Vibrational Stability of NLC Linac accelerating structure

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Abstract

The vibration of components of the NLC linac, such as accelerating structures and girders, is being studied both experimentally and analytically. Various effects are being considered including structural resonances and vibration caused by cooling water in the accelerating structure. This paper reports the status of ongoing work.

1 INTRODUCTION

As part of the R&D effort for the Next Linear Collider (NLC), an extensive program has been started to study the vibration induced by cooling water on the NLC Linac and Final Focus components.

An adequate flow of cooling water to the accelerating structures is required in order to dissipate the heat load caused by the absorption of RF power and 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 – of the order of several micrometers. The concern is that this vibration can couple to the linac quadrupoles either via the beampipe with its bellows or via the supports. The vertical vibration tolerance for the linac quadrupoles is about 10 nm.

In this paper we focus on vibration of accelerating RF structure and girder induced by cooling water. Further papers will report on vibration coupling to quadrupoles [1] and on investigation of additional girder damping [2].

2 EXPERIMENTAL SETUP

For the vibration studies presented, an NLC design accelerating structure [3] was used. This structure is 1.8 m long and is supported by a “strongback” of the same length. In the design it was assumed that 3 such structures would be mounted on a single 6 m long girder. The required water flow is about ∼1 ℓ/s for each structure. It should be noted that the NLC currently plans to use shorter RF structures than the one studied [4].

In the first set of experiments, we measured the vibration induced by different flow rates passing through the structure-girder system, as shown in Figure 1. The water was supplied from the NLC Test Accelerator (NLCTA) area. The 1.8 m long RF structure (∼100 Kg) was mounted on a hollow aluminum girder connected to a concrete block of ∼2225 kg. The block was installed on rubber balls (∼14Hz resonance) to isolate it from the noisy floor of NLCTA. Vibration was monitored by four piezo-accelerometers and one piezo-transducer was used to measure water pressure fluctuations. The diameter of each of the four cooling pipes were 1.9 cm. The flow of water and the pressure were measured by a venturi tube and by two manometers installed at the input and output supply.

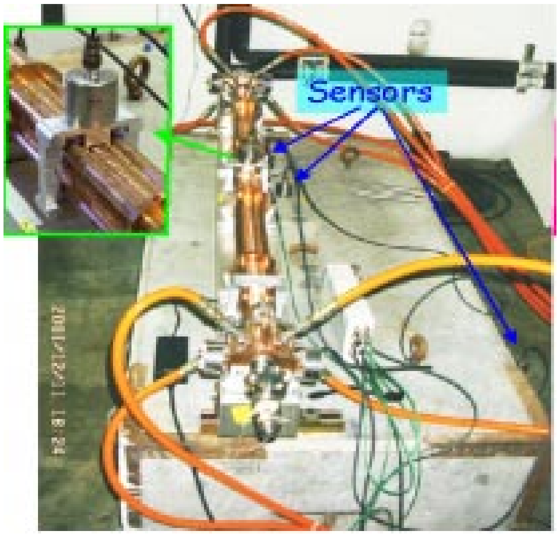

Figure 1: RF structure and girder vibration setup in the NLCTA area.

The second set of experiments were designed to study the vibration caused only by internal turbulence. The structure-girder was installed in a much quieter place on the floor of the SLD collider hall and the water was gravity-fed from a tank located ∼18 m higher. The structure-girder was bolted to a ∼26T concrete block placed on a rubber mat (∼30Hz resonance). The maximum water flow through the structure was limited to about 1.1 ℓ/s.

In each experiment, it was possible to feed the water to the structure either by using the 4 tubes separately or by feeding only 2 tubes on one end which were then connected to the adjacent tubes at the other end. In the latter case, the flow in 2 tubes was in the opposite direction. In all the tests, only vertical vibrations were studied.

3 RESULTS AND DISCUSSION

The first results were obtained when the structure was supplied by water from the NLCTA supply system (Fig.1). Fig.2 shows the variation of the integrated displacement spectrum when the structure is fed with different water flows, including no flow. In the case without flow, both supply and return valves were closed. In the case with flow,

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[*] Work supported by the U.S. Department of Energy, Contract DE-AC03-76SF00515.

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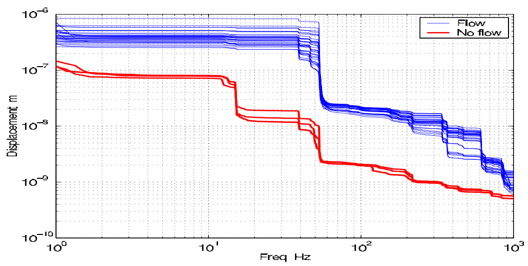

Figure 2: Integrated displacement spectrum of the structure with different flow rates(blue, top curves) and with no flow (red, bottom curves). Several measurements are shown.

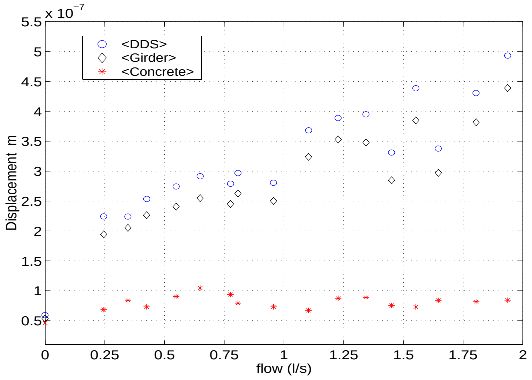

Figure 3: Average integrated displacement above 10Hz of the structure (circles), of the girder (diamonds), and of the concrete block(crosses).

the supply valve was partially closed to regulate the flow. Fig.3 shows the average value of the integrated displacement above 10Hz, for different water flow rates.

Fig.4 shows the integrated displacement of the different elements of the system for a flow of $\sim$1.9 ℓ/s (twice nominal). One can see that the maximum amplitude of the displacement comes from the peak at $\sim$ 52Hz which is believed to be a resonance of the hollow aluminium girder and RF structure assembly. The 52Hz resonance is also seen in the motion of the concrete block, due to coupling of the structure vibration to the block.

The integrated displacement of the structure at maximum flow is about 0.5 μm (see Fig.3 and 4), while it is less than 0.08 μm when no water flows through the structure. The rms amplitude of vibration depends only slowly on the flow rate – a 10-fold change in the flow increases the vibration by only about a factor of 2. Note that the system considered is above the turbulence threshold (Re$>$2000) if the flow $>$ 0.1 ℓ/s, i.e. practically in all the observed range. Such a slow dependence is explained if one assumes that in the NLCTA setup, the structure vibrations were due mostly to turbulence in the water supply system and hence to pressure fluctuations in the incoming water. This assumption is confirmed by Fig.5 which shows that merely opening either supply or return valve, with the other valve closed, produced an integrated displacement of 0.4 μm, almost equal to the maximum displacement observed.

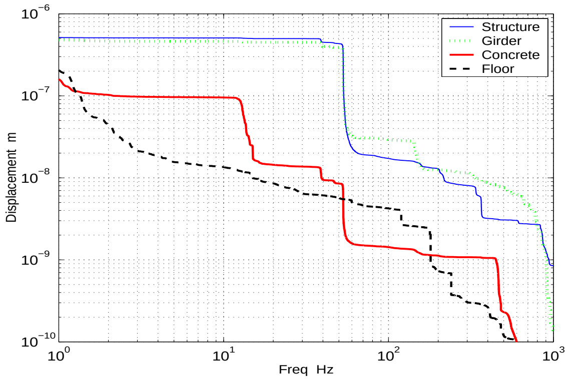

Figure 4: Integrated displacement spectrum of the structure, girder, floor and concrete block with water flow of $\sim$1.9 ℓ/s in the NLCTA setup for a single measurement.

Quantitatively, the incoming water can be characterized by the spectrum of its pressure fluctuations. The integrated spectrum was measured by a pressure piezo-transducer in the NLCTA setup as shown in Fig.7. The incoming pressure causes vibration of the RF structure through the force it exerts on the unbalanced surface of the cooling pipes (usually equal to cross-section of the pipe). It is interesting to note that the spectrum of the incoming NLCTA water is rather smooth and does not contain sharp peaks typically associated with the rotational frequencies of pumps. This indicates that the turbulence itself, and not the pumps, was the cause of the pressure fluctuations.

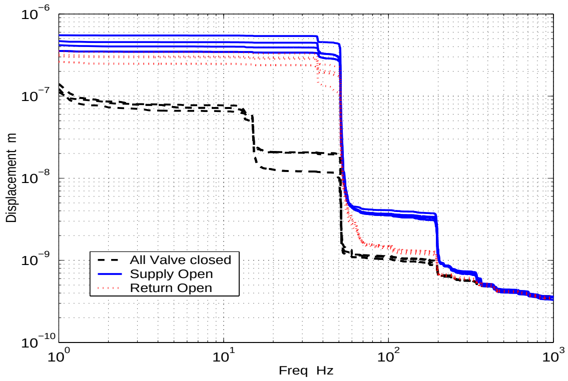

Figure 5: Integrated displacement spectrum of the structure with only the supply open (blue solid line), only the return open (red dotted line), and with all valves closed (black dashed line). In all cases, there is no water flow.

From the results obtained with a normal cooling water system, such as the one used in NLCTA, it is clear that vibrations are caused mostly by the turbulence of the incoming water, and not by irrevocable internal turbulence in the accelerating structure itself. To study the latter, the system was moved to the floor of the SLD detector hall, and fed with "quiet" water coming from a tank at about $\sim$18 m height. The maximum flow obtained in this configuration was $\sim$1.1 ℓ/s (equal to the nominal flow).

Figure 6 shows the variation of the displacement with and without flow obtained in the "gravity fed" experiment. The RF structure vibration is $\sim$0.18 μm in this case, i.e. about a factor of 2 smaller than in the NLCTA setup. The pressure transducer shows that fluctuations in the gravity

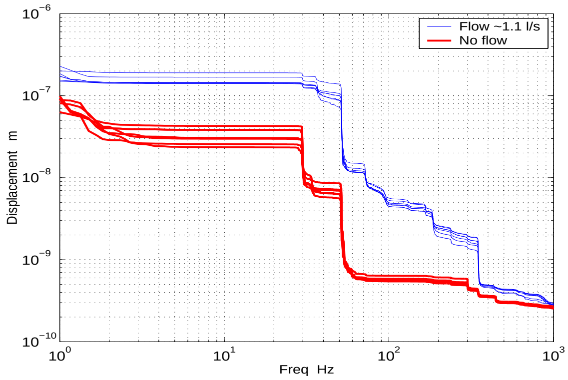

Figure 6: Integrated displacement spectrum of the structure with the nominal water flow (blue) and with no flow (red)

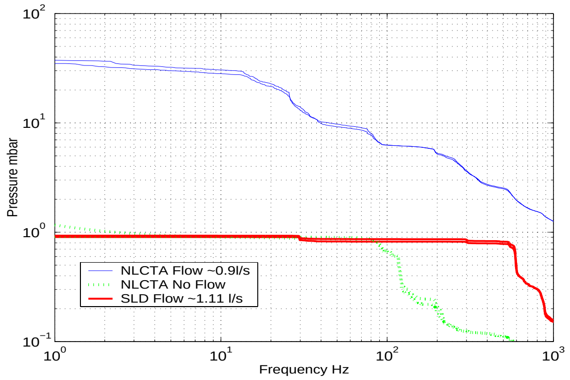

Figure 7: Integrated spectrum of incoming pressure fluctuations in NLCTA water (top curves), in gravity fed water (middle curves), and the sensor internal noise – NLCTA case with all valves closed (bottom curves).

fed incoming water are much smaller than in the NLCTA setup. It is believed that this structure vibration was dominated by internal turbulence.

While the dependence of vibration on flow in the gravity fed experiment has not yet been measured, a semi-analytical model [5] has been developed which predicts that the amplitude will depend on the flow approximately as $flow^{2.5}$ (see Fig.8). It is interesting to compare this predictions with estimations from [6] where the amplitude of vibration caused by internal turbulence almost does not depend on the flow (the dependence is only as $1/flow^{1/8}$).

The model used [5] is based on analytical or measured mode-shape functions of structural resonances for the system considered, as well as on empirical models of power spectrum and spatial coherence properties of pressure fluctuations in turbulent water [7]. For nominal flow, the model predicts $\sim$180 nm amplitude which is in good agreement with the gravity fed experimental data, while for twice the nominal flow its prediction is higher than even what was measured in NLCTA. It is worth noting that most of parameters of the model (including quality factor of the resonance) are difficult to predict analytically. Therefore, caution is required in extending any such model to a different system or parameter range.

Finally, in the gravity fed case, the vibration of a quadrupole connected to the structure via a bellows was also measured and found to be about 6 nm, which is tolerable for NLC. Ongoing work on optimization of the design and on increasing structural damping [8] is expected to further reduce the coupling of vibration to the quadrupoles.

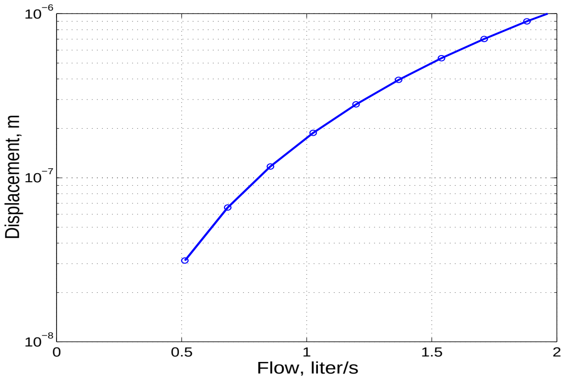

Figure 8: Vibration of the RF structure at a resonance of 52 Hz caused by internal turbulence in the cooling pipes as predicted by a semi-analytical model [5].

4 CONCLUSION

Cooling water can cause vibration of the accelerating structure both through internal turbulence in the cooling pipes in the structure, and through pressure fluctuations in the supply water (external turbulence). The latter does 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. Vibration coupling to a quadrupole was found to be adequately small. Optimization of design and increased mechanical damping is expected to further reduce vibration.

5 ACKNOWLEDGMENTS

We would like to thank Ralph Assmann, Marty Breidenbach, Domenico Dell'Orco, Harry Carter, Tor Raubenheimer, Nikolai Solyak, Cherrill Spencer, Nancy Yu, for help and useful discussions.

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