# K1DM3 Design Note

**Random Vibration Analysis**

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By J. Xavier Prochaska, Jerry Cabak, Jerry Nelson

## I. Overview

Over the course of its lifetime, the K1DM3 module will experience a range of stresses as it is transported to WMKO, handled during installation and coating, and tipped about during observations. As such, it must be designed to survive these conditions and maintain sufficient stability during observations to not significantly degrade the image quality.

There are two particular requirements that the K1DM3 design must satisfy regarding vibrations and the stresses that they incude:

1. The stresses on the mirror must not compromise the structural integrity of the K1DM3 components. Our primary concern is the glass of the mirror which has a maximum tensile strength for Zerodur of 42 MPa (6000 PSI) with a vendor-recommended limit of 10 MPa. We will design K1DM3 to limit stresses to be less than 500 PSI.

2. Motions of the mirror must contribute less than 10% rms to the optimal seeing disk of $0.4''$. As described in the Design Note on Positioning, this implies less than 29 microns (RMS) of translational motion and less than $0.92''$ and $0.46''$ (RMS) for motions in tip and tilt respectively.

In the following note, we examine the predicted performance of the current K1DM3 design in a range of environments.

## II. Forcing Functions

The K1DM3 team has been provided a set of forcing functions that are intended to describe the random motions as a function of frequency that the module would experience in three conditions: (1) during transportation; (2) during handling at WMKO (e.g. installation, removal for coating); (3) during normal operations when installed on the telescope. These three functions are illustrated in Figure 1, presented as power spectral density (PSD) curves as a function of frequency. As one would expect, the transportation function presents the most severe motions with PSD amplitudes many orders-of-magnitude higher than standard operation conditions.

## III. K1DM3 Design

Figure 2 shows the ANSYS version of the K1DM3 design, restricted to the primary components above the drum. This includes the swing arm, mirror assembly, and bipod struts. The mirror assembly assumes a 55 kg ellipsoid of low CTE glass supported by 6 axial rods and 3 lateral rods. See the ANSYS FEA files for further details.

In the following analysis, we consider the deployed and retracted configurations of K1DM3 separately. For the deployed configuration, the bipods and base of the swing arm are held rigidly in place. The swing arm is held rigidly by the kinematic mounts which position the mirror. This will be the configuration of K1DM3 during transportation and handling and it is the relevant configuration for stability analysis regarding image quality. When retracted, the swing arm is held fixed by the linear actuators (with brakes engaged) and may be constrained by a locking mechanism (not yet designed).

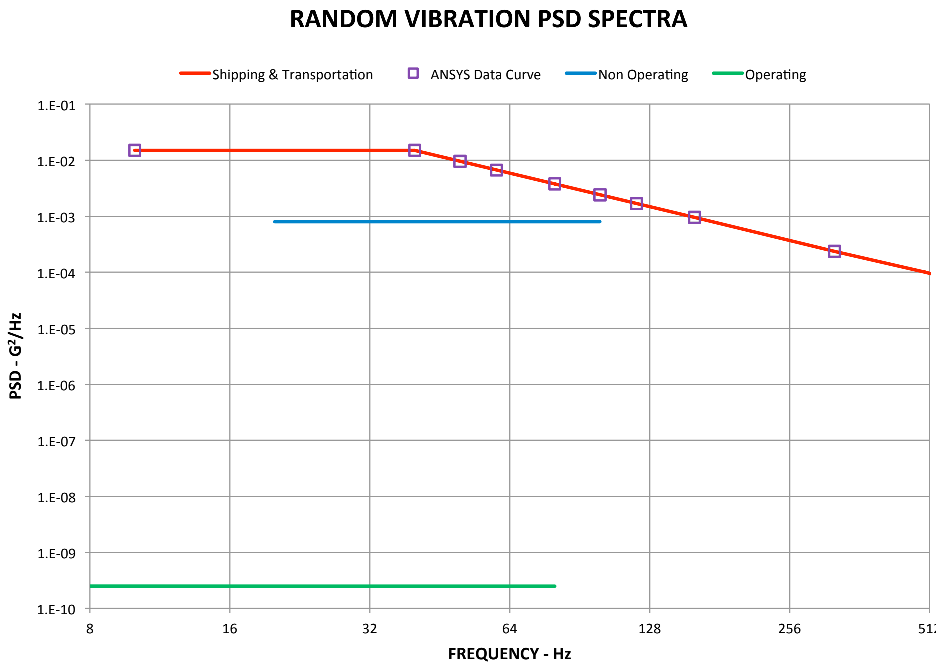


Fig. 1.— PSD spectra used for the vibrational analysis of the K1DM3 design. There are three separate functions for (i) transportation; (ii) handling at WMKO; and (iii) normal operations of K1DM3 on the telescope.

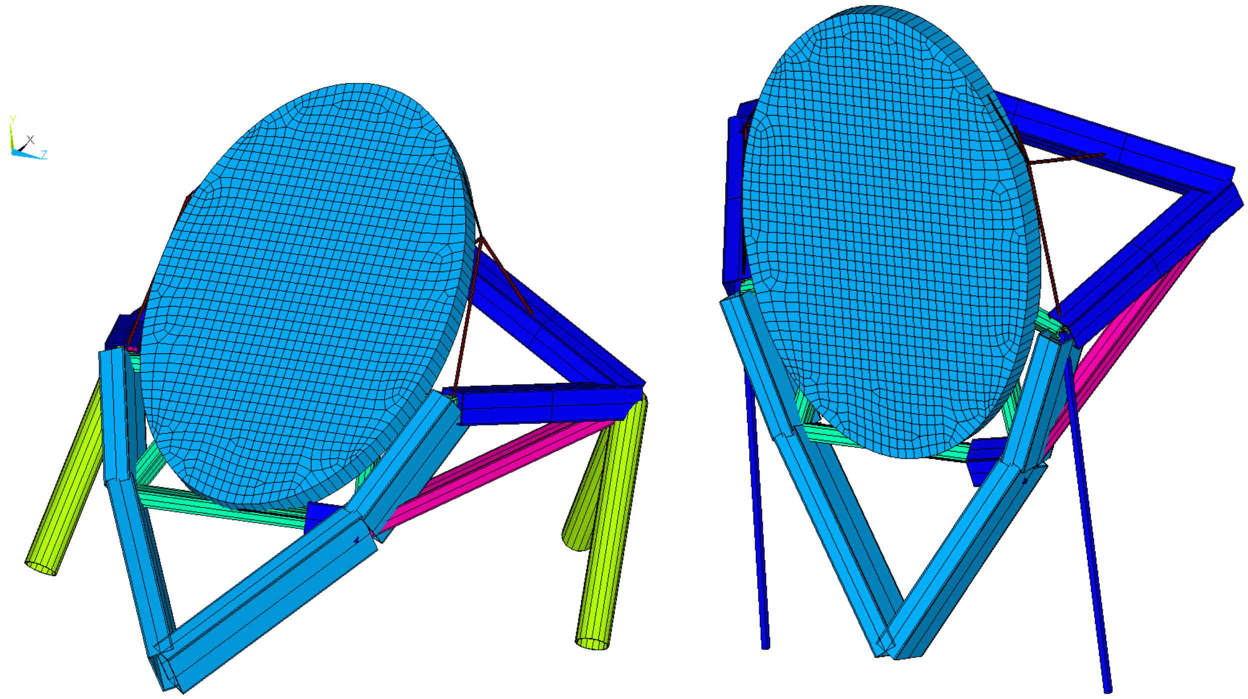

Fig. 2.— Diagram showing the ANSYS version of the K1DM3 detailed design, restricted to the primary components above the drum. This includes the swing arm, the mirror assembly, and the bipod struts. Left panel shows the system deployed and right panel shows the K1DM3 system retracted.

## IV. ANSYS Results (Deployed)

We performed a series of calculations using the ANSYS software package with the forcing functions described in Figure 1 and the K1DM3 design described by Figure 2 for the deployed configuration. The load function (random vibration spec) was applied, independently, in three orthogonal directions. We oriented K1DM3 such that gravity was normal to the module and applied the forcing functions along the the gravity axis and the two axes normal to it. The ANSYS-Z direction is along the elevation axis, the ANSYS-Y direction is vertical along the telescope axis, and ANSYS-X satisfies the right hand coordinate system rule. Results were then calculated yielding the RMS for displacements, the maximum stresses, and the maximum accelerations. Throughout the analysis, we focused on the impacts for the mirror assembly.

*Stresses:*

Figure 3 shows the stresses predicted for handling conditions in units of Pascals. The maximum stresses occur where the lateral rods connect to the mirror and have a value of 34 MPa corresponding to $\approx 5000$ PSI. We recover slightly larger values when driving along the ANSYS-Y axis ( $\approx 5500$ PSI). These stresses greatly exceed our design goal, require further discussion with WMKO, and possibly a mitigation strategy.

We derive even higher stresses and accelerations when driving the system with the PSD for transportation. The maximum stress is approximately 15,000 PSI with a maximum acceleration of 142 g. It is evident, and was expected, that we will need to design packaging for the transportation of K1DM3 that offers additional support for the mirror assembly.

In contrast, Figure 4 shows the stresses during operations. The results indicate a maximum stress of less than 5 PSI. Similarly we record maximum accelerations of less than 0.05 g.

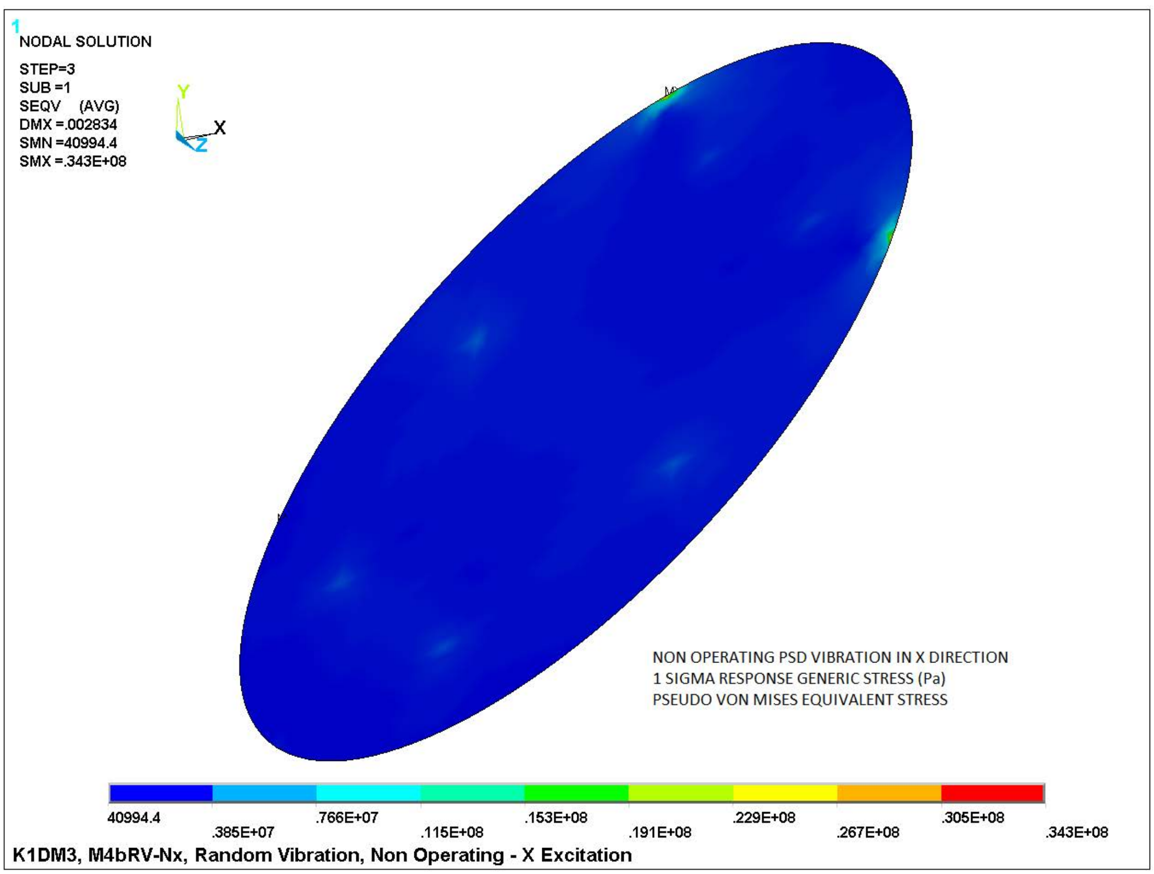


Fig. 3.— Stresses on the mirror assembly for the handling PSD vibrations along the ANSYS-X axis. Units are in Pascals.

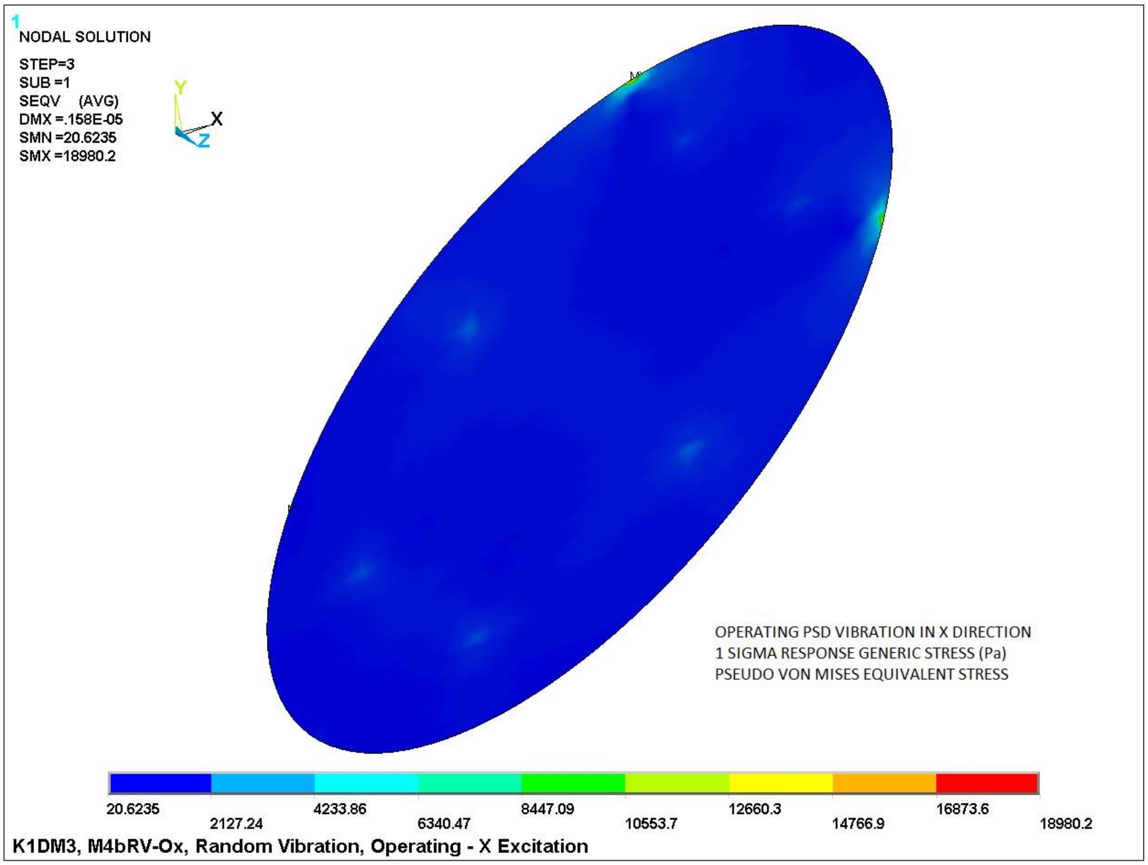


Fig. 4.— Stresses on the mirror assembly for the operating PSD vibrations along the ANSYS-X direction. Units are in Pascals. The maximum stress is less than 5 PSI.

*Image Stability:* The other major consideration for the effects of vibrations is the motion of the mirror during operations. Specifically, the K1DM3 system must hold the mirror in a sufficiently stable position to have a tolerably small effect on the image quality.

Figure 5 shows the RMS displacements of the mirror along the elevation axis for random vibrations along the same axis. These represent the largest response for such vibrations. The calculated RMS is approximately 1 micron which is well within the requirement of 29 microns. Examining the calculations for vibrations driven along the 3 axes, none of the RMS displacements exceed 2 microns along any axis.

The other requirements on image stability relate to rotations of the mirror. In Figure 6, we show representative cases for the tip and tilt of the mirror. For tip, the case shown represent the largest RMS values at approximately $1.5 \times 10^{-6}$ radians or $0.3''$ RMS. These are within the required limit of $0.92''$ RMS.

Figure 6 also shows the RMS tilt rotations of the mirror with vibrations oriented along the telescope $Z$-axis (ANSYS-Y axis; parallel to gravity). The values are also approximately $1.5 \times 10^{-6}$ radians or $0.3''$ (RMS). These also satisfy the required limit for tilt ($0.46''$ RMS) albeit by a rather modest margin.

## V. ANSYS Results (Retracted)

We have also examined the stresses on the K1DM3 module when the system is retracted for each

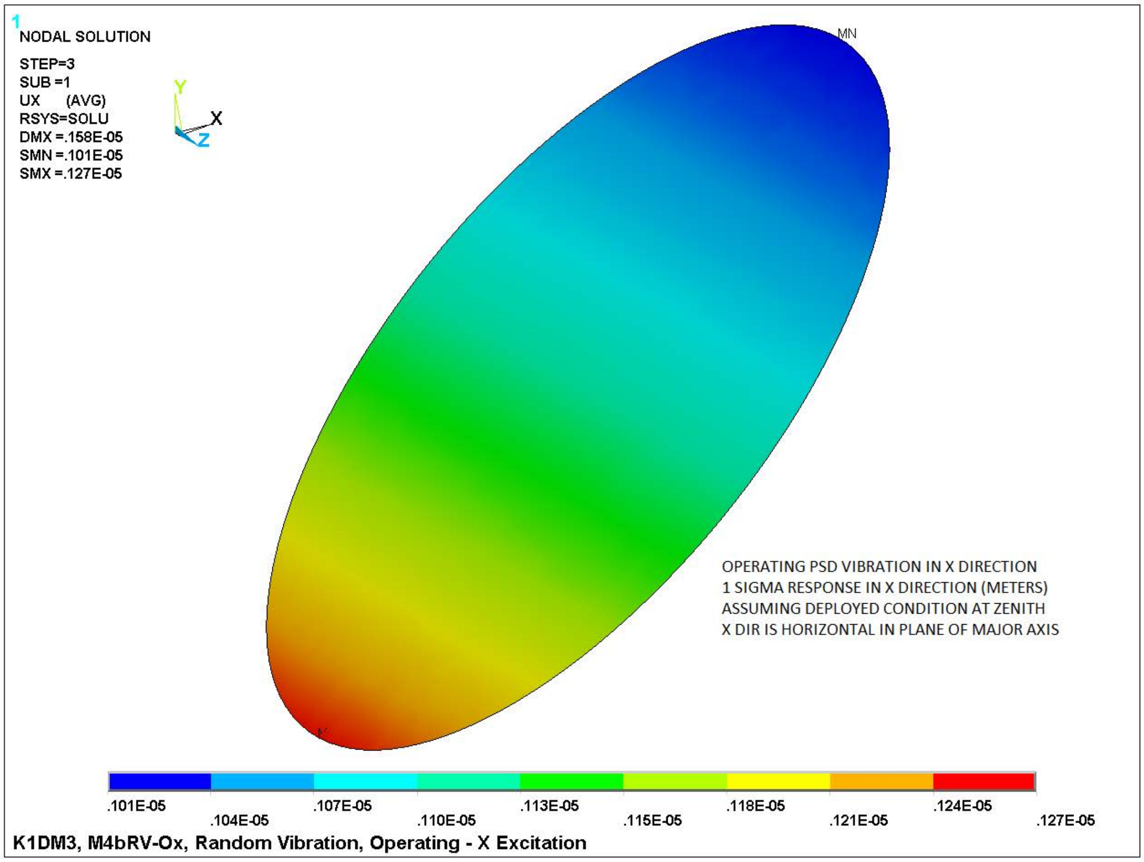


Fig. 5.— RMS displacements along the $X$-axis for PSD vibrations driven along the same axis using the operations spectrum. These show motions of approximately 1 micron RMS and are well within the requirements (29 microns RMS).

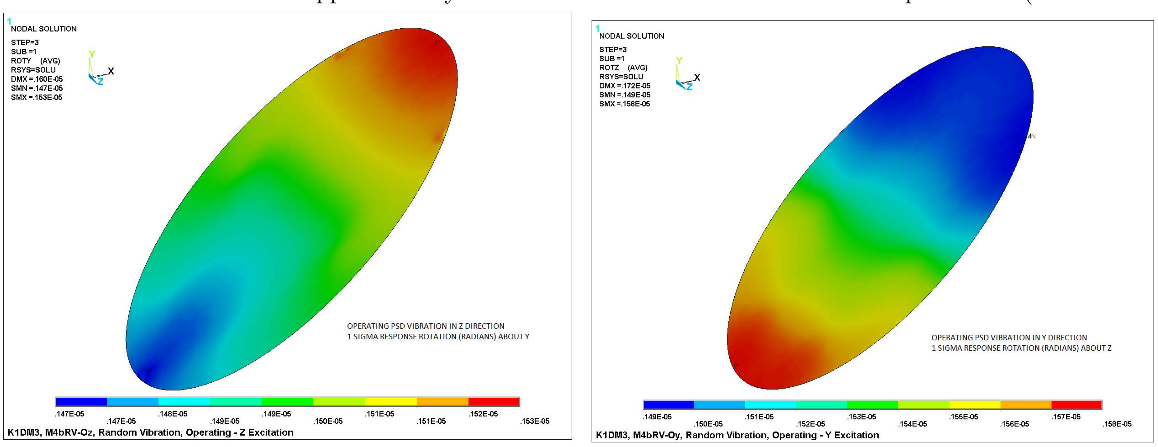


Fig. 6.— (left) RMS rotations of the mirror (radians) for PSD vibrations driven along the minor axis mirror. These correspond to tip rotations of the mirror. (right) RMS tilt rotations of the mirror (radians) for PSD vibrations driven along the telescope $Z$-axis (here corresponding to the ANSYS-Y axis).

of the three PSD spectra. For operation conditions, the maximum stresses are under 5 PSI and pose no threat to the system.

For the non-operating and transportation vibration spectra, we derive maximum stresses of $\approx 5500$ PSI and $\approx 17000$ PSI respectively. Similarly, the accelerations exceed 50 g and 150 g. These stresses are unacceptibly high and must be mitigated to avoid failure of the mirror.

## xx. ToDo

- Consider stresses in the glue bonds
- Update as design refines