An Experimental Investigation of Airflow-Induced Vibrations within the Multiplicity and Vertex Detector

by

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Abstract

This report summarizes an experimental investigation of vibrations within the multiplicity and vertex detector (MVD). In particular, the maximum displacements of several MVD components were determined from accelerometer measurements of vibrations induced by an electronics air-cooling system. For an MVD inlet air volumetric flow rate of 0.022 m^3/s, maximum displacements of several MVD components including a multi-chip module, the Rohacell inlet air plenum, and an aluminum structural cross support, were found to be on the order of 1.5 μm. Consequently, it was concluded that air induced vibrations will not significantly interfere with the MVD's long-term structural integrity or operating performance.

INTRODUCTION

During a previous experimental investigation of an air cooling system for the multichip modules (MCMs) of the multiplicity and vertex detector (MVD) by several of the authors [1], vibrations of various MVD components were observed. An earlier MVD design report [2] speculated that vibrations induced by turbulence within the MVD by an air cooling system would be a design concern. However, the magnitude of these vibrations and their effects on the MVD's long-term structural integrity and operating perfomance were unknown. The purpose of the present study was to determine the displacement magnitudes of the vibrations and assess whether or not they presented serious design complications.

EXPERIMENTAL METHODS

In the present study, a full-scale mock-up of the PHENIX support structure and one half of the MVD were used. Because detailed descriptions and schematic diagrams of these systems have already been published [1], only a brief discussion is presented here. Figure 1 presents a schematic diagram of the MVD air cooling used in this study. The closed-loop cooling system used two variable-speed blowers to circulate cooling air through the MVD. The air inlet temperature and flow rate were controlled by a water-chilled heat exchanger and a fan type anemometer.

The experimental half of the MVD used in the current study is shown in Figure 2 positioned around the beam pipe of the PHENIX support structure. The radial and horizontal MCM plenums used to direct the cooling air around the heat-generating MCMs are labeled in the figure.

An Endevco 2250A-10 accelerometer, connected to an amplifier and a digital oscilloscope, was used to measure the accelerations and displacements of several MVD components, the locations of which are shown in Figure 2. Vibrations of the MCMs were identified previously to be of primary concern [2]. Figure 3 shows a schematic of the accelerometer placement on a simulated MCM within a segment ($1/12^{th}$) of the horizontal air plenum. Prior to taking the measurements, the accelerometer was calibrated with a Bruel & Kjaer Type 4294 Calibration Exciter (frequency = 159.2 Hz, RMS acceleration = 10 m/s^2, RMS velocity = 10 mm/s, RMS displacement = 10 μm) and was found to agree to within 7% of the calibration values.

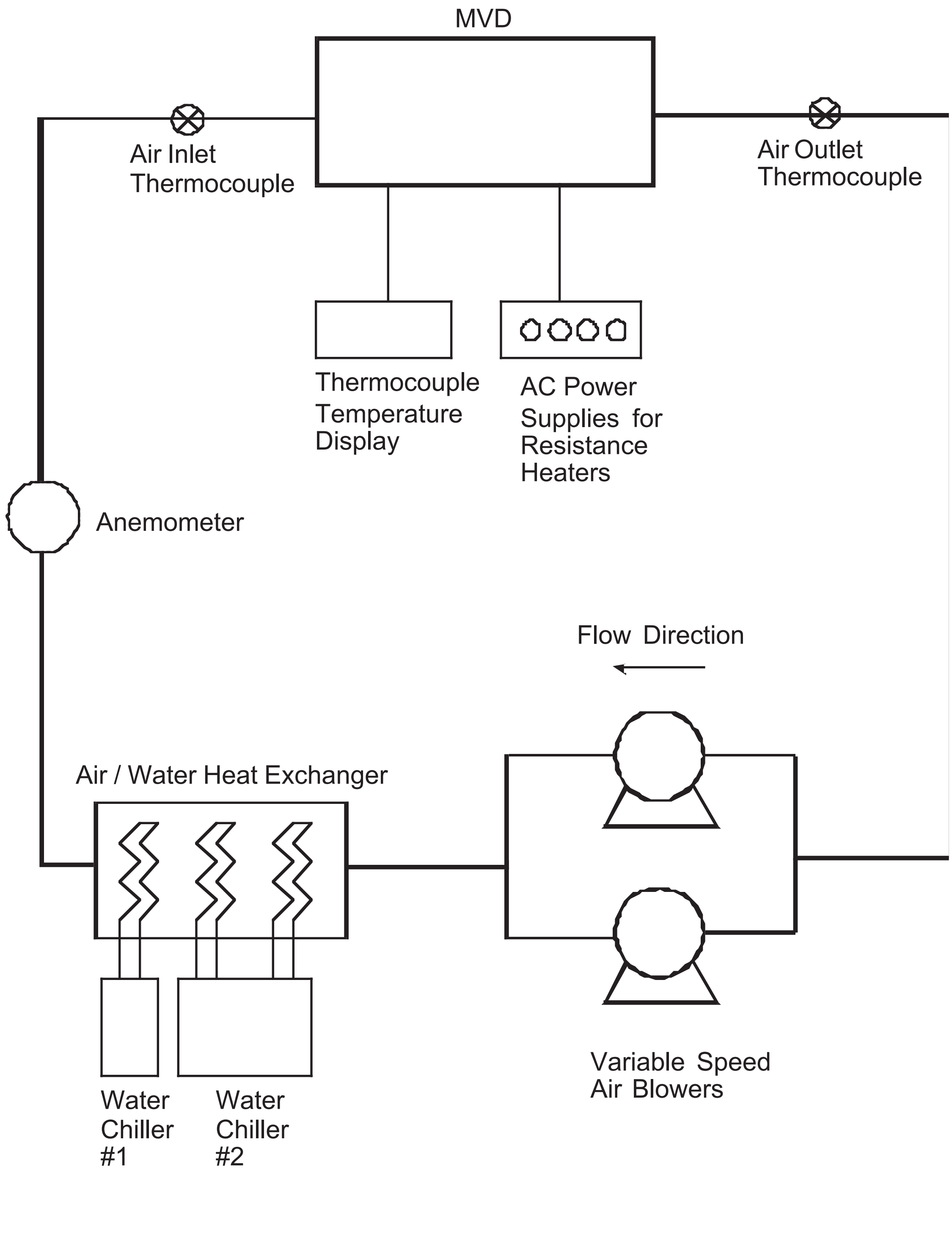

Figure 1. Schematic diagram of the experimental air cooling system for the MVD electronics.

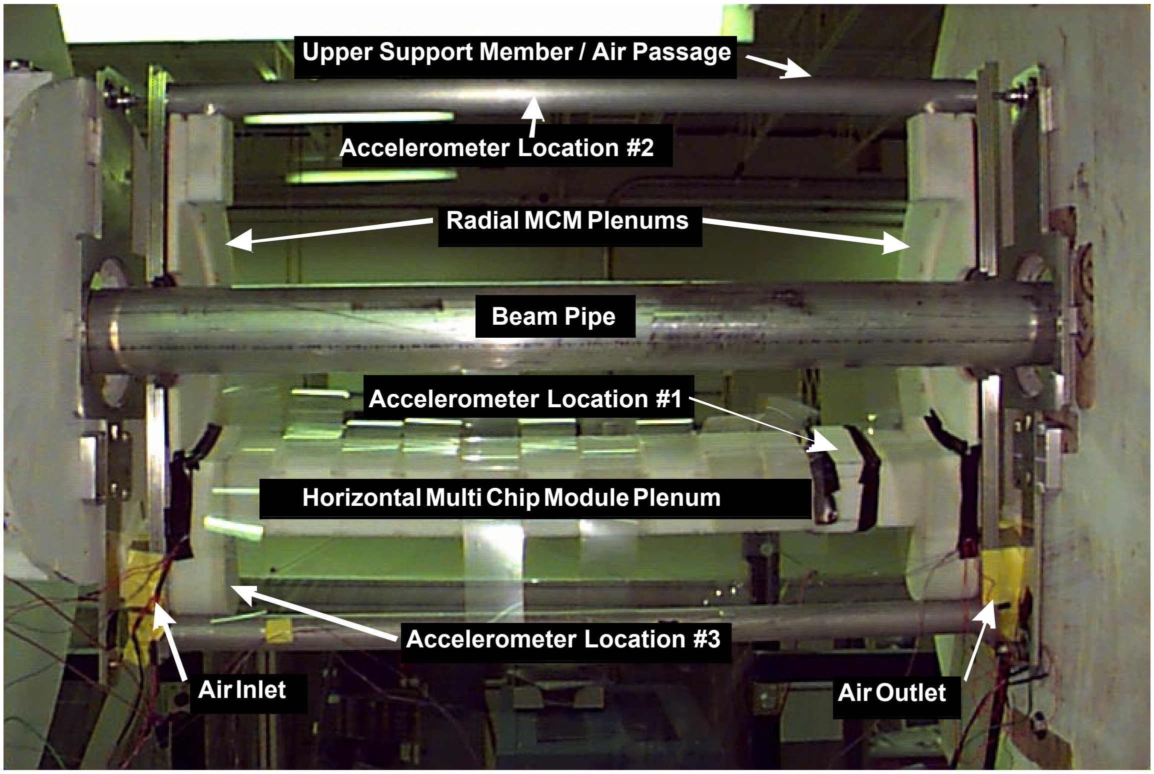

Figure 2. Photograph of the experimental MVD used in the vibration tests.

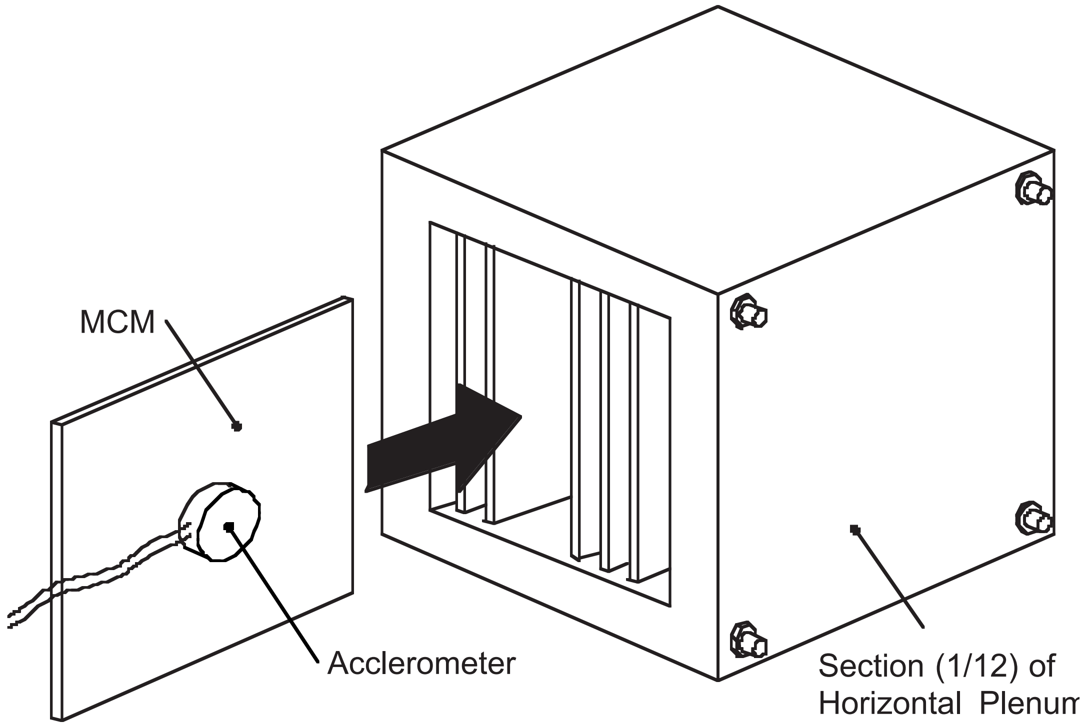

Figure 3. Accelerometer placement on the MCM within the 11th most downstream horizontal plenum component.

The accelerometer's output is a voltage that is directly proportional to acceleration (9.77 mV/g). Therefore, the signal displayed on the oscilloscope (voltage versus time) can be directly converted to an acceleration-versus-time plot. For a purely sinusoidal acceleration time curve,

$$a = a_m \sin(2\,\pi\,f\,t) \qquad (1)$$

where a_m is the maximum acceleration and f is the frequency, the maximum displacement, d_m, can be determined by performing a double integration of Equation (1) with respect to time over the first quarter period, $0 \leq t \leq f/4$ (representing the acceleration history from zero to maximum acceleration),

$$d_m = \frac{a_m}{(2\,\pi\,f\,)^2}\,. \qquad (2)$$

From Equation (2), it is apparent that the largest displacements correspond to the lowest frequency vibrations with the largest acceleration amplitude. Thus for all measurement signals which appeared to contain multiple wavelengths, the displacements were determined from the lowest frequency and highest amplitude present. This was justified because each measurement was dominated by a single low frequency and high amplitude signal.

Following calibration of the accelerometer, the air blowers were set to provide an inlet air volumetric flow rate of 0.022 m^3/s, which had previously been found to lie at the upper end of acceptable cooling air flow rates [1]. Next, the accelerometer output was read by the digital oscilloscope. From the resulting sinusoidal signal, the dominant amplitude and frequency were estimated and the maximum displacement was calculated using Equation (2). Multiple readings were made to ensure reproducibility. This procedure was repeated for the three measurement locations defined earlier in Figure 2.

RESULTS and CONCLUSIONS

The maximum accelerations and displacements of the three components measured in the MVD are summarized in Table 1. While the dominant frequency of vibration was significantly different for each component, the resulting displacements were nearly identical, all on the order of 1.5 μm. The component most susceptible to vibrations was speculated to be the MCM located in the horizontal air plenum. However, its displacement was found to be the smallest of the measurements taken.

Table 1. Summary of maximum accelerations and displacements of several components within the MVD.

Component	Dominant Vibration Frequency (Hz)	Maximum Acceleration (m/s^2)	Maximum Displacement (μm)
MCM	1,111	60.2	1.24
Aluminum Structural Support	200	2.5	1.60
Rohacell Air Inlet Plenum	459	12.1	1.45

The small magnitudes of the vibration-induced displacements indicate that the air flow will not present a danger to the structural integrity of the MVD. In addition, these displacements are less than the machining tolerances of the critical detector components, so the operation of the MVD will not be affected either.

REFERENCES

[1] Bernardin, J. D., Bosze, E., Clark, D., Boissevain, J., and Simon-Gillo, J., 1997, "An Experimental Investigation of an Air Cooling Scheme for the Multi-Chip Modules of the Multiplicity and Vertex Detector," Technical Report, Los Alamos National Laboratory.

[2] Parietti, L., Potter, C., Thompson, T., and Martin, R., 1996, "ESA-DE PHENIX MVD Design Review," Internal design report, Engineering Sciences and Applications Division, Design Engineering, Los Alamos National Laboratory, Los Alamos, NM 87545.