Diagnosis and Cure of a Transverse Instability in the NSLS VUV Ring*

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Abstract

A beam instability occurred as a function of cavity tuner position, restricting the operating range of the tuner and requiring the cavity to operate at an elevated temperature to compensate. The cavity mode responsible for the instability was diagnosed and subsequently damped with a tuned probe terminated in 50 Ω. The instability was cured, and has not been observed up to the design current of 1 ampere stored beam.

I. INTRODUCTION

The NSLS VUV ring is a 750 MeV electron storage ring with a design current of 1 ampere. The ring parameters are given in Table I.

Table I VUV Ring Parameters

Nominal Energy	750 MeV
Nominal Current	1 amp
Circumference	51 meters
Rotation Frequency	5.87544 MHz
Nominal Tunes υ_x, υ_y	3.12, 1.2
R.F. Frequency	52.887 MHz
R.F. Peak Voltage	100 kV
Number of R.F. Buckets	9

The ring is in operations serving the UV user community with brief interruptions for maintenance and machine studies. During these operations, it was discovered that the beam would become unstable, undergoing violent oscillations, and above a nominal current threshold of 800 milliamps the beam would dump. The instability was correlated to a particular cavity tuner position. The tuner is required to compensate for the beam loading of the cavity to maintain the generator current in phase with the cavity voltage. In order to avoid the offending tuner position the cavity was operated at an elevated temperature to obtain the equivalent detuning. This study was undertaken to determine the cause of the instability, cure it and so remove the restriction on tuner movement.

II. DIAGNOSIS

Machine studies were undertaken to discover the cause of the instability. Because of the correlation to the R.F. cavity tuner, a coherent bunch-bunch instability caused by a cavity higher order mode was suspected. After several beam crashes a current threshold was found, below which the beam would oscillate but not drop out. Under these conditions the instability could be studied in more detail, although the beam lifetime was severely curtailed. A spectrum analyzer was connected to an R.F. pickup in the cavity to study the cavity response to the beam excitation. Normal fills of seven bunches were used with rotation line separation of 5.8754 MHz. Sidebands at 800 kHz identified the instability as transverse (horizontal) since the fractional horizontal betatron tune times the rotation frequency equates to the sideband separation from the rotation lines. A deviation from the nominal horizontal tune is noted, which is due to operation with a slightly different tune and perhaps a tune shift associated with the instability.

Further studies identified sidebands around two rotation lines which were found to be of particularly large amplitude. The rotation line at 458 MHz had a lower sideband at 800 kHz separation, (horizontal betatron), whose amplitude was >20 dB above the rotation line, shown in Figure 1.

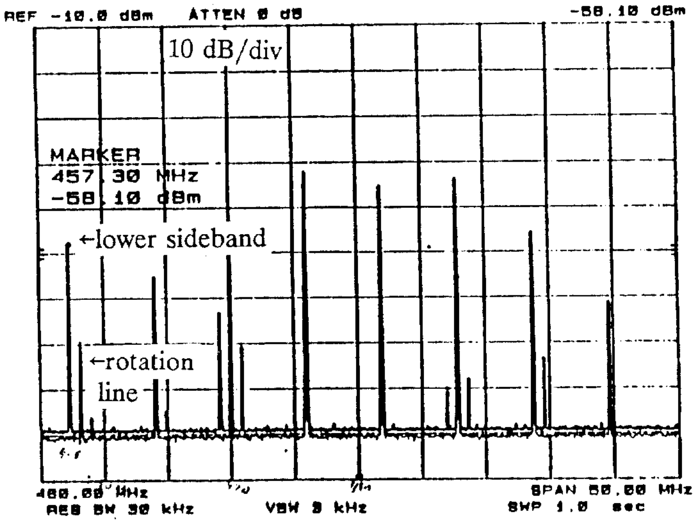

Figure 1. Lower betatron sideband at 458 MHz as measured in cavity with loop pickup, excited with 750 mA stored beam, 7 bunches, during instability.

A second rotation line at 352 MHz (not shown) had a lower betatron sideband whose amplitude was >10 dB above the rotation line. This indicated a high impedance parasitic mode to be slightly lower in frequency than the rotation line, such

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* Work performed under the auspices of the U.S. Dept. of Energy

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that the lower sideband can excite the mode. A narrower span with higher resolution clearly shows the upper and lower sideband response of the cavity to be skewed, again indicating that the cavity mode lies close to, but lower in frequency than the rotation line (Figure 2), which is the unstable (anti-damping) side.

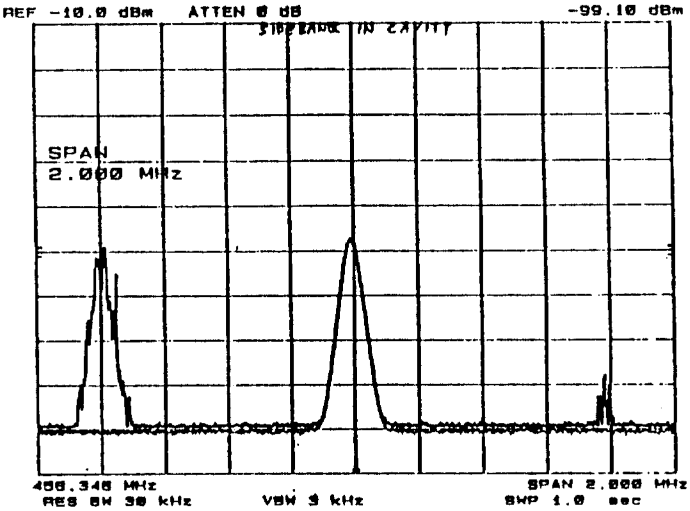

Figure 2. VUV Cavity response as excited by 700 ma 7 bunch.

These measurements were repeated for symmetric bunch fills with three and nine bunches. The beam instability still occurred for the three bunch fill, but could not be initiated with nine bunches (all buckets filled). The VUV ring has known ion trapping problems with nine bunch operation, and a possible explanation for the above result may be the increased Landau damping due to the bunch size increasing during ion trapping.

Cavity mode calculations were then performed with the code URMEL[1] identifying dipole modes near these frequencies. The URMEL cavity parameters for the two modes are listed in Table II.

Table II URMEL Data for dipole modes (mrot=2).

Frequency	Shunt Impedance	Q
353 MHz	4.6 MΩ/m	48139
449 MHz	1.69 MΩ/m	48392

Mode measurements on the cavity were conducted and confirmed cavity modes at these frequencies. Slight differences between calculated and measured mode frequencies are the result of various vacuum ports, slug tuners, and other penetrations on the cavity. Measured frequencies also vary with cavity temperature, and with the RF power on and the cavity actively cooled these modes can shift a MHz or more. A series of measurements made with an identical 52 MHz cavity showed that a dipole mode at 447 MHz had a strong coupling to the loop tuner which would split the dipole into two orthogonal modes with the higher frequency orientation changing frequency over 10 MHz from the retracted to fully inserted position of the tuner. This frequency shift is sufficient to guarantee the mode crossing the lower betatron sideband of a rotation line. The tuner on the VUV cavity is mounted in the horizontal plane, which would lead to the high frequency (magnetic field) perturbation of the dipole to be oriented with a vertical magnetic field in the gap. This corresponds to the observed horizontal instability. The 352 MHz dipole showed a similar behavior, except with the "traveling" or perturbed mode moving lower in frequency indicating electric field coupling to the tuner. The magnetic field in the gap due to the 352 MHz polarization of this dipole was measured to be parallel to the plane of the tuner, corresponding to a horizontal magnetic field in the VUV cavity. This orientation would give rise to vertical beam displacements, and so leads us to believe that it was not responsible for the instability.

III. CURE

Tuned probes were developed on a spare test cavity to damp both the 352 MHz and 458 MHz modes. These probes consist of an E-field probe which is inserted into the maximum electric field of the mode and terminated in a water cooled 50 Ω coaxial termination. There were only four available ports available for the damping antennas, limiting the access to the desired modes. In addition, all experiments had to be performed on a test cavity which was mirror symmetric with respect to the access ports and the tuner, causing differences in the fields between the test cavity and the operational cavity. This was particularly true of the modes we were interested in, which were highly coupled to the tuner.

The E-probe mode suppressors were installed during a maintenance period. The cavity response was measured via loop coupling and is shown in Figure 3 prior to damping and in Figure 4 after damping.

This measurement was made with a network analyzer in a transmission measurement using the main drive loop and a small pickup loop, in a plane at 45 degrees with respect to the tuner providing coupling to both vertical and horizontal polarizations of the dipole.

Significant differences in the performance of the mode suppressors on the test cavity and the VUV cavity were noted. This is assumed to be due to the difference in tuner location and the 8 tuned E-probe mode suppressors which were already in the VUV cavity. The dipole mode at 352 MHz was only damped by approximately 2 dB. The dipole at 458 MHz was damped by greater than 8 dB, however the Q of the mode was not measured before the damping probe was installed, and the response as measured in Figure 3 was made over too wide a span to accurately determine the peak, with too few samples taken for such a high Q mode. The Q was measured after the probes were

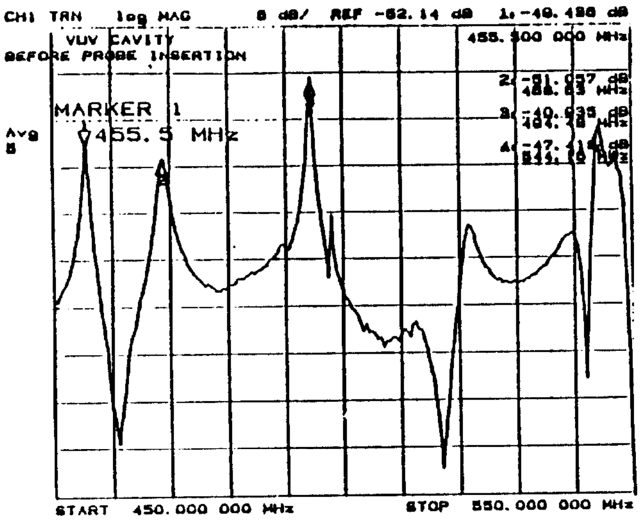

Figure 3. VUV cavity response before installation of tuned HOMS.

installed, and the lower frequency (451 MHz) polarization Q was 150. The higher frequency polarization, believed to cause the instability, response was in the noise, as shown by marker 2 in Figure 4.

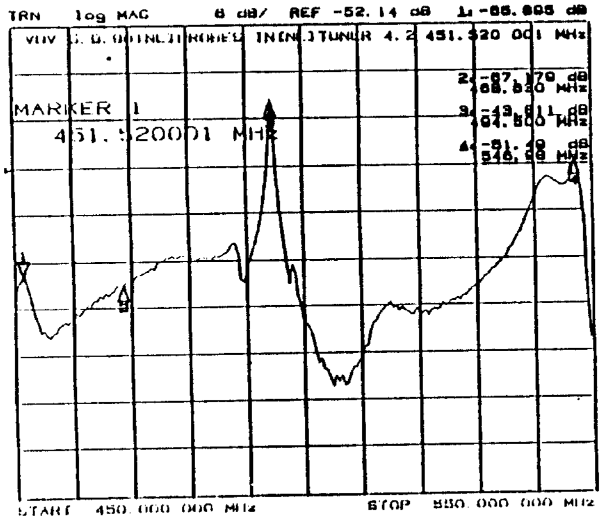

Figure 4. VUV Cavity response after HOMS installation.

After the installation of the mode suppressor probes the transverse instability could not be induced at any tuner position or beam current up to the design current of 1 ampere.

An unwelcome side effect of the probe installation was the shifting of an existing longitudinal instability which was also a function of tuner position to a different tuner position. The temperature setpoint of the cavity was changed to prevent operation about the new location. Prior to the study the tuner had to avoid positions of 130 mm insertion due to the transverse instability and 52 mm due to the longitudinal. After the transverse modes were damped the longitudinal mode moved to a tuner position of 169 mm, close to the maximum insertion of 178 mm. The operating range was moved from the tuner restricted between 130 and 178 mm to values below 169 mm insertion. This allowed the cavity operating temperature, which also acts as a tuner, to be reduced from 67 degrees C to 59.9 degrees C at 800 ma beam current.

IV. SUMMARY

An instability which restricted tuner movement in the RF cavity was determined to be related to a dipole cavity mode at either 352 or 458 MHz. Tuned probes were developed on a test cavity which had port and tuner locations which were a mirror image of the VUV cavity. Significant differences in the performance of the mode dampers prevented any appreciable damping of the 352 MHz mode, but damped the polarization of the 458 MHz dipole responsible for horizontal beam displacements to negligible levels. In retrospect, a three dimensional RF code analysis of the cavity modes as a function of tuner position may have been warranted, and could have led to only a single probe being installed.

Based on the above experience, a broadband mode damper is being developed for the future synchrotron cavities at the NSLS.

1) T. Weiland, Nuclear Instruments and Methods 216, 329 (1983)