Jet Propulsion Laboratory **Interoffice Memorandum**

To: Branislav Kecman May 6, 2005

From: M. R. O'Connell M. O'Connell

Subject: Stereo SEP-C FM1 and FM2 PF Sine and Random Vibration Test Report

References: 1) 'STEREO Environment Definition, Observatory, Component and Instrument Test Requirements Document', Applied Physics Laboratory, December 3, 2001.

2) 352G-WBT-0507, 'STEREO IMPACT Solar Energetic Particles Package (SEP) Dynamic Test Plan', W. B. Tsoi, January 13, 2005.

SUMMARY

Protoflight (PF) level sine and random vibration testing was performed on two Stereo SEP-C instruments in three axes at NTS. Some shifting of response frequencies did occur in both units during the test. Several 0-80 screws were found to have backed out during the vibration test when FM1 and FM2 were disassembled to investigate a short in LET FM1. Some follow on vibration testing is recommended after rework.

Test Approach and Requirements

Two Stereo SEP-C instruments, FM1 and FM2, were subjected to PF sine and random vibration in three axes on April 20 -22 and April 27-28, 2005 at NTS, LAX. Sine vibration surveys (0.25 gpk) were performed before and after vibration testing to the requirements of Table 1. Sine vibration testing was conducted to the requirements of Table 2, References 1 and 2. The sine specification in Table 2 was revised to stay within the NTS shaker capability by raising the frequency of the quasi static portion of the spectrum. Changes in the sine specification were well below the resonant frequencies of the SEP-C and the test load levels were not revised.

Random vibration testing was conducted to the requirements of Table 3 and References 1 and 2. Force limiting was utilized during the vibration test, which limited the interface forces to the 'as tested' requirements of Table 4. The force limit for the Y axis was adjusted downward based on the lower apparent SEP-C mass measured in the Y axis and due to concerns over the high instrument response. Instrument functional tests were performed before and after sine testing, random testing and between axes.

Test Control and Instrumentation

Random vibration levels were computer controlled by NTS's m+p vibration control system. Two control accelerometer locations were used on the vibration test fixture plate. The test axes are defined in Figure 1. Each SEP-C was instrumented with 9

accelerometers at 3 locations as shown in Table 5 and Figure 2 for FM1 and Figure 32 for FM2. Six Kistler 9251A force transducers were installed in between the test fixture plate and the test article (one for each mounting bolt).

Test Configuration and Equipment

SEP-C FM1 and FM2 were in the launch configuration and installed, one at a time, on the vibration fixture in a flight like manner. FM1 is shown installed on the slip table and the shaker head expander in Figures 3 and 4 while FM2 is shown in the same setups in Figures 33 and 34.

Each SEP-C instrument was mounted on top of six force transducers (Kistler 9251A or equivalent) and through bolted with six titanium fasteners to an adapter fixture. The fixture was in turn bolted to an NTS facility vibration test head expander or slip plate. Six Ultem bushings, thermal isolators, were used to support the SEP-C on top of the force transducers. On top of each mounting foot there was an Ultem washer with a shoulder, which prevents the Ti bolt from touching the instrument foot, Figures 2 and 3. Mounting bolt torques were checked as the test proceeded to prevent untorquing of the bolts during test.

FM1, Z Axis Sine Test Results

The 12 gpk input acceleration from the Z axis lateral PF sine test run is shown in Figure 5. The acceleration test input had no notching but response and force limits were in place for all sine test runs (both units) to protect the hardware during the run. The Z axis interface force and sine test response data are shown on Figures 6 through 9. Response data showed only minor amplification at 100 Hz.

FM1, Z Axis Random Test Results

The input acceleration from the Z axis lateral PF random test run is shown in Figure 10. The acceleration test input had a 14 dB notch in the input acceleration spectrum at 120 Hz and a 23 dB notch at 325 Hz, Figure 10. The X axis interface force is shown on Figure 11. Response at the center of gravity was 13.97 gpk 3 sigma (from Figure 11) which was less than the random analysis load of 30 gpk, 3 sigma. Response data, shown in Figures 12 through 14, reached 40.6 gpk, 3 sigma, at the sensor on top of the instrument. These are relatively deep notches for an instrument of this size but were deemed appropriate due to the high vibration Q of the instrument.

Comparison of the pre and post sine sweep data showed no changes in the interface force signature, Figure 15, which was representative of all the response data. Bolt torques were checked between runs to eliminate loosening at the attach bolts.

FM1, X Axis Sine Test Results

The 16 gpk input acceleration from the X axis lateral PF sine test run is shown in Figure 16. The acceleration test input had no notching but response and force limits were in place to protect the hardware during the run. The X axis interface force and instrument top response data showed only minor amplification at 100 Hz, Figures 17 and 18.

FM1, X Axis Random Test Results

The input acceleration from the X axis lateral PF random test run is shown in Figure 19. The acceleration test input had a 12 dB notch in the input acceleration spectrum at 145 Hz and a 23 dB notch at 390 Hz, Figure 19. The X axis interface force is shown on Figure 20. Response at the center of gravity was 15.4 gpk 3 sigma, which was less than the random analysis load of 30 gpk, 3 sigma. Response at the sensor was the highest, Figure 21, reached 42.3 gpk, 3 sigma, at the sensor.

Comparison of the pre and post sine sweep data showed some minor changes in the interface force signature, Figure 22, at the first two high force peaks. These shifts were apparent at all of the response accelerometers as seen in Figures 23 and 24. Bolt torques were again checked between runs to eliminate loosening at the attach bolts.

FM1, Y Axis Sine Test Results

The 12 gpk input acceleration from the Y axis lateral PF sine test run is shown in Figure 25. The acceleration test input had no notching but response and force limits were in place to protect the hardware during the run. The Y axis interface force and sensor response data showed no amplification, Figures 26 and 27.

FM1, Y Axis Random Test Results

The input acceleration from the Y axis lateral PF random test run is shown in Figure 28. The acceleration test input had a 10 dB notch in the input acceleration spectrum at 395 Hz and a 14 dB notch at 575 Hz, Figure 28, with other smaller notches at 330 Hz and 860 Hz. The Y axis interface force is shown on Figure 29. Response at the center of gravity was 32.7 gpk 3 sigma (43.6 g 4 sigma, from Figure 29), which was less than the random analysis load of 50 gpk, 3 sigma. Maximum response data, shown in Figure 30, reached 93.9 gpk, 3 sigma, at the top of the instrument.

Comparison of the pre and post sine sweep data showed no additional changes in the interface force signature, Figure 31, which was representative of all the response data. Bolt torques were checked between runs to eliminate loosening at the attach bolts.

FM2, Z Axis Sine Test Results

The 12 gpk input acceleration from the Z axis lateral PF sine test run is shown in Figure 35. The acceleration test input had no notching but response and force limits were in place for all sine test runs (both units) to protect the hardware during the run. The Z

axis interface force and representative sine test response data are shown on Figures 36 and 37. Response data showed only minor amplification at 100 Hz, as with FM1.

FM2, Z Axis Random Test Results

The input acceleration from the FM2 Z axis lateral PF random test run is shown in Figure 38. The acceleration test input had a 16 dB notch in the input acceleration spectrum at 120 Hz and a 22 dB notch at 325 Hz, Figure 38. The X axis interface force is shown on Figure 39. Response at the center of gravity was 13.8 gpk 3 sigma, which was less than the random analysis load of 30 gpk, 3 sigma. Sensor response data, shown in Figure 40, reached 42.1 gpk, 3 sigma, at the sensor.

Comparison of the pre and post sine sweep data showed no major changes in the interface force signature and the telescope top, Figures 41 and 42, representative of all the response data. Bolt torques were checked between runs to eliminate loosening at the attach bolts.

FM2, X Axis Sine Test Results

The 16 gpk input acceleration from the X axis lateral PF sine test run is shown in Figure 43. The acceleration test input had no notching but response and force limits were in place during the run. The X axis interface force and instrument top response data showed only minor amplification at 100 Hz, Figures 44 and 45.

FM2, X Axis Random Test Results

The input acceleration from the X axis lateral PF random test run is shown in Figure 46. The acceleration test input had a 13 dB notch in the input acceleration spectrum at 144 Hz and a 24 dB notch at 390 Hz, Figure 46. The X axis interface force is shown on Figure 47. Response at the center of gravity was 15.7 gpk 3 sigma and response at the telescope top, Figure 48, reached 46.2 gpk, 3 sigma.

Comparison of the pre and post sine sweep data showed no changes in the interface force signature or the telescope top, Figures 49 and 50. Bolt torques were again checked between runs to eliminate loosening at the attach bolts.

FM2, Y Axis Sine Test Results

The 12 gpk input acceleration from the Y axis lateral PF sine test run is shown in Figure 51. The acceleration test input had no notching but response and force limits were in place to protect the hardware during the run. The Y axis interface force data showed no amplification, Figure 52.

FM2, Y Axis Random Test Results

The input acceleration from the Y axis lateral PF random test run is shown in Figure 53. The acceleration test input had a 4 dB notch in the input acceleration spectrum at 395 Hz and 800 Hz, and a 6 dB notch at 505 Hz and at 665 Hz, Figure 53. The Y axis interface force is shown on Figure 54. Response at the center of gravity was 36.9 gpk 3 sigma (49.3 g 4 sigma, from Figure 54), which was still within the random analysis load of 50 gpk, 3 sigma. Maximum response data, shown in Figure 55, reached 113.1 gpk, 3 sigma, at the top of the instrument.

Comparison of the pre and post sine sweep data showed a significant change in the interface force signature at the first high force peak at 591.5 Hz, Figure 56. The initial single peak split at 591.5 Hz into two peaks. This mode split was representative of all the response data as seen at the telescope top in Figure 57. Hardware functional tests were performed and bolt torques were checked and the last survey repeated with the same split mode result.

Conclusion

SEP-C FM1 and FM2 were subjected to PF level sine vibration and force limited PF random vibration testing. Some frequency shifts were noted during vibration testing but these were judged to not be significant enough to stop testing. Later, disassembly and inspection revealed that several 0-80 screws inside FM1 and FM2 had backed out during the vibration testing. Both units will be opened to re-torque unstaked screws and stake them (mostly in LET sensor). Some follow on vibration testing should be performed on both FM1 and FM2.

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Table 1. SEP-C Sine Vibration Signature Survey Specification

Frequency, Hz	Survey Level
5-2000	0.25 gpk

Sweep Rate: 2 octaves/minute, sweep up only

Table 2. SEP-C 3 Axis PF Sine Vibration Test Specification

Frequency (Hz)	Acceleration (zero to peak), Thrust Axis, Xsc	Frequency (Hz)	Acceleration (zero to peak), Zsc, Ysc
5 to 7.4 7.4 to 24 28.25 to 30.25 34 to 100	0.5 in. 1.4 g 16.0 g 1.4 g	5 to 7.4 7.4 to 24 28.25 to 30.25 34 to 100	0.5 in. 1.0 g 12.0 g 1.0 g

Sweep Rate: 4 octaves/minute, sweep up only

Table 3. SEP-C 3 Axis PF Random Vibration Test Specification

Axis	Frequency, Hz	PF Level
Perpendicular to Mounting Panel, Ysc	20 20 – 80 80 – 800 800 – 2000 2000 Overall	0.0063 g^2/Hz + 6 dB/octave 0.1 g^2/Hz - 9 dB/octave 0.0065 g^2/Hz 10.4 g_{rms}
Parallel to Mounting Panel, Xsc, Zsc	20 20 – 80 80 – 800 800 – 2000 2000 Overall	0.0031 g^2/Hz + 6 dB/octave 0.05 g^2/Hz - 9 dB/octave 0.0032 g^2/Hz 7.4 g_{rms}

Duration: 1 minute per axis, 3 orthogonal axes

Table 4. 'As Run' Final SEP-C PF Force Specifications

Axis	Frequency, Hz	PF Level
Xsc	20 – 145 2000	20.25 lb^2/Hz 0.106 lb^2/Hz
Ysc	20 - 609 2000	9.25 lb^2/Hz 0.86 lb^2/Hz
Zsc	20 – 120 2000	20.25 lb^2/Hz 0.073 lb^2/Hz

Table 5. SEP-C Response Accelerometer Locations

Accelerometer Designation	Accelerometer Location
A1X, A1Y, A1Z	LET Telescope Top
A2X, A2Y, A2Z	LET Telescope Sensor
A3X, A3Y, A3Z	LET Telescope Base

Figure 1. SEP-C and Spacecraft Axes

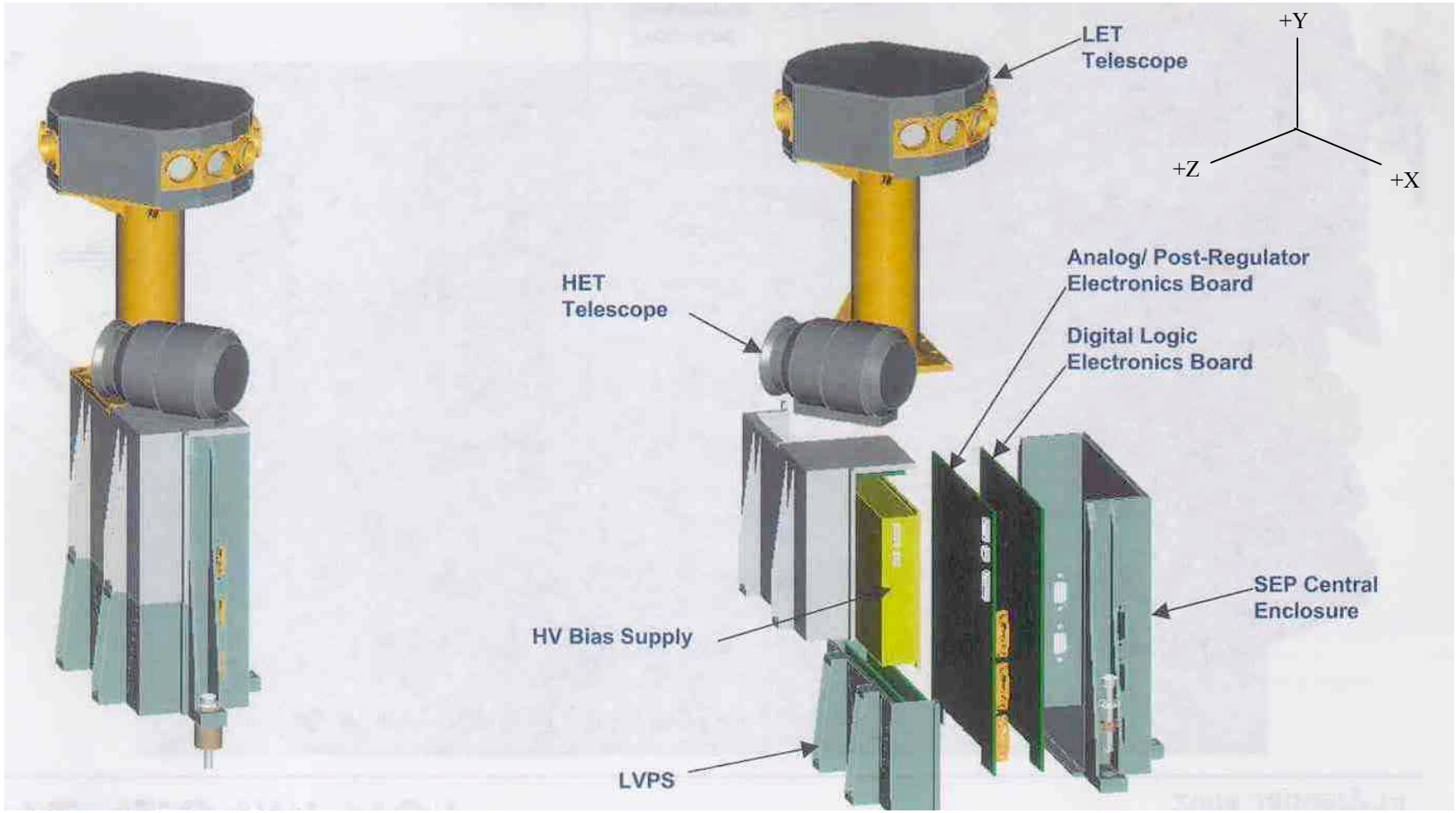

Figure 2. SEP-C FM1 Accelerometer Locations

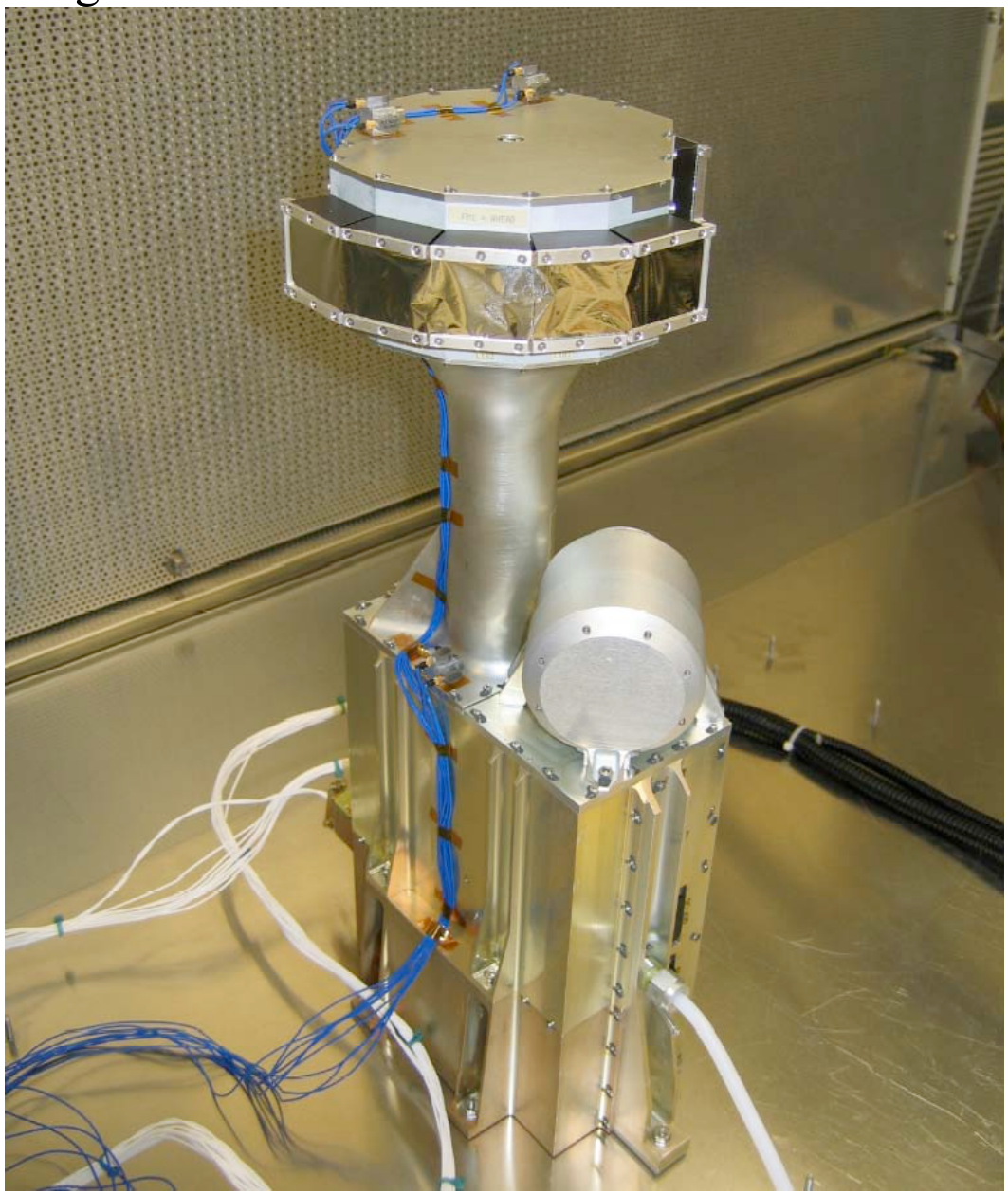

Figure 3. SEP-C FM1, Z Axis Test Setup on Slip Table

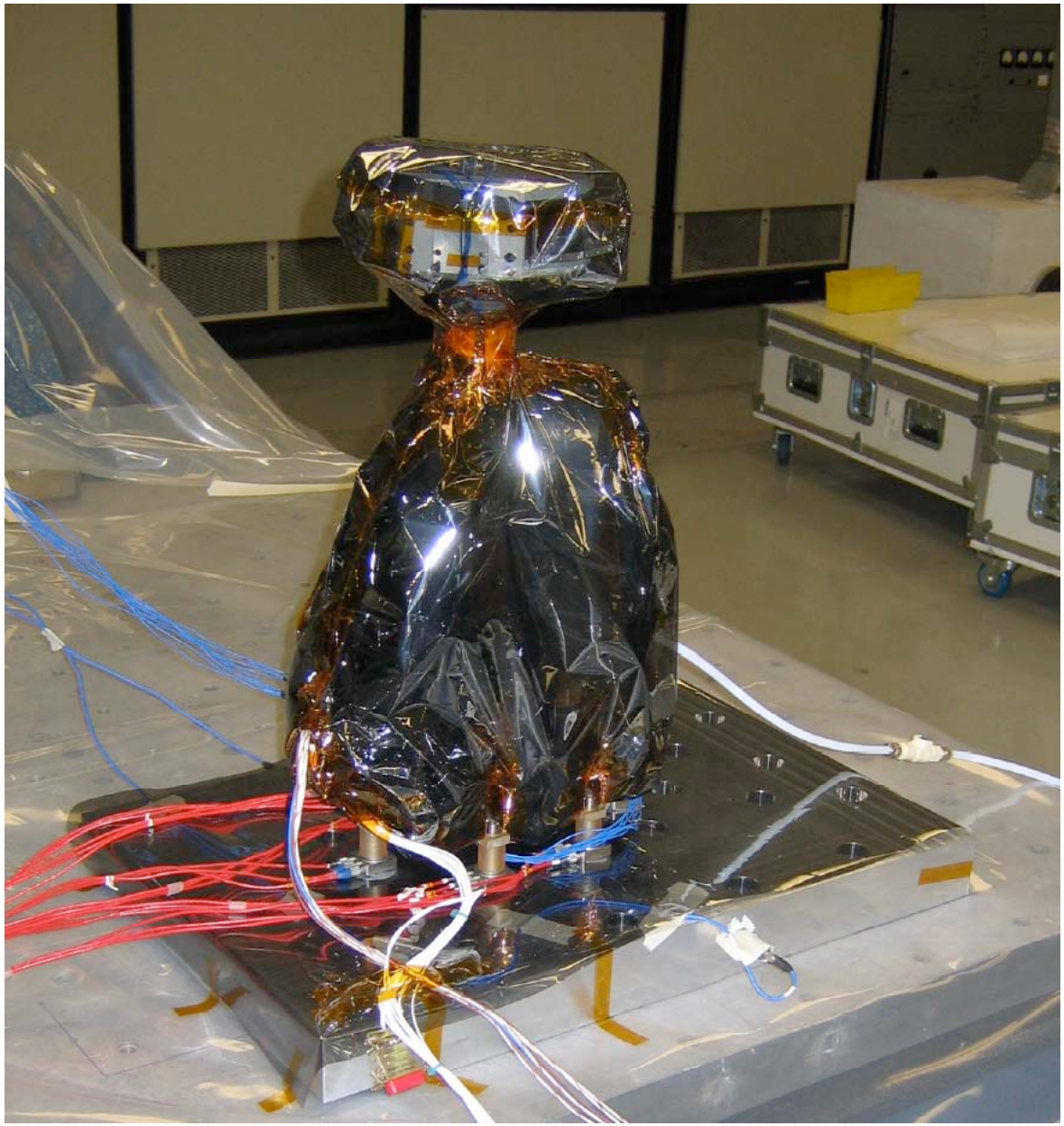

Figure 4. SEP-C FM1, Y Axis Test Setup on Head Expander

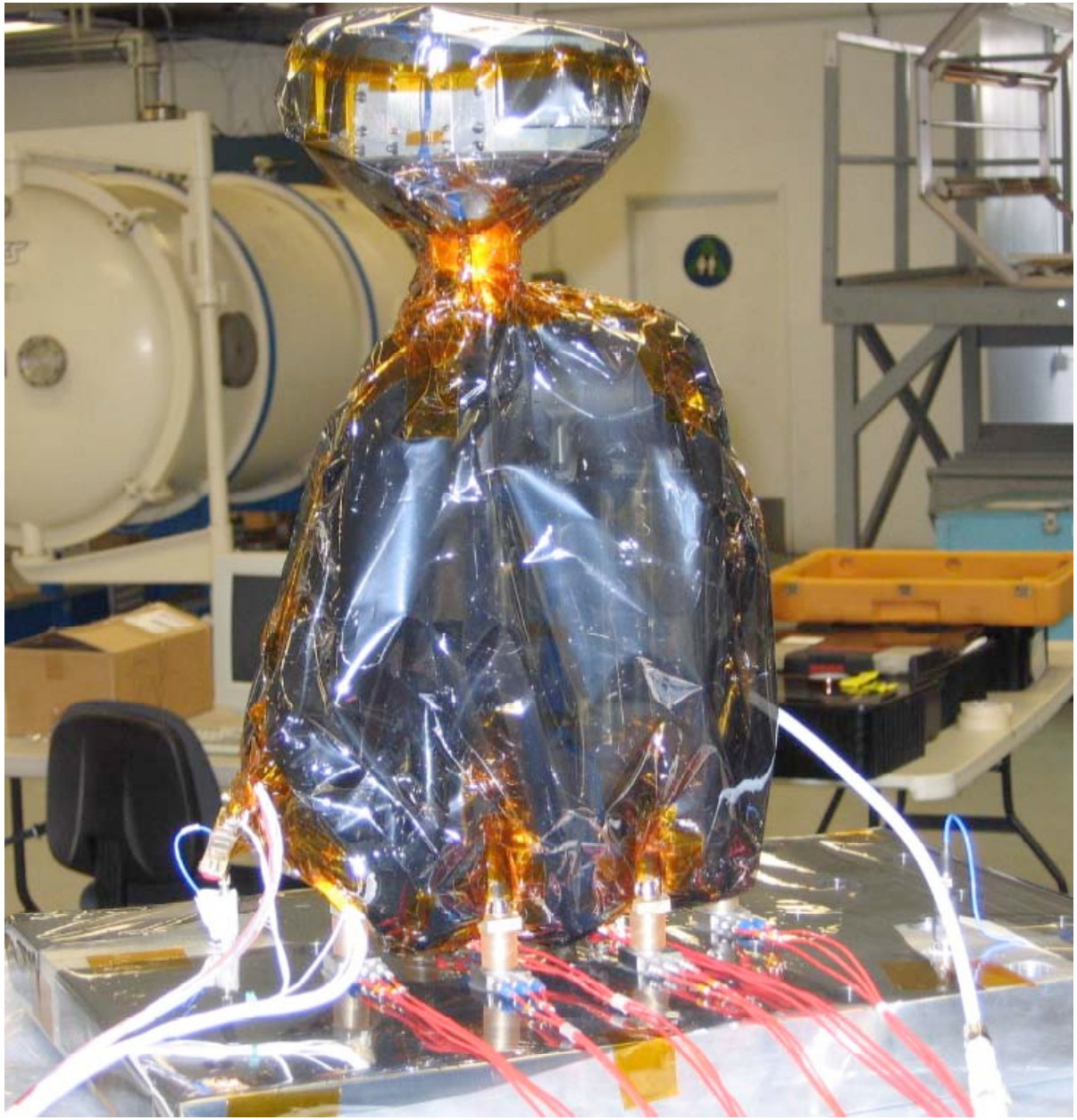

Figure 5. SEP-C FM1, Z Axis PF Sine Input

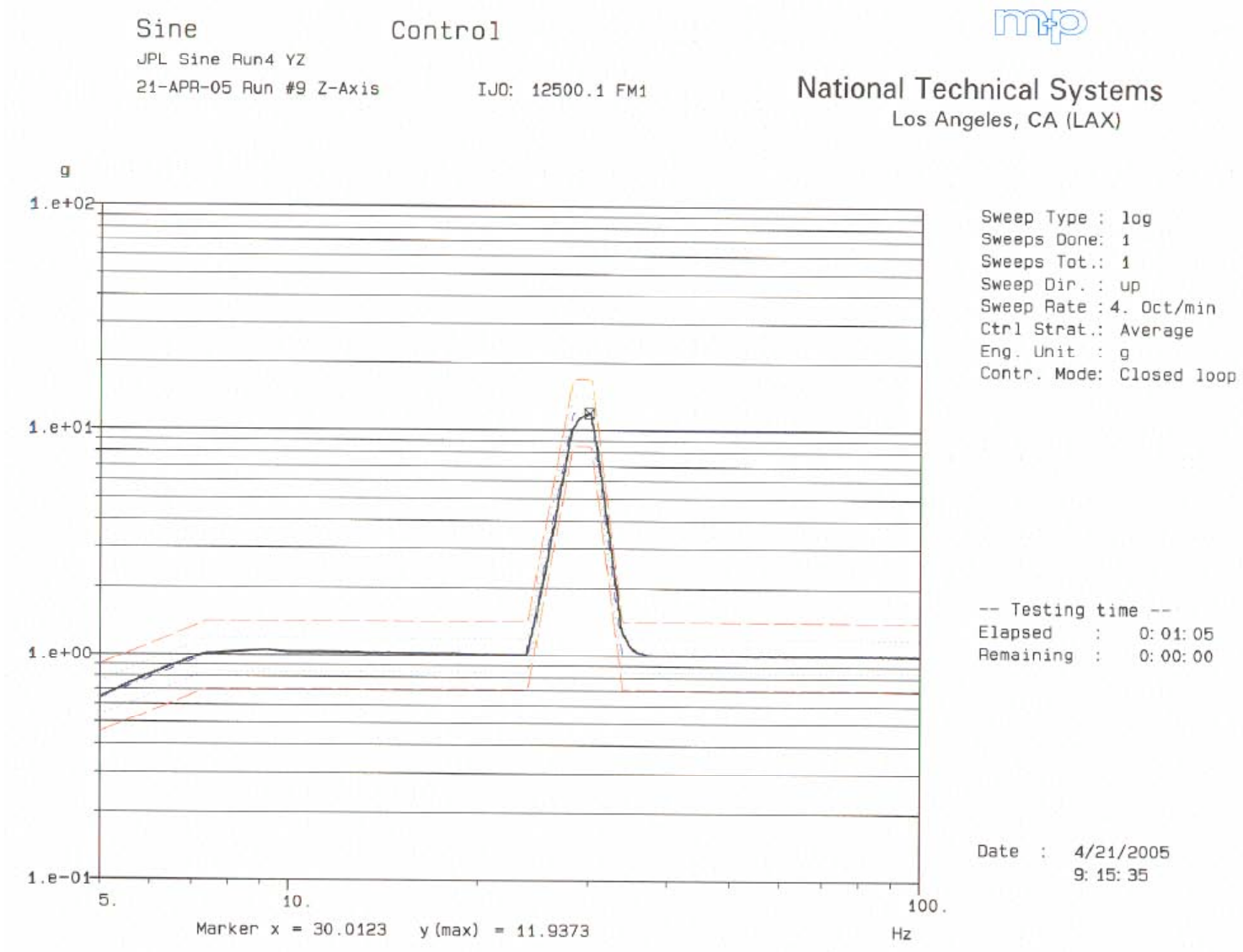

Figure 6. SEP-C FM1, Z Axis PF Sine, Summed Z Interface Force

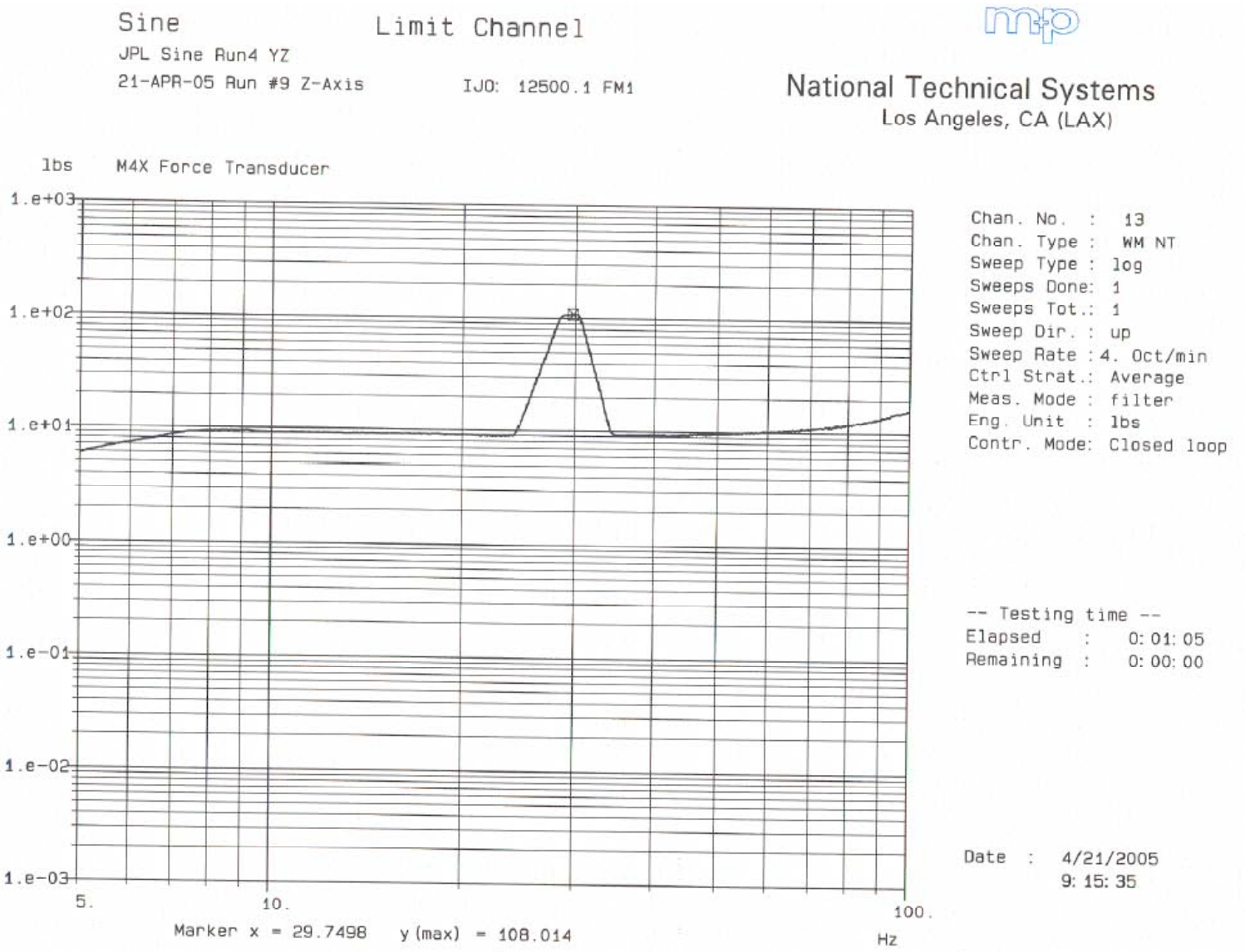

Figure 7. SEP-C FM1, Z Axis PF Sine, Telescope Top

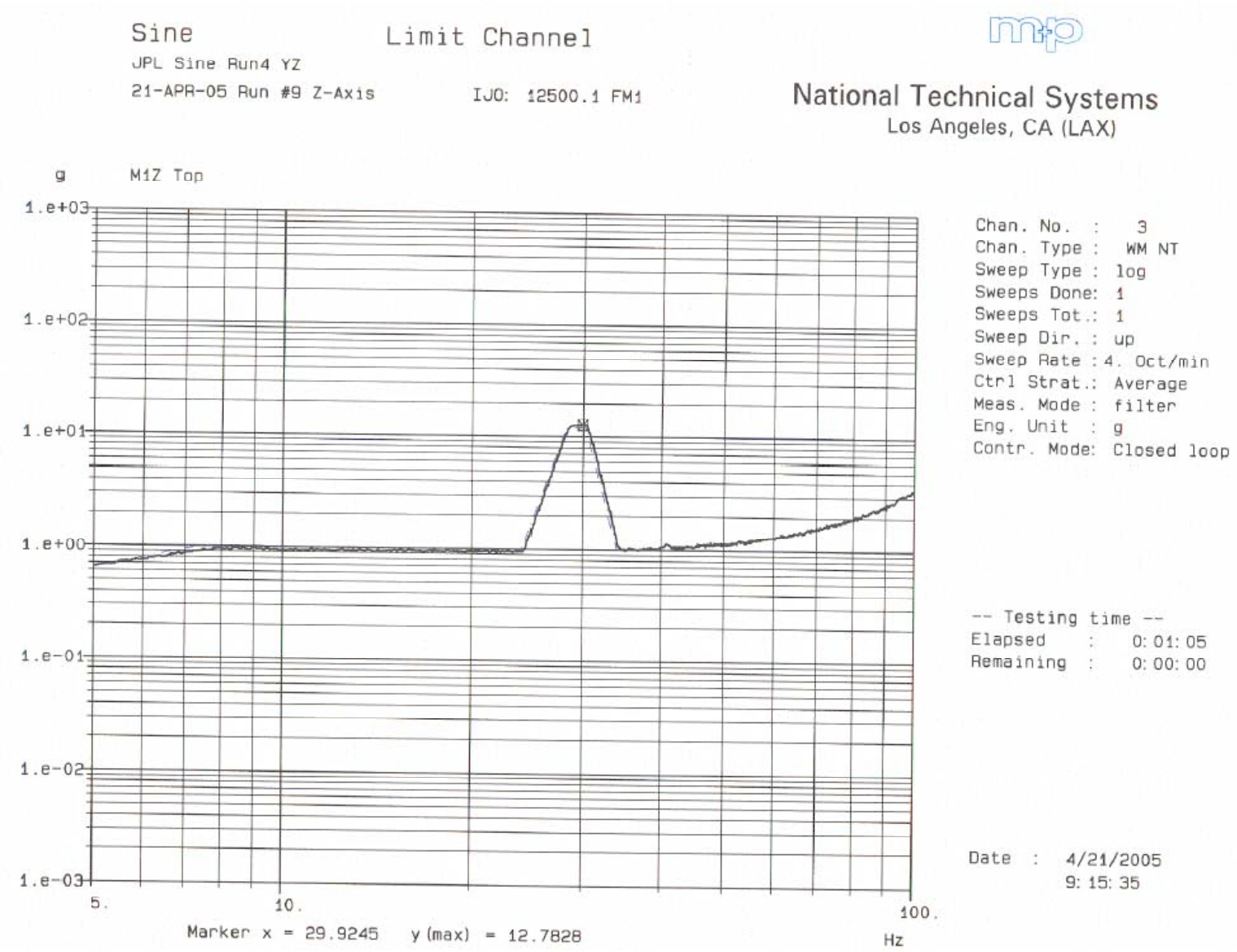

Figure 8. SEP-C FM1, Z Axis PF Sine, Telescope Sensor

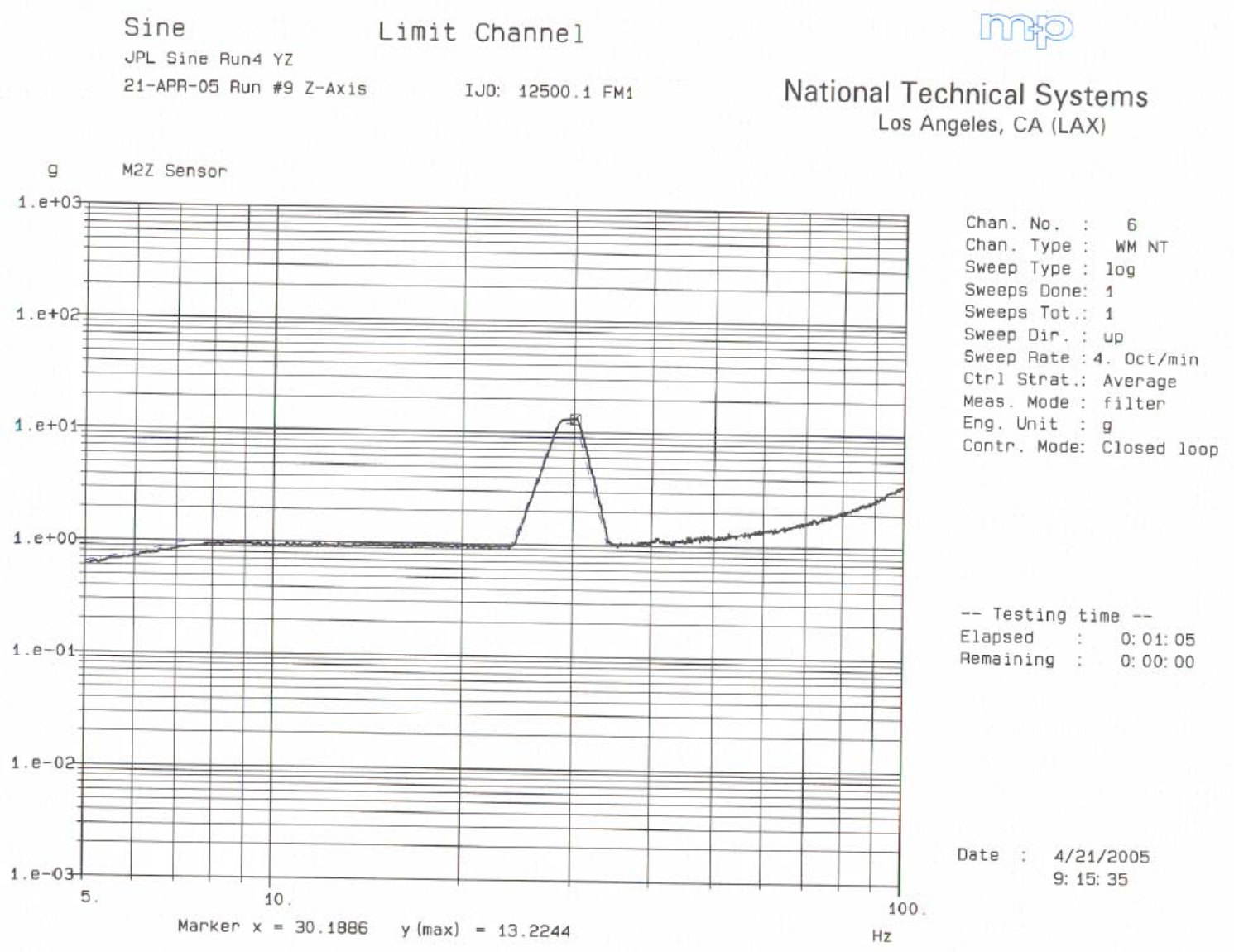

Figure 9. SEP-C FM1, Z Axis PF Sine, Telescope Base

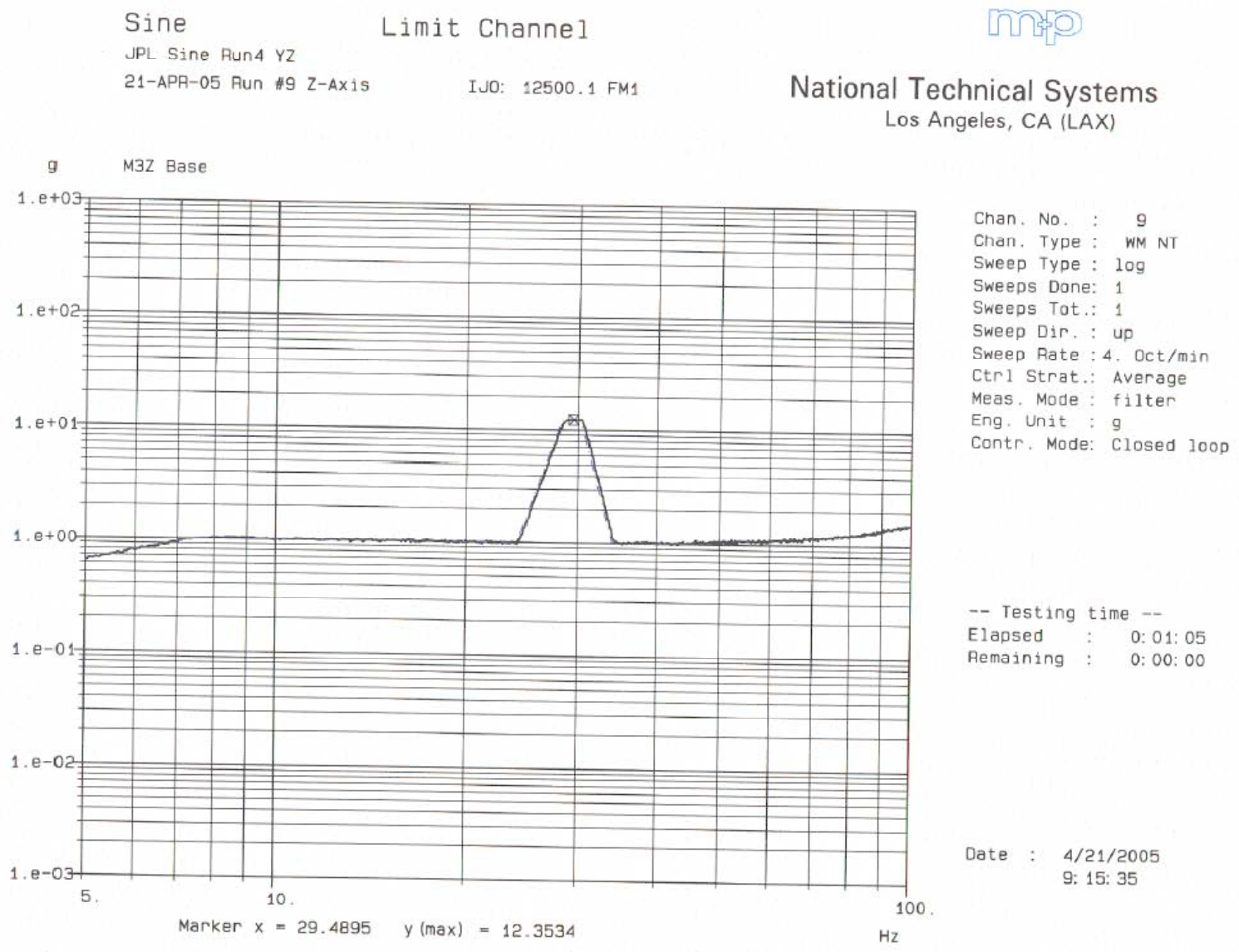

Figure 10. SEP-C FM1, Z Axis PF Random Vibration Input, Force Limited

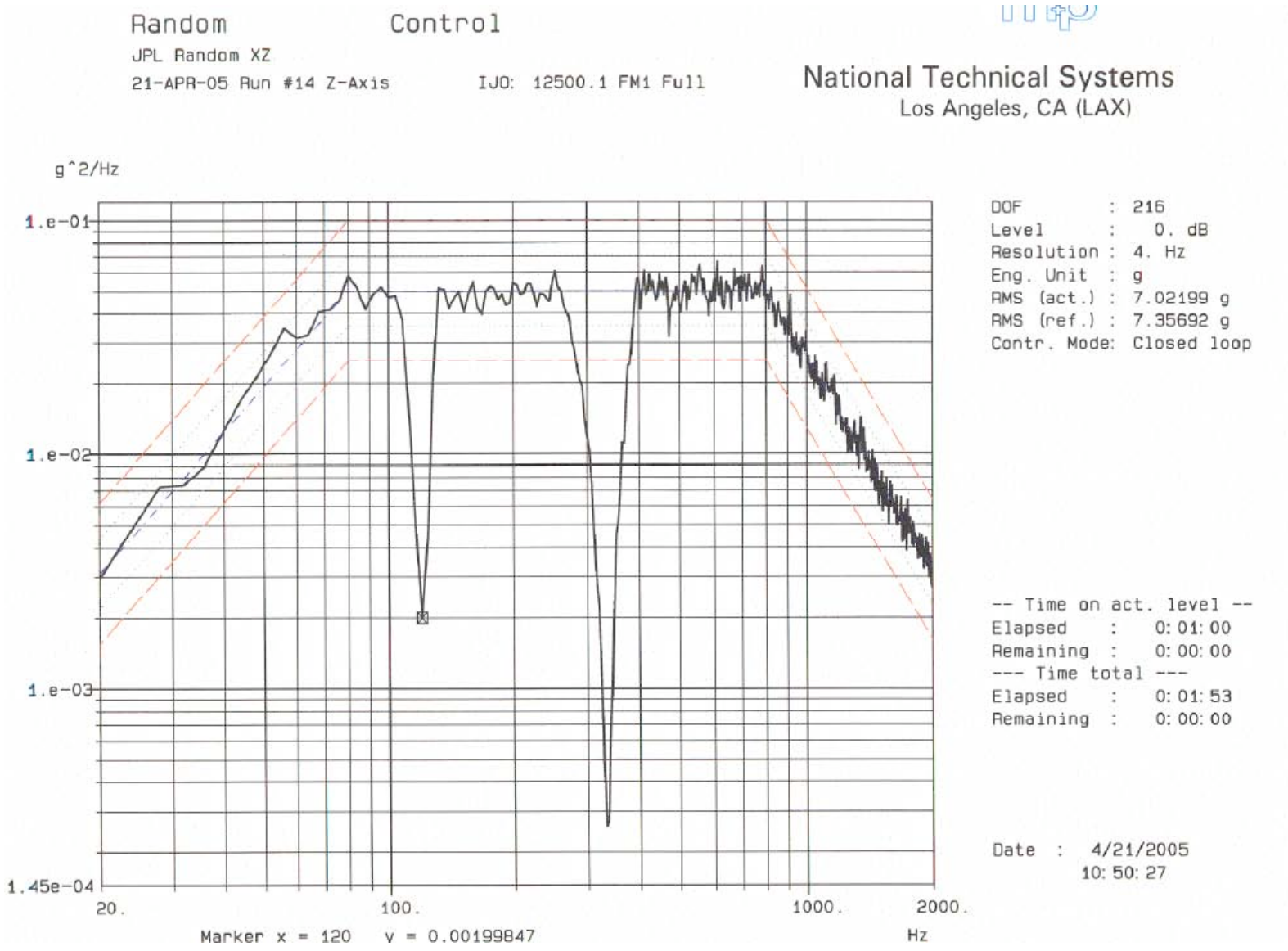

Figure 11. SEP-C FM1, Z Axis PF Random Summed Interface Force

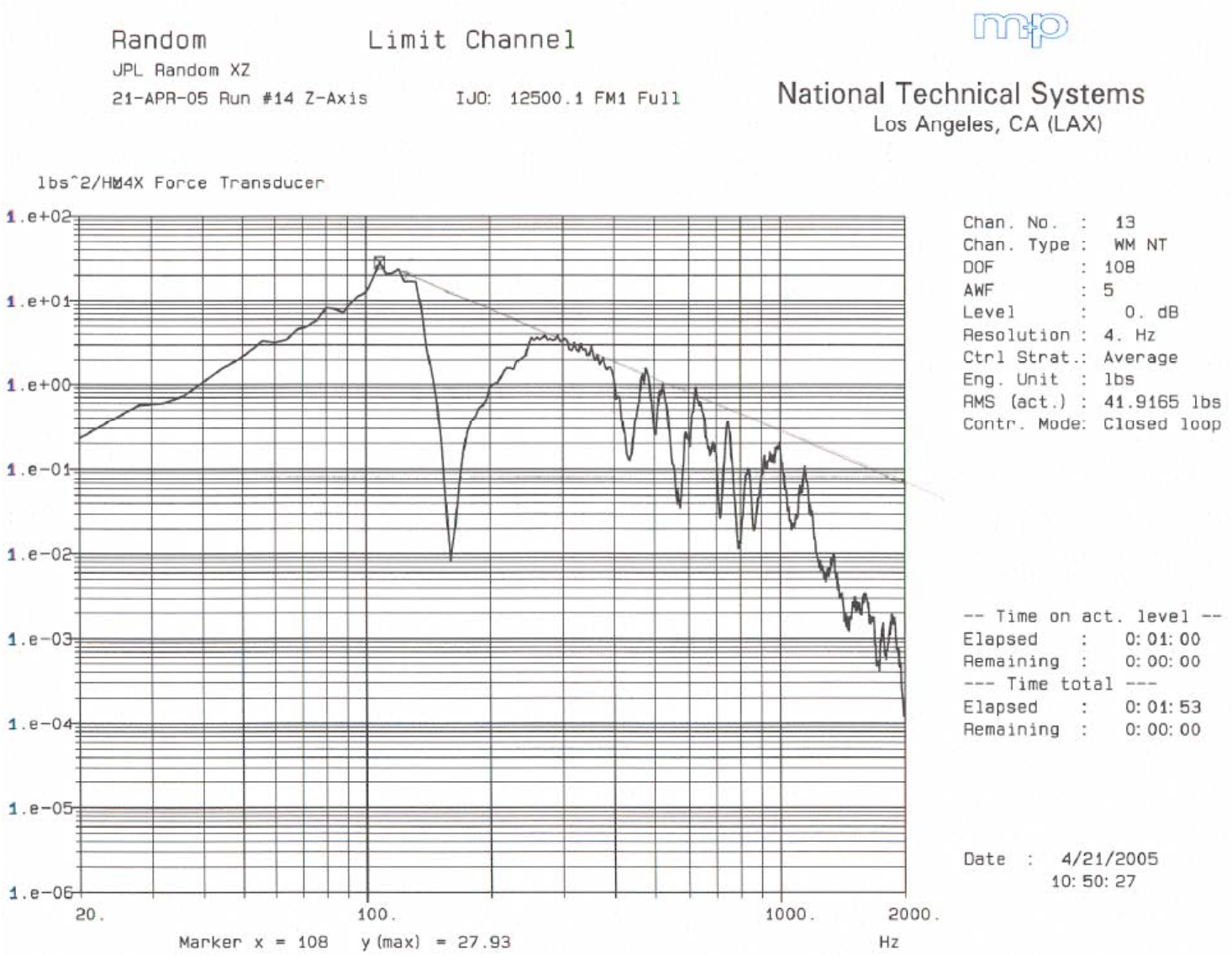

Figure 12. SEP-C FM1, Z Axis PF Random Telescope Top Response

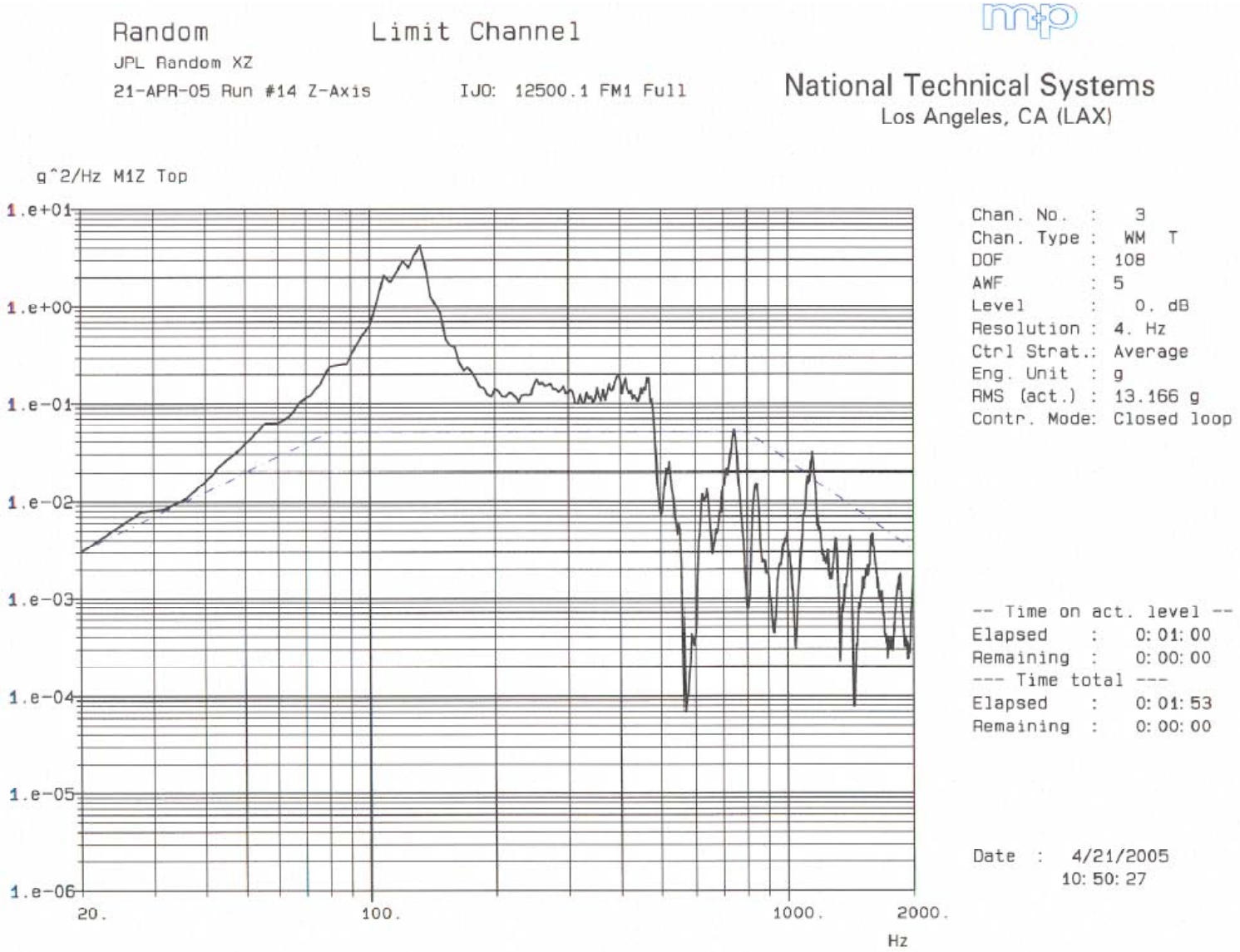

Figure 13. SEP-C FM1, Z Axis Telescope Sensor Response

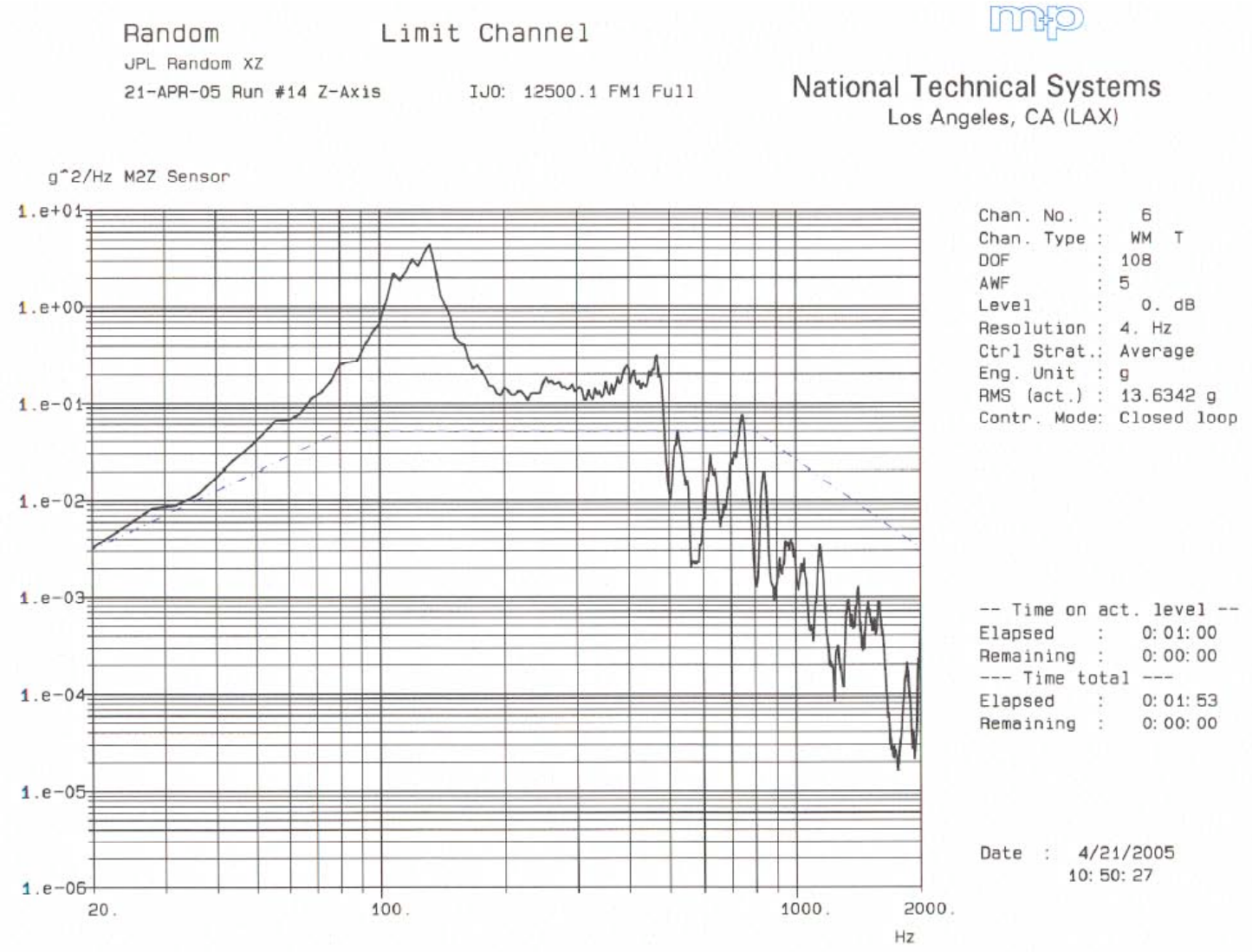

Figure 14. SEP-C FM1, Z Axis Telescope Base Response

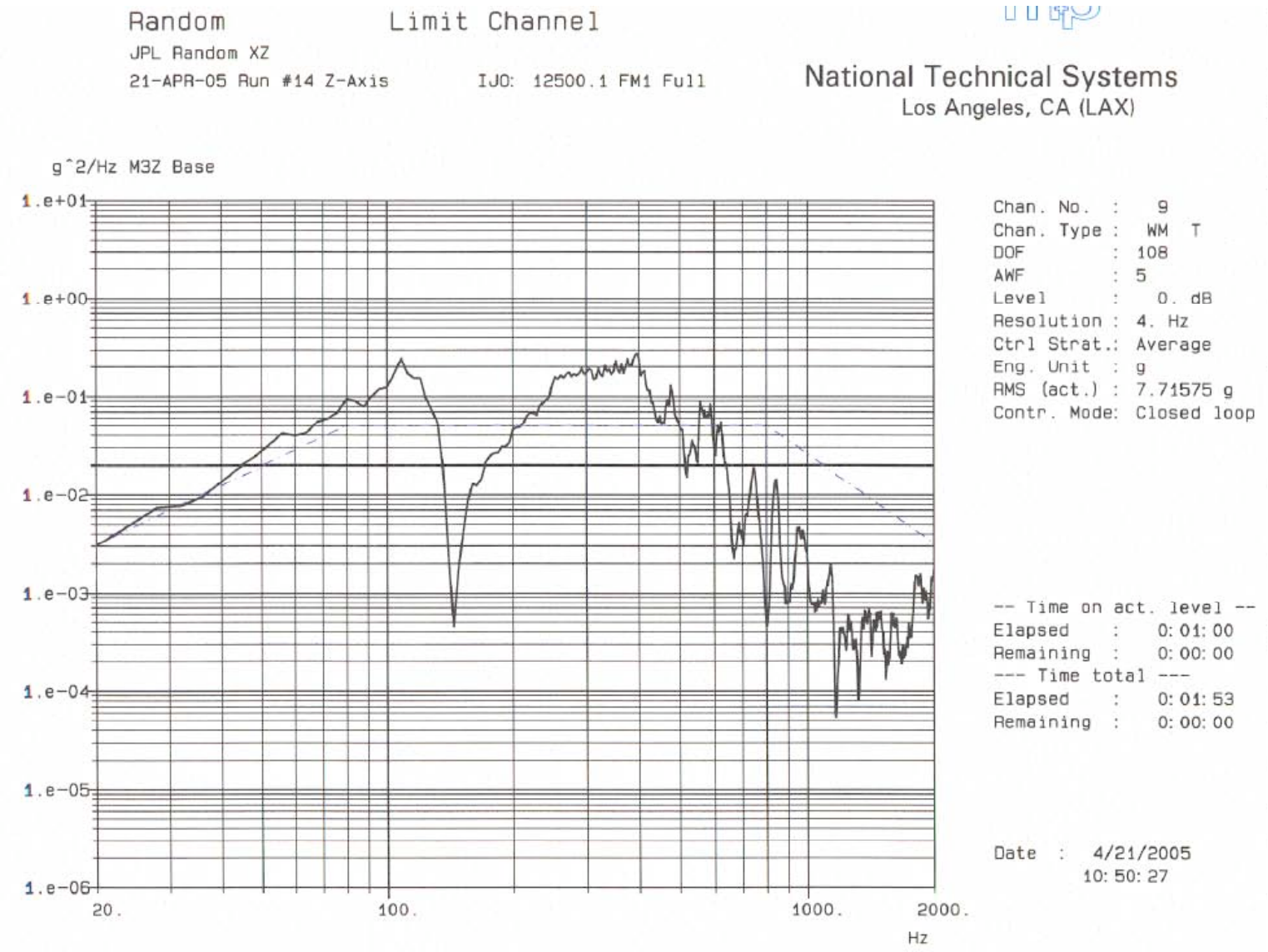

Figure 15. SEP-C FM1, Z Axis Pre and Post Sine Survey Interface Force

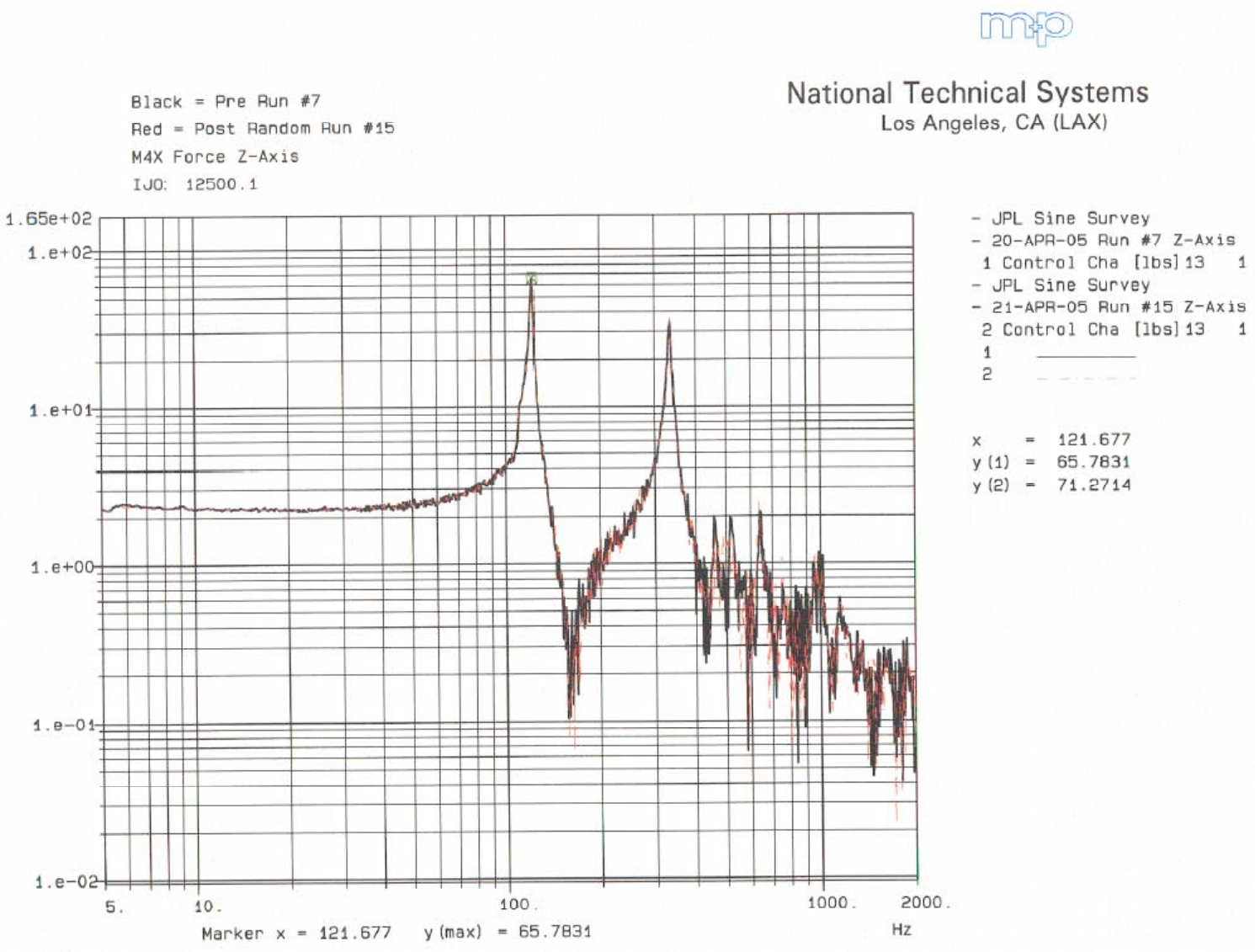

Figure 16. SEP-C FM1, X Axis PF Sine Input

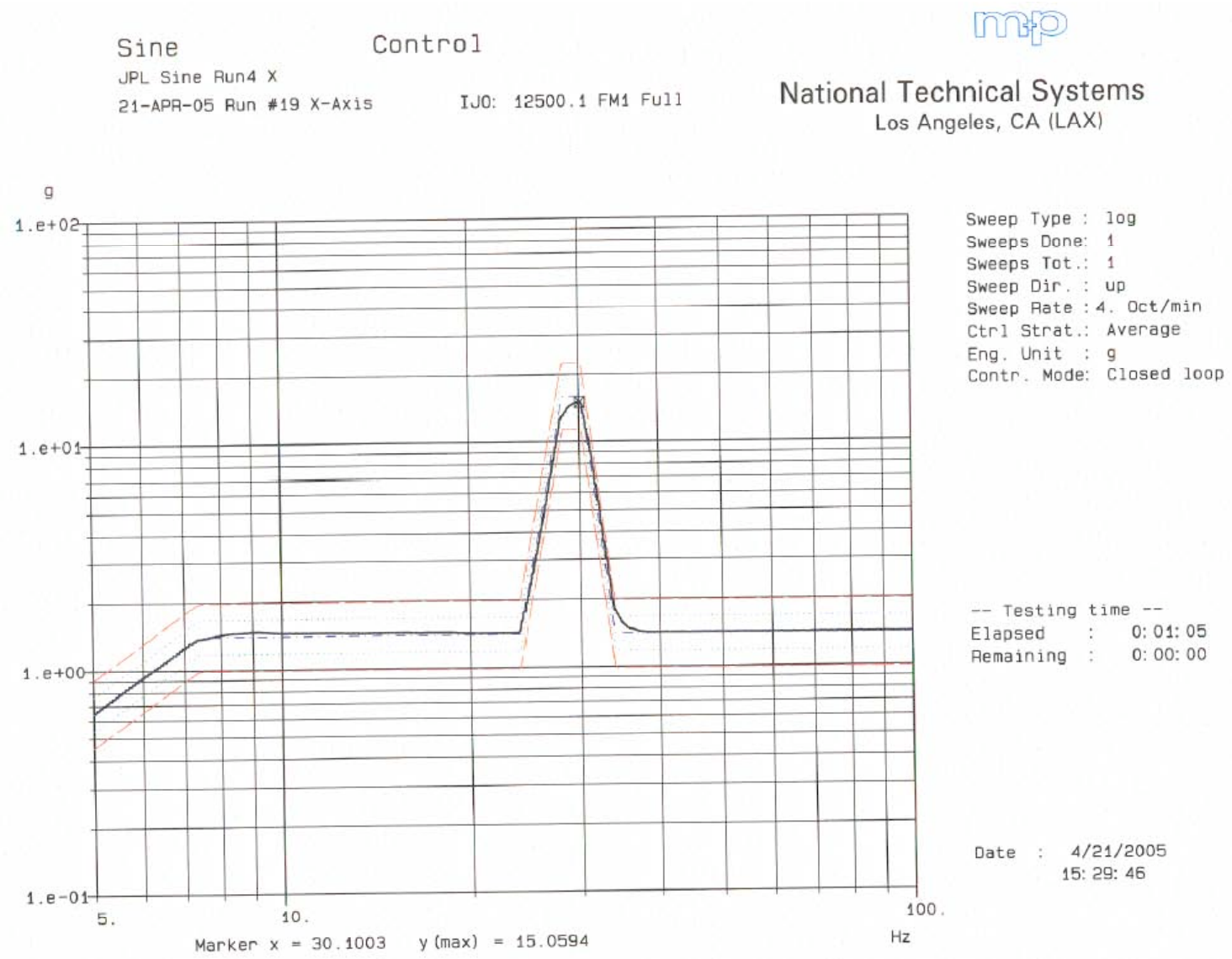

Figure 17. SEP-C FM1, X Axis PF Sine Response, Telescope Top

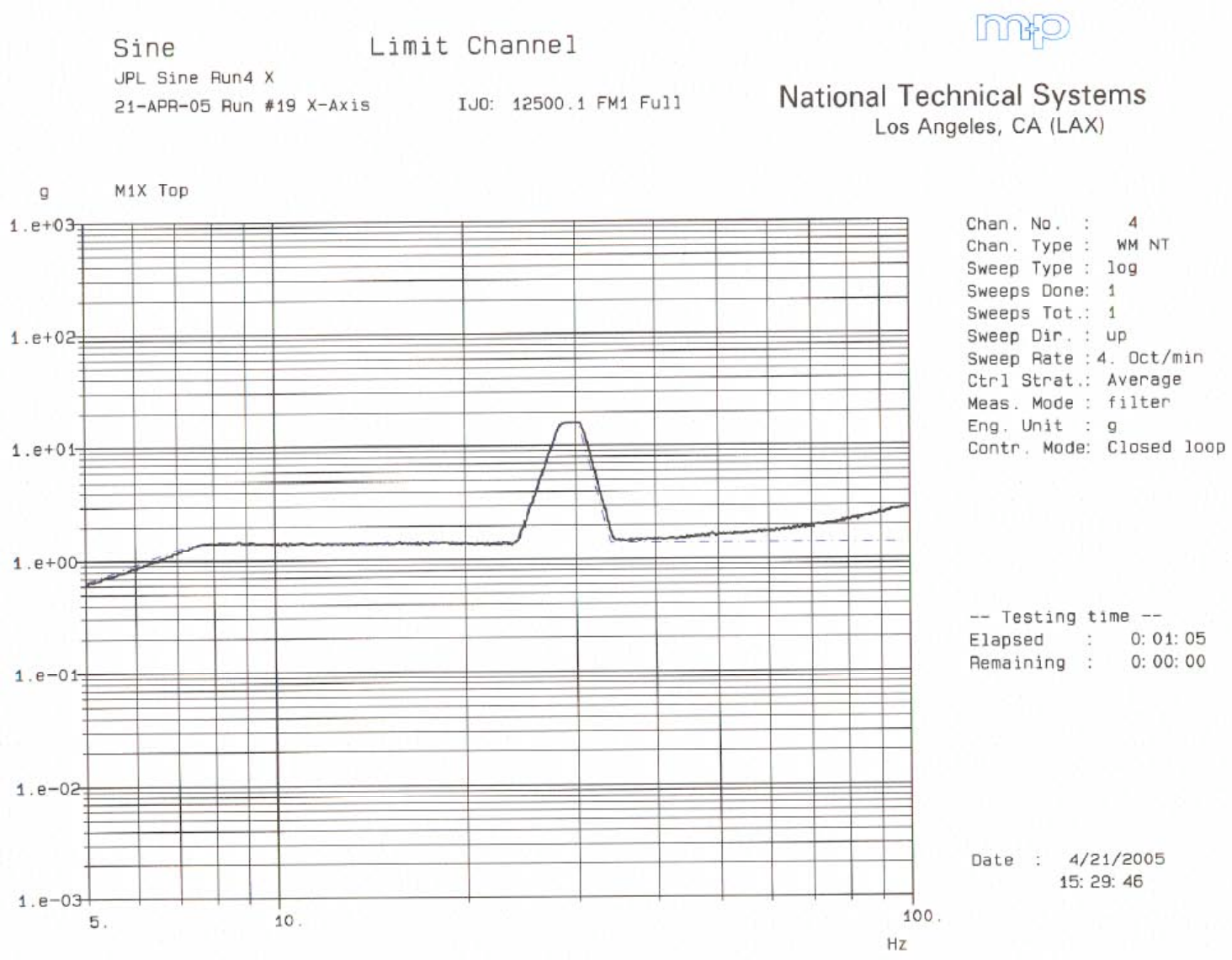

Figure 18. SEP-C FM1, X Axis PF Sine, Summed X Interface Force

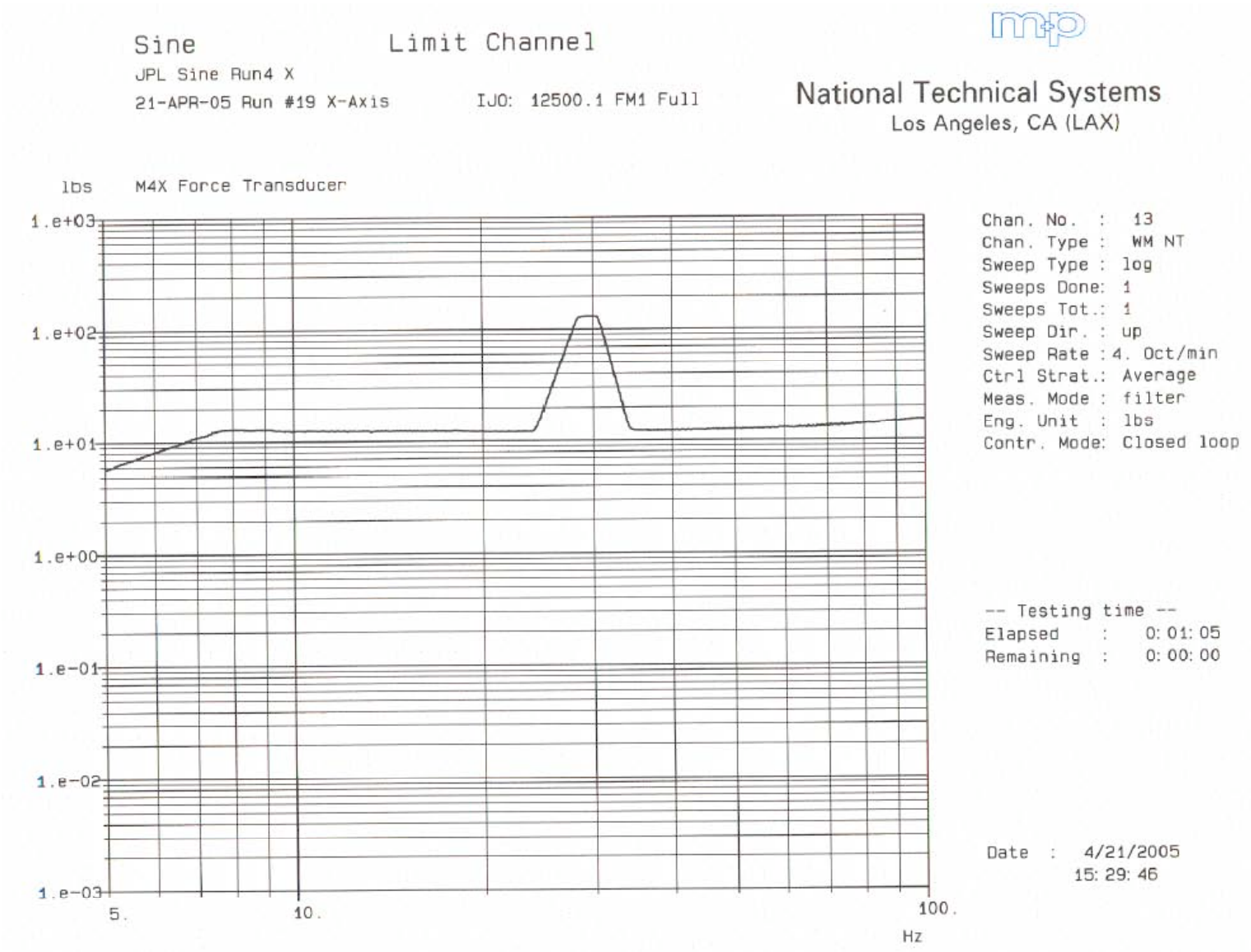

Figure 19. SEP-C FM1, X Axis PF Random Vibration Input, Force Limited

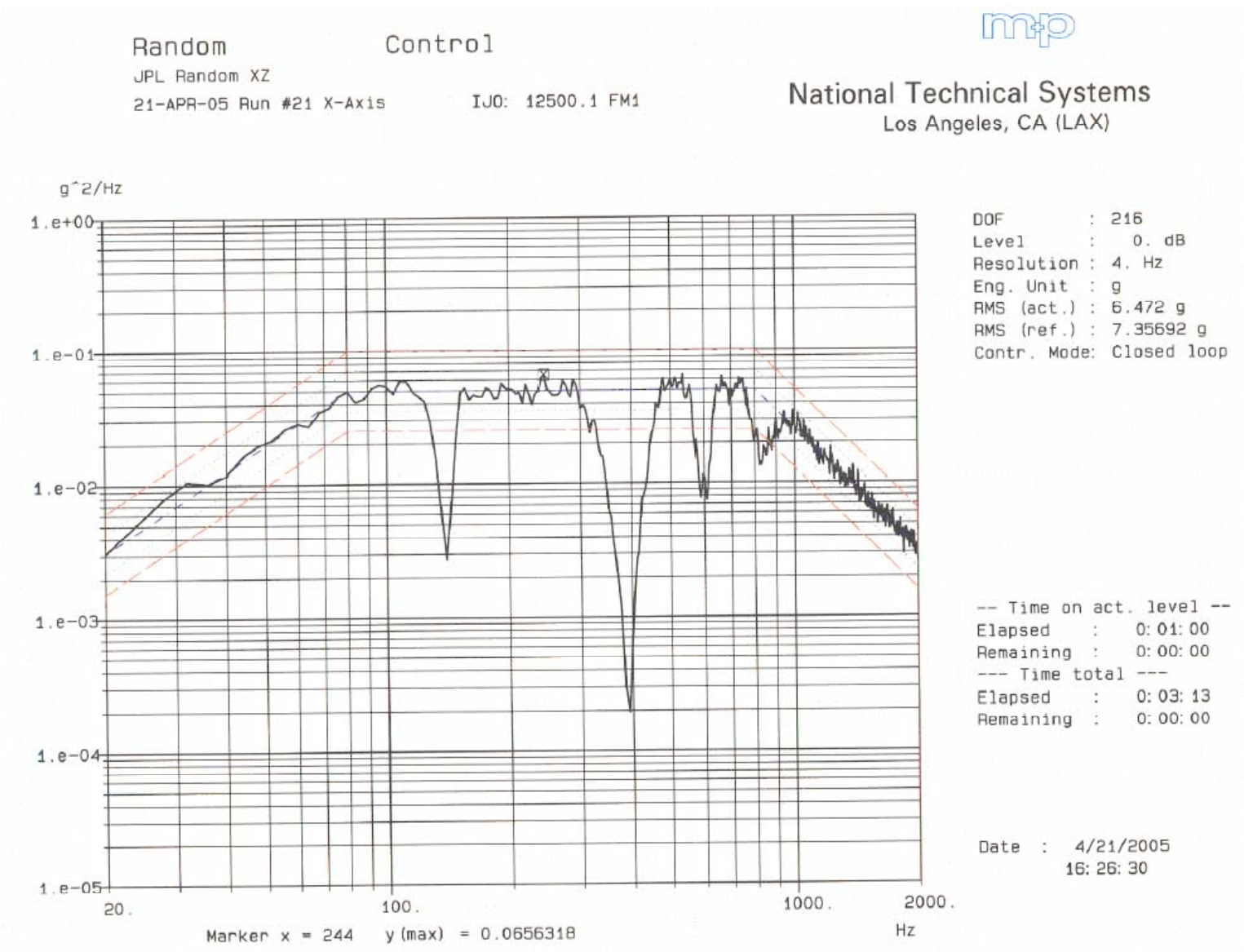

Figure 20. SEP-C FM1, X Axis PF Random Summed Interface Force

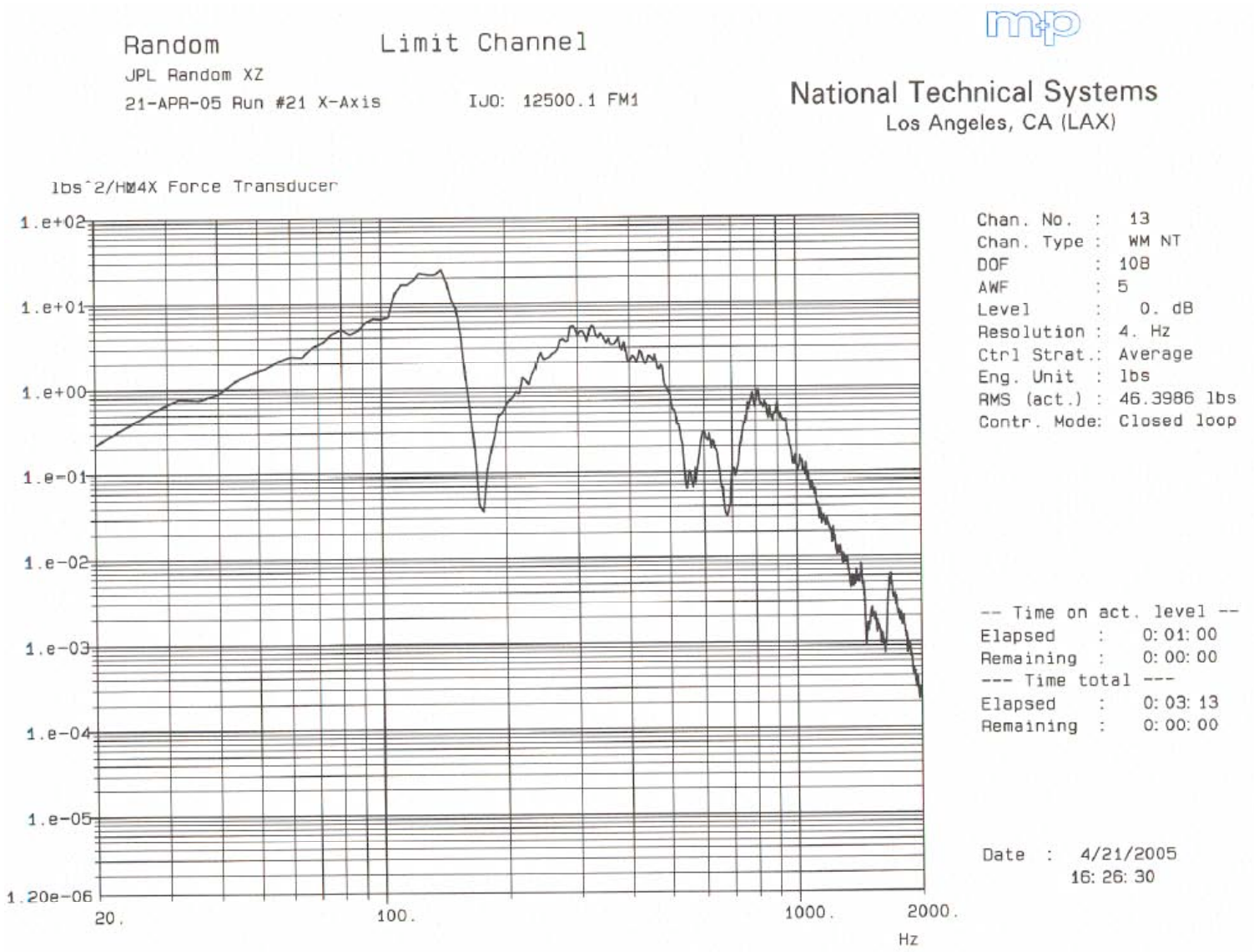

Figure 21. SEP-C FM1, X Axis PF Random Telescope Sensor

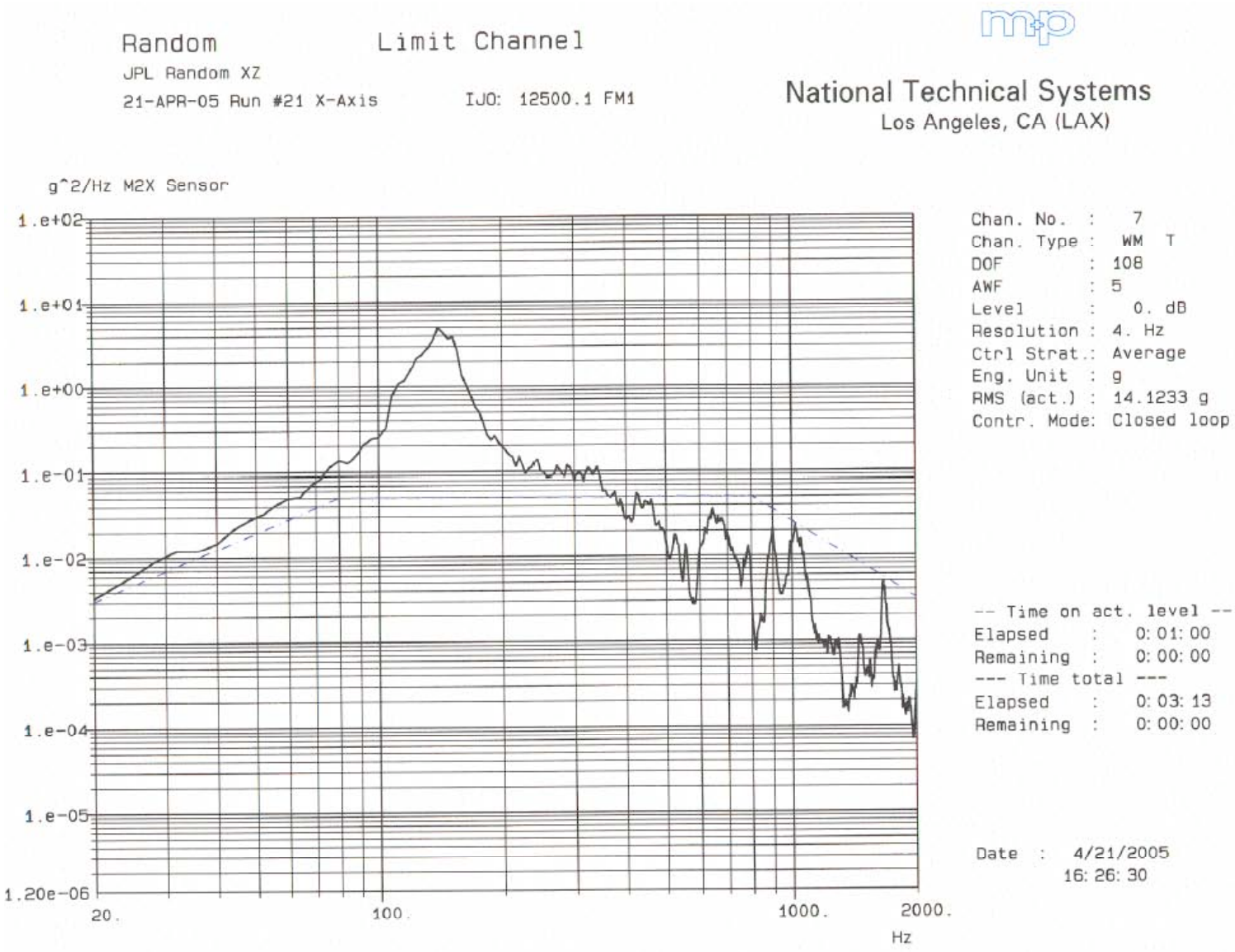

Figure 22. SEP-C FM1, X Axis Pre and Post Sine Survey Interface Force

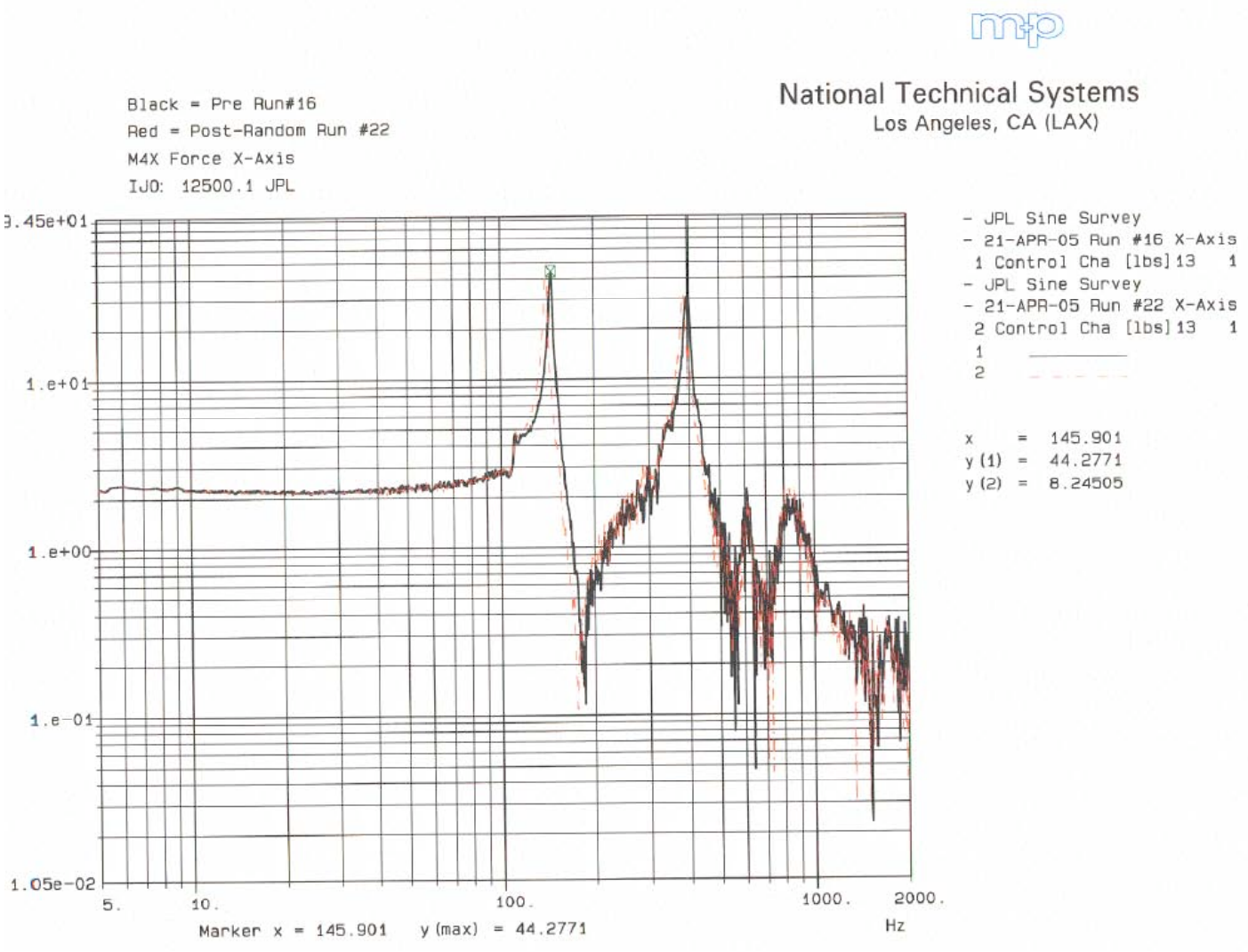

Figure 23. SEP-C FM1, X Axis Pre and Post Sine Survey, Telescope Sensor

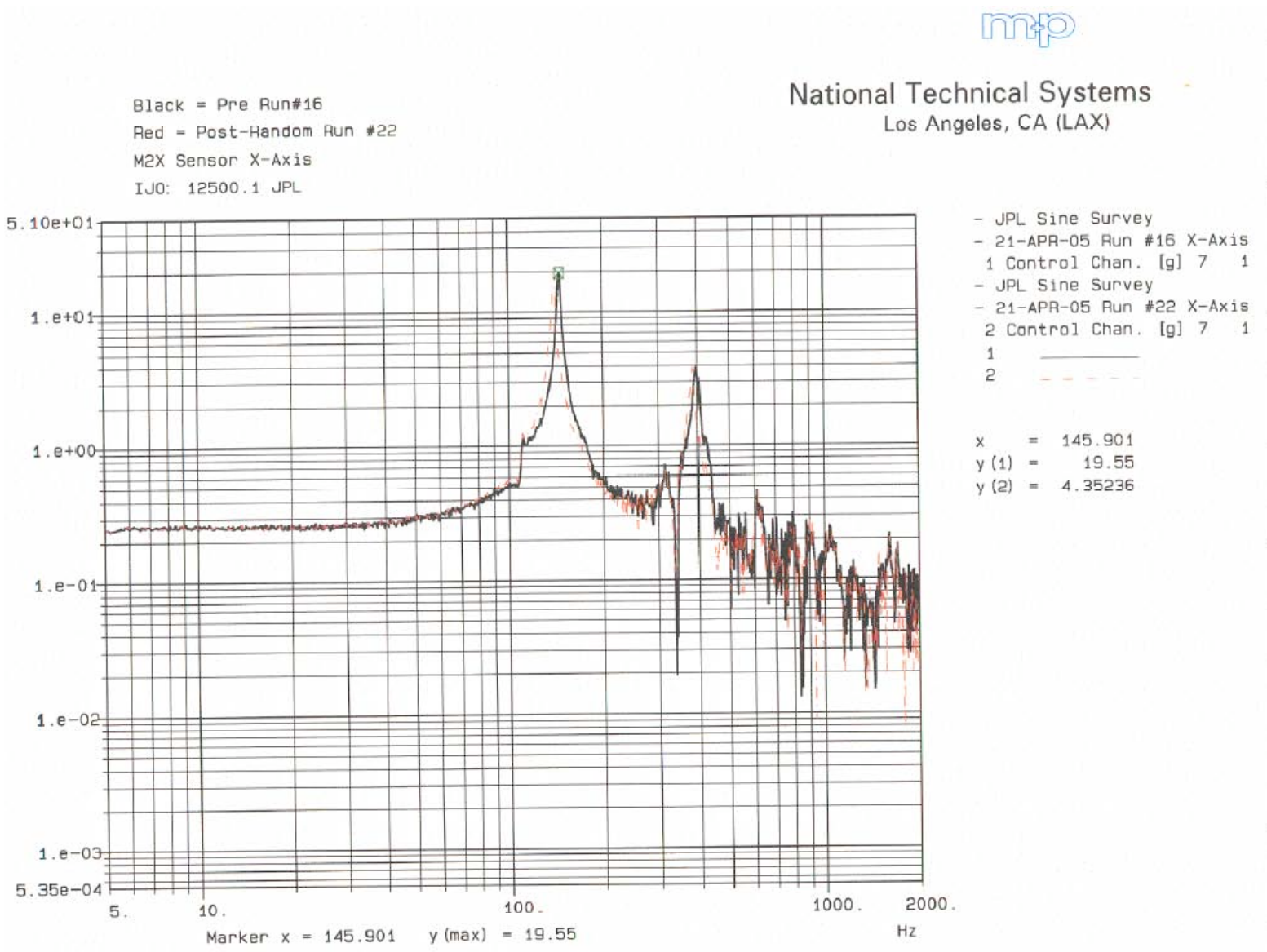

Figure 24. SEP-C FM1, X Axis Pre and Post Sine Survey, Telescope Top

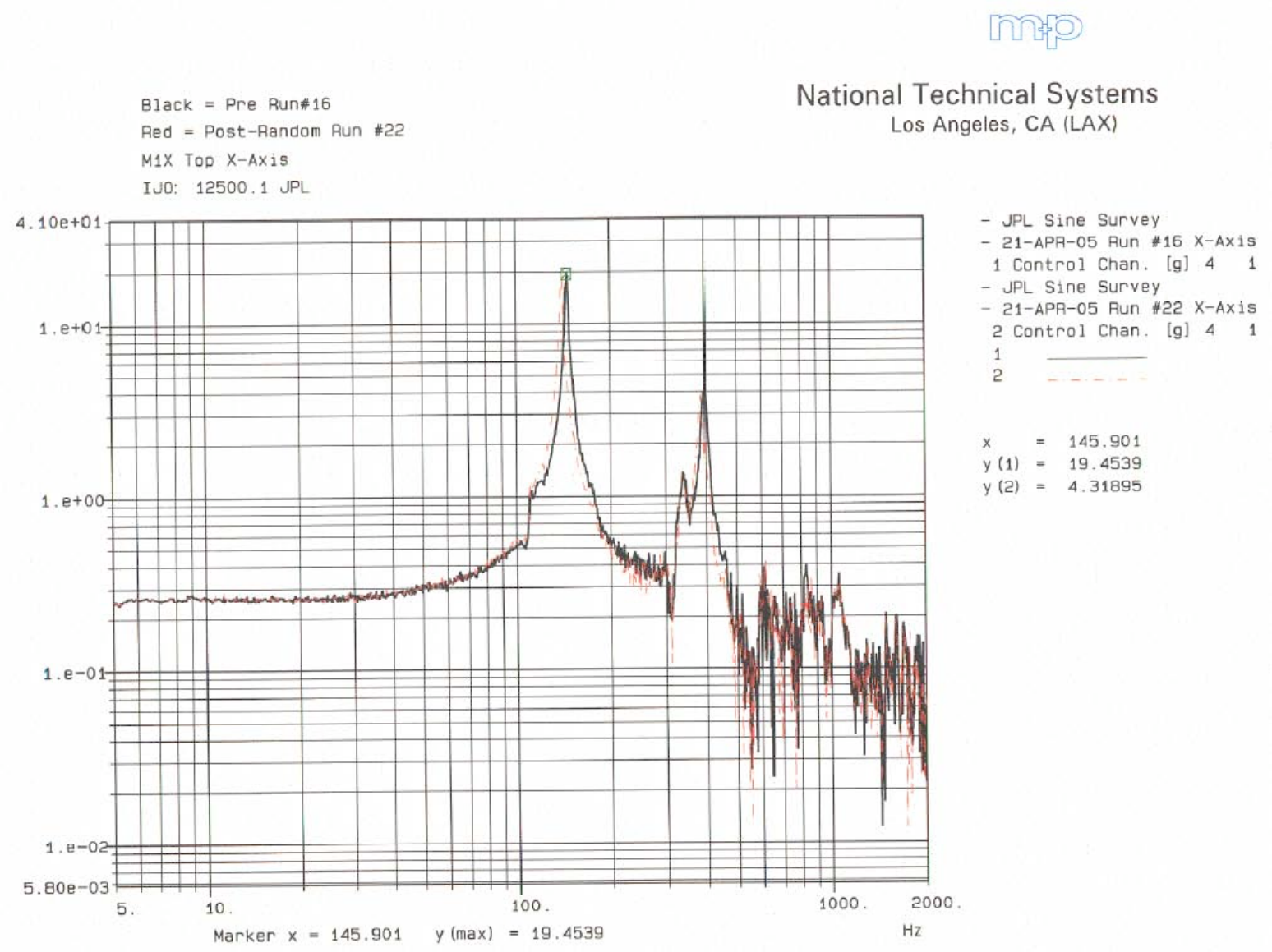

Figure 25. SEP-C FM1, Y Axis Sine Input

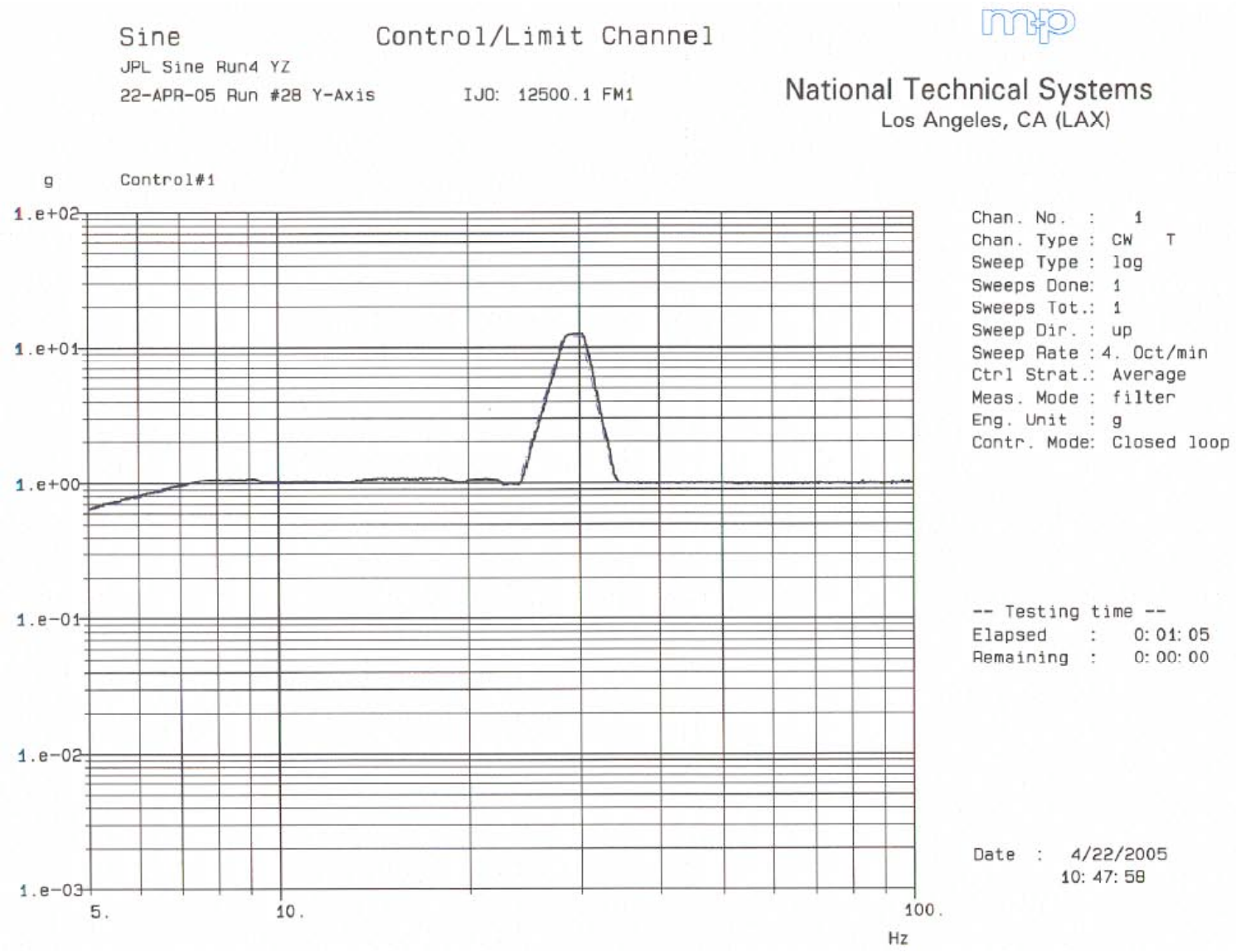

Figure 26. SEP-C FM1, Y Axis PF Sine, Summed Y Interface Force

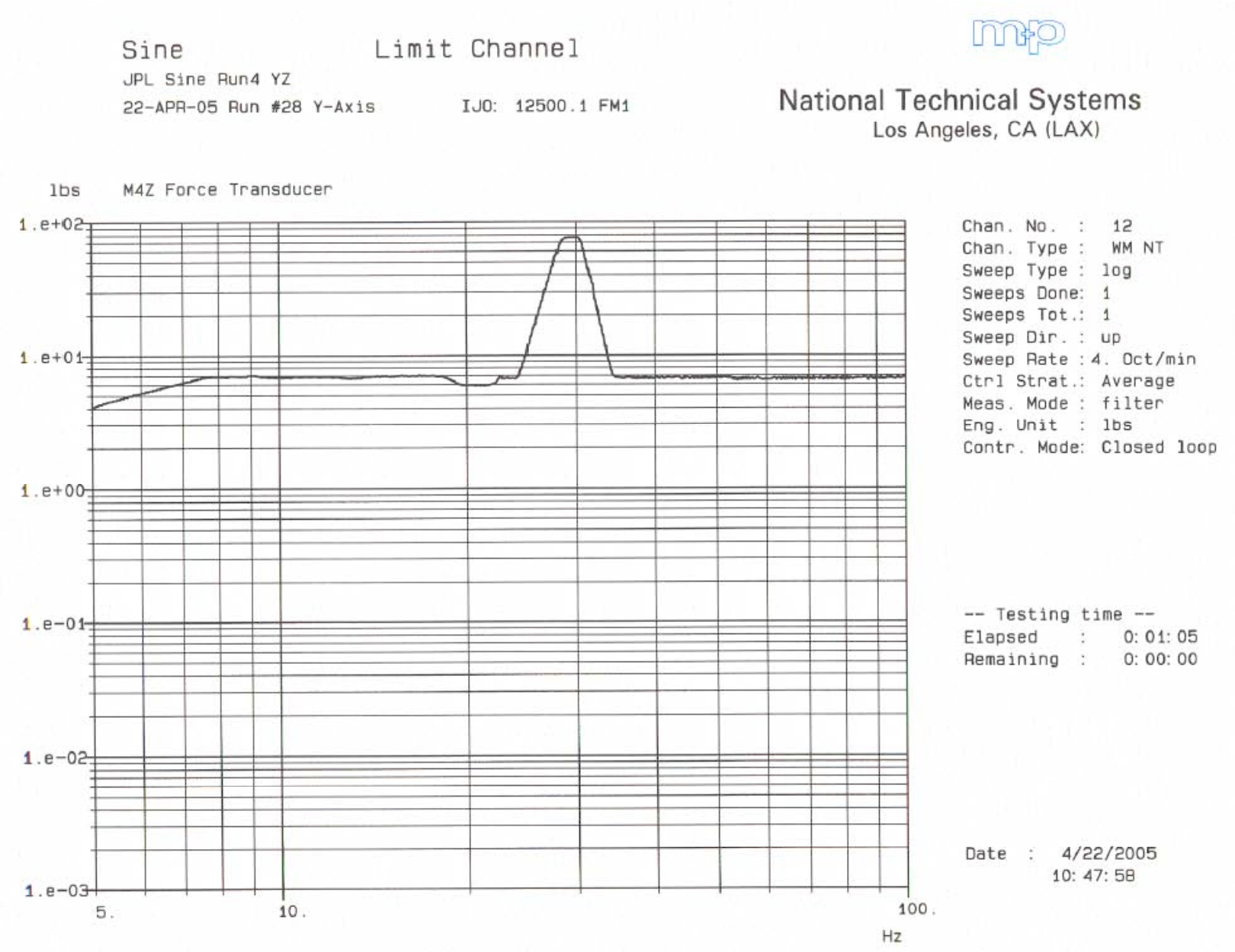

Figure 27. SEP-C FM1, Y Axis PF Sine, Telescope Sensor

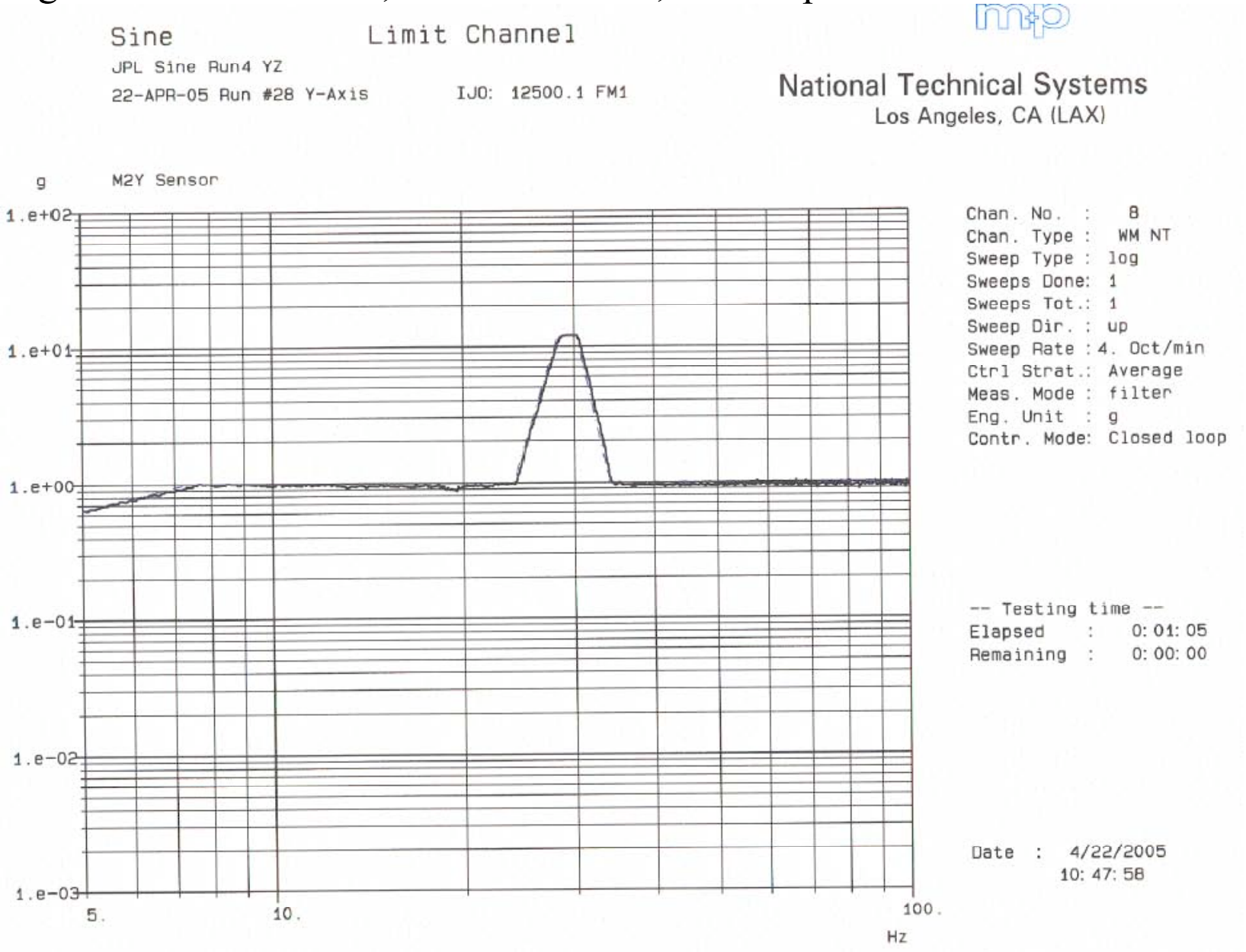

Figure 28. SEP-C FM1, Y Axis PF Random Vibration Input, Force Limited

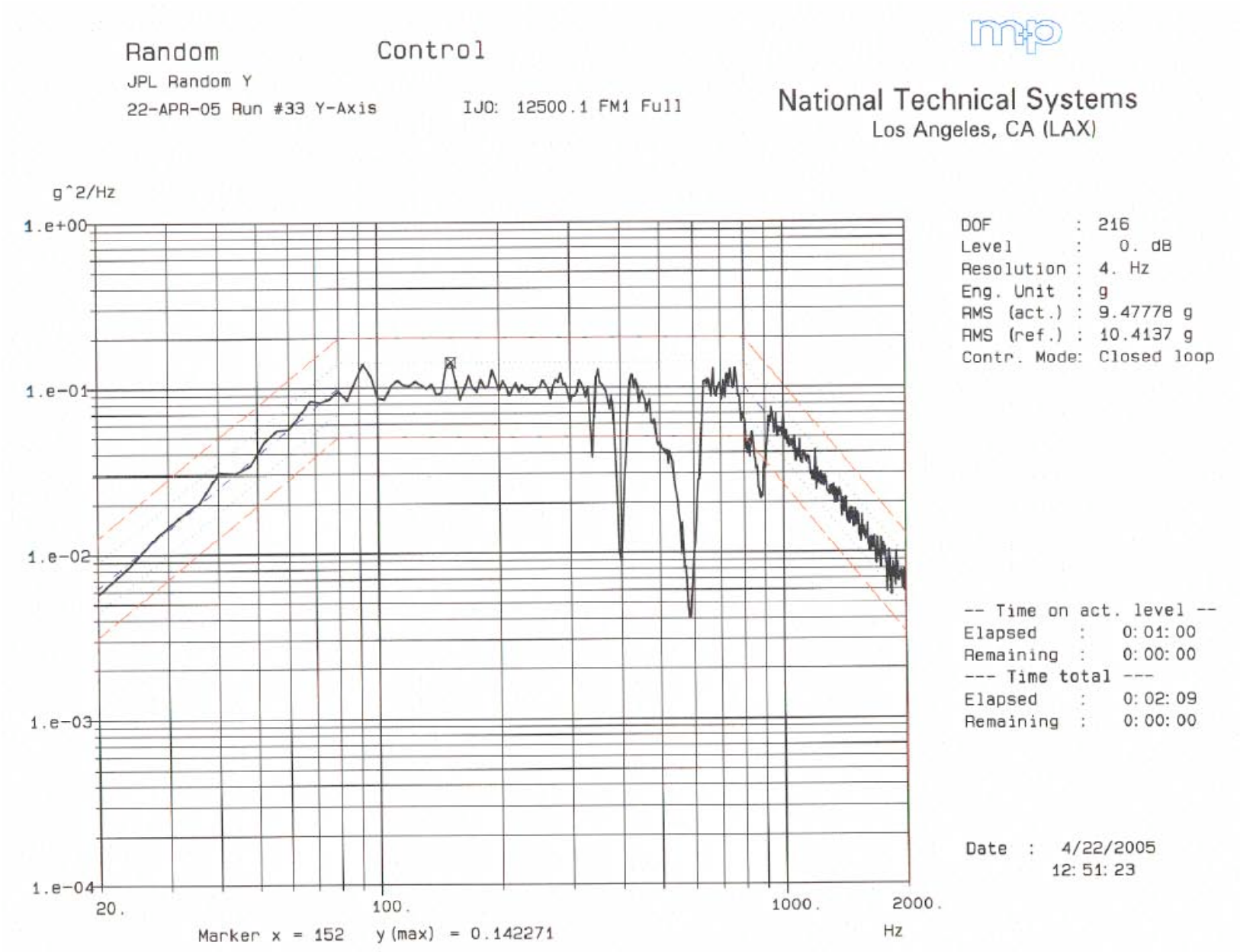

Figure 29. SEP-C FM1, Y Axis PF Random Summed Interface Force

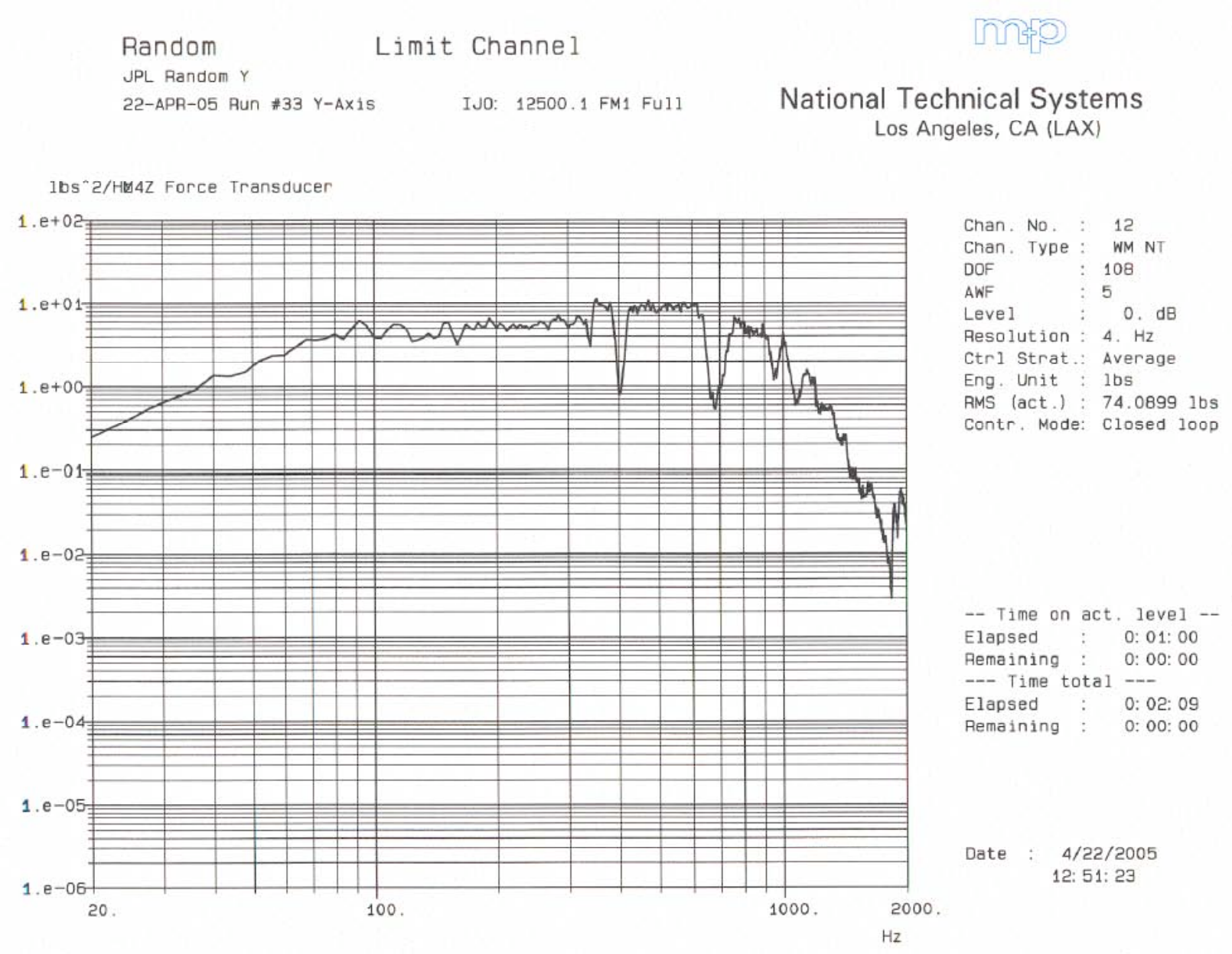

Figure 30. SEP-C FM1, Y Axis PF Random Telescope Top Response

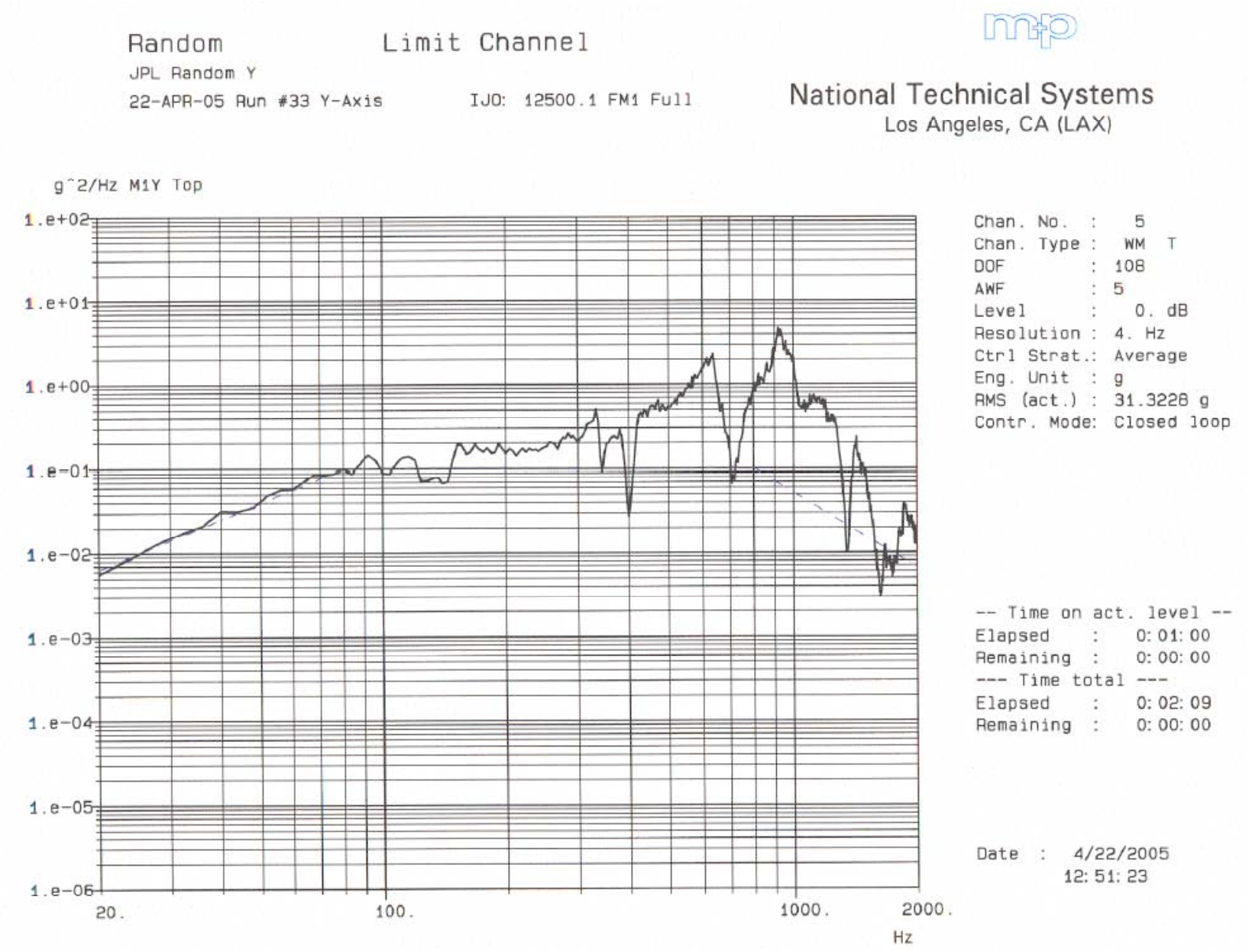

Figure 31. SEP-C FM1, Y Axis Pre and Post Sine Survey Interface Force

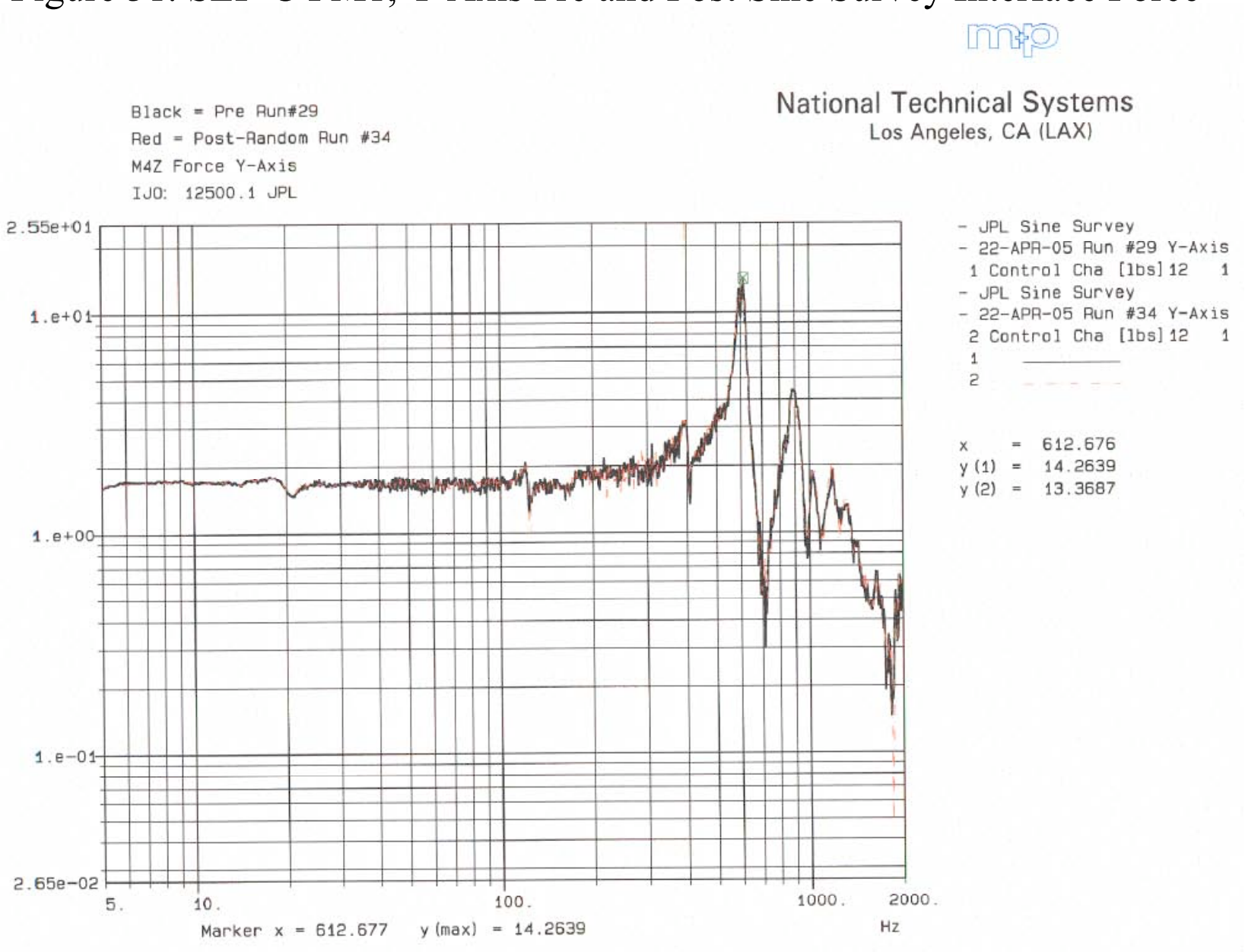

Figure 32. SEP-C FM2 Accelerometer Locations

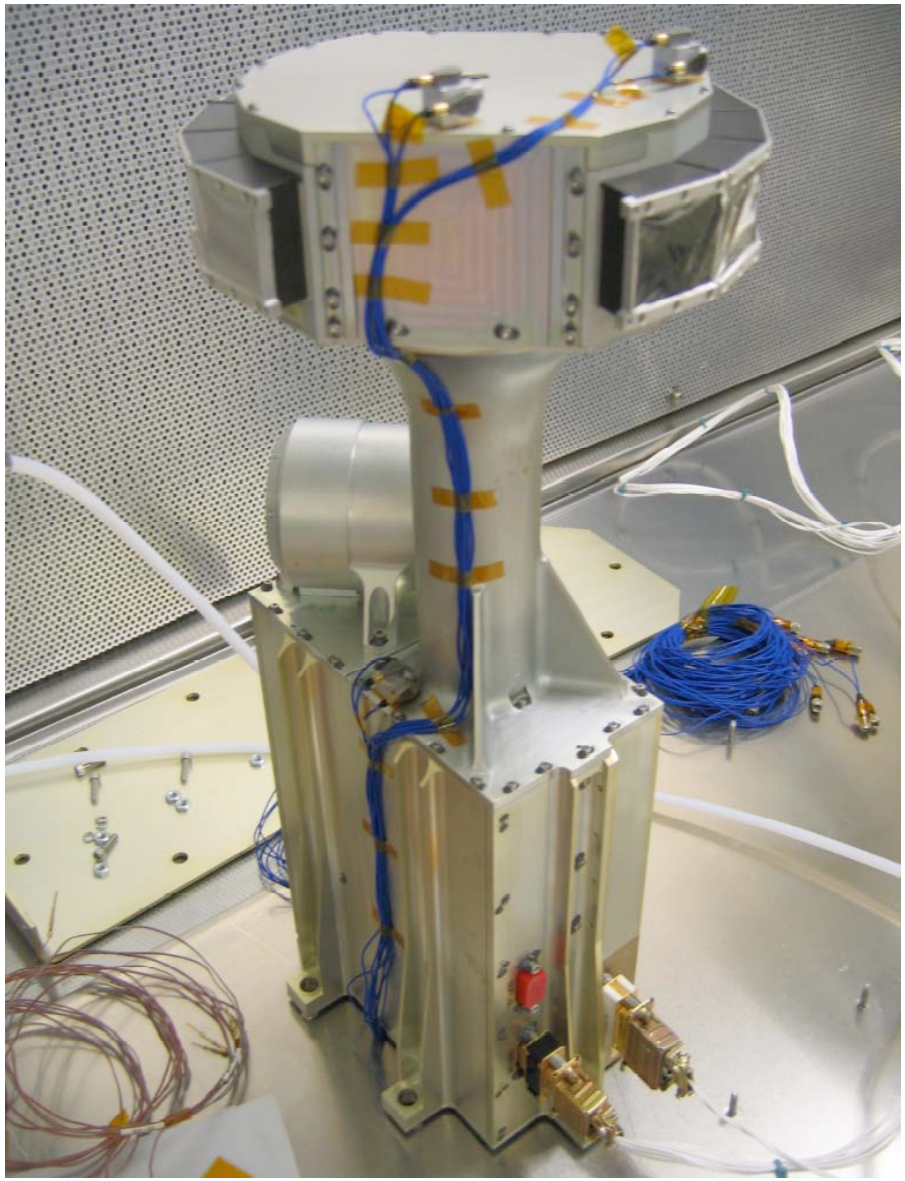

Figure 33. SEP-C FM1, Z Axis Test Setup

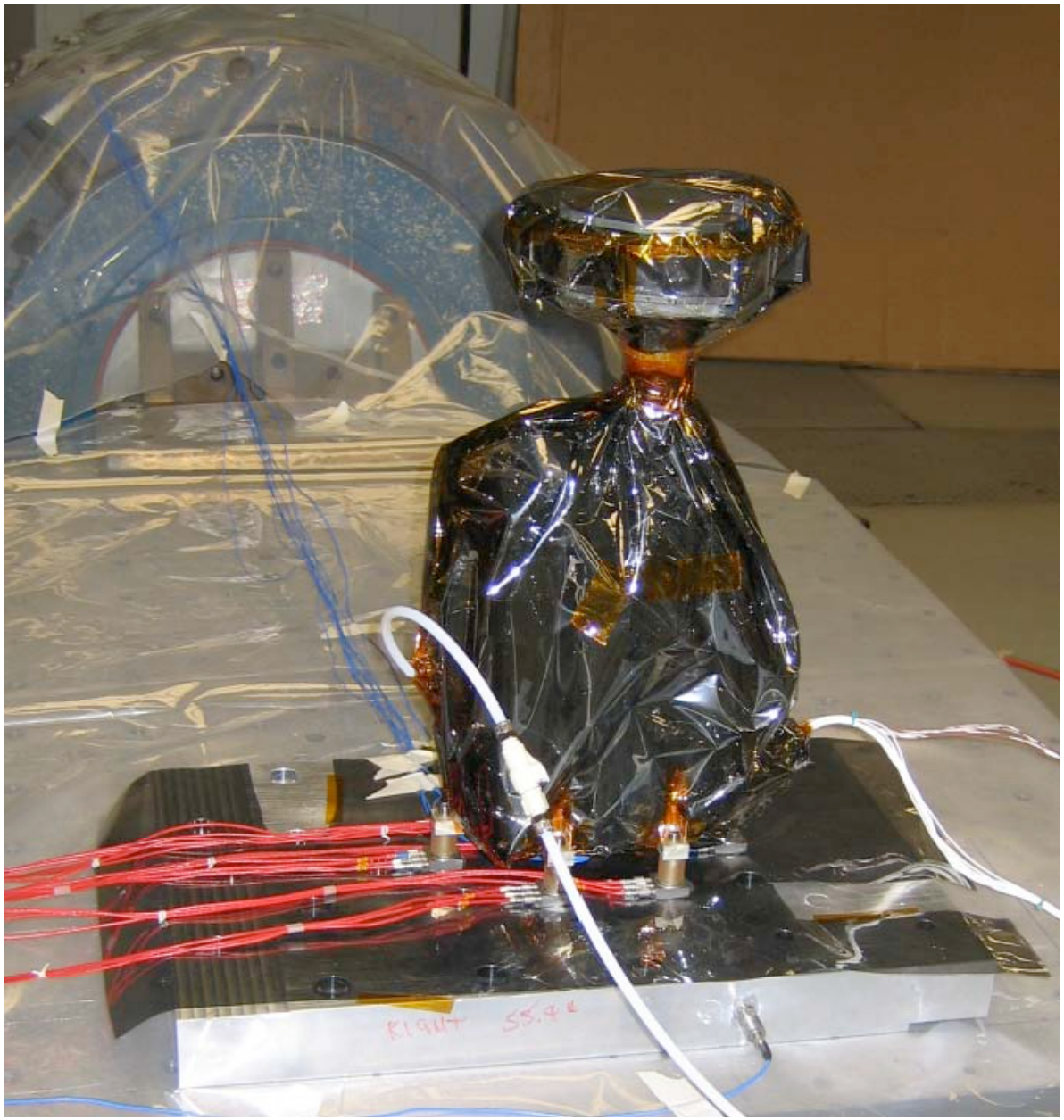

Figure 34. SEP-C FM1, Y Axis Test Setup

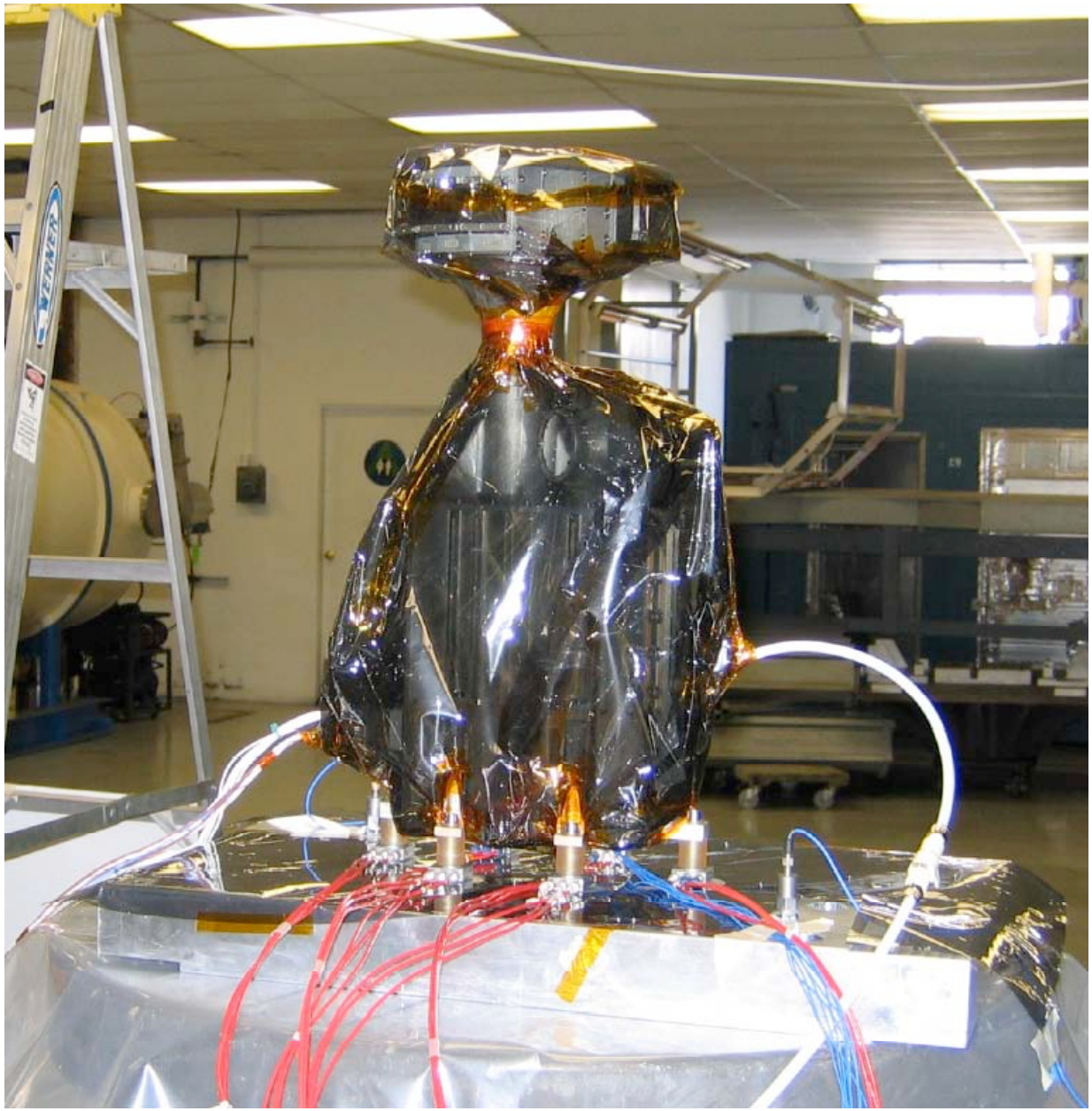

Figure 35. SEP-C FM2, Z Axis Sine Input

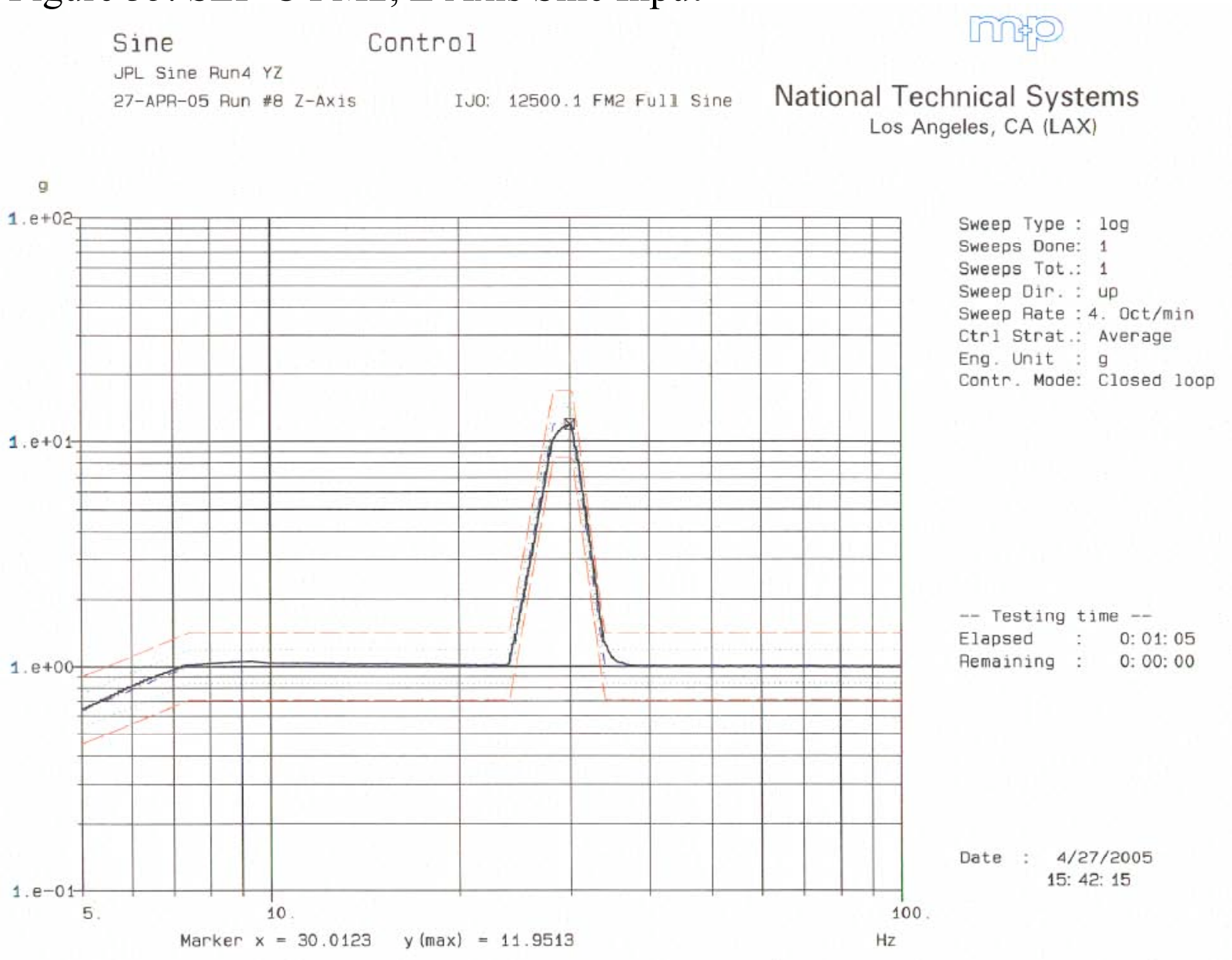

Figure 36. SEP-C FM2, Z Axis PF Sine, Summed Z Interface Force

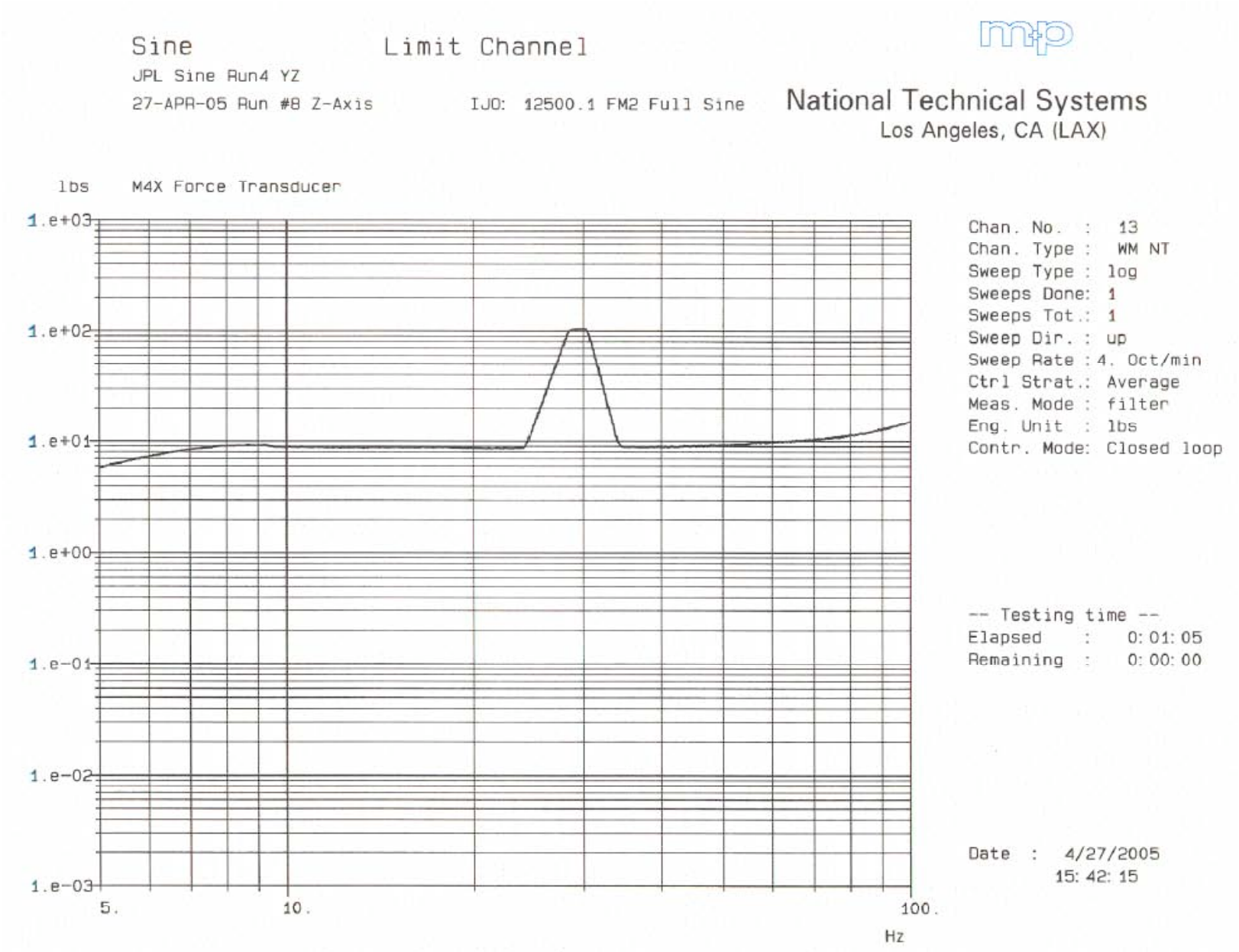

Figure 37. SEP-C FM2, Z Axis PF Sine, Telescope Top

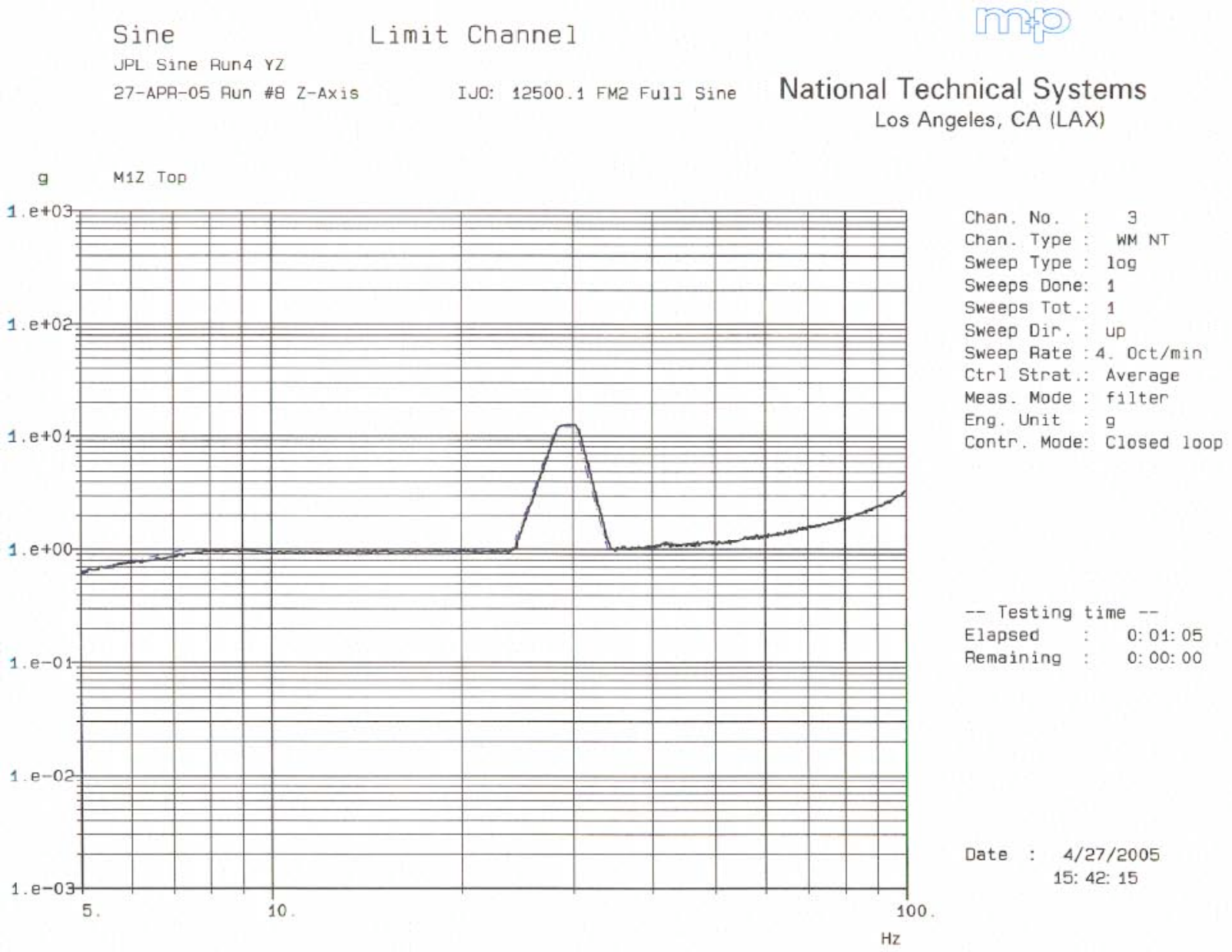

Figure 38. SEP-C FM2, Z Axis PF Random Vibration Input, Force Limited

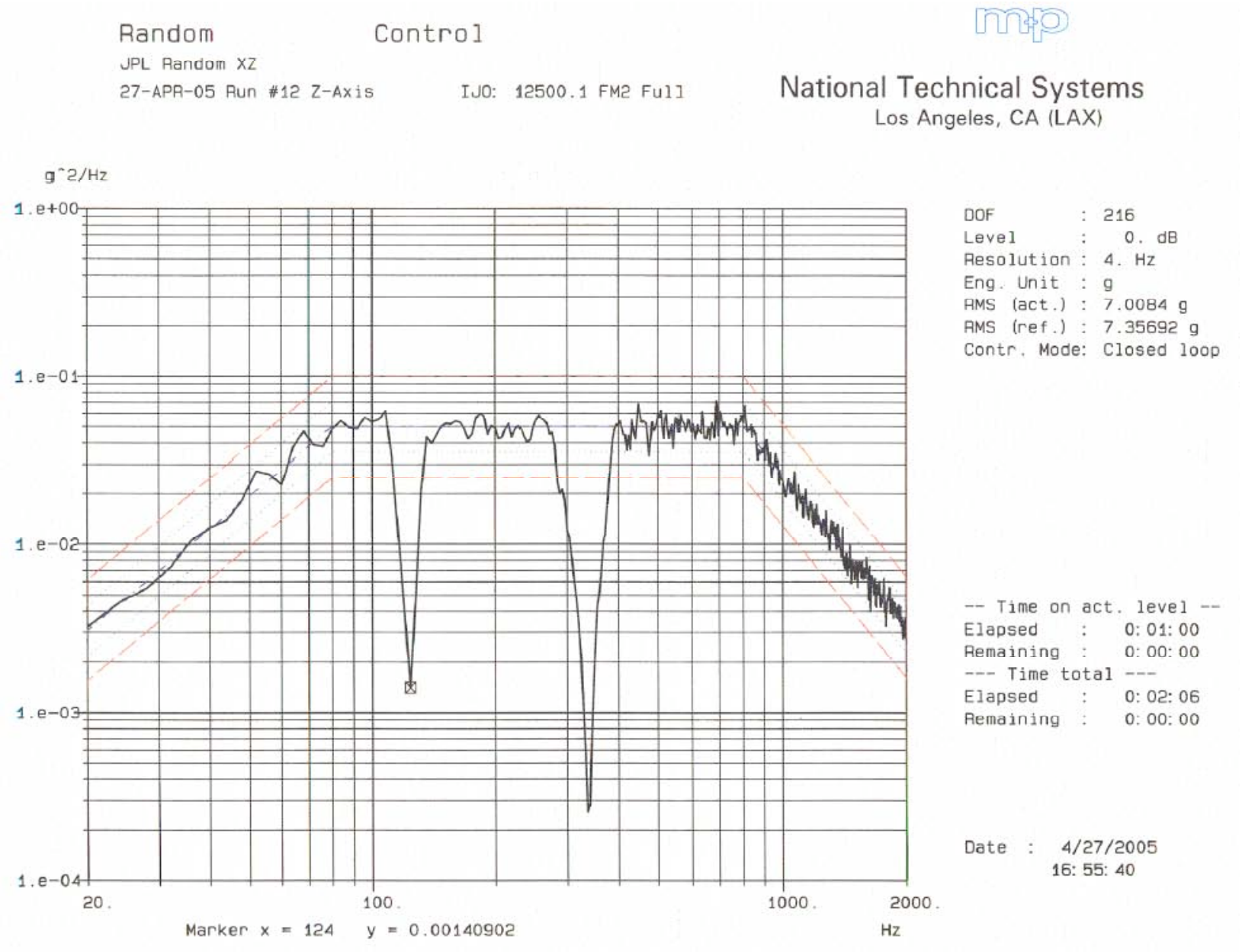

Figure 39. SEP-C FM2, Z Axis PF Random Summed Interface Force 352G: MOC: 0527

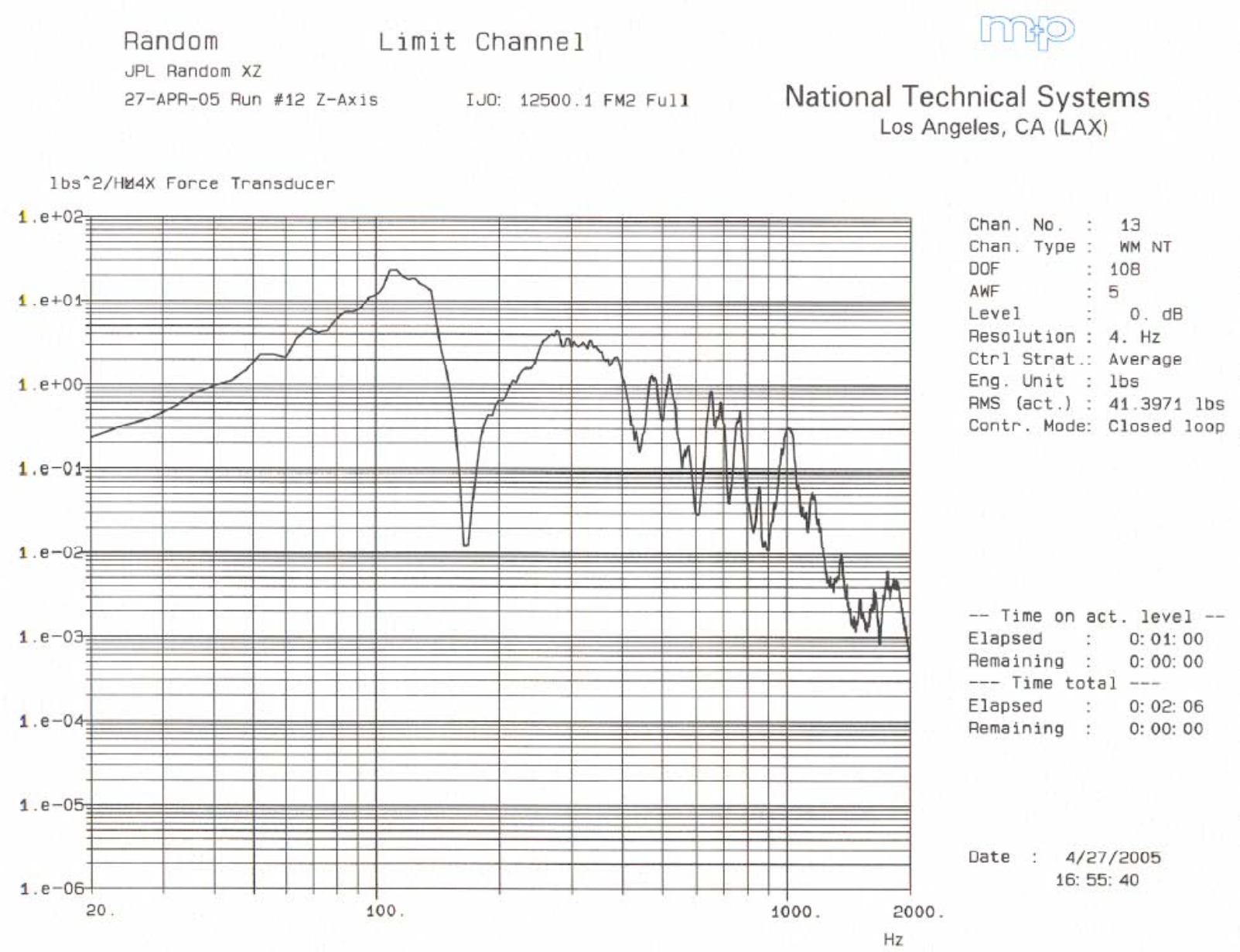

Figure 40. SEP-C FM2, Z Axis Telescope Sensor Response

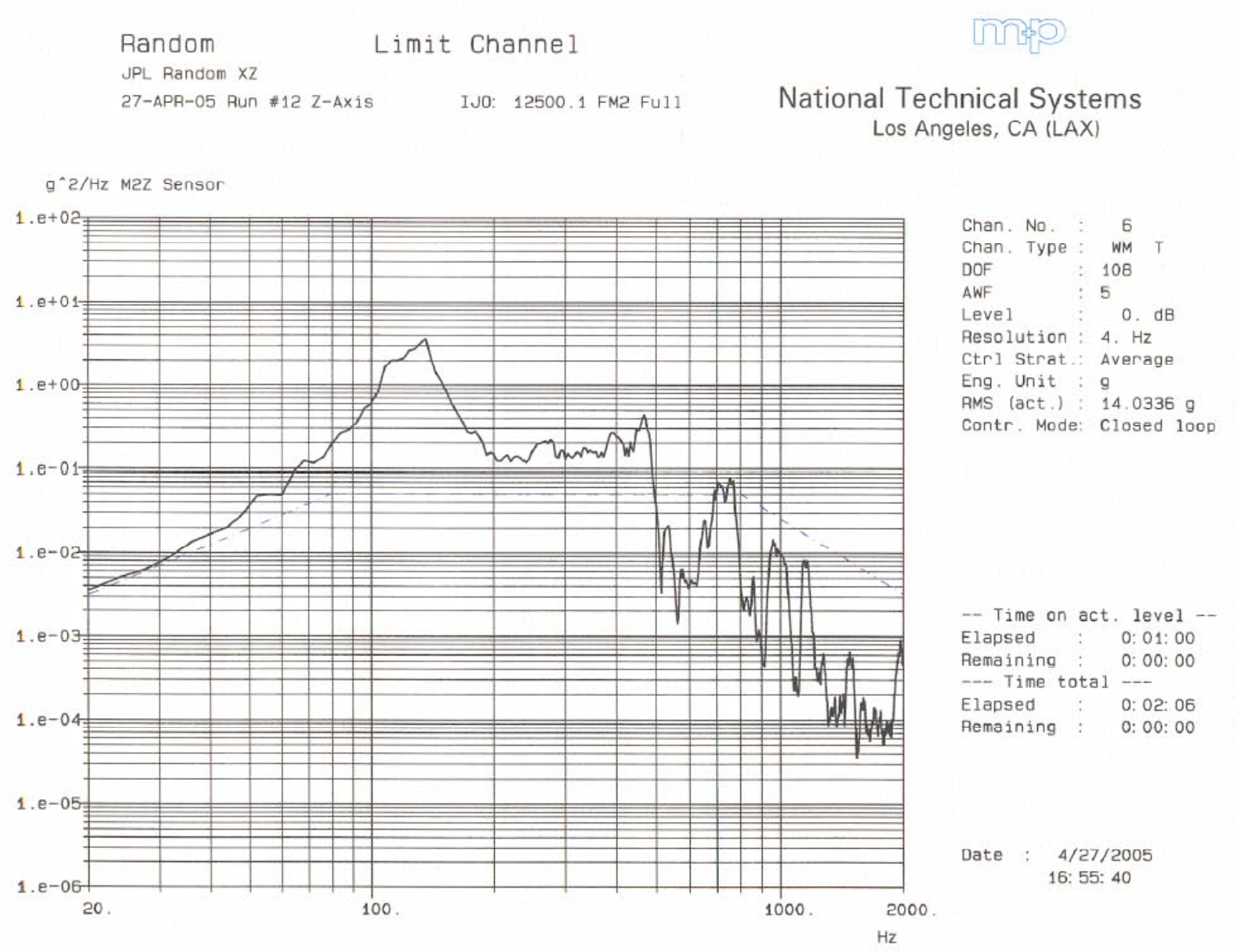

Figure 41. SEP-C FM2, Z Axis Pre and Post Sine Survey Interface Force

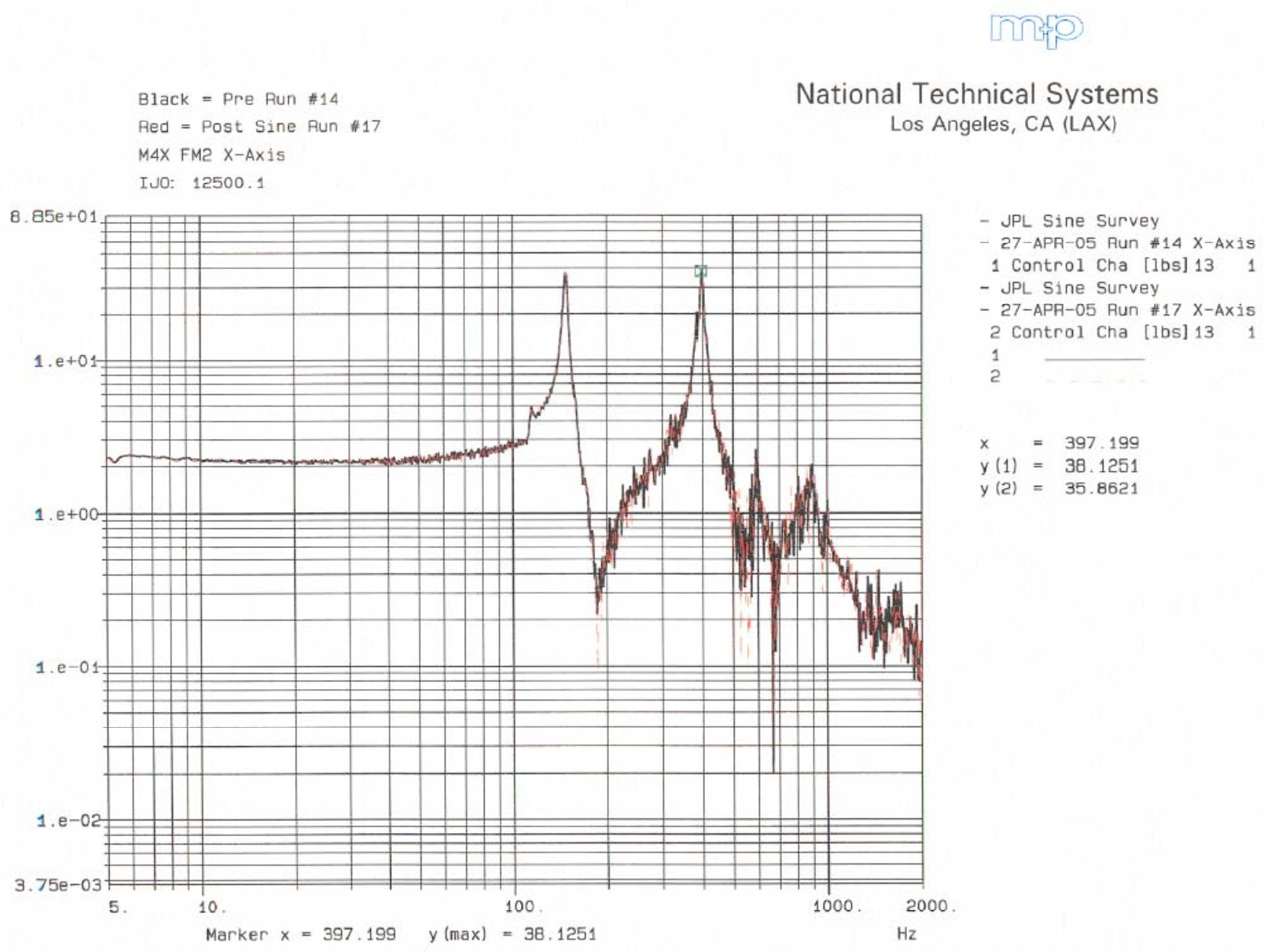

Figure 42. SEP-C FM2, Z Axis Pre and Post Sine Survey Telescope Top

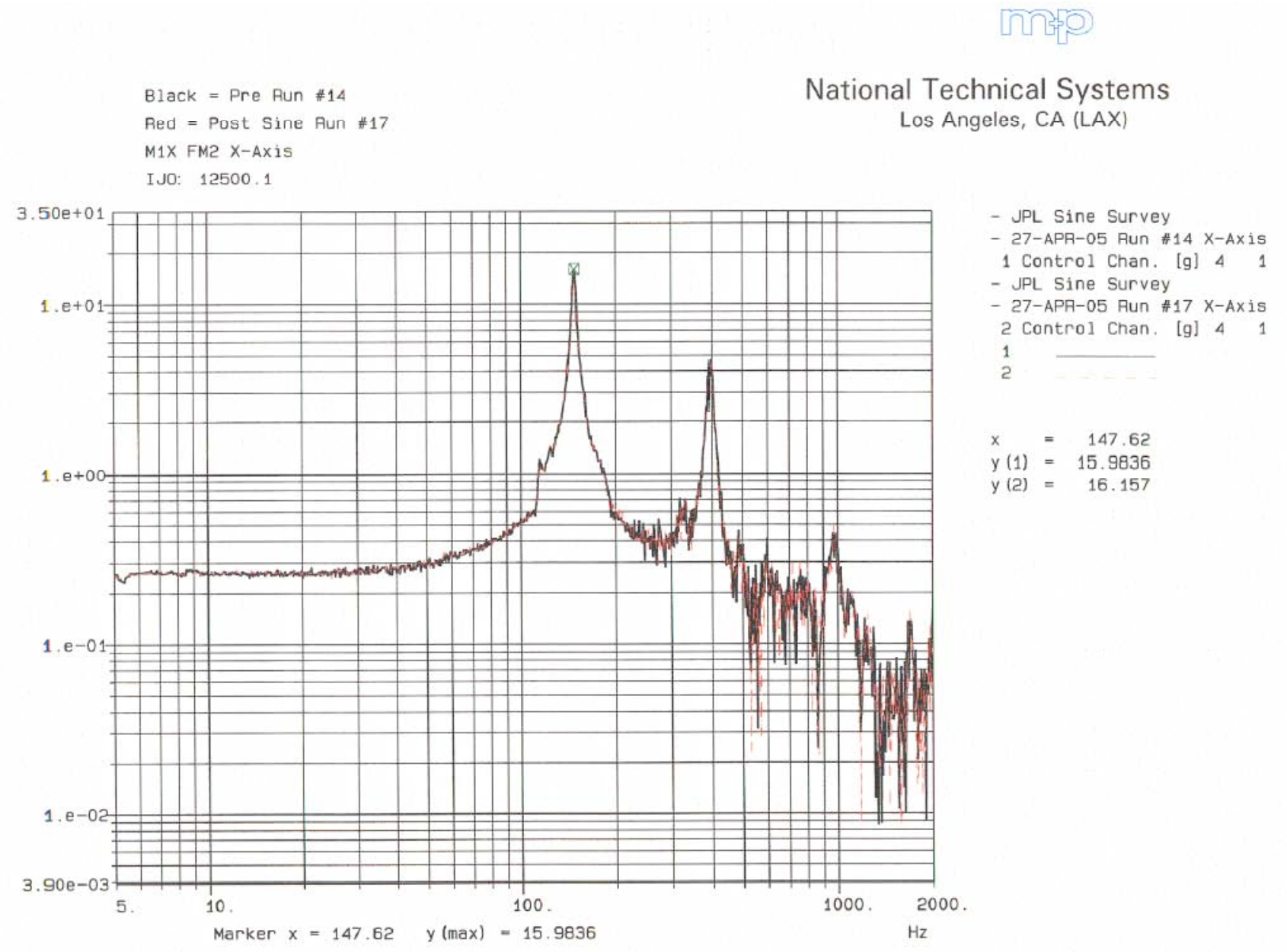

Figure 43. SEP-C FM2, X Axis Sine Input

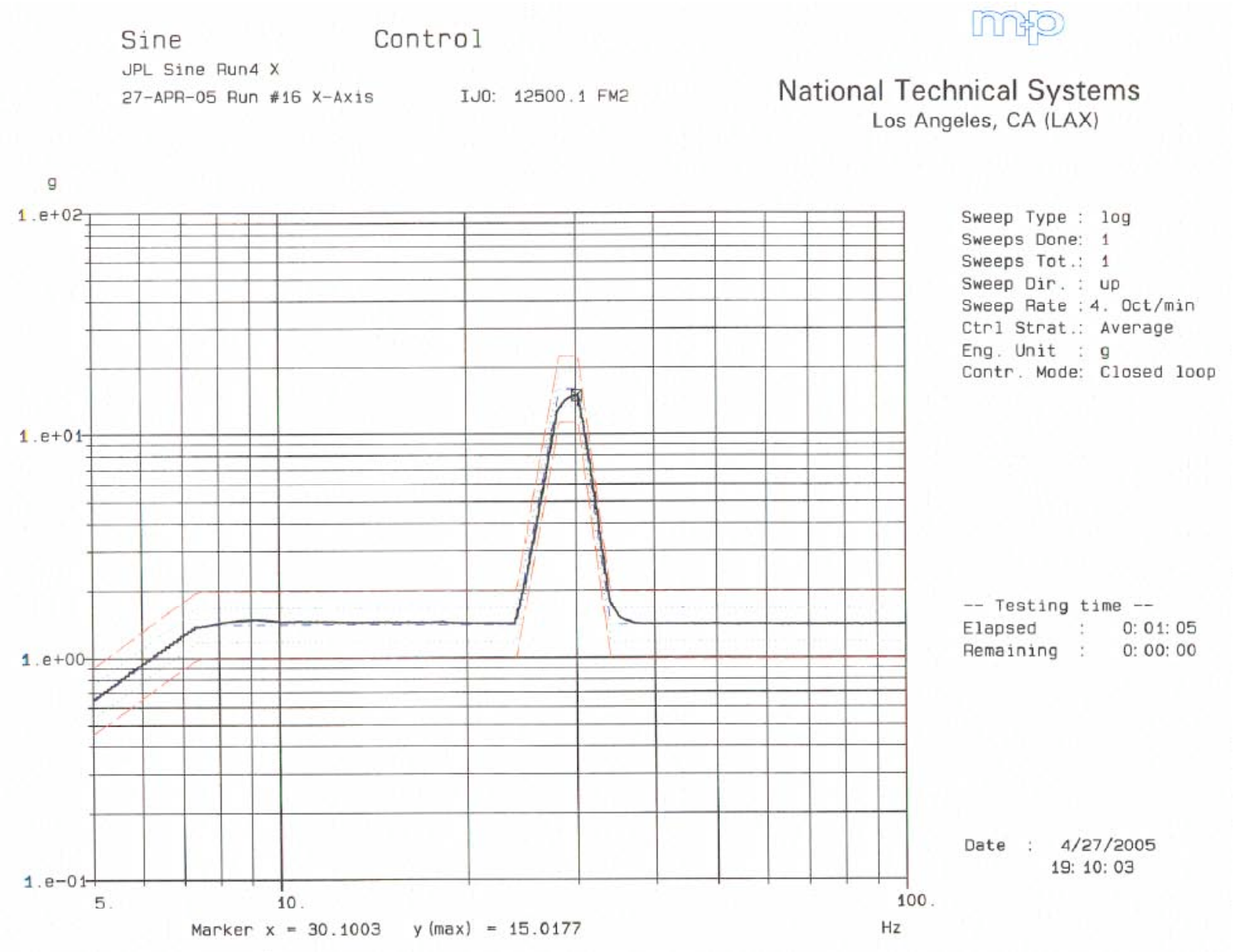

Figure 44. SEP-C FM2, X Axis Sine Interface Force

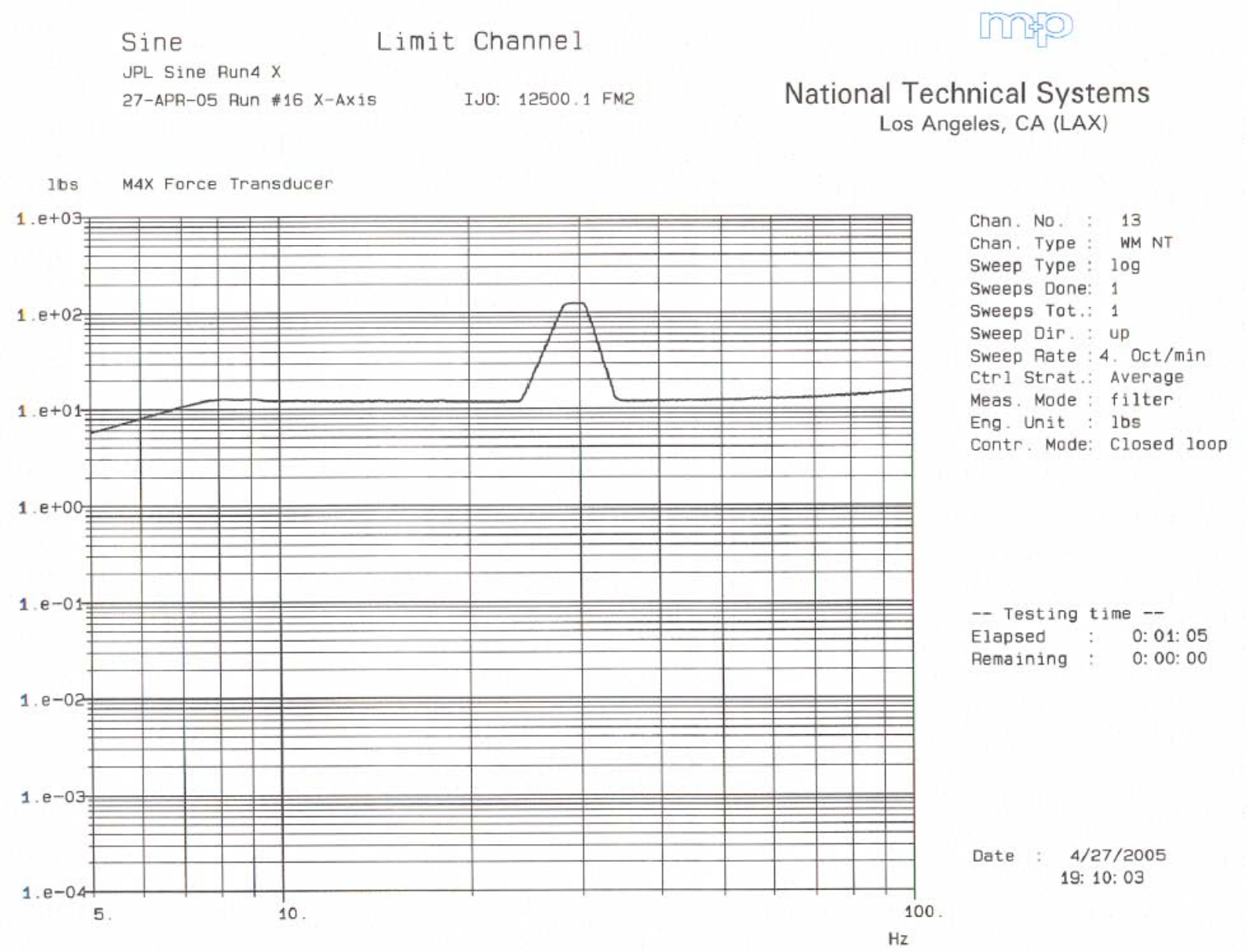

Figure 45. SEP-C FM2, X Axis Sine Telescope Top

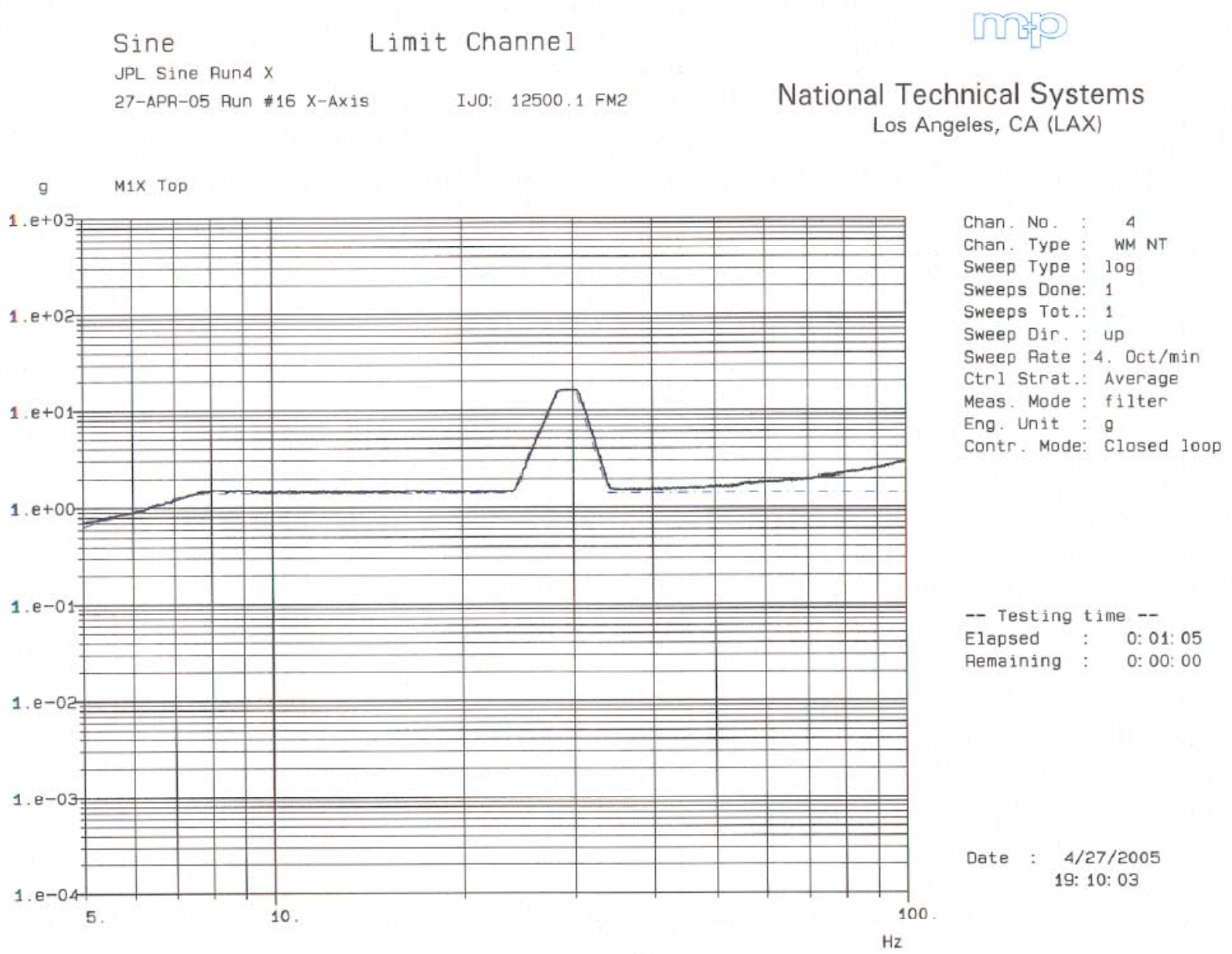

Figure 46. SEP-C FM2, X Axis PF Random Vibration Input, Force Limited

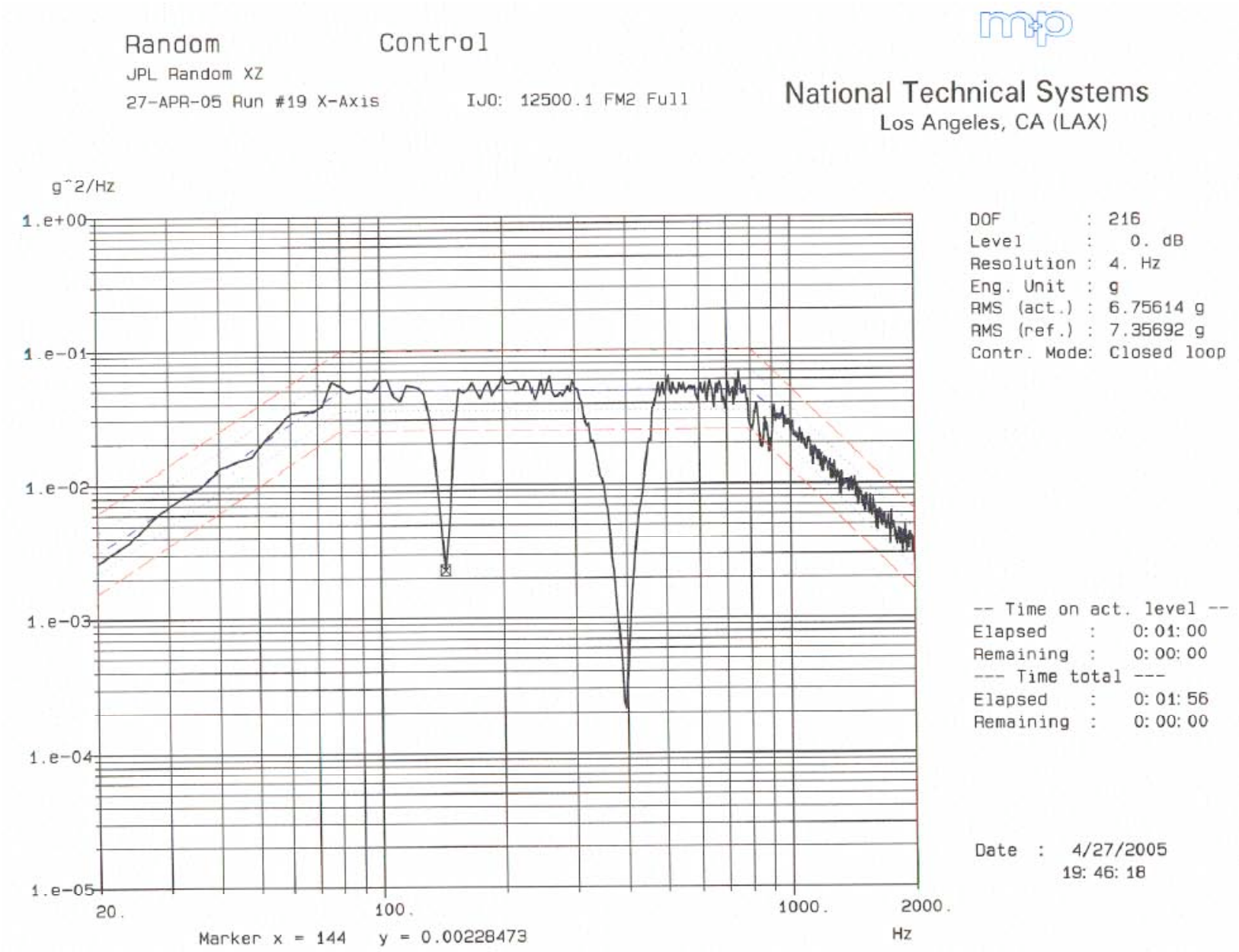

Figure 47. SEP-C FM2, X Axis PF Random Summed Interface Force

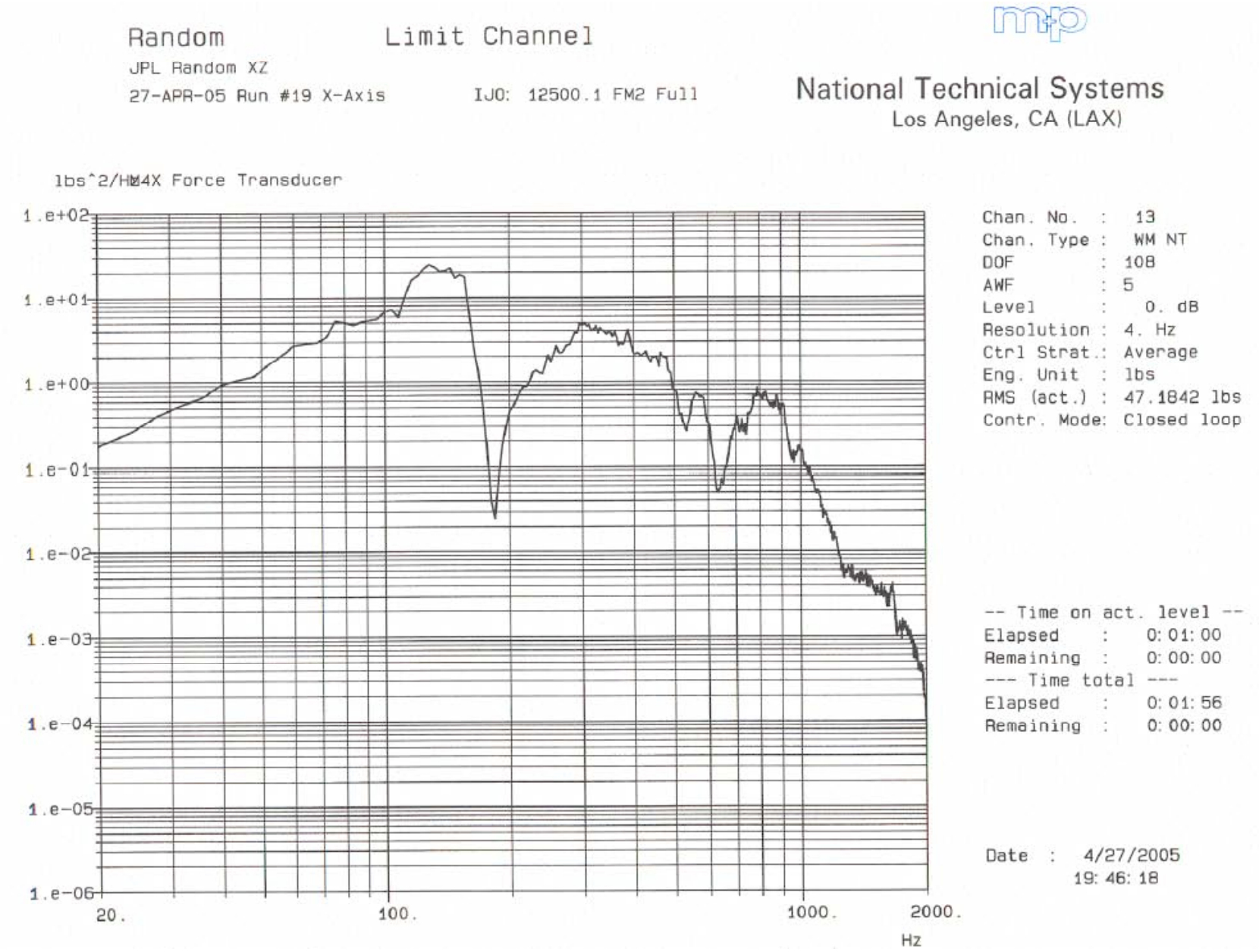

Figure 48. SEP-C FM2, X Axis PF Random Telescope Top Response

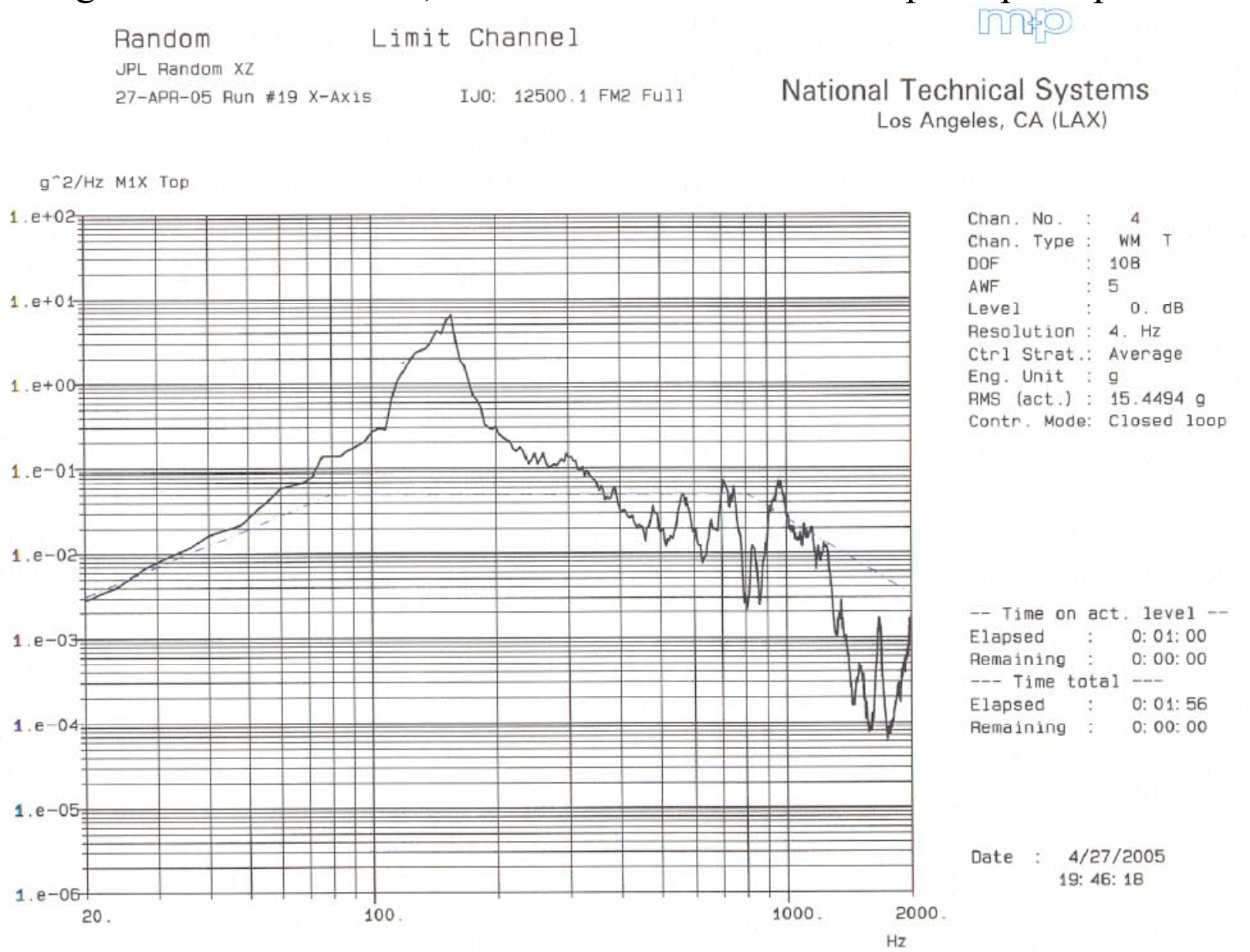

Figure 49. SEP-C FM2, X Axis Pre and Post Sine Survey Interface Force

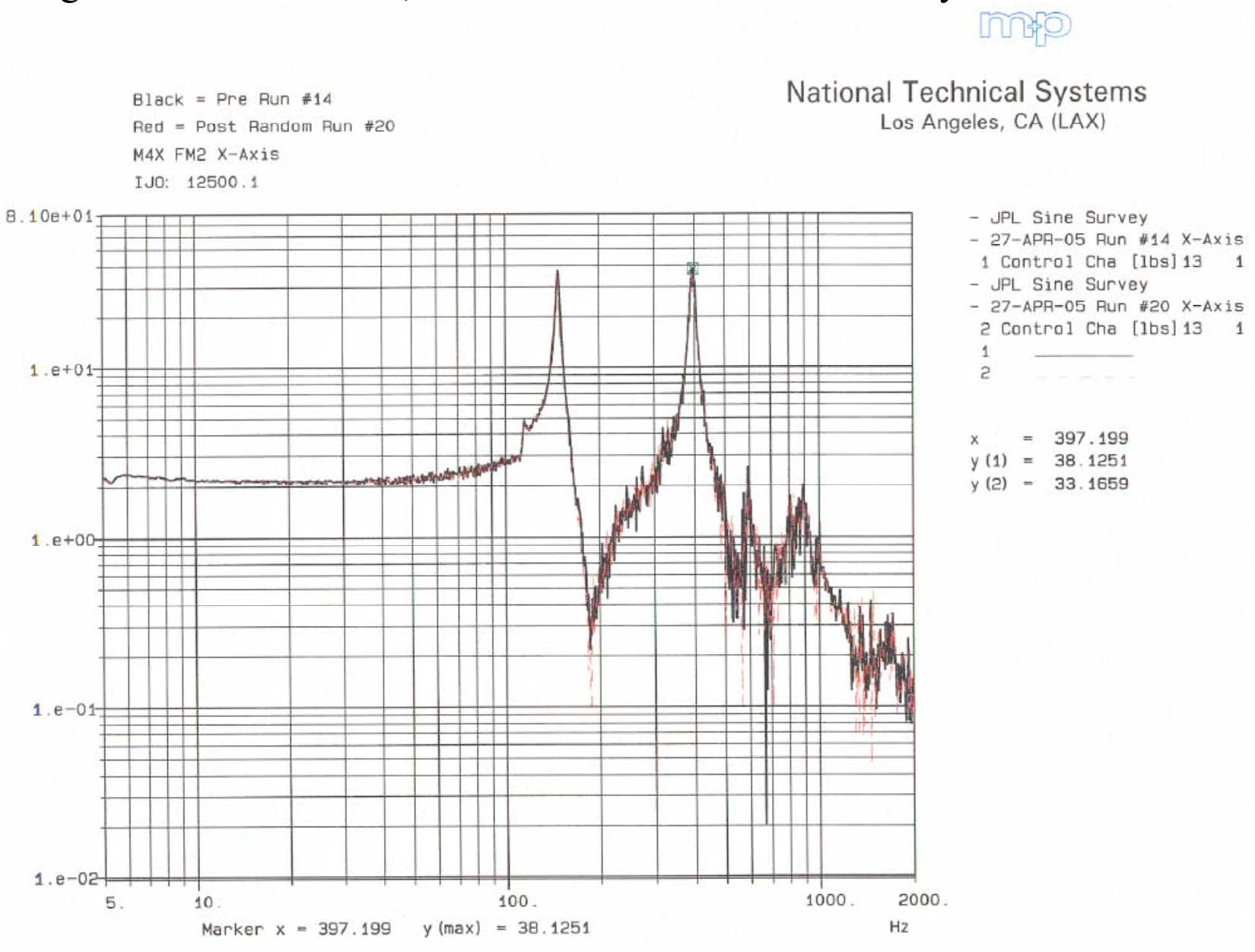

Figure 50. SEP-C FM2, X Axis Pre and Post Sine Survey Telescope Top

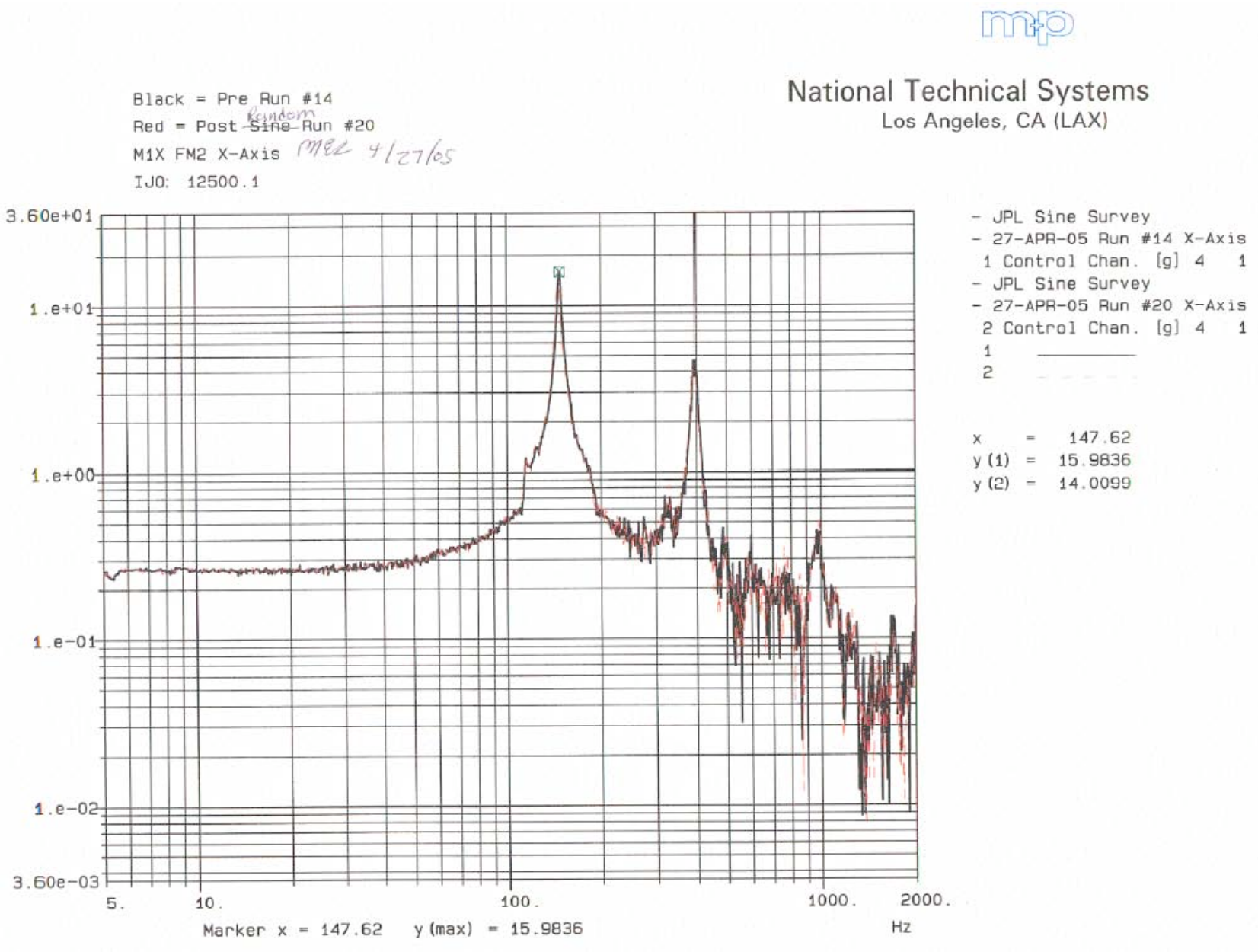

Figure 51. SEP-C FM2, Y Axis Sine Input

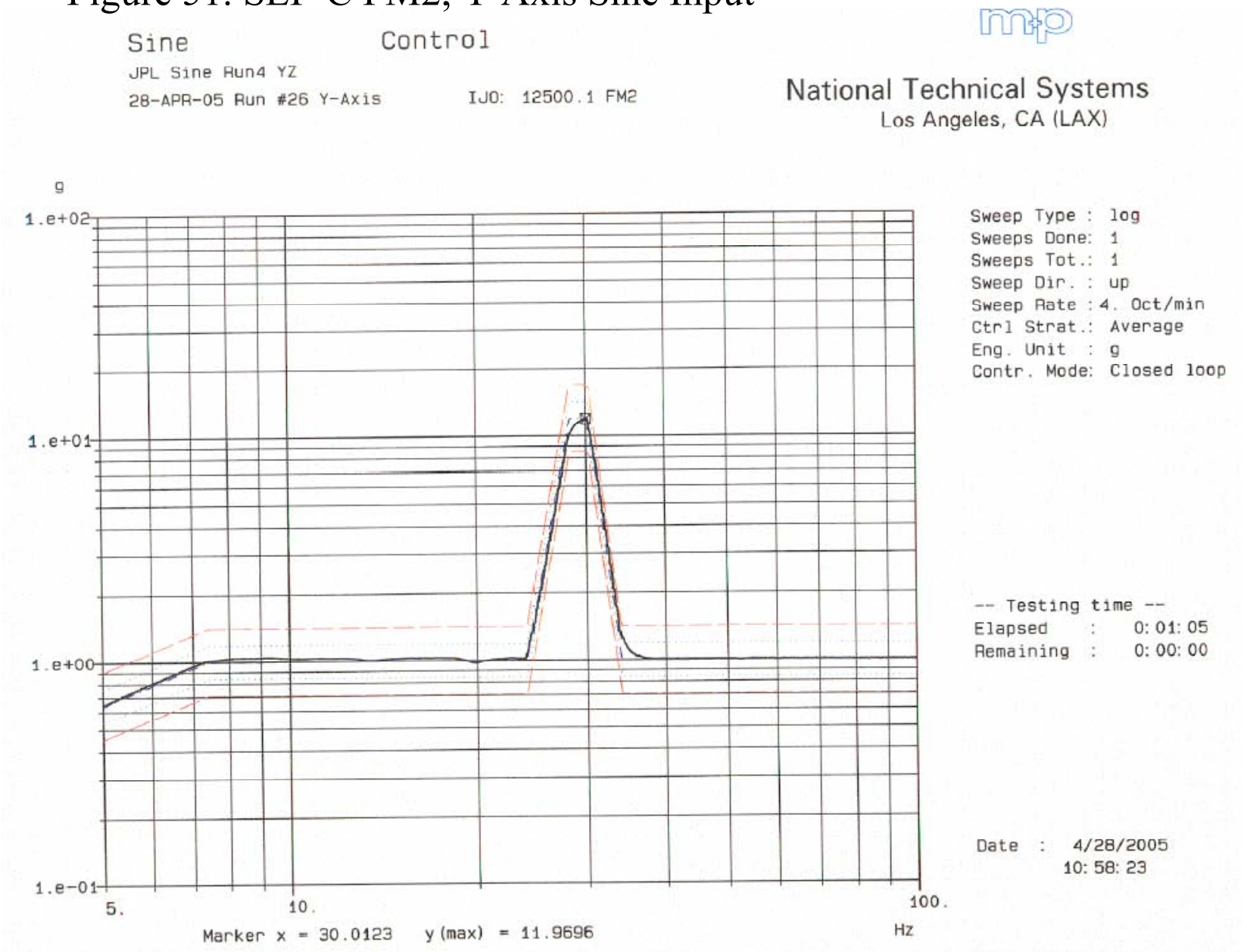

Figure 52. SEP-C FM2, Y Axis Interface Force

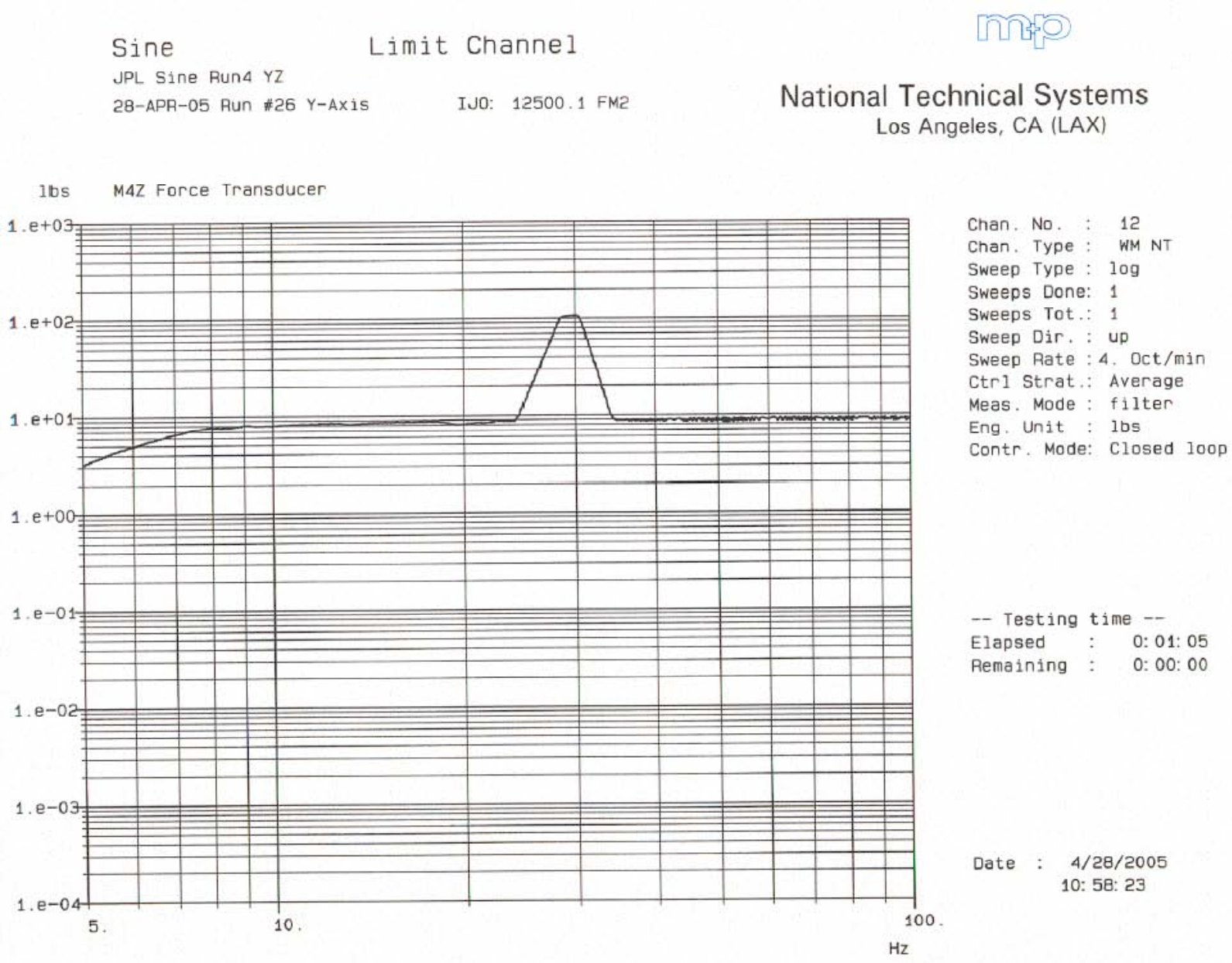

Figure 53. SEP-C FM2, Y Axis PF Random Vibration Input, Force Limited

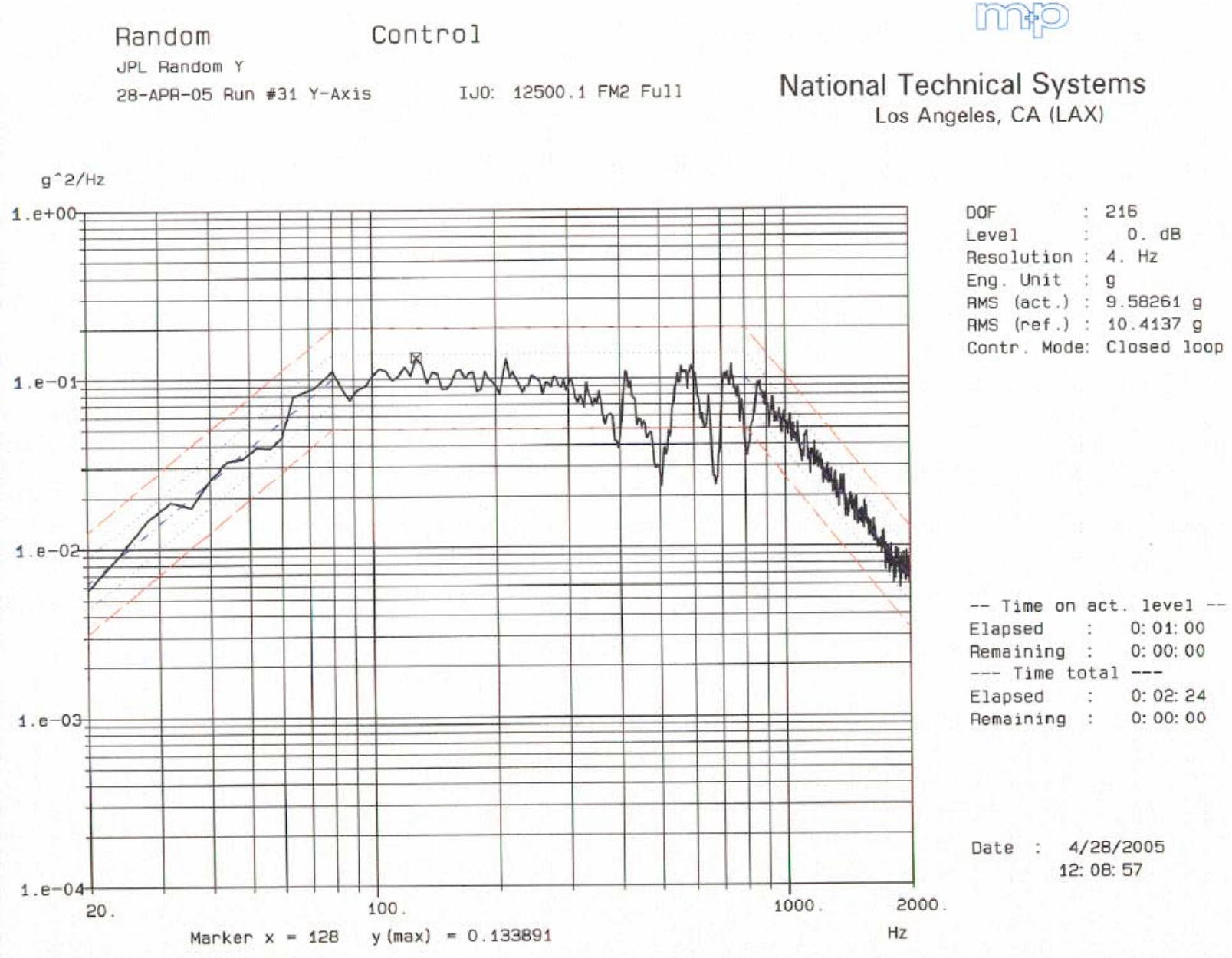

Figure 54. SEP-C FM2, Y Axis PF Random Summed Interface Force

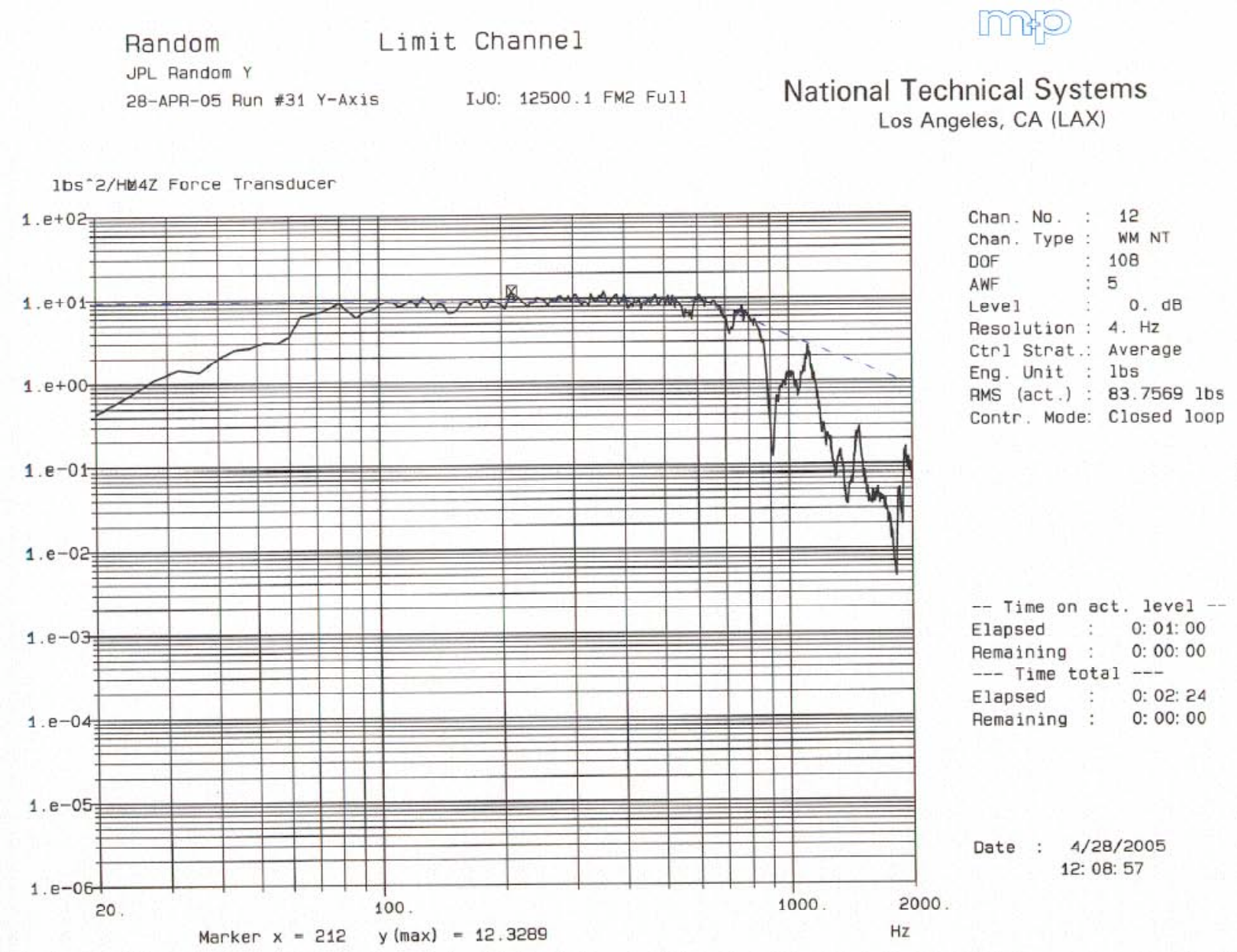

Figure 55. SEP-C FM2, Y Axis PF Random Telescope Top Response

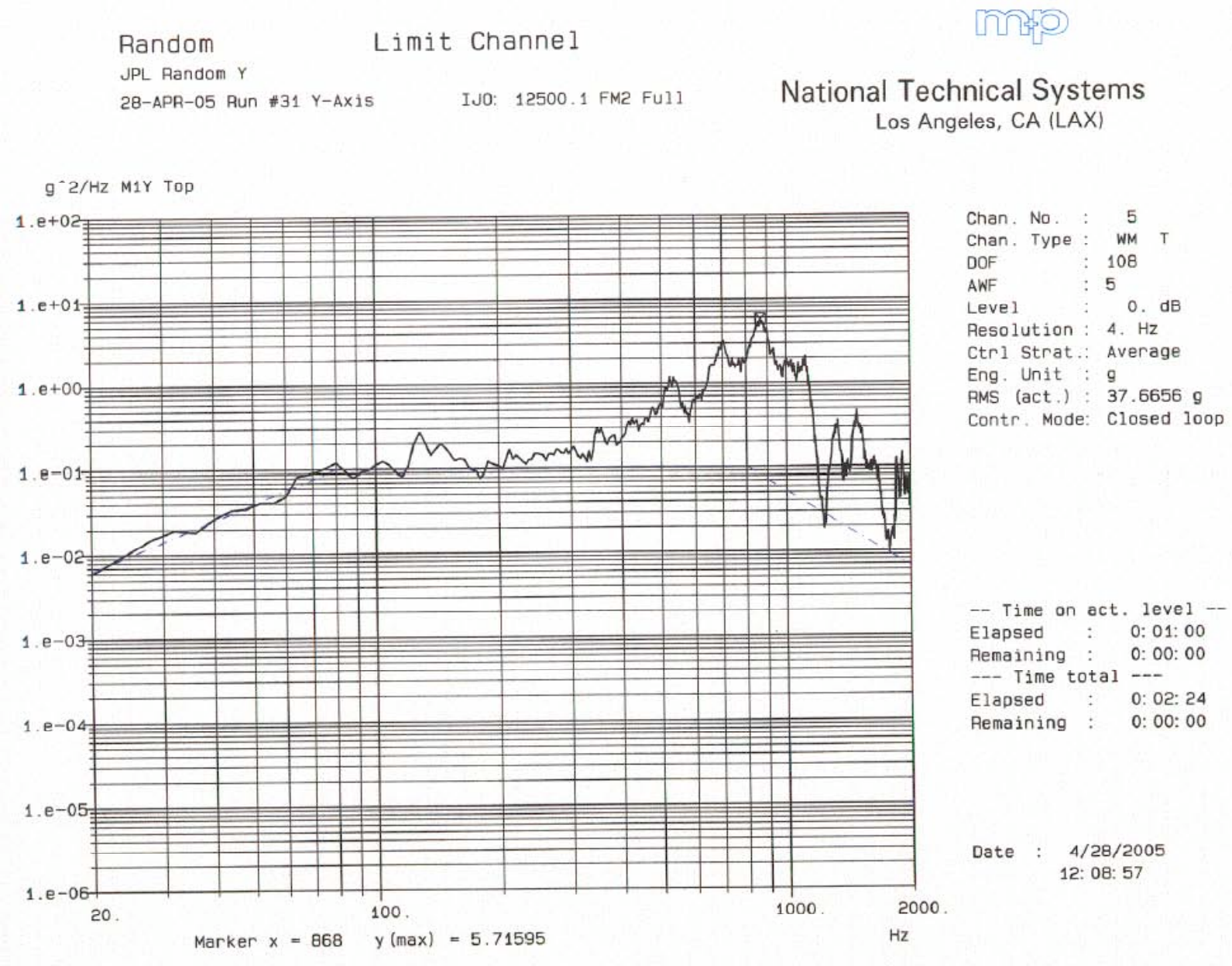

Figure 56. SEP-C FM2, Y Axis Pre and Post Sine Survey Interface Force

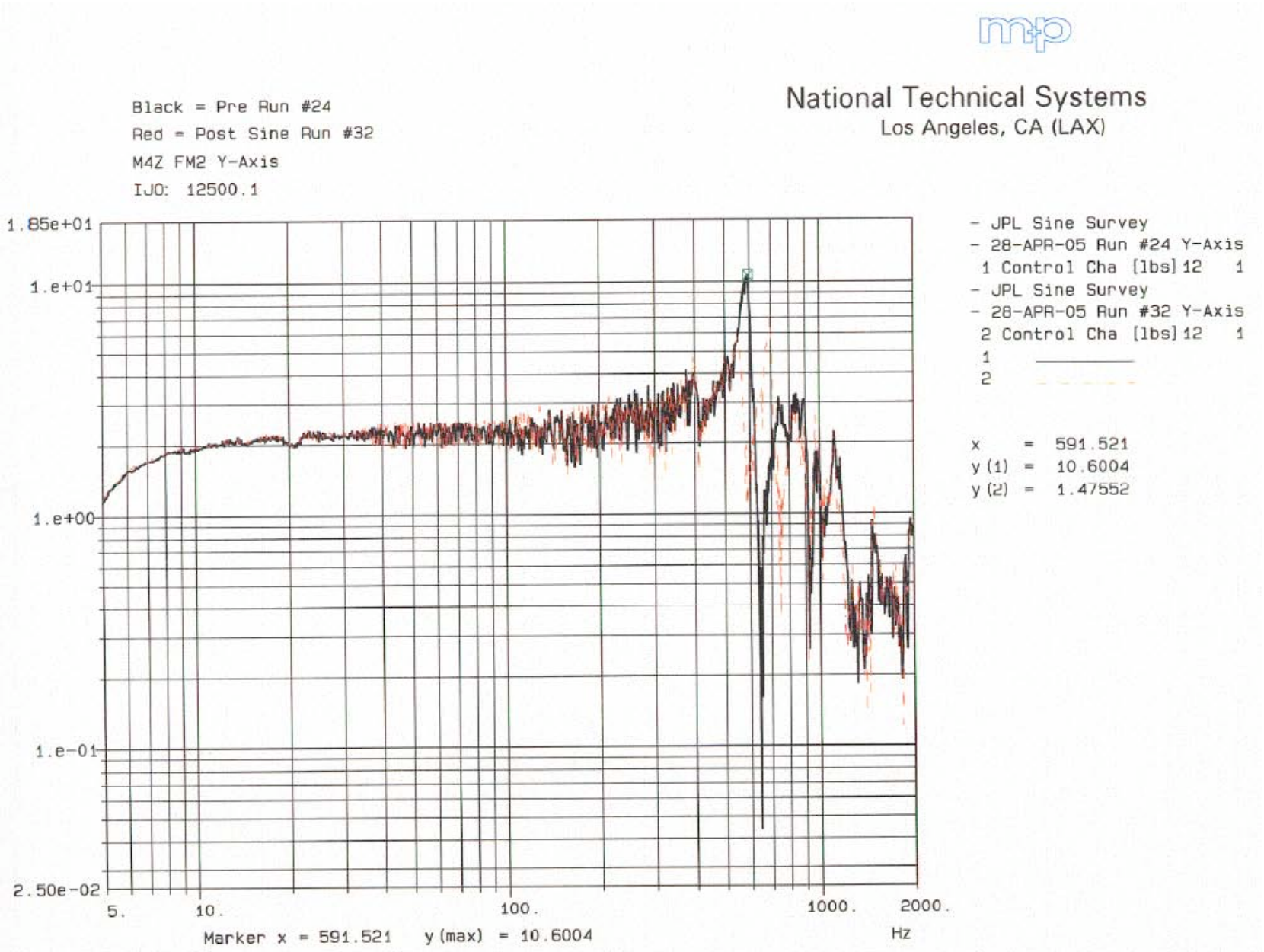

Figure 57. SEP-C FM2, Y Axis Pre and Post Sine Survey Telescope Top