SPEAR 2 RF SYSTEM LOADS*

J. Sebek†, A. Hill, J. Judkins‡, A. Krasnykh, S. Park, H. Schwarz
Stanford Linear Accelerator Center, Stanford, California 94025

Abstract

The design and performance of higher order mode (HOM) dampers for the SPEAR 2 RF system is presented. The SPEAR beam had experienced occasional periods of instability due to transverse oscillations which were driven by HOMs in the RF cavities. A substantial fraction of this RF energy was coupled out of the cavity into the waveguide connecting the cavity to the klystron. This waveguide was modified by adding a stub of smaller cross section, terminated by a ferrite tile load, to the system. Design considerations of the load, and its effect on HOMs and beam stability will be discussed.

1 INTRODUCTION

SPEAR is a 3 GeV electron storage ring used for synchrotron radiation. It was built before the various impedance mechanisms causing instabilities were well understood, so its radio-frequency (RF) accelerating system lacks many of the items now standard in such systems. Since the RF system will be completely replaced in the 2003 SPEAR 3 upgrade, it is not reasonable to completely modernize the old system. Rather, we have limited our improvements to those needed to provide stable, reliable beam during the remaining lifetime of the RF system.

SPEAR has two RF stations, each consisting of a 358.533 MHz klystron, waveguide, and cavity. These systems were built with no circulators, temperature regulation, or higher order mode (HOM) dampers. The waveguide runs are long (one runs for 75 meters and the other about half that length) and most of the waveguide is outside, in the open air. Changes in environmental conditions, ambient temperature and pressure, have caused beam instabilities that are documented elsewhere [1]. Fortunately, the thresholds of these observed instabilities have been high enough that, as these causes have been discovered, they have been eliminated with inexpensive solutions targeted for the specific problems.

2 TRANSVERSE INSTABILITY

A horizontal transverse instability correlated with small deviations of the waveguide dimensions had been discovered several years earlier [1]. The instability strength was large enough to create beam motion that disrupted user data collection, but not large enough to cause beam loss. Minute adjustment of the guide dimensions changed the resonant frequency of the structure enough to detune the resonance that drove the instability. This control was sufficient to keep the beam stable almost all of the time. During the summer months, when daily temperature excursions are maximum, however, the range of the waveguide control was insufficient to always keep the beam stable.

Our solution for this problem was to install an HOM damper in the waveguide. The cavities, themselves, have neither dampers nor ports for them. Designing a damper for the cavity would have involved substantial R&D and the time needed to design, construct, and install a cavity damper was longer than the normal summer shutdown would allow. However, a damper in the waveguide could be built relatively quickly as a replaceable waveguide section, is outside of the vacuum system, and, in the event of unforseen problems, could be easily replaced with the original configuration. What needed to be determined was if such a damper would be effective.

2.1 Observations

We could measure and quantify the existing system. Our waveguides have directional couplers, normally used to measure the forward and reflected power of the RF fundamental, mounted along the broad wall of the guide. These couplers are broadband, so that they could be used to identify the existence and strength of the mode in the guide, as well as the total broadband power travelling from the cavity into the guide.

HOM Identification The waveguide spectra, spanning the range from 358 MHz to 3 GHz, were acquired automatically, via GPIB, from a laboratory spectrum analyzer connected to the coupler. The presence of the signal in the guide was verified by comparing the spectra of betatron sidebands when the instabilities were present and absent. The instability was sufficiently weak that it was confined to the Fourier mode excited by the driving resonator impedance. In the guide, of course, the signal aliased into the other harmonics n of that Fourier mode where n satisfies

$$n f_{rev} = (p \cdot h + q_{HOM})\, f_{rev},$$

with h the SPEAR harmonic number, q_{HOM} the Fourier mode number, and p an arbitrary integer. After comparing this spectra with that from a pickup in the cavity, the signal from the driving resonance, around 1.2 GHz, was verified to couple into the guide.

Power Requirements The power handling requirement for the waveguide load also needed to be determined.

* Work supported by Department of Energy contract DE-AC03-76SF00515.

† sebek@slac.stanford.edu
‡ Currently with Tropian, Inc., Cupertino, CA

0-7803-7191-7/01/$10.00 ©2001 IEEE.

This number could be calculated with the same data obtained in the above measurement. The integrated total power spectrum gives the maximum power the load must handle, about 3 kW. This is, of course, a conservative estimate, since not all of the power will be absorbed by the load.

3 LOAD DESIGN

3.1 Size and Placement

The first part of the design was to identify a location for the load which would have reasonable coupling to the HOM in the guide. There is an H-mitre three meters from one cavity and an E-mitre at the other. These were identified as the sections that would be modified to include the load. The guide is standard WR2100 (21×10.5 in) with a cutoff frequency of 281 MHz. By cutting a 10.5 in square hole in the mitre, and using that for a port to the load, one can pass virtually all of frequencies that can be supported in the cavity while stopping the RF fundamental, with an 11 cm evanescent length. By extending the load port over .5 m before attaching the load, the fundamental power dissipated in the load becomes entirely negligible.

It should be noted that, although one specific mode was identified as the source of last year's instability, experience with the cavity suggests that there are probably other modes nearly as harmful in a similar frequency range. Therefore the load should be rather broadband, coupling rather well to frequencies of 1 GHz and higher.

In this range the guide is overmoded, and we were not able to make any invasive measurements to detemine the structure of the spatial mode(s) in the guide that contribute to the instability. From the geometry of the coupler that brings the fundamental into the cavity, we could make an educated guess of the modes that couple out of the cavity.

The coupler has a "J" shape; the vertical post is in the waveguide, centered in the broad wall, and the loop is in the cavity. It couples strongly only to guide modes that have a vertical electric field in the center of the broad wall, so only waves out of the cavity with this spatial characteristic will couple to the guide. By placing the load port in the center of guide, one can insure that the load will couple well to these modes.

3.2 Simulations

Simulations were performed using both HFSS and MAFIA to calculate S_{31} of the modified mitre, the transmission coefficient from the cavity to the load. Both of these codes calculated a range of $.2 \lesssim |S_{31}| \lesssim .5$ for S_{31} over the frequency range.

HFSS was also used to calculate the matching post required to tune the modified mitre assembly. Even though the fundamental does not propagate in the load, the load still presents a reactive impedance to the fundamental propagating from the klystron to the cavity. Failure to compensate this impedance would produce a standing wave in the guide, increasing both the field strengths in the guide and the reflected power seen by the klystron. A capacitive diaphram provided the necessary compensation for one mitre; a capacitive post matched the other.

Figure 1: Mitre converted into port for waveguide load. Note the cylindrical pipe welded into the inner broadside corner for matching f_{RF}.

3.3 Load Construction

The port was constructed simply by cutting a square hole in the tapered section of the mitre. An aluminum duct, with square cross section, was fabricated and welded to the hole in the mitre. The open end of the duct was tapered at a 45^o angle with respect to the vertical. The load was attached to a waveguide flange that was welded to this end of the duct.

The design of the load is derived from similar loads built first at ALS [2] and then for the PEP-II RF system [3][4]. In fact it is even simpler than the PEP-II design. While the PEP-II load is under vacuum, and therefore has stringent manufacturing requirements, the SPEAR load is only in the dry air waveguide environment. The load is composed of an array of 5 cm square ferrite tiles. These tiles are brazed onto a copper plate thick enough to have water passages drilled parallel to the face of the plates. The calculated maximum 3 kW power load is easily dissipated by standard water cooling. The load plate assembly is mounted at a 45^o angle to the vertical. Previous measurements of the PEP-II load showed this design to be very well matched, with its $VSWR \simeq 1.1$.

3.4 Testing

The only tests required for the load assembly were to guarantee the matching of the fundamental. The operating strength of the field in the waveguide is well below the guide rating, so no high power tests were required. A laboratory network analyzer, using a calibrated WR2100 test kit, was used to accurately position the tuning posts. It

Figure 2: Ferrite tiles brazed on copper plate with cooling lines attached.

was straightforward to obtain reflected power levels such that $|S_{11}| < .01$.

Figure 3: Test setup for adjusting matching for f_{RF} in modified mitre.

4 OPERATIONAL EXPERIENCE

The performance of the loads has met expectations. The targeted transverse instabilities have been eliminated throughout the last run. Also, the machine tuning required to avoid other instabilities, both longitudinal and transverse, is much less sensitive now than before the installation of the loads. The cooling of the loads is also more than adequate. Temperature measurements of the output water record negligible temperature rises.

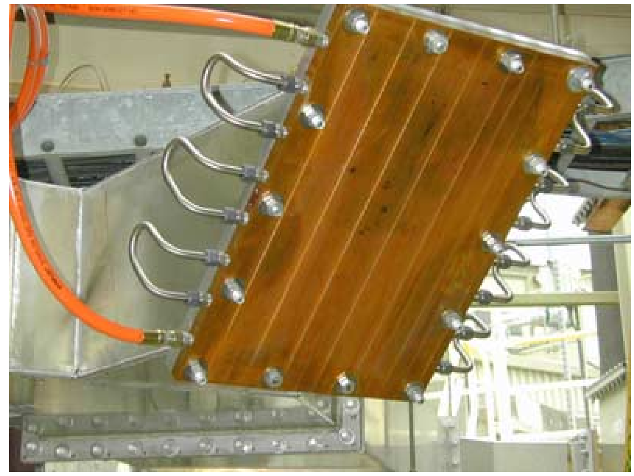

Figure 4: Finished waveguide load installed and in operation.

5 SUMMARY

Changes in the RF waveguide, due to environmental conditions, introduced HOMs which caused infrequent transverse instabilities that corrupted user data. By characterizing the frequency and strength of the responsible impedance, we could specify the requirements for a load that would damp these oscillations. Using the technology and experience gained during the development of the PEP-II RF system, we were able to efficiently design and construct these loads. The installation of these loads has eliminated the targeted instablility problem and reduced the machine sensitivity to other HOM instabilities.

6 ACKNOWLEDGEMENTS

The authors would like to thank the SSRL and SLAC technical departments which accurately and efficiently fabricated, constructed, and installed these loads. We also thank Max Cornacchia for his strong support in all phases of this accelerator improvement project.

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