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HIGH DUTY FACTOR STRUCTURES FOR e^+e^- STORAGE RINGS*

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Abstract

The next generation e^+e^- storage rings will need rf systems similar to those required for a continuous-duty linac of over 50 MeV. For the PEP Storage Ring at 18 GeV, it is presently planned to provide a peak accelerating voltage of 77 MV in 18 aluminum accelerating structures, each structure consisting of five slot-coupled cells operating in the π mode. The power dissipation will be 100 kW per cell for a total of 500 kW per five-cell structure at 353 MHz. A two-cell model has been designed and built to dissipate 100 kW per cell or a total of 200 kW. This structure has been powered (cw) to over 100 kW per cell and detailed calorimetric data have been taken and compared with the original heat transfer calculations. The power level achieved corresponds to a peak accelerating field (transit-time factor included) in the two-cell model of 0.8 MV per cell or 1.9 MV/meter. Operating experience with the SPEAR five-cell structure is discussed. The four SPEAR structures are each designed to operate with wall losses of 75 kW and up to 50 kW into the stored beam. Power to each structure is provided by a 125-kW high-efficiency four-cavity klystron. No isolation has been used and the resulting interaction between the accelerating structures, klystrons and the stored beams is discussed.

Introduction

At the last linac conference held in Los Alamos in 1972, a report was made [1] on considerations being given to using linac-type rf structures for high energy storage rings. For the upgrading of SPEAR, the e^+e^- storage ring at SLAC, it was necessary to produce cavity designs with the highest obtainable shunt impedances since the straight section space available for cavities was limited. An accelerating structure consisting of five cavities of high-shunt impedance-shaped cell design as shown in Figure 1 was built and successfully run in SPEAR.[2]

The cavities were constructed with 6061 aluminum alloy. Coupling is provided by azimuthal slots in the common end walls for operation in the π mode and cooling is provided by means of radial cooling channels bored close to the nose cones in the manner shown in Figure 2. The end walls of the cavities were machined from forgings and the outer shells were rolled from aluminum plates with cooling provided by circumferential water channels with externally welded covers. Each cell is provided with a water-cooled tuner and the coupling of rf power is by means of a water-cooled loop in the center cavity. Each cell was designed to dissipate 15 kW of rf power for a total of 75 kW for each five-cell structure. The power is fed to the coax loop from WR2100 wave-guide through a coax-to-wave-guide transition in which there is a cylindrical ceramic window as shown

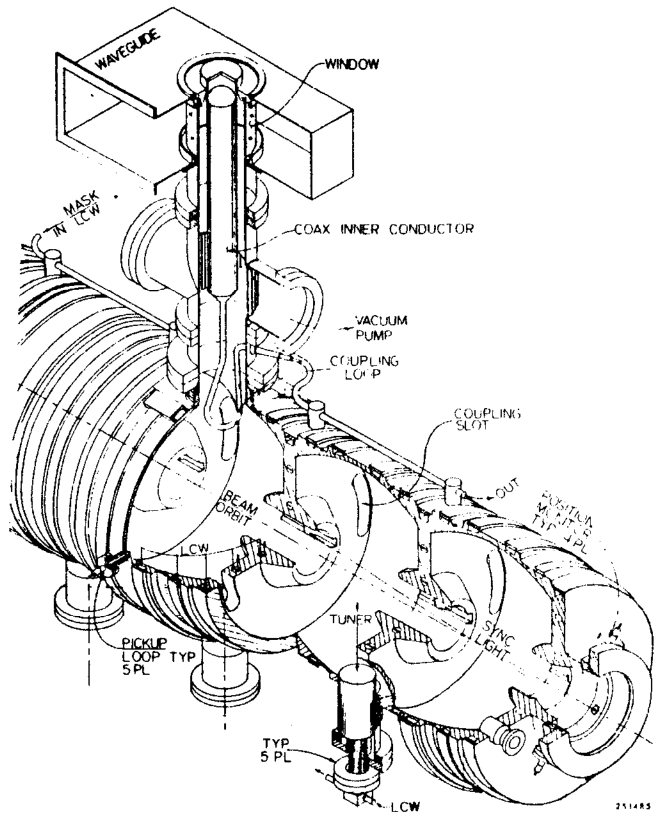

FIGURE 1. Cut-away drawing of SPEAR structure.

in Figure 1. To inhibit multipactor, the cavities were coated with a thin layer of titanium nitride. Each five-cell accelerator section is powered by a CW 125-kW klystron which was developed at SLAC.[3] Four of these cavities have been installed in the SPEAR storage ring and colliding beams have been obtained up to 4 GeV where the peak accelerating voltage required is over 6 MV.

An 18 GeV storage ring (PEP) is presently under design and construction at SLAC. In order to run at the highest energies, a peak accelerating voltage of about 80 MV is required. One mode of operation will be to provide this acceleration voltage by means of 18 five-cell accelerating structures similar to the ones described above. However, this will require power dissipation of 100 kW per cell for a total of 500 kW per five-cell structure. This paper describes the design and operation of a two-cell experimental structure capable of dissipating 100 kW per cell at the PEP rf frequency of 353 MHz.

Structure Design

It was desired to take advantage of the experience with the highly successful SPEAR II structures in order to minimize development time and costs. Although the SPEAR II cavities serve as a

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model for PEP cavities they required modifications to accomodate a small decrease in frequency, higher power dissipation and other required changes. As part of this redesign, cost reductions were effected wherever practical. The reduction in frequency meant scaling the size of the cavities up to approximately 1.5% to bring the frequency down from 358.54 MHz to 353.21 MHz.

The spherical shape of the SPEAR cavity shells was abandoned in favor of a more economical cylindrical shape, 1100-F aluminum plate material was substituted for 6061 throughout, and plate substituted for

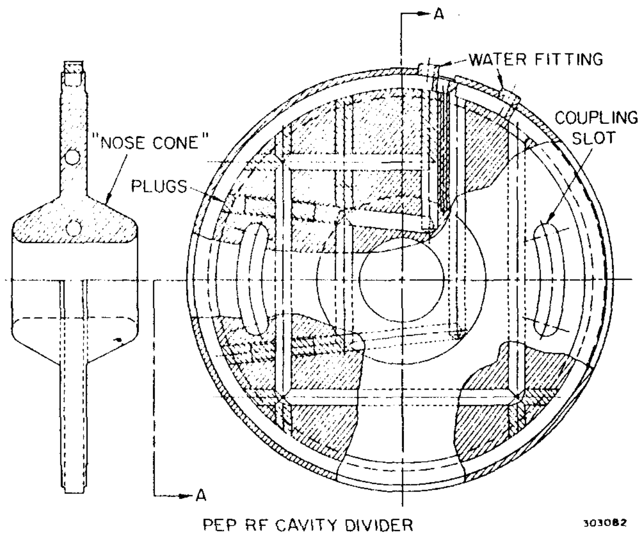

FIGURE 2. Cut-away drawing of cavity divider wall.

aluminum forgings for the dividers and end closures. The decrease in shunt impedance brought about by the cylindrical shape was offset by the increase in shunt impedance by the use of the higher electrical conductivity (about 16%) 1100 alloy. This change in alloy also increased thermal conduction and the change to plate simplified material acquisition and lowered costs. The modified SPEAR cavity design was then subjected to a heat transfer analysis and compared with the original design. The first analysis assumed the same nose cone shape (and certain other cooling water parameters) as in SPEAR. The maximum temperature of the nose tip was then calculated to be 160^{o}C and 118^{o}C above that of the bulk cooling water temperature for 6061 -T4 and 1100-F aluminum materials respectively. Since the PEP cooling water will be supplied to the cavities at 35^{o}C, and rises 20^{o}C in the cavities, one should add the resulting 45^o mean bulk water temperature to the above differentials. Nose tip temperatures of 205^{o}C and 163^{o}C would then be indicated for the 6061 and 1100 materials respectively. Thickening the nose cone and using 1100-F aluminum reduced the predicted nose tip temperature to 125^{o}C. This was felt to be adequately below the 180^{o}C bakeout temperature to minimize outgassing. Further detailed heat transfer analyses indicated requirements for increased cooling in the coupling loops and tuners. The net effect of the above changes on thermal detuning was calculated to be within the range of the cavity tuners.

Experimental Model

A 2-cell cavity, shown in Figure 3, was constructed to test the new design at the PEP operating level of 100 kW dissipation per cavity cell and a modified SPEAR klystron was used to power it to over 200 kW. Since the SPEAR klystron was available, the cavity was designed to the SPEAR frequency of 358 MHz. A coating of titanium nitride was added as a multipactor inhibitor by evaporating a source of titanium in each cell in a partial pressure of 2 x 10^5 Torr nitrogen. It was planned to deposit a layer of between 100 and 1000 A^o thick but unfortunately considerably more was deposited with a consequent reduction in the unloaded Q_0 and shunt impedance R. The measured Q_0 was 22000 (Q_L was 12,500 with the loop set for critical coupling). The R/Q by a sapphire rod measurement is 302 MΩ transit time corrected, giving a shunt impedance of 6.6 MΩ. Thus, at 100 kW per cell the peak accelerating field with transit-time factor is 0.8 MV per cell or 1.9 MV/meter. If the Q_0 was at design value of 25,000, the accelerating field would have been over 2 MV/meter.

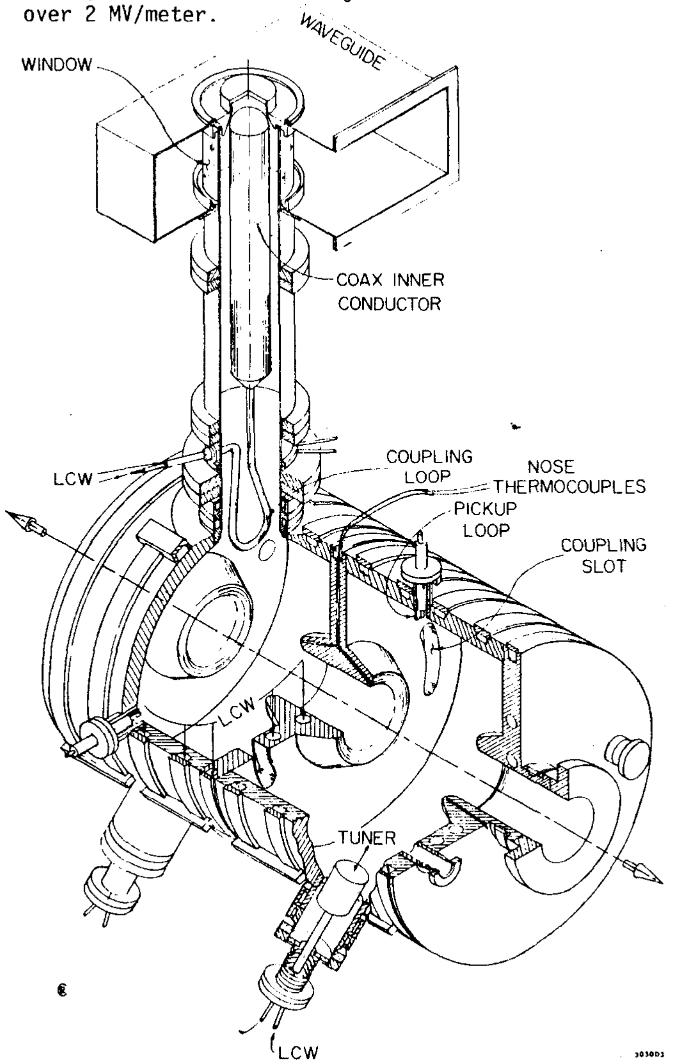

FIGURE 3. Cut-away drawing of experimental 2-cell structure.

Calometric data on all water cooling channels was taken at several power levels into the cavity. These were taken using venturi meters to measure flow rates and thermocouples to measure input and output water temperatures. The predicted nose-tip temperature was verified by direct measurements using thermocouples imbedded in the nose cones. The results are shown in Figure 4 where the nose cone temperatures are given as a function of power into both cavity cells. It is noted that the nose cone temperature rise is as predicted by the heat transfer analysis and is adequately cooled to allow the structure to receive a 100 kW per cell. Less than half of the available tuner travel was required to correct for 100 kW per cell power dissipation changes. The remaining travel is available to correct for unequal power distribution between the cells, beam loading, manufacturing variations, and other variables.

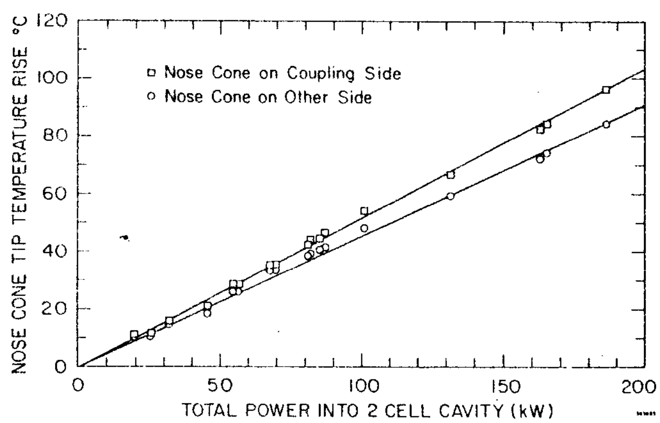

FIGURE 4. Temperature of nose cones as function of total rf power.

Further experiments were conducted for the purpose of identifying major sources of the thermal detuning. By decreasing or increasing flow through individual water channels it was possible to identify those channels that had the most effect on tuning. The amount of compensating tuner movement was used as a measure of thermal detuning. Normal water flow rate was taken to be that which resulted in a 20^{o}C rise when the cavity was operated at 100 kW per cell. The largest tuner movements were observed to occur when the water flow in the shells were varied. By simply increasing the water flow through the shells, thermal detuning was shown to decrease significantly. Insufficient water velocity and resulting loss of surface coefficient of heat transfer in the shell was identified as the major single source of detuning and will be corrected by a plumbing change.

The cavity was also operated with one tuner fixed to test if omission of three out of five tuners in the PEP cavities is feasible.

The strong coupling between cells allows the tuner placed in one cell to pull the frequency of the entire structure. If $\delta\omega/\omega$ is the frequency shift by a tuner in one cell, the droop in field profile to the untuned cell is given by [1,4]

$$\frac{\Delta E}{E} = \frac{1}{2k}\frac{\delta\omega}{\omega}$$

$$k = \frac{2[\omega(\pi) - \omega(o)]}{\omega(\pi) + \omega(o)}$$

For the two cell model k = .005 and thus to keep the field droop to less than 1 db, the frequency shift between cells must not be greater than about 0.4 MHz.

Typical test results are shown in Figure 5. The tests were conducted at power levels up to 150 kW (75 kW/cavity). One tuner was fixed while the other tuner kept the two coupled cells on resonance. The cavity field levels show the resulting relative power division between the two cells. Note that the two cells show no field droop at 110 kW (55 kW per cell). The power levels corresponding to no field droop could be altered by changing the position of the fixed tuner. The tests indicate that while operation at 100 kW per cell with one tuner fixed is marginal, operation at lower power levels may be feasible. The problem as stated above has been identified as due to inadequate cooling probably largely in the shells. As the shells expand, the cells detune at a rate of 1.15 MHz/cm change in shell length. Thus to keep the field droop due to shell expansion within 1 db using only one tuner, the thermal expansion of the shells must be kept below 3.5 mm and this can be achieved by increasing the water flow to the shells. For the 5-cell PEP structure the coupling k will be almost .01 since in the 3 center cells there are four coupling slots per cell instead of the two coupling slots per end cell, and it is anticipated that tuners in only two of the five cells will be sufficient to accomodate both thermal detuning and beam loading.

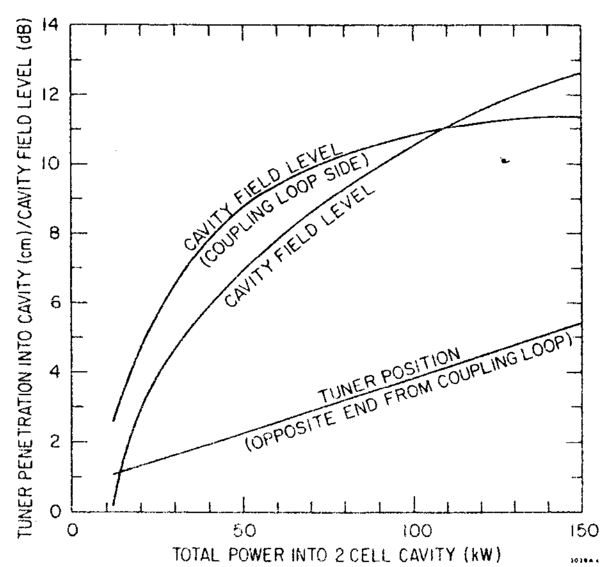

FIGURE 5. Tuner movement with one tuner fixed.

Operation in a Storage Ring

The installation of the four 5-cell cavities into SPEAR was completed almost two years ago. The four cavities were each designed to operate with wall losses of 75 kW and up to 50 kW into the stored beam. The power to each cavity is provided by the SPEAR 125 kW high efficiency four-cavity klystron.[5]

Initial operation was made difficult due to instabilities in the klystrons when they were operated below saturation. Adjustments of klystron cavity tuning eliminated many of these instabilities. The klystron was still very sensitive to the load impedence since no isolator was employed. The electrical length between the klystron detuned short position and the cavity detuned short position was measured and all klystron positions were located to make that electrical length an integral number of half wave lengths.[5] This stabilized the klystron over most of its operating range. There are, however, still values of klystron collector voltage at which the klystron puts out spurious oscilations, but these values can be avoided in normal storage ring operation.

Conclusion

The two-cell experimental results and the SPEAR operating experiment provides a firm basis for the design of the PEP rf system. This system is similar to the rf system of a continuous-duty linac in the greater than 50·MeV range.

References

1. M. A. Allen and P. B. Wilson, Proceedings of the 1972 Proton Linear Accelerator Conference, Report No. LA-5115, Los Alamos Scientific Laboratory, Los Alamos Scientific Laboratory, Los Alamos, New Mexico (November 1972), p. 279.

2. M. A. Allen, et al., IEEE Trans Nucl Sci NS-22 1269 (1975).

3. G. T. Konrad, Trans Nucl Sci NS-22 1249 (1975).

4. P. B. Wilson, IEEE Trans Nucl Sci NS-16, 1092 (1969).

5. E. Hartwig and R. A. McConnell, Private Communication, 1976.

Acknowledgements

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