Vibrational Stability of NLC Linac and Final Focus Components

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Abstract

Vertical vibration of linac components (accelerating structures, girders and quadrupoles) in the NLC has been studied experimentally and analytically. Effects such as structural resonances and vibration caused by cooling water both in accelerating structures and quadrupoles have been considered. Experimental data has been compared with analytical predictions and simulations using ANSYS. A design, incorporating the proper decoupling of structure vibrations from the linac quadrupoles, is being pursued.

1 INTRODUCTION

As part of the R&D effort for the Next Linear Collider (NLC), a program has developed to study the vibrations induced by cooling water on the NLC components.

An adequate flow of cooling water to the accelerating structures is required in order to maintain the structure at the designated operating temperature. This flow may cause vibration of the structure and its supporting girder. The acceptable tolerance for vibration of the structure itself is rather loose $\sim 1\mu m$. However our concern is that this vibration can couple to the linac quadrupoles, where the vibration tolerance is 10 nm, either via the beam pipe with its bellows or via the supports.

In this paper we will briefly show results obtained for the NLC RF structure and girder [1], and then focus on vibration of a linac quadrupole, including consideration of coupling between the structure and the quadrupole.

2 VIBRATION OF RF STRUCTURE

The structure studied is 1.8 m long and is supported by a "strongback" (hollow aluminum beam 4x6 inches) of the same length, Fig.1. In the design, it was assumed that 3 such structures would be mounted on a single 6 m long girder [2]. The required water flow (at 70MV/m) is about $\sim 1\ \ell$/s for each structure (in total, through four cooling copper tubes). The structure was connected to the quad with a bellow, and a simple mock-up of a BPM was connected (glued) to the quadrupole. It should be noted that the NLC currently plans to use shorter RF structures than the one studied [3].

Fig.2 displays the results obtained in measuring the vertical vibration induced by different flow rates passing through the structure-girder system [1]. Note that the system considered is above the turbulence threshold (Re>2000) when the flow > 0.1 ℓ/s. In Fig.2 the water was
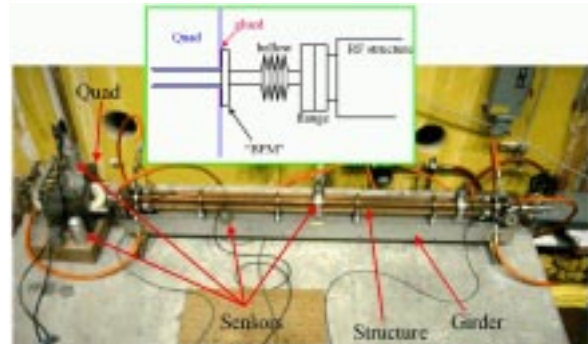
Figure 1: Experimental setup in the SLD pit: RF structure-Girder system connected to the EM quad.

supplied by the NLC Test Accelerator (NLCTA) water system. In this case, the displacement of the structure-girder is weakly dependant of the flow variation in the structure because the supplying cooling water has significant fluctuations of pressure in it (external turbulence).

The NLC cooling system will be designed so that pressure fluctuations in the cooling water will be limited (if necessary, by use of passive devices as typically done in industry). Thus, aiming to understand the contribution to vibration of the internal turbulence occurring inside the structure itself, we conducted the second set of experiments. In this case, the structure-girder was installed in a quieter place on the floor of the SLD (SLAC Large Detector) collider hall and the cooling water was gravity-fed from a tank located $\sim$18 m higher. The structure-girder was bolted to a $\sim$26T concrete block initially placed on a rubber mat and then on sand (in the first configuration the block had resonance at $\sim$35Hz which was decreased in the second case). The vibrations were monitored either by piezo-accelerometers or by seismometers and one piezo-transducer was used to measure water pressure fluctuations. In both sets of experiments (NLCTA and SLD) the flows in four cooling tubes were in opposite direction (2 by 2).

We have shown in [1] that the vibration spectrum of the girder-structure system exhibits a vertical resonance at $\sim$52Hz. Simulations using ANSYS code have shown that the natural first resonant frequency for such design is about $\sim$49 Hz, in good agreement with measurements, and corresponds to simplest vertical bending mode Fig.3. These simulations also indicate that the second and the third modes are the horizontal dipole at $\sim$69 Hz and vertical two-nodes mode at $\sim$117 Hz, while the fourth resonance is torsional $\sim$146 Hz. The driving forces (ground motion, pressure DP/P,) decrease rapidly with frequency. One possibility to further reduce the vibration of the structure-girder system is to design a girder which has a higher first resonant frequency. For further studies, we have set a goal of increasing the lowest resonance frequency to 130 Hz and performed

simulations to understand what modifications this would require. One way to stiffen the girder is to increase its dimensions. Simulations have shown that keeping the same material and design but increasing the girder size (6"x4" to 10"x10") and the wall thickness (from 0.25" to 1") lead to a lowest natural frequency of 120 Hz. Such big increase of the resonance frequency may not be necessary, but the studies have shown that significant improvement is possible with simple modification of the girder design.
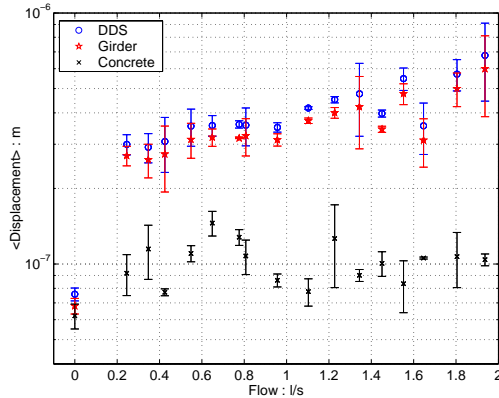

Figure 2: Average integrated displacement above 4Hz of the RF structure (DDS), girder, and of the support (concrete block) with NLCTA water supply.
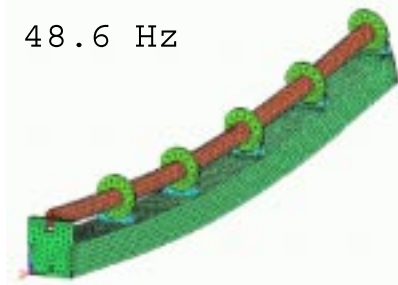

Figure 3: ANSYS simulation of the RF structure and Al girder, showing the lowest resonance mode.

3   VIBRATION OF RF STRUCTURE AND COUPLING TO QUADRUPOLE

Using the setup of Fig.1 we have studied the vibration of RF structure versus flow, and the coupling of vibration from the RF structure to the EM quadrupole in the case when RF structure is cooled with gravity-fed water.

Vibration of the RF structure versus flow is shown in Fig.4. In this case, vibrations are caused mostly by the internal turbulence occurring in the RF structure. At nominal flow $1\ell/s$ vibration of the structure is $\sim$110nm, in comparison with 350nm obtained with NLCTA cooling water [1]. Additional vibrations of the quadrupole are small. Performing multiple measurements with and without flow, and analyzing spectra of quadrupole vibration (Fig.5), we found that the additional vibration of the quadrupole due to cooling of RF structure above 30Hz is 2.4nm (obtained as $(4.3^2 - 3.6^2)^{0.5}$, assuming vibrations are uncorrelated), see Fig.6. Taking lower cut frequency would be statistically uncertain, due to high background noise. These results suggest that coupling from RF structure to the quadrupole is

about 2% in the current configuration. We also investigated influence of vacuum in the RF structure (and possible stiffening of the bellow) on this coupling. No noticeable difference was observed with or without vacuum (the results displayed in Fig.4 are obtained with a primary vacuum of about 10^{-1} Torr in the structure-quadrupole system). However, we have not yet studied how much coupling is due to the bellow connection and how much due to transmission via support and concrete.
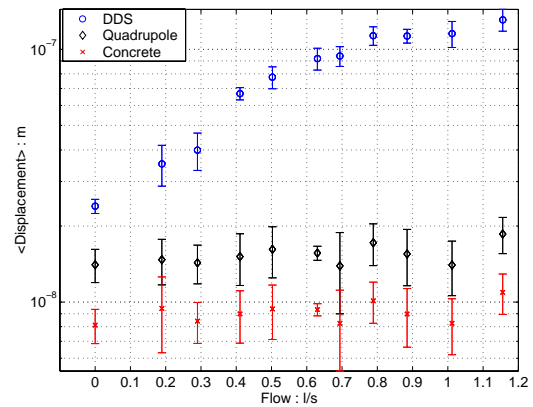

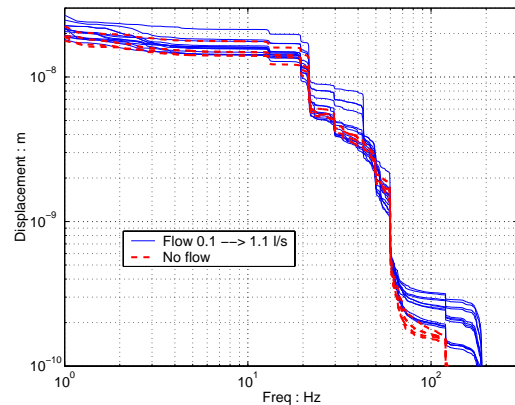Figure 4: Average integrated displacement above 4Hz, with vacuum and gravity fed water.

Figure 5: Quadrupole integrated displacement with four different flows in the RF-structure, -SLD measurement.

One should also note that the present set up is simplified. In particular, the quadrupole was placed on small granite stand (with shims to adjust the height), which was placed on concrete block (without rigid connections). Such system had amplification – the quadrupole vibration is higher than the concrete as seen in Fig.4. This can be avoided in real system.

4   VIBRATION OF EM QUADRUPOLE

The NLC project calls for maximal use of permanent magnet (PM) quadrupoles which will not have cooling water. The electromagnet quadrupoles (EM) however are also prototyped for NLC and we studied vibration caused by cooling water in such EM quadrupole. The EM quadrupoles was fed by a standard water supply for a nominal flow of $\sim$0.1 ℓ/s obtained with pressure difference of 8.5 bar. The quadrupole was installed on a granite table
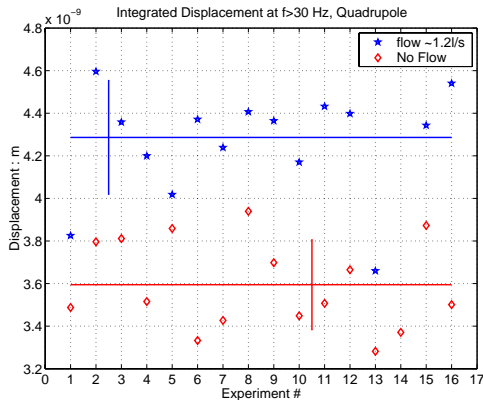
Figure 6: Coupling from the water cooled RF-structure to the Quadrupole above 30Hz.

Fig.7. The table was installed on rubber pads to isolate the table from the high frequency vibration in the noisy environment where measurements were performed. This reduced the high frequency background, but significantly amplified frequencies below 6-9 Hz, making it possible to study the effect of cooling water on quadrupole vibration only above about 10Hz.

For f>20Hz, the vibration induced by the flow of ~ 0.1 ℓ/s in the quad is roughly 3.5 nm$\pm$0.25 nm while 1 nm$\pm$0.25 nm at rest (averaged on several measurements). Assuming that the additional vibration is uncorrelated, the effect due to cooling water itself is: $\sqrt{(3.5^2 - 1)} =$ 3.35 nm. The result is similar if a lower cut frequency (e.g. 15Hz) was considered, until below 10Hz where statistical error becomes too big. Note that earlier studies of FFTB quadrupole stability [4] have shown that the effect of the cooling water is on a nanometer level as well, for quadrupoles that were (in contrast to our study) also properly placed on movers.

With these data, we can estimate that in the pessimistic case, if the cooling water will be similar to NLCTA (with similar pressure fluctuations), vibration of the quadrupoles will scale to about 7.6nm due to coupling to the RF structures. In the case of EM quadrupoles, there will be about 3.3nm additional due to cooling of the quadrupoles themselves, which in total amounts to $\sqrt{(7.6^2 + 3.3^2)} = 8.3$nm. This value is below the tolerance but has little margin. However, simple design optimizations, discussed above, are expected to reduce these numbers considerably.

Among further studies of RF structure and quadrupole vibration planned at FNAL and SLAC are: performing measurements in quieter place, to quantify lower frequency range; study the case of quadrupole been placed on movers and realistic independent supports; continuing optimization of the system as a whole.

5 CONCLUSION

Cooling water can cause vibration of an accelerating structure both through internal turbulence in the cooling pipes on the structure, and through pressure fluctuations in the supply water (external turbulence) [1]. The latter does

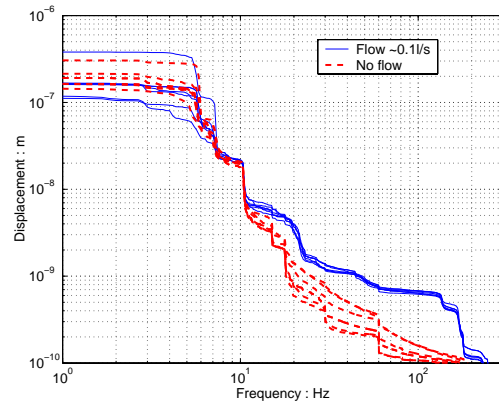Figure 7: EM quadrupole vibration measurement setup.

Figure 8: Integrated Displacement Spectrum of the water induced vibration in the EM quadrupole at nominal flow. The region below 10Hz is disturbed by resonances of the concrete table installed on rubber pads.

not depend on the flow rate through the structure and can be the dominant source of vibration in practical situations. For the case studied, mechanical resonances of the structure-girder assembly explain the measured amplitudes. Optimization of design to increase resonance frequencies is expected to reduce vibration. Coupling from RF structure to linac quadrupoles can occur via bellows and the support but was measured to be at the percent level. Present studies suggest that the vibration tolerances for the NLC linac quadrupoles are met, but without much margin. Optimization of the girder design to improve its vibration property is highly desirable and will be pursued.

6 ACKNOWLEDGMENTS

7 REFERENCES

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