MICROPHONIC ANALYSIS OF CRYO-MODULE DESIGN[1]

A. Marziali and H.A.Schwettman
W.W.Hansen Experimental Physics Laboratory
Stanford University
Stanford, CA 94305-4085

Abstract

Mechanical resonances in superconducting accelerator structures and cryo-module components can lead to coupling between mechanical noise and electron beam parameters. We have studied the mechanical resonance spectrum of a 500 MHz 2-cell structure and cryo-module that was designed and built by Siemens for TRW, Inc., and have measured the effect of these vibrational modes on the RF eigenfrequency of the structure. We identify the most dangerous resonances of this system and discuss related design issues.

I. Introduction

Mechanical vibrations in superconducting accelerator structures can lead to unwanted modulation of the structure RF eigenfrequency and the electron beam energy, position, and direction. Though eigenfrequency modulation produces well-documented problems for RF control systems, modes also exist which modulate electron beam parameters without modulating the RF eigenfrequency[1].

The frequency and character of mechanical modes which affect the operation of an accelerator are determined by the mechanical design of both the accelerating structure and the cryo-module. The microphonic behavior of a specific design is determined by how it addresses the issues of mechanical isolation, damping of unwanted motion, frequency of resonant modes, and by the mechanical constraints imposed on the accelerator structure.

We have performed vibrational measurements on a 500 MHz 2-cell cryo-module designed and built by Siemens for TRW, Inc.. The accelerometers used for the present tests have been improved over those used in our previous measurements[2] to provide a flat (±1 dB) response from 8 Hz to 500 Hz. Mechanical vibrations are induced by a small speaker in contact with the outer vessel of the cryo-module. In this paper we analyze the observed mechanical modes of this cryo-module and assess their effect on the structure eigenfrequency. We identify design elements which have contributed to the creation of dangerous mechanical modes and discuss related design issues.

II. Mechanical modes of the accelerator structure

The mechanical mode spectrum of the freely-suspended accelerator structure was measured before installation in the cryo-module. The lowest longitudinal mode was found at 94 Hz and the lowest transverse mode at approximately 40 Hz. When the structure is mounted in the cryo-module, its length is, to good approximation, constrained and thus the structure modes resemble those of a 'clamped' beam, retaining the same frequencies as in the 'free' case. The lowest longitudinal mode (L1) of the installed structure was found at 100 Hz while the lowest frequency transverse modes (T1) were found at 40.6 Hz in the vertical and at 50.0 Hz in the horizontal direction.

In the lowest longitudinal mode (L1), the structure length remains fixed while the iris between the two cells oscillates longitudinally. This motion has no effect on the eigenfrequency of the structure but causes electron beam energy modulation[1]. The relative energy modulation expected when driving this mode at resonance with a 0.5 N force is calculated to be 2×10^{-5}. In the lowest transverse mode (T1), the maximum motion occurs at the iris while nodes occur near the position where the structure is attached to the cryo-module. Previous work[2] indicates that, due to symmetry, this sort of bending motion should not produce any modulation of the eigenfrequency at the mechanical oscillation frequency. The large eigenfrequency shift observed at the 40.6 Hz mode is due to asymmetries of the motion, caused by asymmetries of the structure and by mixing of the mode with other cryo-module modes.

III. Mechanical modes of the cryo-module

A schematic diagram of the cryo-module indicating regions of mechanical flexibility (for frequencies below 150 Hz) is shown in Figure 1. At these frequencies, it can be assumed that vessel side-walls are relatively stiff, while flexing mostly takes place in the vessel end-walls, the cell walls of the accelerator structure, and the short section of beam tube connecting the helium vessel and the outer vessel. To allow RF tuning by changes in the structure length, one end of the helium vessel is connected to the beam tube by a bellows and is therefore represented as being unconstrained at that connection. Thin steel rods connecting the helium vessel to the outer vessel provide some restoring force for both vertical and horizontal transverse motions.

[1]Work supported in part by the Office of Naval Research, Contract No. N00014-91-J-4152.

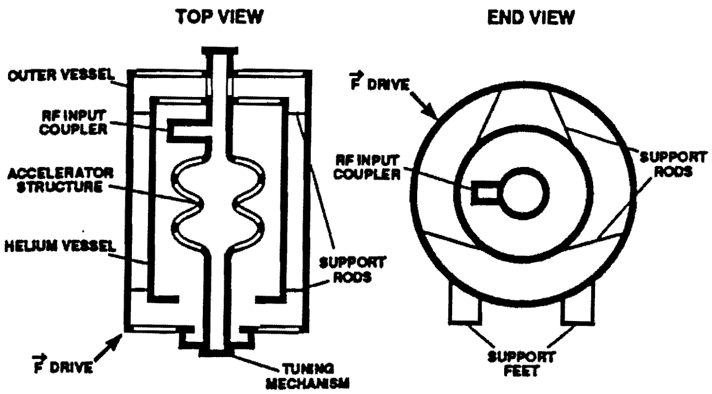

Figure 1. Schematic of cryo-module. The empty lines represent module components which are flexible at low frequencies.

Mechanical modes are classified as either longitudinal, transverse (horizontal and vertical), or torsional, and have been segregated as being principally related to the support system, to the helium vessel or outer vessel, or to the accelerator structure. Table 1 lists the principal modes below 150 Hz. Table 2 lists the amplitude of RF eigenfrequency modulation and the amplitude of structure motion for the most interesting modes when driven by a 0.5 N frequency-swept force applied to the outer vessel at the location shown in Figure 1. These amplitudes are up to 100 times larger when the force is applied at resonance. Mechanical Q values range from 60 to 100 with the exception of the horizontal support modes for which the Q value is 150 to 200.

Table I: Mechanical modes of a 500 MHz cryo-module.

Mode Type	Frequency in Hz Longitudinal	Horizontal	Vertical	Torsional
Support	13 (split)	8.5 (0) 11.6 (π)	30.2 (0) 36.6 (π)	23.7
Helium Vessel	36.6 40.6	39.1	40.6	72 79
Structure	99.9(L1)	50 (T1) 72,79(T2)	40.6 (T1) 51.8 (T2)	
Outer Vessel	138			

Table II: Effects of Selected Modes.

Mode Type	Freq.(Hz)	RFΔf(Hz)	Δx cell(nm)
Horizontal Support	8.5	12	7000 (hor.)
Longitudinal Support	13.5	17	800 (lon.)
Longitudinal He Vessel + Vertical Support	36.6	7.5	6 (lon.) 95 (ver.)
Longitudinal He Vessel + Vertical He Vessel+ Vertical T1 Structure	40.6	8.5	69 (lon.) 154 (ver.)
Horizontal T1 Structure	50	< 1	102 (hor.)
Horizontal T2 Structure + Torsional He Vessel	72 79	< 1	11 (hor.) 32 (hor.)
Longitudinal L1 Structure	99.9	< 1	3.6 (lon.)
Longitudinal Outer Vessel	137.8	12	9.2 (lon.)

***Support structure modes*:** As listed in Table 1, the lowest frequency modes of the cryo-module result from motion associated with the supports (Fig. 1). In all these modes, the helium vessel, outer vessel and structure move as one large mass against restoring forces provided by the supports. Bending takes place in the outer vessel wall where the supports are attached. The transverse modes of this set are split into 0 and π modes. The 0 modes consist of transverse center-of-mass motion of the entire module during which the ends move in phase. The π modes consist of transverse rotation about the center of mass, during which the module ends move in opposite directions. Frequency splitting of the longitudinal mode was observed but could not be attributed to any cryo-module element. Despite the relatively small amount of structure deformation expected in these modes, large eigenfrequency modulation occurs as a result of the enormous amplitudes of motion associated with these low frequencies (see Table 2).

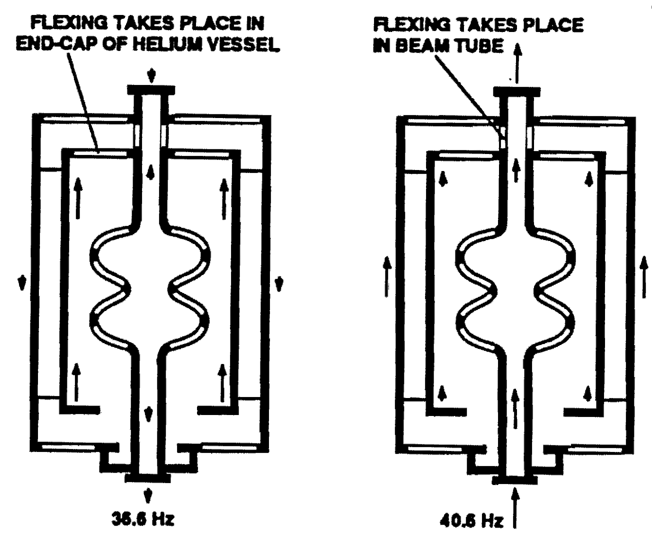

Figure 2. Longitudinal mechanical modes associated with the helium vessel. Only longitudinal motion is shown.

Helium Vessel and Outer Vessel modes: Figure 2 shows the two longitudinal modes associated with motion of the helium vessel relative to the outer vessel. The arrows indicate relative magnitude and direction of motion. The 36.6 Hz mode consists of the mass of the helium vessel moving against the outer vessel mass. Flexing takes place primarily in the end-wall of the helium vessel, with some flexing also occurring in the beam tube connecting the helium vessel to the outer vessel. In the 40.6 Hz mode, the helium vessel and outer vessel move longitudinally in the same direction but with different amplitudes. Vertical motion also takes place and will be discussed later. Flexing in this mode occurs primarily in the beam tube with some flexing occurring in the helium vessel end-wall. For both these modes, the outer vessel end-walls are rigid. Both modes produce substantial change in the length of the accelerator structure, thus causing a marked shift in eigenfrequency (see Table 2).

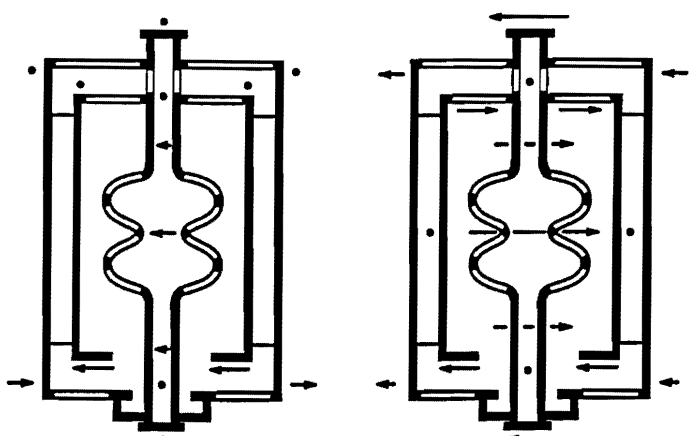

Figure 3. Selected transverse modes of cryo-module. Only transverse motion is shown.

Transverse motion of the helium vessel with respect to the outer vessel occurs at 39.1 Hz and 40.6 Hz. As seen in Figure 3, this motion consists of the helium vessel pivoting on its fixed end and moving transversely in opposition to the outer vessel. Restoring forces are provided by both the beam tube and by the 1/4" steel rods connecting the two vessels. These modes also cause substantial structure deformation as a result of torques applied to the beam tube at the pivot point of the motion. Torsional motion of the helium vessel in opposition to the outer vessel occurs at 72 Hz and 79 Hz. This mode couples weakly to a horizontal transverse structure mode and consequently is split into two modes.

At 138 Hz, the outer vessel cylinder moves longitudinally in opposition to the helium vessel which is attached through a beam tube to one of the end-walls. In the resulting motion, the end-walls flex and move out-of-phase with each other, producing large eigenfrequency modulation even for small amplitudes of motion.

Mixing of modes: Problems associated with some modes are made worse by frequency coincidence with other modes. The 36.6 Hz mode is both a longitudinal helium vessel mode and a vertical support mode and strongly couples vertical support motion, which causes little deformation of the structure, to a mode which causes substantial deformation. An even worse case occurs at 40.6 Hz where longitudinal and vertical helium vessel modes couple to a vertical transverse mode of the accelerator structure. The resulting mode produces large amplitude transverse motion in the structure and large eigenfrequency modulation. Weak coupling may cause frequency splitting of modes as seen at 72 Hz / 79 Hz.

IV. Cryo-module design issues

To reduce microphonics, one should attempt to isolate the accelerator structure from external noise sources, avoid low frequency resonances in the structure and cryo-module, raise the frequency of unavoidable resonances, and apply damping when practical. Also, coupling between mechanical vibrations and electron beam parameters must be reduced. Our studies indicate that avoiding asymmetries in the structure and cryo-module, and avoiding mixing of mechanical modes helps achieve this. Our measurements also show that in the design of load-bearing supports of the system, such as the support feet and rods of Figure 1, care must be taken to avoid low frequency oscillation of the large masses supported.

An important issue in cryo-module design is support of the accelerator structure. This issue is often complicated by the desire to perform RF tuning through structure length variation. The approach taken in the system studied here is to use the cryo-module vessels to both support the structure and constrain its length. This provides direct coupling between cryo-module motion and structure length, and is the cause of many of the dangerous vibrational modes we encountered. If the structure length is to be constrained by a mechanical element, this element should not be coupled to the cryo-module and should be designed such that its lowest modes of vibration are at high frequency. Very dangerous modes will result if resonances of the structure coincide with resonances in its length constraining components.

V. Conclusion

We have documented mechanical modes and identified elements of the Siemens cryo-module design which lead to microphonic sensitivity. Design issues have been discussed which, if appropriately addressed, may reduce microphonic effects in future designs.

VI. References

[1] H..A.Schwettman, "Microphonics and RF Stabilization in Electron Linac Structures", Proceedings of the Fifth Workshop on RF Superconductivity, Hamburg, Germany, 1991.

[2] A.Marziali, H.A.Schwettman, "Microphonic Measurements on Superconducting Linac Structures", Proceedings of the 1992 Linear Accelerator Conference, Ottawa, Canada, 1992.