VIBRATIONAL ANALYSIS OF THE TESLA STRUCTURE[1]

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Abstract

The vibrational mode spectrum of the TESLA accelerator structure has been calculated using COSMOS/M, a 3-D finite element code. The effect of the stiffeners, couplers, and helium vessel on the spectrum has been investigated. We report the results of these calculations and comment on their relevance to TESLA.

I. Introduction

Mechanical vibrations of multi-cell accelerator structures produce RF eigenfrequency modulation which can inhibit RF stabilization. Such vibrations can also produce energy and pointing modulation of the electron beam despite RF stabilization[1]. In most superconducting linacs vibrations of the structure are driven by 'external' noise sources or ground motion and a partial solution to the vibrational problem can be found by removing or abating these noise sources. In

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TESLA (TeV Superconducting Linear Accelerator) however, the accelerator is operated in a pulsed mode and the pulsed RF fields provide an 'internal' noise source that cannot be eliminated. It is proposed that the RF accelerating fields will be pulsed on for approximately 1 ms at a 10 Hz repetition rate, and thus the internal noise spectrum will have pulses at all multiples of 10 Hz extending to 1 kHz. Care must be taken to ensure that the effects of this noise source are minimized. As a first step toward that goal, we have calculated the vibrational mode spectrum of the TESLA accelerator structure in different configurations.

The 1300 MHz TESLA structure[2] with the DESY Higher Order Mode (HOM) couplers is shown in Figure 1. The structure consists of nine cells and two beam tubes all made of high RRR niobium. Annular stiffeners are welded around each iris and at the base of the beam tubes to stiffen the cell walls against electromagnetic pressures. One input coupler (not shown), two HOM couplers, and one monitor probe (not shown) are attached to the beam tubes. Three of the four couplers lie in one plane, while one of the HOM couplers is mounted 30 degrees offset from this plane. It is assumed that the helium vessel will connect to the stiffeners located at the junction between the beam tubes and the end half cells. The beam tube and couplers remain outside the helium vessel.

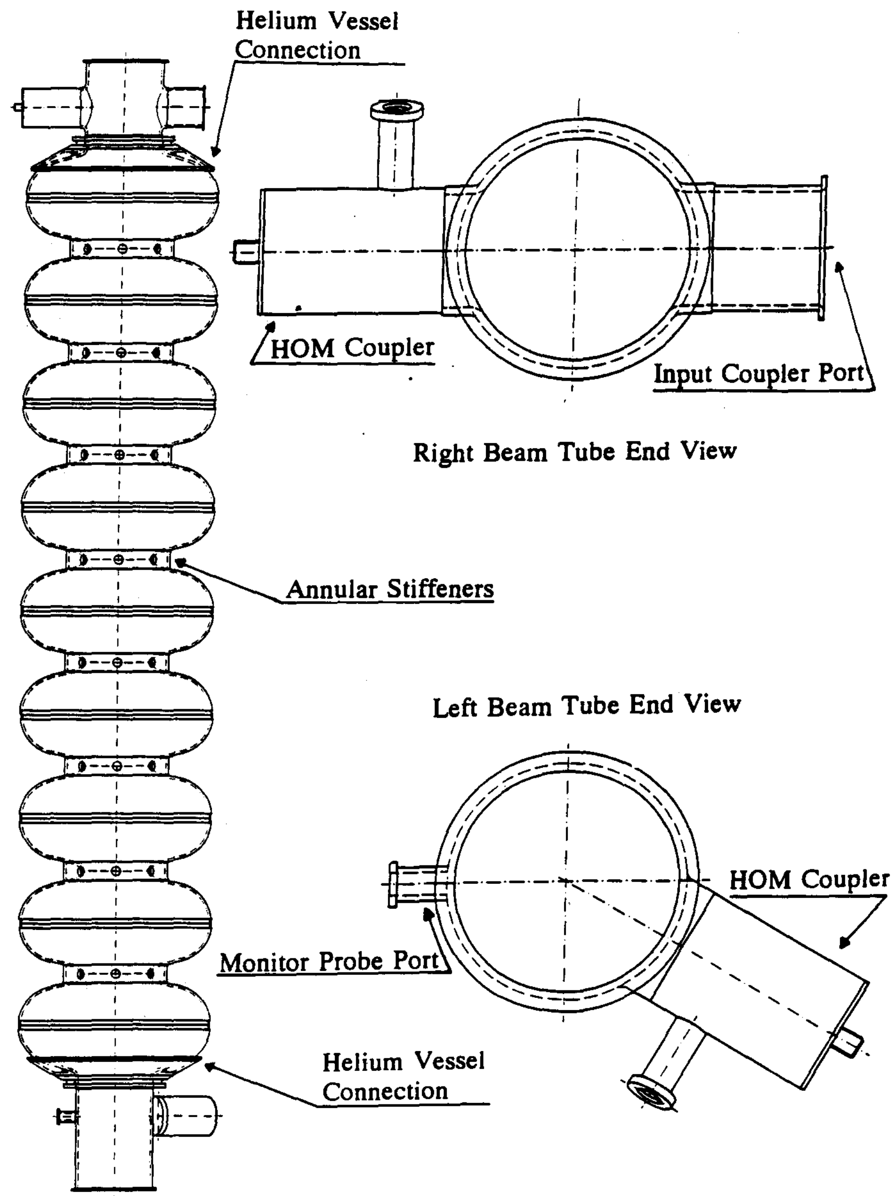

Figure 1. TESLA structure with DESY HOM couplers. The input coupler and monitor probe are not shown.

The vibrational mode spectrum of the TESLA structure was calculated using COSMOS/M, a 3-D finite element code. The structure geometry was modelled using approximately 6000 thin shell elements while the couplers and end flanges were represented by localized masses with appropriate moments of inertia. The section of input coupler that is rigidly connected to the beam tube is estimated to weigh 5 Kg and is approximately 30 cm long. The structure walls were modelled as constant thickness (2.5 mm) niobium with a Young's modulus of 1.049E11 Pa, and a density of 8.58E3 kg/m^3. Stiffeners were modelled as niobium of thickness 3 mm. The modelling method and calculations were verified to be accurate by modelling an existing structure and comparing the simulated vibrational mode spectrum to that measured with accelerometers.

Since details of the helium vessel design are not available at this time, we modelled the helium vessel as a rigid container. We did this by setting zero displacement boundary conditions at the stiffeners to which the helium vessel will be attached. The results of such calculations allow the evaluation of structure modes in the most favorable scenario. The modes that occur with a real helium vessel will be lower in frequency and more complicated.

This paper documents the calculated vibrational modes for the accelerator structure (without couplers) in various configurations. The effect of couplers on the vibrational mode spectrum and the lowest beam tube and coupler modes for a rigid helium vessel are also presented. Finally, the relevance of these calculations to TESLA is discussed.

II. Vibrational modes of the accelerator structure

Longitudinal and transverse vibrational mode frequencies were calculated for the structure in three configurations. First, the 'bare structure' (without the annular stiffening elements, end flanges or couplers) was modelled and the mode frequencies calculated. The annular stiffeners were then added to the structure, and a new mode spectrum for the 'stiffened structure' was calculated. Finally, the structure with annular stiffeners was modelled with boundary conditions of zero displacement at the stiffener surfaces where the helium vessel is to be attached. These last results are identified as the 'constrained structure'. These calculations are presented in Figure 2 and Table 1. Due to limitations on computing power, some of the highest frequency longitudinal modes have been estimated rather than calculated directly. All modes below 1 kHz are calculated directly.

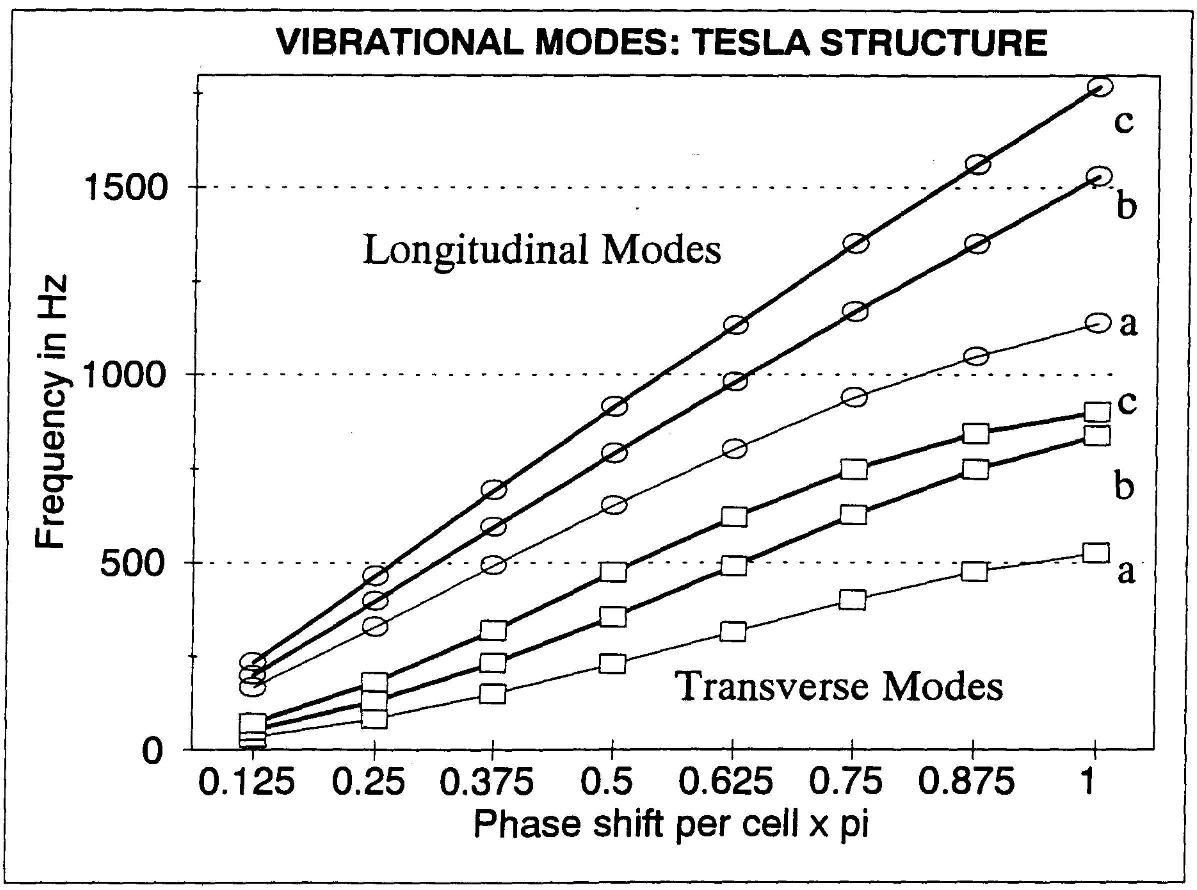

Figure 2. Vibrational modes of the TESLA structure: a) the bare structure, b) the structure with annular stiffeners, c) the structure (with stiffeners) constrained by a rigid helium vessel.

TABLE 1: VIBRATIONAL MODE FREQUENCIES

A) TRANSVERSE MODE FREQUENCIES IN HZ

Mode	Bare Struc.	Stiffened	Constrained
T1	32.8	50.8	70.9
T2	83	129	181
T3	150	233	322
T4	230	357	474
T5	317	491	621
T6	402	627	748
T7	475	749	844
T8	525	838	900

B) LONGITUDINAL MODE FREQUENCIES IN HZ

Mode	Bare Struc.	Stiffened	Constrained
L1	166	199	234
L2	331	398	465
L3	493	595	693
L4	651	790	915
L5	801	980	1135
L6	938	1170	1350
L7	1050	1350	1560
L8	1140	1530	1770

The lowest frequency modes for the structure without stiffeners are 33 Hz for transverse motion and 166 Hz for longitudinal motion. The annular stiffeners in the iris regions raise all mode frequencies by approximately 50%. The mode frequencies are increased further for the 'constrained structure'. The mode spectrum for a uniform beam with 'free end' boundary conditions and that of the same beam with 'fixed ends' is identical. However, in the 'constrained structure' the boundary conditions fix the position of the beam tube bases, not the ends, thus decreasing the length and the mass involved in the oscillation and raising the frequency of the modes. For the 'constrained structure' the lowest transverse mode lies at only 71 Hz. A snapshot of this mode is shown in Figure 3.

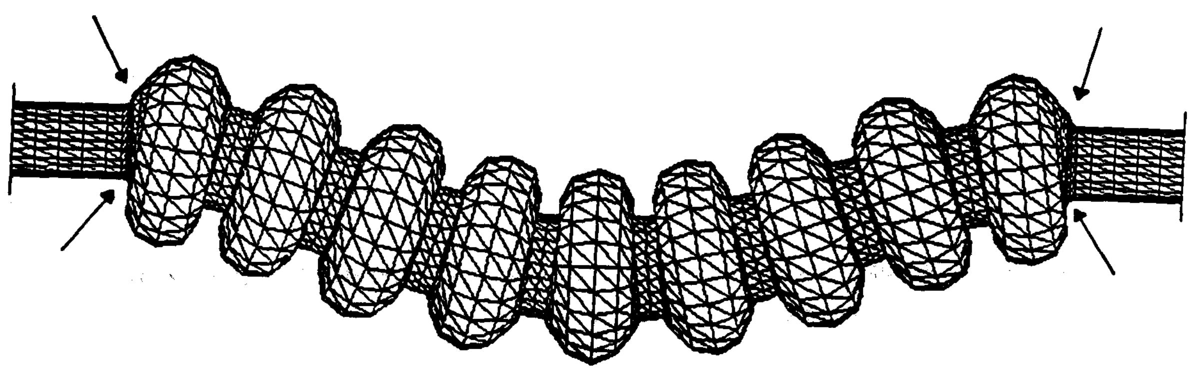

Figure 3. Snapshot of the lowest transverse mode for the structure (with stiffeners) constrained by a rigid helium vessel (not shown). The arrows indicate the points where the helium vessel connects to the structure.

III. Effect of couplers on the vibrational mode spectrum.

The addition of couplers and end flanges to the stiffened but unconstrained structure lowers the vibrational mode frequencies. The couplers are placed as shown in Figure 1. The right beam tube contains one HOM coupler and the input coupler positioned on opposite sides of the tube. The left beam tube contains one monitor probe and one HOM coupler 150 degrees apart. The masses and moments of inertia of the couplers were estimated from available drawings. In the case of the input coupler, only the components connected rigidly to the structure were considered. The effect of the couplers on beam tube modes was determined by modelling each coupler as several point masses with appropriate moments of inertia. The validity of this simplified modelling scheme was established through independent calculations. The effect of the couplers on the lowest frequency structure modes is shown in Table 2.

TABLE 2: EFFECT OF COUPLERS ON LOWEST MODES

Mode	Stiffened Structure	Stiffened structure with couplers
T1	51 Hz	31 Hz (pol. 1) 36 Hz (pol. 2)
L1	199 Hz	155 Hz

As indicated by the behavior of the modes listed in Table 2, the couplers decrease the frequencies of both longitudinal and transverse modes. For transverse modes, the couplers also break the cylindrical symmetry, define axes of polarization, and split the frequencies of the two polarizations. In the table, the polarization plane that is parallel to the input coupler is defined as polarization 1 (pol. 1). Higher frequency transverse modes further split due to mixing with input coupler modes.

With the structure constrained by a rigid helium vessel, the beam tubes and couplers no longer have any effect on the vibrational modes of the structure inside the helium vessel. Independent beam tube and coupler mode frequencies, however, can be calculated for the 'constrained structure' and these are listed in Table 3. Modes were calculated for the DESY input coupler (Full Length Input Coupler) and for a fictional coupler 1/2 the length of the DESY coupler (Half Length Input Coupler).

TABLE 3: LOWEST BEAM TUBE AND COUPLER MODES

Mode Type	Full Length Input Coupler	Half Length Input Coupler
Input Coupler (Azimuthal motion)	45 Hz	92 Hz
Input Coupler (Axial Motion)	89 Hz	178 Hz
Right Beam Tube (with input coupler)	520 Hz (pol.1) 540 Hz (pol. 2)	640 Hz (pol.1) 660 Hz (pol.2)
Left Beam Tube (w/out input coupler)	~770 Hz (pol. 1) ~800 Hz (pol.2)	~770 Hz (pol.1) ~800 Hz (pol.2)

The lowest frequency modes of the beam tubes result from oscillations of the input coupler. The large moment of inertia of this coupler allows it to oscillate at very low frequency by flexing the beam tube wall where the coupler is attached. In its lowest mode, the coupler oscillates in the azimuthal direction as defined by the axis of the accelerator structure. At twice this frequency, similar oscillation occurs, in the axial direction. Both of these oscillations distort the region of the beam tube where the coupler is connected thus potentially modulating the RF coupling.

The next modes are the lowest transverse modes in which the beam tube bends at the base (where the boundary condition is applied). These modes have two polarizations defined by the couplers. In the right beam tube the lowest frequency polarization is in the plane defined by the input coupler. In the left beam tube, the highest frequency polarization is in the plane which bisects the distance between the couplers.

IV. Conclusions

The high gradient pulsed operation planned for TESLA provides an 'internal' noise source which can drive large amplitude vibrations in the accelerator structure. Since the pulse length is expected to be 1 ms, repeated every 100 ms, the RF pulses will generate a noise spectrum with spikes every 10 Hz to frequencies beyond 1 kHz. There is great potential for resonantly driving a vibrational mode of the structure.

There are several methods that might be considered for limiting the potential vibrational mode problem. One might 'tune' the RF pulse repetition frequency or 'randomize' the RF pulse timing to avoid resonant excitation of modes. Alternatively, one might further stiffen or constrain the structure to raise the vibrational mode spectrum. Finally, one might attempt to damp the vibrational modes. The lowest frequency mode for the 'constrained structure' appears at approximately 70 Hz. For excitations in this mode to decay in less than 100 ms, its Q must be less than 40. Achieving damping of this magnitude might prove troublesome. Previous measurements[3] have indicated that Q's in excess of 1000 can exist in accelerator structures immersed in liquid helium.

The low frequency modes of the input coupler may also prove to be a concern as they may affect the stability of the RF coupling. In this case, damping should prove relatively easy as the input coupler motion can be transmitted to warmer regions where conventional damping methods may be applied.

V. 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] Private Communication, H.Kaiser.

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