Beam Jitter and Quadrupole Motion in the Stanford Linear Collider*

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Abstract. Spectral analysis of beam jitter in the Stanford Linear Collider (SLC) has shown that some beam motion is confined to narrow frequency bands. Vibration analyses of linac quadrupoles using high-resolution accelerometers yield spectra having a similar footprint. It was found that motion at 59 Hz is driven by a pressure oscillation in the accelerator structure cooling water, while other frequencies were found to be vibrational modes of the structure itself (1). This paper presents motivating beam data, describes instrumentation used for vibration measurements, presents vibration-related data, and summarizes the solutions used to reduce quadrupole motion.

INTRODUCTION

Jitter measurements of the SLC beams during 1994/95 running show motion at around 59 Hz. This jitter was severe enough to have a significant detrimental effect on the luminosity. Subsequent measurements of the linac quadrupoles using sensitive accelerometers revealed a 59 Hz peak in vertical motion having sufficient magnitude to produce the observed beam jitter. The source of the 59 Hz vibration was traced to the pumps for the accelerator structure cooling water system, which rotate at 59 Hz (2). Spectral analysis using a water pressure transducer and a signal analyzer revealed a strong 59 Hz pressure modulation from some of the pumps.

Using a portable signal analyzer and a laptop computer, correlations were made between quadrupole motion, water pressure modulation, and specific pumps. A test stand was set up where pumps could be studied while they were out of service and possible solutions could be tried. Asymmetry in the pump impellers, which were crude sand castings, was suspected to be the main source of the pressure modulation. It was also found that a flexible rubber coupling or “boot” at the discharge of the pump would reduce the pressure modulations by a factor of about two. The experimental setup is

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described, excerpts from the data are presented and solutions that have been tried or proposed are discussed.

SETUP

Beam jitter data was taken through the SLC control system, then processed and plotted offline in Matlab (3). To facilitate field measurements of quadrupole motion and water pressure variation, a portable Hewlett Packard 3560A Dynamic Signal Analyzer was used for data acquisition in conjunction with an Apple 5300c PowerBook for further data analysis. The entire set-up was packed in a rolling, foam-lined suitcase (Figure 1), which could be lowered down the linac access shafts to make quadrupole motion measurements. Quadrupole motion was measured with a PCB Piezotronics model 393B31 accelerometer, which has a sensitivity of 10 V/g and a resolution of 5 μg. It is a single-axis accelerometer and was placed directly on top of the quadrupole for the measurements. All data presented here represent vertical motion. Water pressure modulations were detected using an Ashcroft pressure transducer with a range of 150 psi and an output of 26 mV/psi with an upper frequency limit of at least 2 kHz. The water pressure measurements were taken directly at the discharge piping on the pumps.

Data was acquired with the signal analyzer operating in spectrometer mode, integrated twice to yield displacement, and displayed as a power spectral density (PSD) plot. The processed data was then transferred through the serial ports to the laptop where the data is further processed using Matlab.

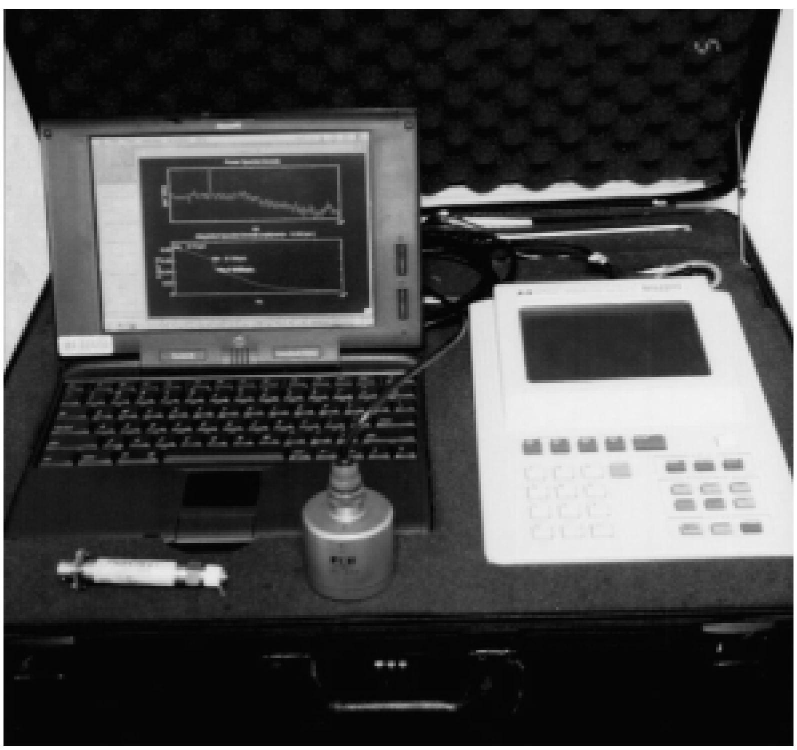

FIGURE 1. Field measurement setup showing the Apple PowerBook 5300c and the Hewlett Packard 3560A Dynamic Signal Analyzer packed in a rolling foam lined suitcase. In the foreground are the pressure transducer and the accelerometer that were used in the measurements.

MEASUREMENTS

Figure 2 shows an example of the beam data that prompted these studies. It shows the FFT of buffered vertical beam position monitor data taken pulse by pulse. The motion at 59 Hz is clearly seen. In the bottom graph of the figure, the right to left integral of the top plot is mapped. The advantage of this plot is that the vertical steps indicate the amount of power introduced at a particular frequency. The "Int" in this and subsequent figures indicates the integrated amplitude contributed between the "I" of "Int" and the next higher frequency "Int."

Investigation in the linac housing with the sensitive accelerometer revealed vertical motion on some of the quadrupoles. Data on one of the quads is plotted in Figure 3. The sharp step on the bottom plot indicates that most of the power is at 59 Hz resulting in 229 nm of motion at that frequency.

Measurements with the water on and off indicated that the source of the 59 Hz was in the accelerator structure cooling water system. This led to investigation using a water pressure transducer, which produced the data in Figure 4 where we see a very strong pressure modulation at 59 Hz. This data was taken on the pump for the same Linac sector as the quadrupole motion data presented in Figure 3. Further measurements at other Linac sectors show that where there was little 59 Hz pressure modulation there was no detectable 59 Hz motion on the quadrupoles.

The transfer function plotted in Figure 5 was obtained by comparing the magnitude of the quadrupole motion with the magnitude of the water pressure modulation for five different frequencies. The frequencies are the first five harmonics of 59 Hz.

During our measurements, a project was undertaken to install flexible rubber couplings or "boots" at the discharge piping of the pumps. These were intended to make removal and replacement of the pumps quicker and easier. Before and after measurements (see Figure 6) showed that they reduced the 59 Hz quadrupole motion by a factor of two.

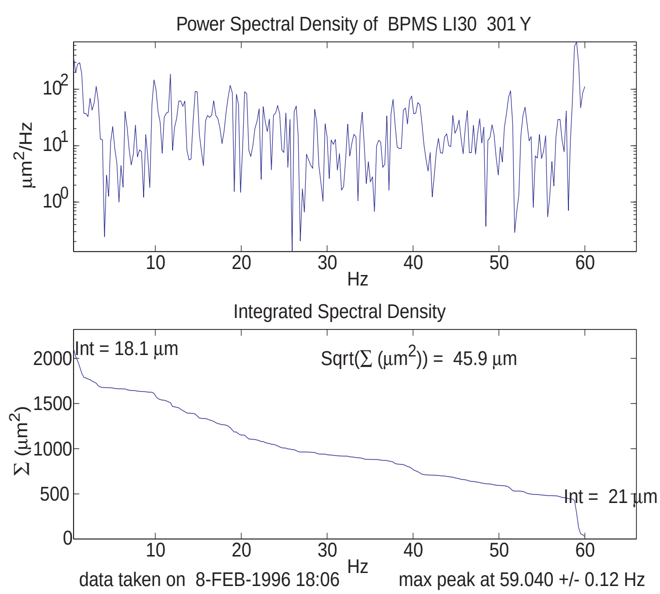

FIGURE 2. Jitter measurements of the SLC beams during 1994/95 running show a peak in the vertical motion at approximately 59 Hz. This jitter had a significant detrimental impact on the luminosity.

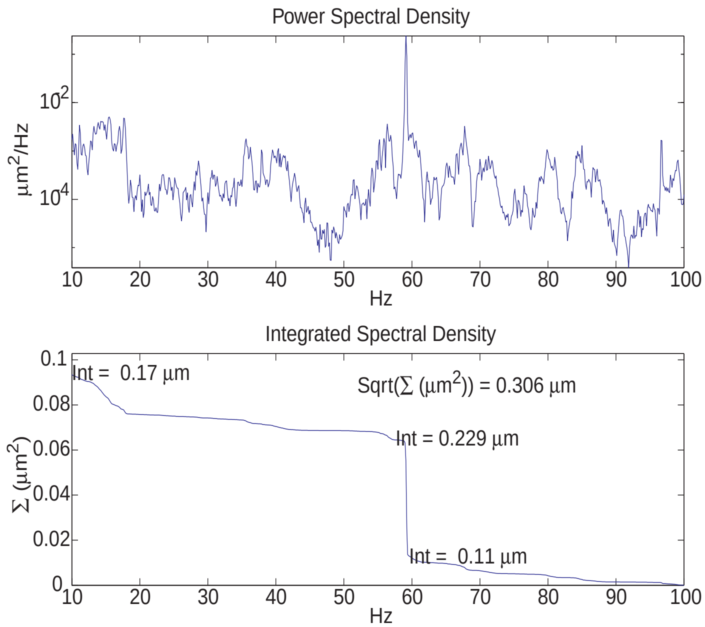

FIGURE 3. Accelerometer measurements on selected LINAC quadrupoles reveal a 59 Hz peak in the vertical motion of a magnitude sufficient to produce the observed beam jitter.

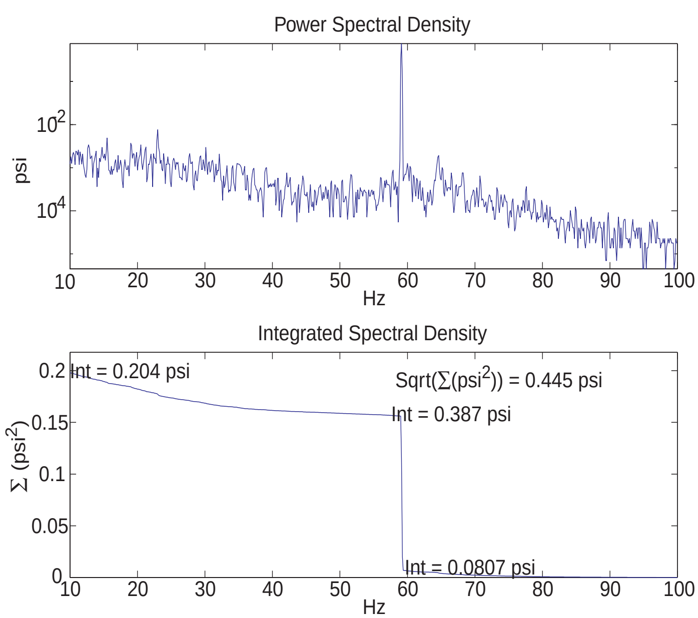

FIGURE 4. Spectral analysis of the accelerator structure LCW pressure modulation shows a strong 59 Hz component. This 59 Hz corresponds to the rotation rate of the pump motors.

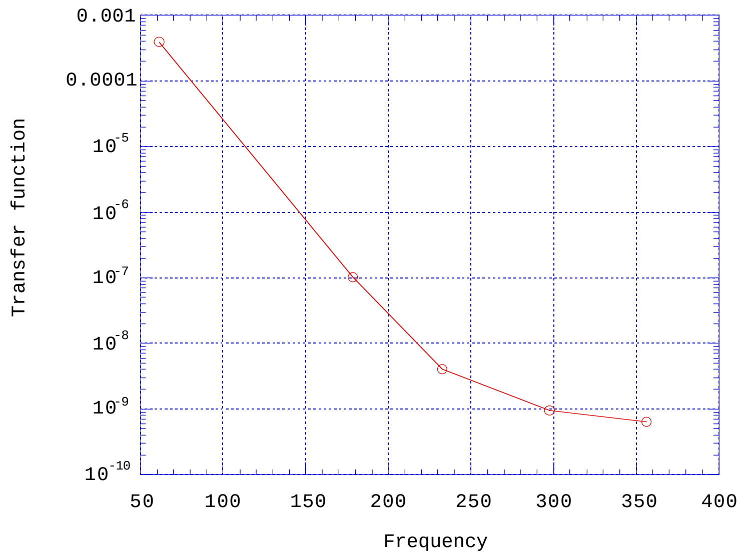

FIGURE 5. Transfer function from the accelerator cooling water to the vertical motion measured on the linac quadrupoles.

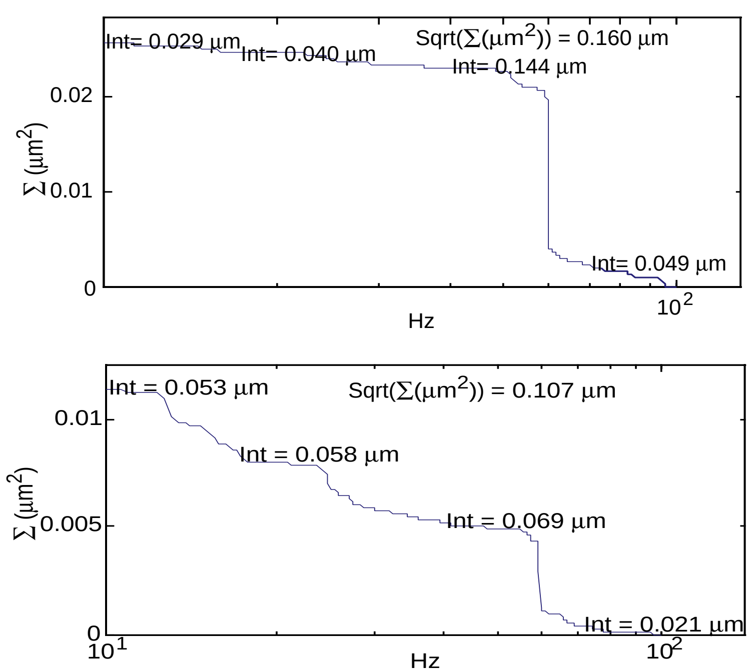

FIGURE 6. The 59 Hz motion of the quads can be reduced by a factor of two with the installation of a rubber "boot" at the output of pumps. The top plot shows quadrupole motion without the boot and the bottom plot shows the motion after installation of the boot.

SUMMARY AND CONCLUSIONS

Clearly the boots on the pumps help reduce motion by about a factor of two. An apparent major source of the 59 Hz is asymmetry in the impeller castings. A project to replace these with better impellers has not yet proved fruitful but measurements at the test stand have shown that other factors such as balancing and bearings must also be considered. Future accelerator installations should try to avoid this problem by specifying vibration criteria at the design stage.

REFERENCES

[1] Turner, J. L., et al, "Vibration Studies of the Stanford Linear Accelerator," presented at the Particle Accelerator Conference, 1995.

[2] Turner, J. L., Stege, R. E., "Vibration of Linac Quadrupoles at 59 Hz", Collider Note 399, SLAC internal publication, 1995.

[3] Matlab is a math software package by The MathWorks.