulation device that provides high-intensity proton bunches to a neutron source located some distance away. Physics experimentation takes place with the neutron pulses thus obtained, rather than with the circulating beam in the Ring.

Protons are accumulated in the Ring in the form of bunches. The desired short bunch length is preserved by passing the beam through several rf buncher cavities operating in the cylindrical TM_{010} mode. The required frequency is 503.125 MHz, the 180th harmonic of the bunch circulation frequency. The Fourier component of the beam current frequency spectrum drives the cavities resonantly, inducing a large voltage in the buncher cavities. This voltage is in phase with the beam current, and is much larger than the bunching voltage supplied by the rf source, which leads the beam current by 90°. The vector sum of the beam-induced voltage and the source voltage must always be 90° ahead of the beam current to maintain bunching. If this condition is not satisfied, the stored beam will be accelerated or decelerated.

The cavity resonant frequency can be adjusted in proportion to the beam current to maintain the correct phase relation between the net cavity voltage and beam current. If the amount of cavity detuning is chosen to exactly compensate for the beam loading, no variation is required in either rf-source amplitude or phase. Because the accumulated beam current rises from zero to its maximum value in 100 μs, the buncher cavity resonant frequency should be capable of modulation at frequencies up to 100 kHz. The needed maximum-frequency swing in the buncher cavity can be obtained by resonant coupling to a tuning cavity whose frequency is varied over a much larger range, using ferrite that is subjected to a time-dependent bias magnetic field. Described here is a unique multicavity system that allows both bunching and tuning cavities to be separately optimized for their specific functions.

Resonantly Coupled, Ferrite-Tuned Buncher-Cavity System

A layout of the Ring is shown in Fig. 1. The 503.125-MHz buncher is split into four identical sections located in two diametrically opposite Ring locations. Each section consists of two buncher cavities, with a tuner cavity coupled to it. The tuner/buncher system shown in Fig. 2 is resonantly coupled and operates in the π/2 mode. Resonant coupling is used because it reduces amplitude changes in the cavities caused by detuning to a second-order

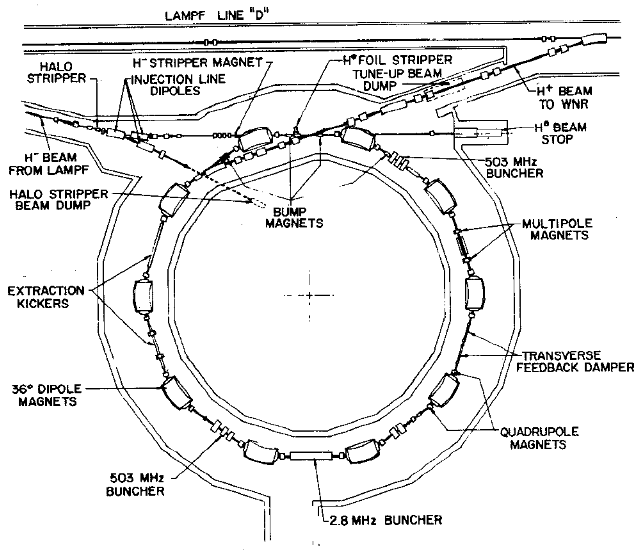

Fig. 1. Layout of the Los Alamos PSR.

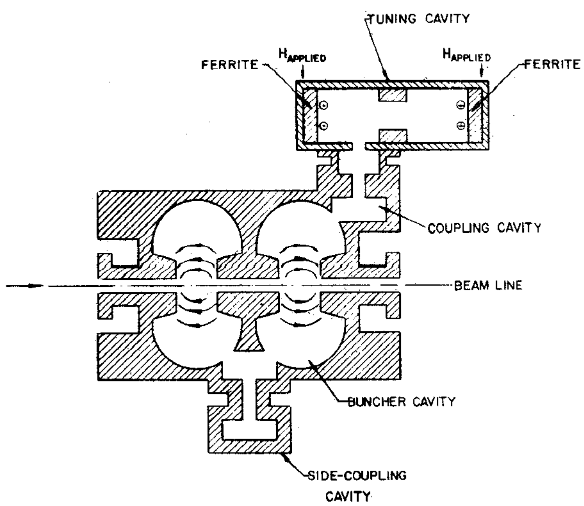

Fig. 2. Resonantly coupled, ferrite-tuned buncher-cavity system.

*Work sponsored by the US Department of Energy.

0149-645X/82/0000-0246 $00.75 © 1982 IEEE

effect. This resonant coupling permits excellent control of the amplitude ratio between the buncher and tuner cavities. The multicavity resonant-coupling design allows the buncher cavity to be optimized for interaction with the beam. The separate tuning cavity allows the ferrite to be placed in a region of low-rf-power density and allows effective cooling of the ferrite.

The tuning cavity consists of a shorted piece of ridge waveguide loaded with ferrite slabs placed against the side walls, where the rf magnetic fields are largest. The ferrite will be biased at an applied magnetic field far above the bias field needed for resonance, where losses are low and $\mu \gg \mu_0$. This applied field allows the cavity Q to approach the Q of an unloaded cavity. In this case, the rf magnetic fields in the cavity are perpendicular to the bias magnetic field.

Cavity Design

The buncher cavities were designed using the computer program SUPERFISH. This program solves the boundary value problem for the fields in a cylindrically symmetric cavity. Calculations were made for the resonant frequency, for the unloaded cavity Q, and for field profiles. Figure 3 shows a SUPERFISH output giving the electric field lines for the buncher cavity.

The program SUPERFISH was again used for the tuning cavity design. An option of the program allows the calculation of TE cutoff modes for a rectangular geometry. Another recently introduced option of SUPERFISH is the ability to place dielectric and magnetic materials in a cavity geometry. The SUPERFISH output for the tuning cavity is shown in Fig. 4. The calculated frequencies are for the cutoff mode. Since the tuning cavity is uniform in cross section along its entire length, the resonant frequency of the cavity can be calculated using the cutoff mode frequency.

The ratio of stored energy between the buncher and tuner is 100:1 to keep the power dissipated in the ferrite low. The ratio of tuning ranges is proportional to the inverse of the stored-energy ratio between the two cavities. Thus, a tuning range of 10 MHz in the tuner provides the needed 100-kHz range in the buncher. The rf power level in each of the bunchers is estimated to be 8.7 kW. Because of the difference in Q and stored energy in the buncher and tuner, ~575 W are dissipated in each tuning cavity. The ferrite will occupy ~3% of the volume of the tuning cavity. The expected dissipated power in the ferrite per tuning cavity is 115 W. This gives a power density of ~1.0 W/cm^3, which is to be removed by thermally bonding the ferrite to the cooled tuner-cavity walls.

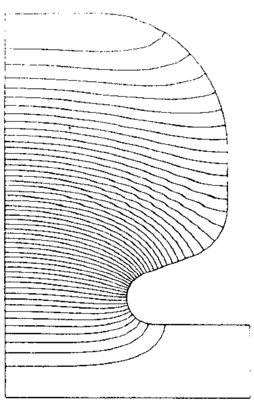

Fig. 3. SUPERFISH output for the buncher cavity showing the resonant frequency and electric field lines.

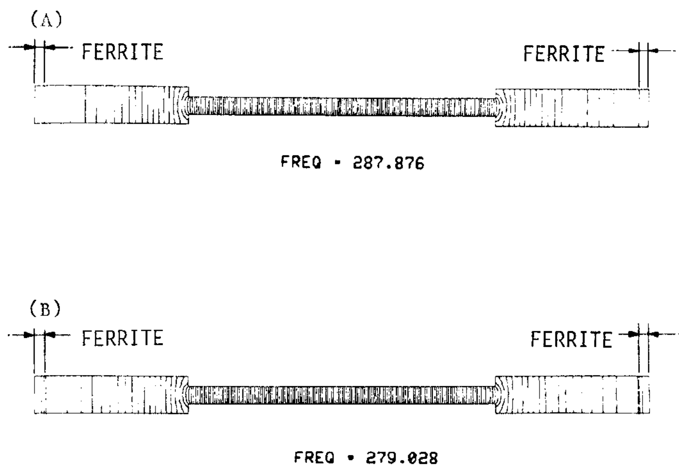

Fig. 4. SUPERFISH output for the tuning cavity showing the electric field lines for the cavity cross section. Resonant frequency calculations are for the cutoff mode in both cases. The dielectric properties for the two cases are (A) $\epsilon_r = 1$ and $\mu_r = 1$ and (B) $\epsilon_r = 14$ and $\mu_r = 2$.

Tuning-Cavity Experimental Results

A prototype tuner cavity (Fig. 5) was built to select an appropriate ferrite. Because far-above-resonance operation is used, a material with a low value of ΔH_k (spin-wave line width) is needed to obtain a high Q in the tuning cavity. Aluminum-doped garnets meet this requirement and also have a $4\pi M_s$ (saturation magnetization) value of 200 to 800 G. Several materials were tested, including calcium-vanadium garnet and aluminum-doped yttrium-iron garnet (YIG), but aluminum-doped YIG showed less loss

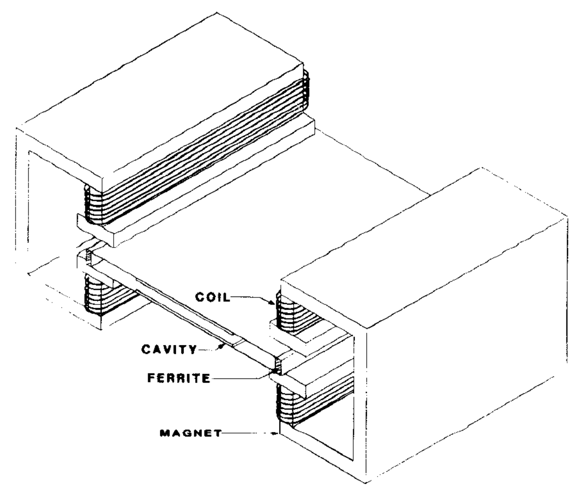

Fig. 5. Sketch of the ferrite-loaded tuning cavity prototype and bias magnet.

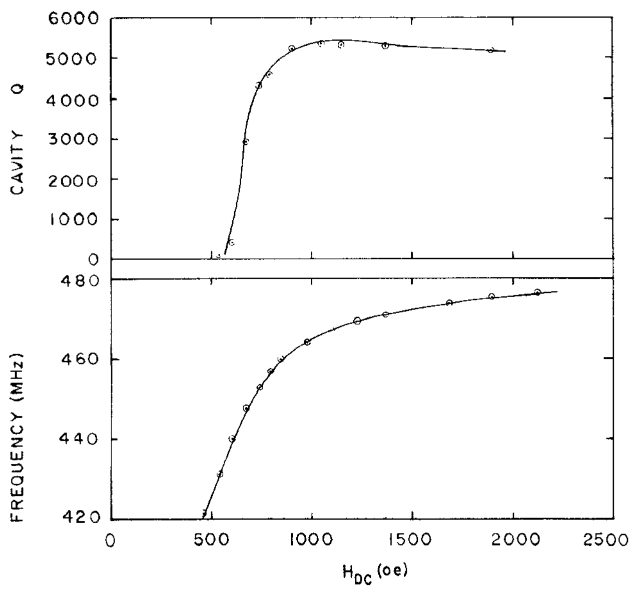

Fig. 6. Plot of resonant frequency and cavity Q versus applied magnetic field for the tuning-cavity prototype. The ferrite is Trans-Tech G-810.

for the same tuning range. Results from the prototype tuning cavity indicate >20-MHz tuning ranges (near 500 MHz) are possible at Q values above 5000. Figure 6 shows the results for one aluminum-doped YIG ferrite, Trans-Tech G-810, which has a $4\pi Ms$ value of 800 G and a ΔH_k value of 1.5 oersted. Plotted are the resonant frequency and Q value versus applied bias magnetic field. In this test the ferrite comprised 3% of the total cavity volume. The unloaded prototype tuner had a resonant frequency of 488.66 MHz and a Q of 5350.

The frequency tuning and Q measurements were done at low signal levels for selecting an appropriate ferrite. Using Trans-Tech G-810 ($4\pi Ms$ = 800 G) and Trans-Tech G-610 ($4\pi Ms$ = 600 G) tests were performed at power levels up to 40 W cw and 400 W pulsed. Peak power levels in the tuner cavities are expected to run near this value in the final system configuration. The pulse tests were made with a pulse width varying between 300 μs and 2 ms and a 60 Hz-pulse repetition rate. There were no observable nonlinear effects. The Q measurements were repeated at the higher power levels and no changes in cavity Q were found.

Conclusion

The resonant-coupling system separates the problem of designing a cavity for the interaction with the bunched beam from the problem of designing a tunable cavity incorporating a ferrite in an external magnetic field. The buncher cavity can be designed for high shunt impedance, whereas the tuning cavity can be designed to accommodate the requirements of the ferrite. Resonant coupling prevents the field distribution from being adversely affected by the detuning of only one cavity in the system. In addition, if the required tuning range is small, the stored energy in the tuning cavity can be reduced, trading tuning range for decreased power density in the ferrite. Finally, the experimental results from the prototype tuning cavity indicate a high Q value can be achieved over the required 10-MHz tuning range.

Acknowledgment

The authors would like to thank R. Vignato for his work on medium-power rf measurements.

References

1. G. R. Jones, J. C. Cacheris, and C. A. Morrison, "Magnetic Tuning of Resonant Cavities and Wideband Frequency Modulation of Klystrons," Proc. IRE, Vol. 44, pp. 1431-1438; October 1956.

2. C. E. Fay, "Ferrite-Tuned Resonant Cavities," Proc. IRE, Vol. 44, pp. 1446-1449; October 1956.

3. C. E. Nelson, "Ferrite-Tunable Microwave Cavities and the Introduction of a New Reflectionless, Tunable Microwave Filter," Proc. IRE, Vol. 44, pp. 1449-1455; October 1956.