# TECHNICAL PROGRESS REPORT

OCTOBER 1993

# DEVELOP ADVANCED NONLINEAR SIGNAL ANALYSIS TOPOGRAPHICAL MAPPING SYSTEM

NASA CONTRACT NO. NAS8-39393

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GEORGE C. MARSHALL SPACE FLIGHT CENTER
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by

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AI SIGNAL RESEARCH TECHNICAL REPORT TR-4002-93-10

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| | Contracting Officer: L. Van Wagner |

# DEVELOP ADVANCED NONLINEAR SIGNAL ANALYSIS TOPOGRAPHICAL MAPPING SYSTEM
# ( NASA CONTRACT NO. NAS8-39393 )

The SSME has been undergoing extensive flight certification and developmental testing, which involves some 250 health monitoring measurements. Under the severe temperature, pressure, and dynamic environments sustained during operation, numerous major component failures have occurred, resulting in extensive engine hardware damage and scheduling losses. To enhance SSME safety and reliability, detailed analysis and evaluation of the measurements signal are mandatory to assess its dynamic characteristics and operational condition. Efficient and reliable signal detection techniques will reduce catastrophic system failure risks and expedite the evaluation of both flight and ground test data, and thereby reduce launch turn-around time.

The basic objective of this contract are threefold:

(1) Develop and validate a hierarchy of innovative signal analysis techniques for nonlinear and nonstationary time-frequency analysis. Performance evaluation will be carried out through detailed analysis of extensive SSME static firing and flight data. These techniques will be incorporated into a fully automated system.

(2) Develop an advanced nonlinear signal analysis topographical mapping system (ATMS) to generate a Compressed SSME TOPO Data Base (CSTDB). This ATMS system will convert tremendous amount of complex vibration signals from the entire SSME test history into a bank of succinct image-like patterns while retaining all respective phase information. High compression ratio can be achieved to allow minimal storage requirement, while providing fast signature retrieval, pattern comparison, and identification capabilities.

(3) Integrate the nonlinear correlation techniques into the CSTDB data base with compatible TOPO input data format. Such integrated ATMS system will provide the large test archives necessary for quick signature comparison.

This study will provide timely assessment of SSME component operational status, identify probable causes of malfunction, and indicate feasible engineering solutions. The final result of this program will yield an ATMS system of nonlinear and nonstationary spectral analysis software package integrated with the Compressed SSME TOPO Data Base (CSTDB) on the same platform. This system will allow NASA engineers to retrieve any unique defect signatures and trends associated with different failure modes and anomalous phenomena over the entire SSME test history across turbopump families.

## REPORTS

In addition to monthly technical progress reports, informal analysis results of SSME test are prepared and presented at irregular intervals. Software routines and database are provided for application on MSFC computers. The final report will document all analysis results, new techniques and computer software generated under this contract.

## TECHNICAL PROGRESS

This is October 1993 monthly technical progress report on the subject contract for the development of an advanced nonlinear signal analysis topographical mapping system (ATMS) for SSME diagnostic evaluation. Specific tasks performed in this reporting period are summarized as follows:

High frequency analysis of envelop detection was performed during this reporting period to continue the investigation of the high amplitude Sync RMS spikes anomalies that has been reported in last (September) progress report. The high Sync spikes anomaly were observed on the external acceleration measurements of High Pressure Oxygen Pump (HPOP) during a series of ATD (Alternate Turbopump Development) engine tests. As described in last report, detailed analysis were performed on test 904-164 in order to correlate the roller bearing cage signature with the Sync spike anomaly. The recovered envelop signal indeed shows similar spiking phenomenon on the cage frequency component except the timings of the Cage spikes do no correlate directly with that of the Sync spikes. Similar analysis was performed on another ATD engine test, test 904-163. The results are summarized in this report.

Figure 1-a to 1-d shows the RMS tracking for Sync, 2N, 4N and composite of the turbine end external acceleration measurements HPOT RAD 126 for test 904-163. A strong Sync spike occurs at S+420 second in figure 1-a. The RMS trackings of all the other components do not show any special event or trending at this particular moment. The major objective is to identify if there exists any other signature that might be correlated with this Sync spike anomaly.

Figures 2 shows the PSD of measurement HPOT RAD 126 at S+200 second. The peaks marked "N", "2N", "3N" and "4N" are the Sync frequency component and its harmonics. The harmonics of the 60 Hz line noise are also presented at 180 Hz, 200 Hz, 420 Hz and 540 Hz. The Outer Roller Pass (ORP) component of the Turbine End roller bearing (which has 14 rollers) is also presented at 2280 Hz. No other significant phenomenon is observed in the PSD.

As with test 904-164, the frequency of the analysis window is then open up to 50 KHz in order to perform envelop detection. Figure 3 shows the 50 KHz PSDs of measurements HPOT RAD 126 and RAD 90 at S+400. Most of the PSD peaks are just higher harmonics of Sync of HPOP (N) or Sync of HPFP (N'), and some high frequency line noise. Again, a broad PSD peak is present in 30 to 40 KHz frequency band which is corresponding to the resonant frequency of the accelerometer. As stated in last report, such a sensor's resonant response might carry some valuable bearing response signature through amplitude modulation, and which can be recovered by envelop detection technique.

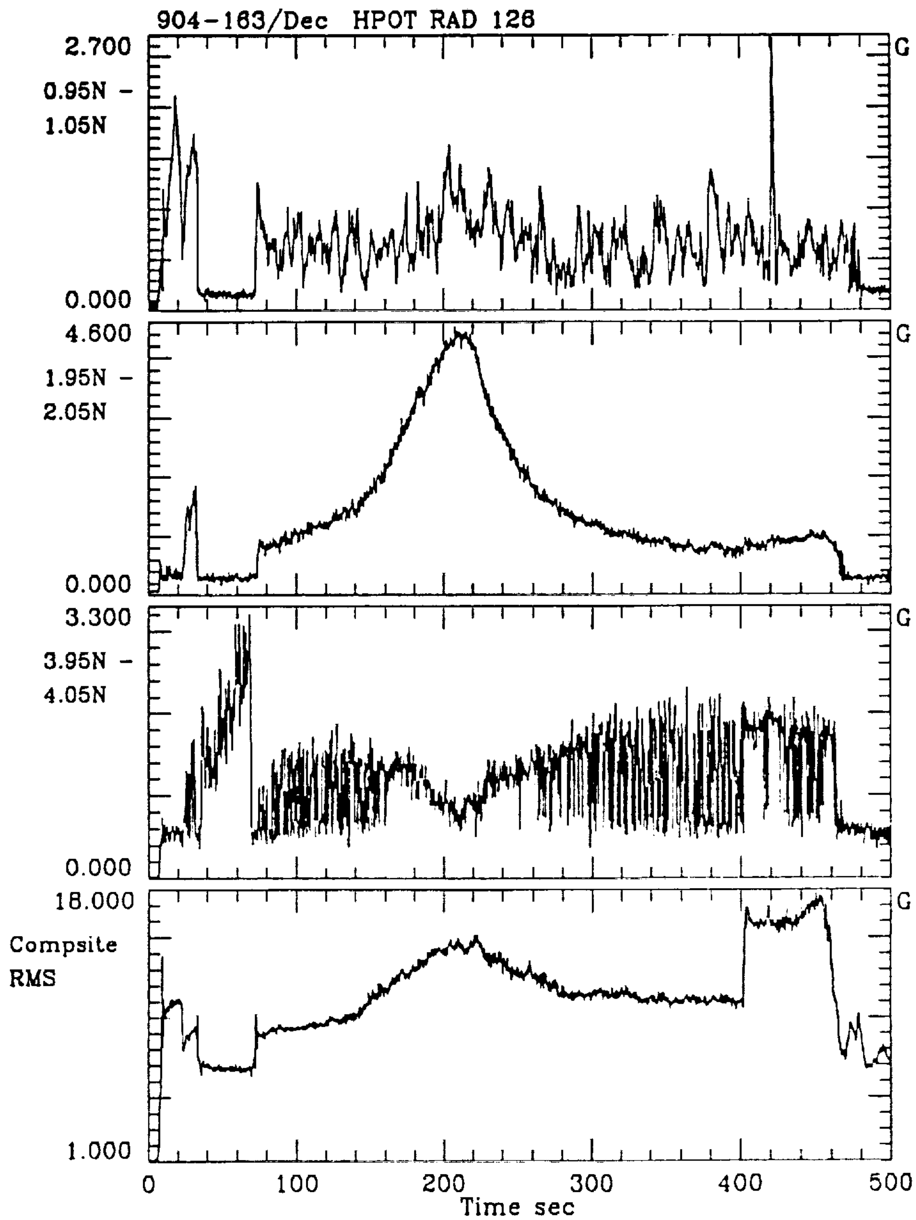
To obtain the envelope of a complex signal, the raw signal is first bandpass filtered over the frequency band of the structural resonance ( 32 Khz to 40 Khz). The 90-degree phase shifted signal is then obtained by Hilbert Transform (HT). The envelop signal can be obtained from the original signal and the 90-degree phase shifted signal from the Hilbert Transform. Figure 4 shows the TOPO plot of the resulting envelop signal. Several intermittent spectral components are observed, which is similar to the case of test 904-164. The most interesting activities are present in the low-frequency region (0 to 1000 Hz). Figure 5 shows the PSD of the envelop signal at S+100 with several meaningful spectral components present. Again, similar to test 904-164, the frequencies of these peaks turn out to be the Cage frequency of the turbine end roller bearing and its harmonics. This indicates that during the time when these cage components occurred, some striking motion from the rolling elements was present whose signal is imbedded in the sensor's resonant response in the form of amplitude modulation.

Figure 6 shows the RMS tracking of the envelop signal for cage component "C" and its harmonics 2C, 5C, and composite. Compare to the Sync RMS tracking of the raw signal in figure 1-a, the cage component and its harmonics are going through some erratic motion around the time when the Sync spike occurs. The strongest peak is corresponding to the 2C component at S+414, which is 6 second before the Sync spike. Even though the timing of these cage spikes still do not match exactly to that of the Sync spike, this result indicates the bearing condition indeed went through some significant change when the Sync spike occurs. Similar high frequency analysis on test 904-169 with Sync spike anomalies is currently under investigation. The results will be reported in the next progress report.

Prepared and approved by

Jong Jen - Yi

Jen Jong
Program Manager




RMS Tracking

Fig - 1

| | | |
|---|---|---|
| 1- | 12.21- | 0.0473 |
| 2- | 24.41- | 0.0270 |
| 3- | 61.04- | 0.0536 |
| 4- | 94.60- | 0.0024 |
| 5- | 119.02- | 0.0009 |
| 6- | 149.54- | 0.0007 |
| 7- | 167.85- | 0.0006 |
| 8- | 180.05- | 0.1914 |
| 9- | 198.36- | 0.0006 |
| 10- | 216.67- | 0.0005 |
| 11- | 250.24- | 0.0004 |
| 12- | 265.50- | 0.0006 |
| 13- | 299.07- | 0.0565 |
| 14- | 332.64- | 0.0031 |
| 15- | 366.21- | 0.0020 |
| 16- | 384.52- | 0.1100 |
| 17- | 399.78- | 0.0023 |
| 18- | 421.14- | 0.0031 |
| 19- | 433.35- | 0.0030 |
| 20- | 448.61- | 0.0009 |
| 21- | 488.28- | 0.0011 |
| 22- | 500.49- | 0.0012 |
| 23- | 515.75- | 0.0008 |
| 24- | 540.16- | 0.0084 |
| 25- | 570.68- | 0.0038 |
| 26- | 582.89- | 0.0195 |
| 27- | 595.09- | 0.0021 |
| 28- | 616.46- | 0.0015 |
| 29- | 631.71- | 0.0017 |
| 30- | 659.18- | 0.0030 |
| 31- | 711.06- | 0.0027 |
| 32- | 765.99- | 1.5232 |
| 33- | 814.82- | 0.0045 |
| 34- | 900.27- | 0.0029 |
| 35- | 1016.24- | 0.0118 |
| 36- | 1055.91- | 0.0128 |
| 37- | 1068.12- | 0.0123 |
| 38- | 1080.32- | 0.0127 |
| 39- | 1104.74- | 0.0130 |
| 40- | 1150.51- | 0.0289 |
| 41- | 1220.70- | 0.0074 |
| 42- | 1309.20- | 0.0062 |
| 43- | 1321.41- | 0.0057 |
| 44- | 1467.90- | 0.0111 |
| 45- | 1480.10- | 0.0128 |
| 46- | 1504.52- | 0.0113 |
| 47- | 1516.72- | 0.0134 |
| 48- | 1528.93- | 0.1740 |
| 49- | 1901.25- | 0.0052 |
| 50- | 1916.50- | 0.0064 |
| 51- | 2139.28- | 0.0038 |
| 52- | 2151.49- | 0.0046 |
| 53- | 2169.80- | 0.0040 |
| 54- | 2215.58- | 0.0045 |
| 55- | 2227.78- | 0.0045 |
| 56- | 2261.35- | 0.0049 |
| 57- | 2279.66- | 0.0251 |
| 58- | 2297.97- | 0.0286 |
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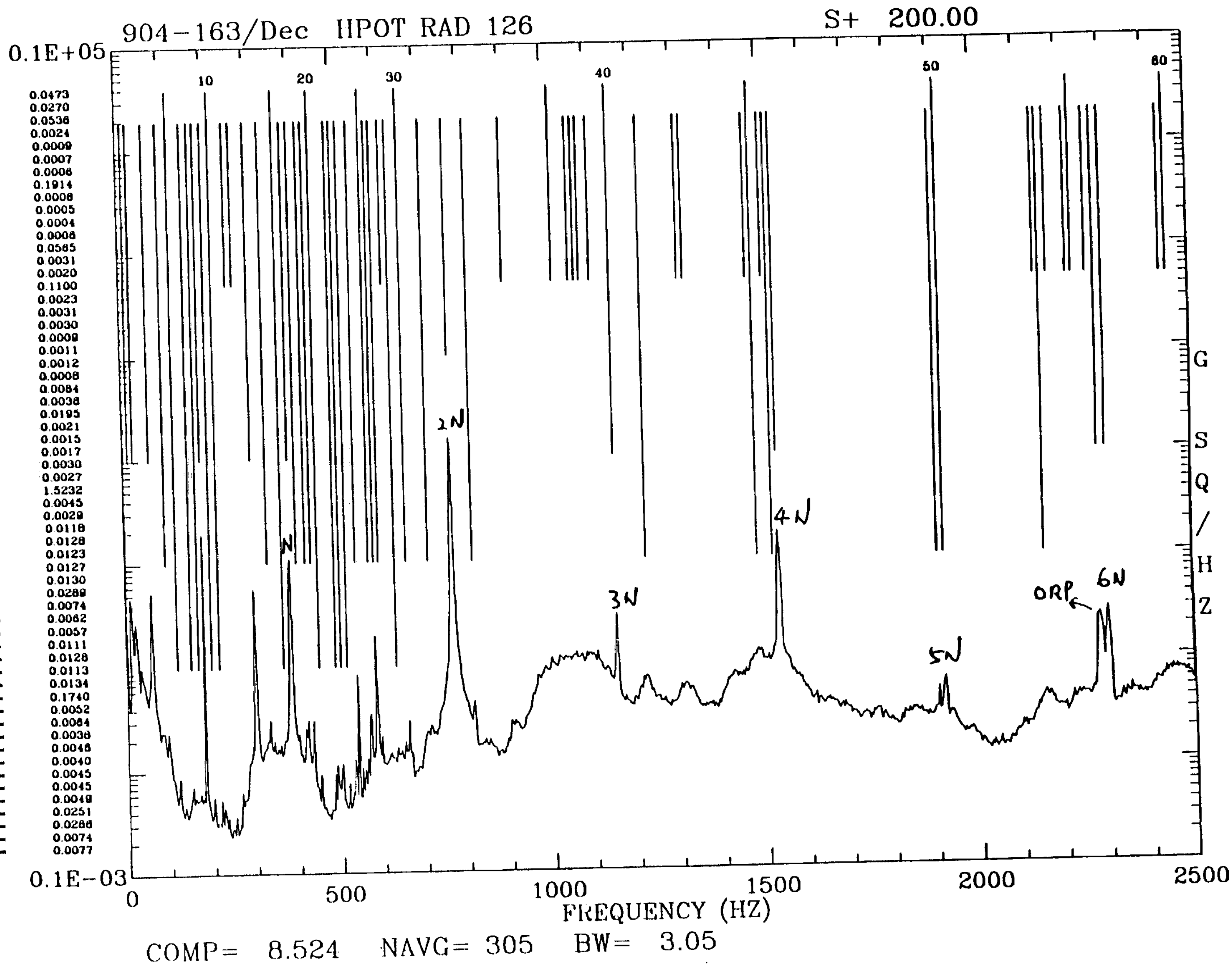
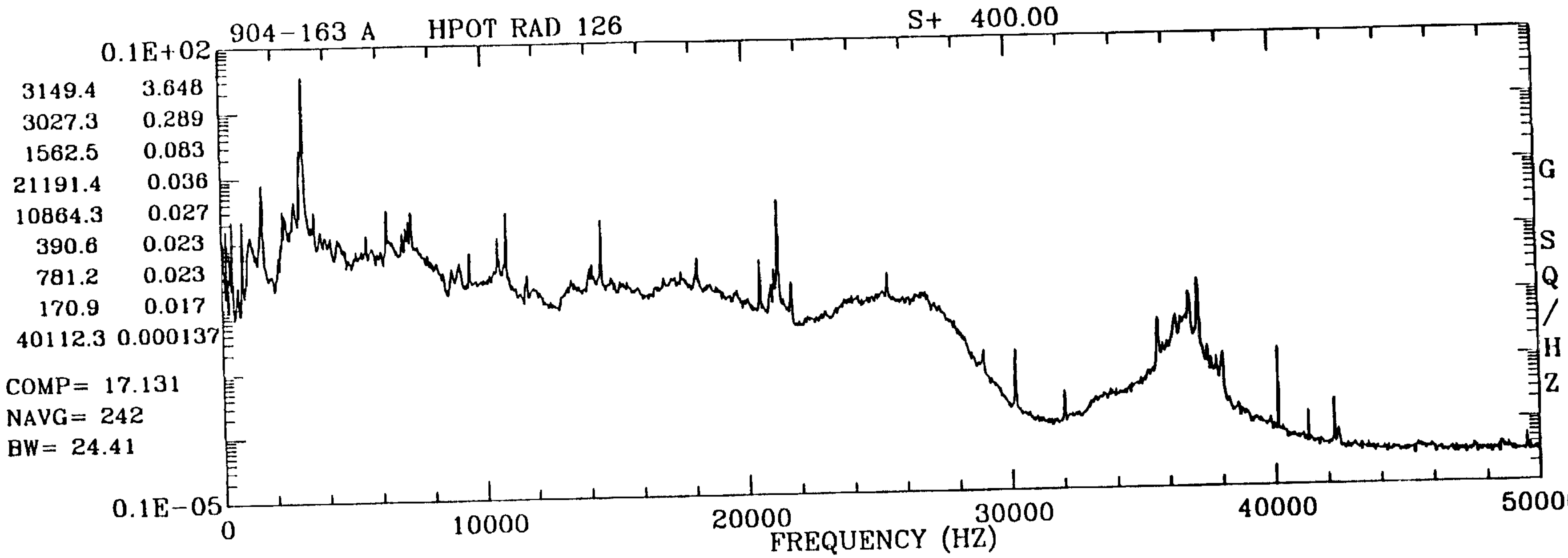



Fig -2


904-163 A HPOT RAD 126
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0.1E+02
3149.4 3.648
3027.3 0.289
1562.5 0.083
21191.4 0.036
10864.3 0.027
390.6 0.023
781.2 0.023
170.9 0.017
40112.3 0.000137
COMP= 17.131
NAVG= 242
BW= 24.41
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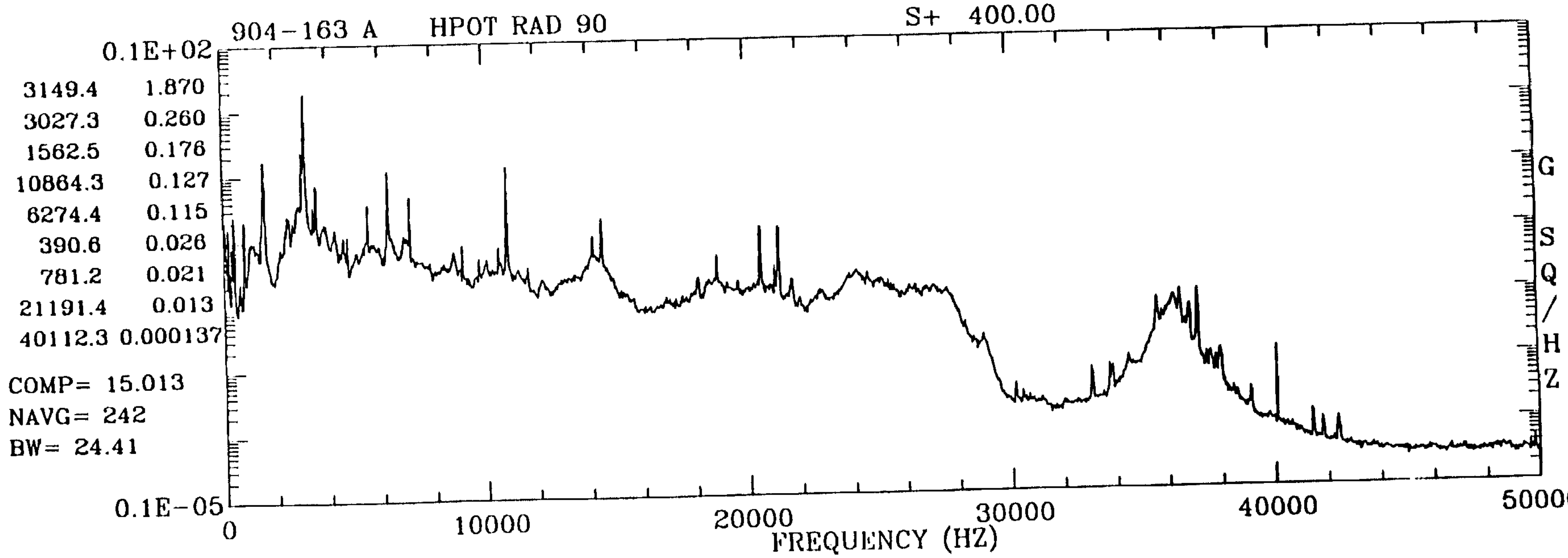
0
10000
20000
30000
40000
50000
FREQUENCY (HZ)
G
S
Q
/
H
Z


904-163 A HPOT RAD 90
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0.1E+02
3149.4 1.870
3027.3 0.260
1562.5 0.176
10864.3 0.127
6274.4 0.115
390.6 0.026
781.2 0.021
21191.4 0.013
40112.3 0.000137
COMP= 15.013
NAVG= 242
BW= 24.41
0.1E-05
0
10000
20000
30000
40000
50000
FREQUENCY (HZ)
G
S
Q
/
H
Z

Fig-3

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isp = 4
neigh = 12
ipara = 8
mx = 1
my = 1

nPSDs = 381
nAVGs = 4
BW = 3.1

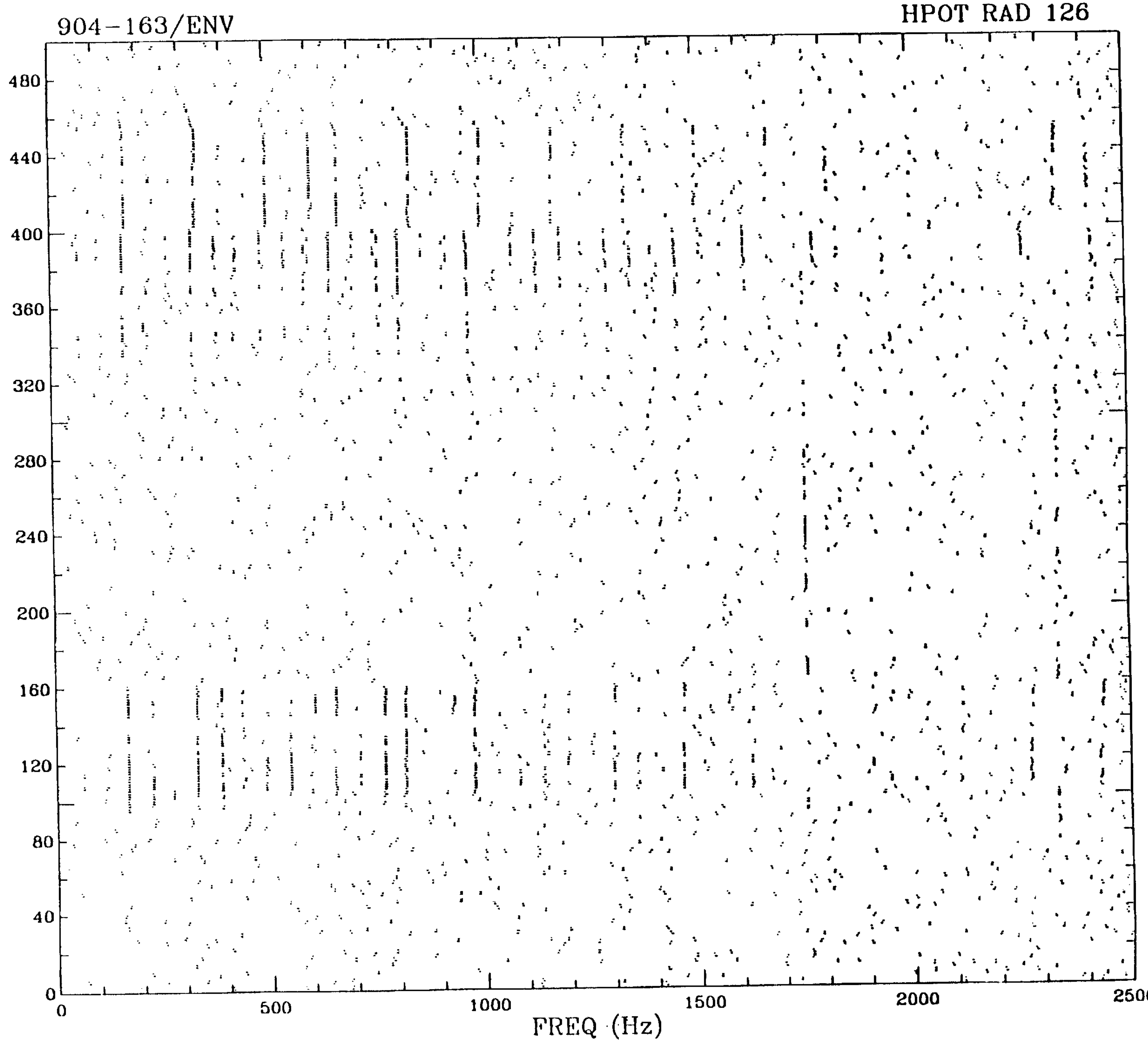


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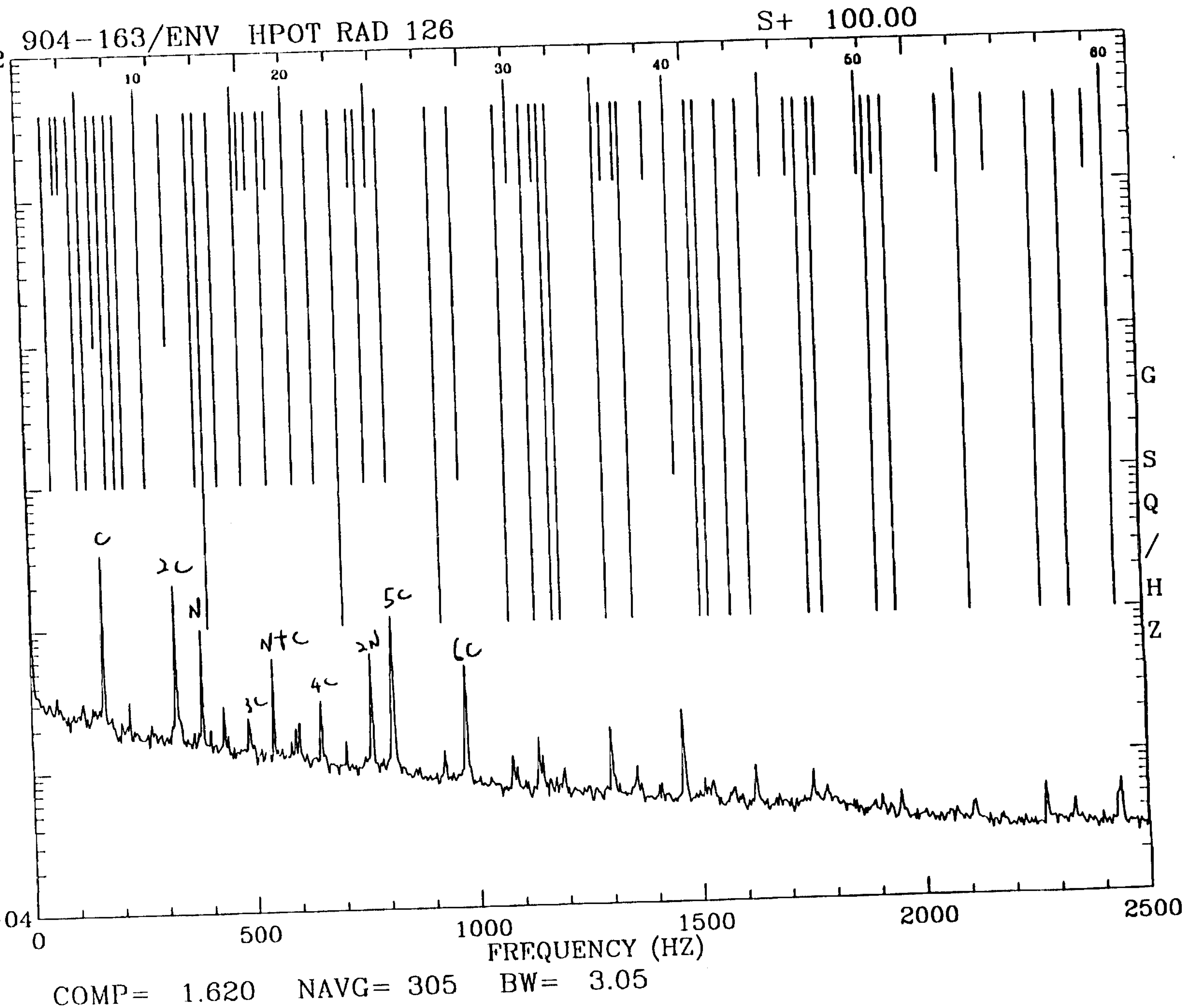
Fig - 4




| | | |
|---|---|---|
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| 2- | 82.40- | 0.0003 |
| 3- | 94.60- | 0.0003 |
| 4- | 115.97- | 0.0003 |
| 5- | 137.33- | 0.0003 |
| 6- | 161.74- | 0.0034 |
| 7- | 180.05- | 0.0003 |
| 8- | 201.42- | 0.0002 |
| 9- | 219.73- | 0.0003 |
| 10- | 268.55- | 0.0002 |
| 11- | 323.49- | 0.0021 |
| 12- | 381.47- | 0.0010 |
| 13- | 399.78- | 0.0002 |
| 14- | 430.30- | 0.0003 |
| 15- | 485.23- | 0.0002 |
| 16- | 497.44- | 0.0002 |
| 17- | 515.75- | 0.0001 |
| 18- | 543.21- | 0.0008 |
| 19- | 561.52- | 0.0001 |
| 20- | 601.20- | 0.0002 |
| 21- | 650.02- | 0.0003 |
| 22- | 704.95- | 0.0002 |
| 23- | 747.68- | 0.0001 |
| 24- | 762.94- | 0.0008 |
| 25- | 787.35- | 0.0001 |
| 26- | 811.77- | 0.0011 |
| 27- | 924.68- | 0.0001 |
| 28- | 973.51- | 0.0005 |
| 29- | 1077.27- | 0.0001 |
| 30- | 1104.74- | 0.0001 |
| 31- | 1135.25- | 0.0002 |
| 32- | 1159.67- | 0.0001 |
| 33- | 1174.93- | 0.0001 |
| 34- | 1193.24- | 0.0001 |
| 35- | 1297.00- | 0.0002 |
| 36- | 1315.31- | 0.0001 |
| 37- | 1342.77- | 0.0001 |
| 38- | 1354.98- | 0.0001 |
| 39- | 1409.91- | 0.0001 |
| 40- | 1458.74- | 0.0002 |
| 41- | 1507.57- | 0.0001 |
| 42- | 1525.88- | 0.0001 |
| 43- | 1574.71- | 0.0001 |
| 44- | 1620.48- | 0.0001 |
| 45- | 1672.36- | 0.0001 |
| 46- | 1730.35- | 0.0001 |
| 47- | 1751.71- | 0.0001 |
| 48- | 1782.23- | 0.0001 |
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| 51- | 1904.30- | 0.0001 |
| 52- | 1922.61- | 0.0000 |
| 53- | 1947.02- | 0.0001 |
| 54- | 2069.09- | 0.0000 |
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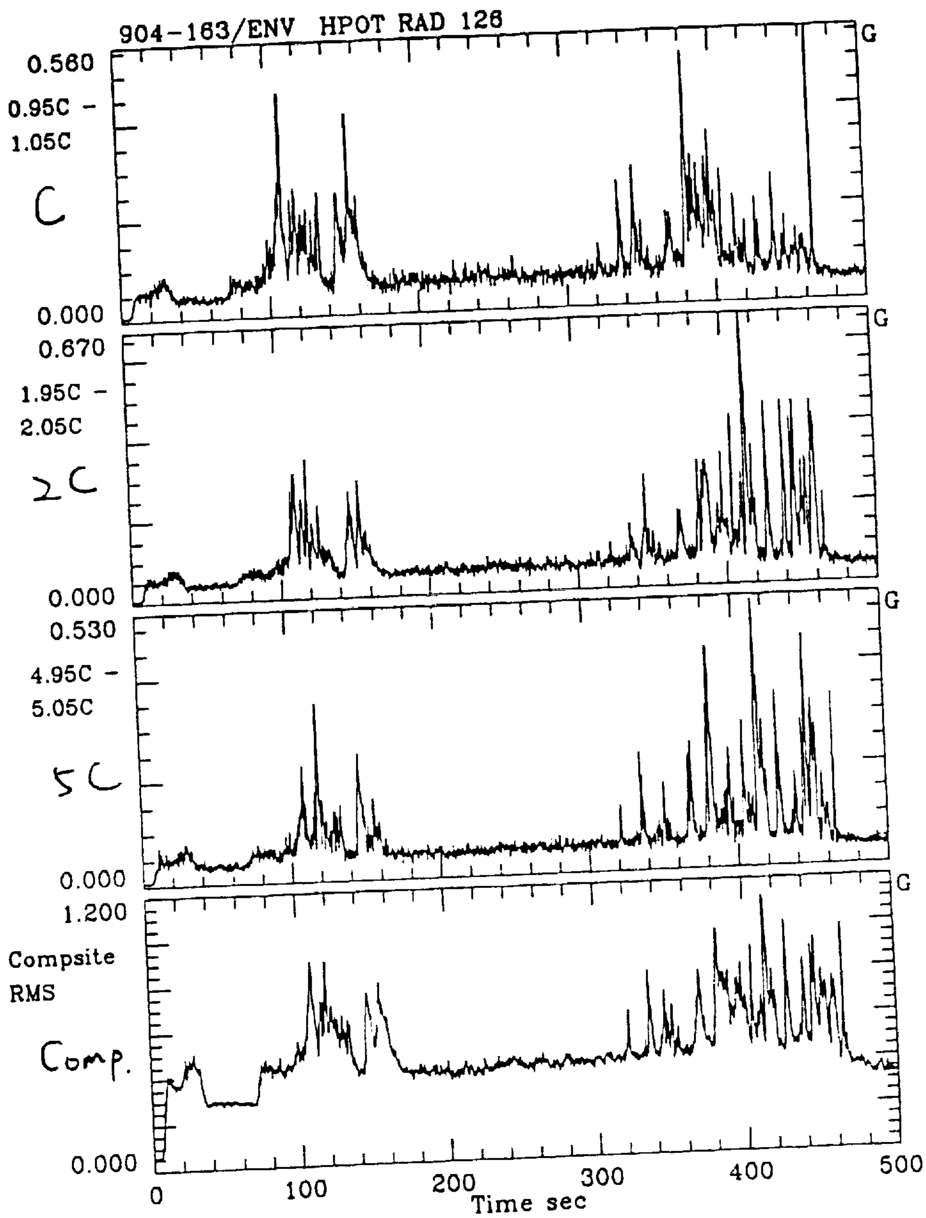
| 60- | 2438.35- | 0.0001 |

Fig-5




RMS Tracking

Fig-6

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13. ABSTRACT (Maximum 200 words)

High frequency analysis of envelop detection was performed during this reporting period to continue the investigation of the high amplitude Sync RMS spikes anomalies that has been reported in last (September) progress report. The high Sync spikes anomaly were observed on the external acceleration measurements of High Pressure Oxygen Pump (HPOP) during a series of ATD (Alternate Turbopump Development) engine tests. As described in last report, detailed analysis were performed on test 904-164 in order to correlate the roller bearing cage signature with the Sync spike anomaly. The recovered envelop signal indeed shows similar spiking phenomenon on the cage frequency component except the timings of the Cage spikes do no correlate directly with that of the Sync spikes. Similar analysis was performed on another ATD engine test, test 904-163. The results are summarized in this report.

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