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Vibrational Testing of Optical Fiber Connector Joints

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VIBRATIONAL TESTING OF OPTICAL FIBER CONNECTOR JOINTS

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SUMMARY

An experimental study was performed to determine the effects of vibration on the propagation of light through SMA- and ST-type fiber-optic connectors. A multimode, fiber-optic link was vibrated from 0 to 10,000 Hz at a constant peak acceleration along the connector transverse and longitudinal axes. All other environmental parameters were ambient. Transfer characteristics through the connection were examined as a function of vibrational frequency using both laser and LED light to illuminate the system. Slight differences in operation between the SMA and ST connectors were observed with no appreciative attenuation as a result of vibration. Vibration did cause the constant-amplitude input light to be modulated in the connector; however, the amplitude of vibration-induced noise was less than 3 standard deviations from the mean.

INTRODUCTION

Interest is increasing in the use of fiber-optic sensors and harnesses for rocket engine condition monitoring. Because of this interest, there is a need to better understand the behavior of fiber systems in harsh environments. As a result, studies are being conducted at the Lewis Research Center to determine which fiber-optic technologies are feasible for incorporation in rocket engines in the near term and which need further development. Using the space shuttle main engine requirements to typify environmental conditions, we anticipated that vibration would be particularly perturbing to the light transfer characteristics through a fiber-optic system. Therefore, tests were performed to qualitatively determine the effects of vibration on optical throughput in a fiber-optic connector.

BACKGROUND

Vibration can induce several changes in an optical signal passing through a fiber-optic connector. One such change is attenuation caused by axial or transverse misalignment of the fibers. Connector feedthroughs (such as the SMA- and ST-types tested in these experiments) mechanically hold two fibers face-to-face, typically passing the signal with a 1-dB loss (ref. 1). Vibration may cause the fibers or connectors to move with respect to each other within the feedthrough, thereby inducing increased losses due to misalignment. This misalignment will cause less light to couple through the connector. Since the misalignments occur at the frequencies of vibration, the detection circuitry will see the frequency content.

Vibration may also cause signal attenuation due to microbending of the fiber at the fiber-connector interface. Microbend losses occur when the fiber is bent around a radius smaller than its "minimum bend radius," allowing the propagating light waves to become radiating waves which escape the fiber cladding. Such bending of the fiber not only introduces a loss mechanism but weakens the fiber and may cause damage. Microbending is most probable at points in a fiber-optic system where the fibers are attached to heavy components such as a controller or bulk-optic sensor.

TEST SETUP

Figure 1 shows the experimental setup for the vibration tests. Light from an optical source illuminates the fiber and passes through the vibrating fiber-optic connector interface to the second fiber. The intensity of this light arriving at the detector is converted to a voltage and then amplified. Signal attenuation is determined statistically from a time domain signal, and the frequency components are determined with a digital spectrum analyzer.

Because of the significant differences in their mechanical structures, both SMA- and ST-type connectors were tested. Both types are commercially available and commonly used. SMA connectors fasten by a threaded screw mechanism and ST connectors use a spring lock similar to coaxial cable connectors. Schematic drawings of an ST and an SMA connector are shown in figure 2.

Illumination sources used include a laser beam from a single frequency helium-neon laser and broadband light from a light-emitting diode (LED). The laser was used since many sensing techniques, such as interferometry, require a coherent source. The LED's may be used for sensors, such as intensity-modulated sensors, that do not require a coherent source. Separate tests were performed using each type of light source.

The connector feedthrough was attached to a mechanical shaker, which was driven by a 0 to 10 kHz random-frequency generator. The shaker provided for both horizontal and vertical mounting of the connector and an accelerometer to measure the vibration.

The equipment used in these experiments were a Hewlett Packard model HP3582A digital spectrum analyzer, a Hewlett Packard model HP54111D digital storage oscilloscope, and a Hewlett Packard series 9000 model 360 computer. In the 0 to 10 kHz frequency range, the spectrum analyzer had a resolution of 40 Hz. For signal average and standard deviation calculations, 8000 samples were included in the population, sampled at a rate of 25,000 samples per second.

TEST PROCEDURE

Initial testing to verify the test setup was performed by disconnecting the fiber-optic connector from the shaker, applying a random voltage to the shaker, and monitoring the detector outputs. This confirmed that vibration did not affect the light input or the fibers themselves and that effects occurring with the shaker connected to the system were indeed due to vibration effects in the connectors.

Tests were repeated several times to insure that connect-disconnect discontinuities did not cause significant changes in the experimental results. No measurable differences were found.

To measure vibration-induced attenuation in the connector, a constant-amplitude light signal was applied to the system and the detector output was monitored and digitized by a digital storage oscilloscope. First, the average light intensity and its corresponding standard deviation were calculated without vibration being applied to the connector. The connector was subjected to random-frequency, constant-force vibrations, and the detector output was compared to the nominal average and standard deviations.

When the detector output was examined with a spectrum analyzer, modulations of the signal at frequencies corresponding to the excitation frequencies were observed. Measurements of light intensity versus frequency were recorded without vibration applied to the system. These were then compared to the measurements of intensity versus frequency during vibration, from which light throughput as a function of vibration could be identified.

Both connectors were evaluated with light from an LED under longitudinal and transverse vibration. Only the SMA connector was tested with laser illumination.

RESULTS AND CONCLUSIONS

Figures 3 to 8 display the amplitude of light passing through the connector as a function of signal frequency. For the six test configurations, the dashed lines indicate optical throughput without vibration, and the solid lines indicate optical throughput with vibration. Figure 9 displays three plots: each plot corresponds to light amplitude versus frequency at different vibrational amplitudes using laser light and an SMA connector vibrating in the longitudinal direction. Figures 10 and 11 display the time domain signal during vibration for this setup, with lines corresponding to the signal average and three standard deviations from the average calculated from the detector output during no vibration. All tests were repeated several times to verify the data with no significant variations. Vibrational effects on laser and LED systems with the two types of fiber-optic connections are now summarized, including the dependence of these results on axis of vibration.

Axis of Vibration

Figures 7 and 8 show that transverse and longitudinal vibration of the feedthrough produced similar results in the coherent laser system. The LED systems in figures 3 to 6 showed sensitivity related to the axis of vibration. SMA connectors exhibited modulation in the lower two-thirds of the frequency range of testing for vibrations occurring along both the longitudinal and transverse axes. ST connectors showed no effects of vibration past 2 kHz along the connector's transverse axis; however, they showed significant modulation at all frequencies tested when vibration occurred along the longitudinal axis.

Modulation: LED System

The digital spectrum analyzer showed that the LED signal was being modulated at low frequencies but not at all frequencies of vibration. Broadband systems have been shown to average out affects which appear in single-mode systems because of the wide range of propagating modes and velocities (ref. 2). Therefore, it was expected that this system would be less affected by vibration than by the laser system. Figures 3 to 6 show that vibration-induced modulation is damped for certain frequencies and exhibits different characteristics for the different types of connectors tested.

It is important to note that this modulation does not occur over the entire range of frequencies tested, except through the ST connector under longitudinal vibration (fig. 6). Figure 6 suggests that the ST connector's spring is not responding to the vibrations and could be damaged.

Modulation: Laser System

Modulation of the laser light inside the connectors did occur at all frequencies of vibration. This modulation is shown in figures 7 and 8 by the approximate 25-decibel greater throughput over the frequencies when the shaker was activated. Peaks occurring in the plots are most likely due to the resonant frequencies of the mechanical setup. Therefore, the laser system is equally sensitive to vibrations at all frequencies, up to 10,000 kHz and 20 g's acceleration.

Level of Vibration

The frequency distribution of a fiber link under different levels of vibration is plotted in figure 9. For the levels of vibration tested, the amplitude of oscillation (frequency is held constant) did not have a significant effect on signal modulation. At very small amplitudes, enough of the signal is chopped to cause a constant-amplitude signal to exhibit oscillatory behavior, which will be seen by the detector circuitry as noise.

Signal-to-Noise Ratio

As a signal is modulated, the added frequency content can be seen by the detection circuitry as noise. This noise becomes significant to the system if the peak-to-peak amplitudes are greater than those of the original signal. Figure 10 shows that the noise bandwidth with vibration applied to the system is not greater than the nominal bandwidth for the broadband system. The laser system in figure 11 shows a noise bandwidth exceeding the 3-sigma band, with a corresponding increase in signal-to-noise ratio of 6 percent.

Attenuation

The calculated mean intensities in figures 10 and 11 show that there was no significant attenuation of the system's total power output due to vibration. The LED system in figure 10 had means for the nonvibrating and vibrating setups, respectively, of 0.7813 and 0.7811 V. The laser system means were 0.6908 V under no vibration and 0.6880 V with vibration.

It is therefore concluded that, at the levels of vibration tested in this experiment, no appreciable change in the total power output level occurs as a result of vibrations.

CONCLUDING REMARKS

The tests performed show that vibration has an effect on the frequency content of light propagating through a fiber-optic link. The single-mode laser light exhibited modulation over the range of frequencies tested, while broadband light from an LED exhibited different levels of modulation corresponding to different vibrational frequencies. For sensors such as interferometers and multiplexing schemes such as heterodyning, this behavior must be studied carefully before application of such sensors and multiplexing schemes to a vibrating environment may be considered practical (ref. 3). These frequency-dependent effects must also be noted when optimizing the amount of signal processing and active optical feedback required in a fiber-optic sensor bus.

Though anticipated, no significant amounts of total power attenuation due to microbending at the connector interface were found. Although intensity-modulated sensors will experience a reduction in signal-to-noise ratio as a result of the oscillatory behavior, they will not be limited by severe reductions in total power throughput.

Neither of the two commonly used connectors tested could eliminate modulation due to vibration along both axes. Further experimentation needs to be performed with a statistically valid sample of connector types and quantities. Other mechanical configurations are available and should be studied for resistance to vibrational effects.

In order to determine the applicability of fiber optics to rocket engines, many more environmental parameters need to be considered (ref. 4). Shock levels up to 40 g's, temperature transients from cryogenic to hot gas temperatures, and a harsh chemical environment are all expected to impose limits on the fiber-optic technologies that can be applied to rocket engines.

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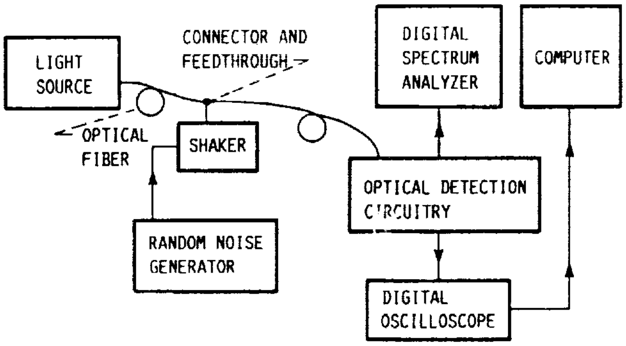

FIGURE 1. - SCHEMATIC OF THE TEST SETUP.

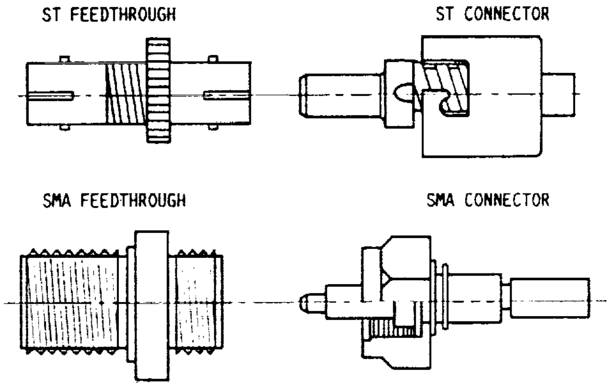

FIGURE 2. - SIDE VIEW SCHEMATICS OF ST AND SMA CONNECTORS AND FEEDTHROUGHS.

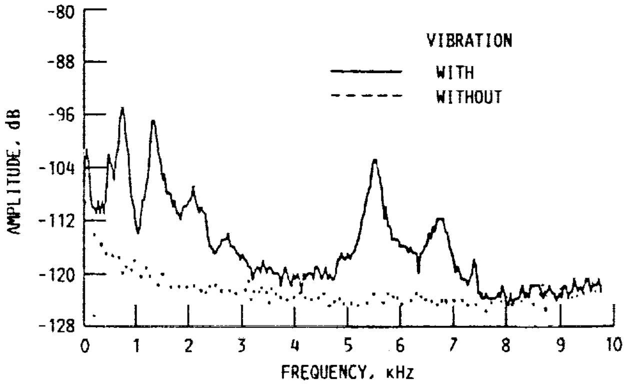

FIGURE 3. - AMPLITUDE VERSUS FREQUENCY OF THE DETECTOR OUTPUT WHEN LIGHT FROM AN LED IS SENT THROUGH AN SMA CONNECTOR UNDER TRANSVERSE VIBRATIONS.

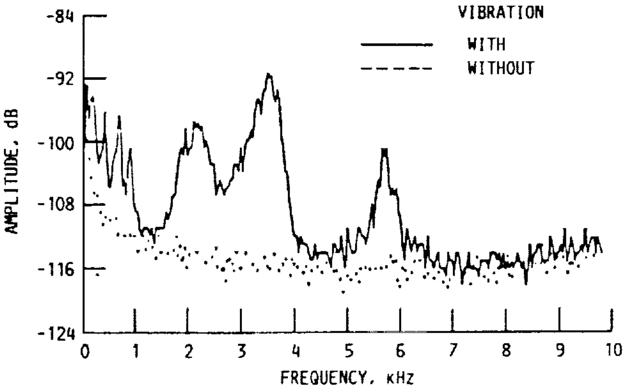

FIGURE 4. - AMPLITUDE VERSUS FREQUENCY OF THE DETECTOR OUTPUT WHEN LIGHT FROM AN LED IS SENT THROUGH AN SMA CONNECTOR UNDER LONGITUDINAL VIBRATIONS.

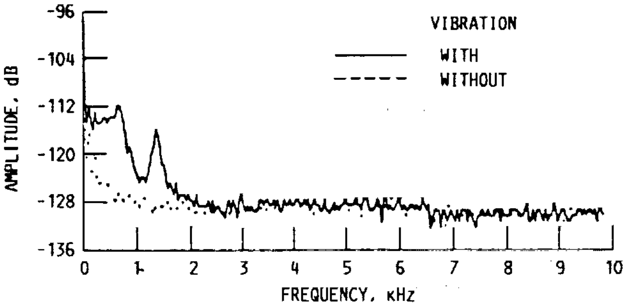

FIGURE 5. - AMPLITUDE VERSUS FREQUENCY OF THE DETECTOR OUTPUT WHEN LIGHT FROM AN LED IS SENT THROUGH AN ST CONNECTOR UNDER TRANSVERSE VIBRATIONS.

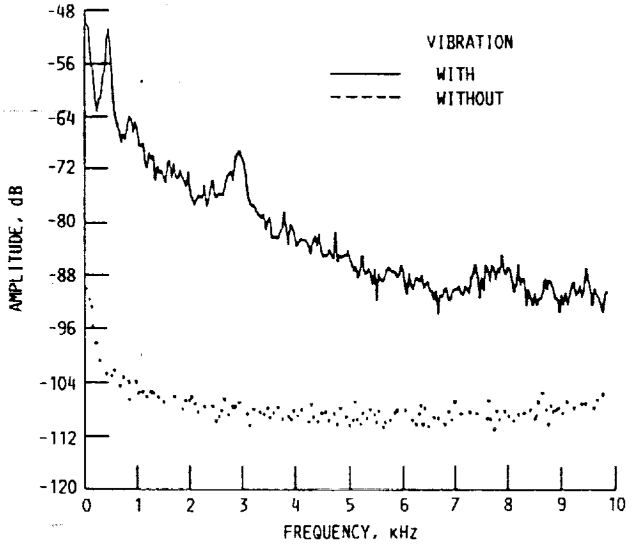

FIGURE 6. - AMPLITUDE VERSUS FREQUENCY OF THE DETECTOR OUTPUT WHEN LIGHT FROM AN LED IS SENT THROUGH AN ST CONNECTOR UNDER LONGITUDINAL VIBRATIONS.

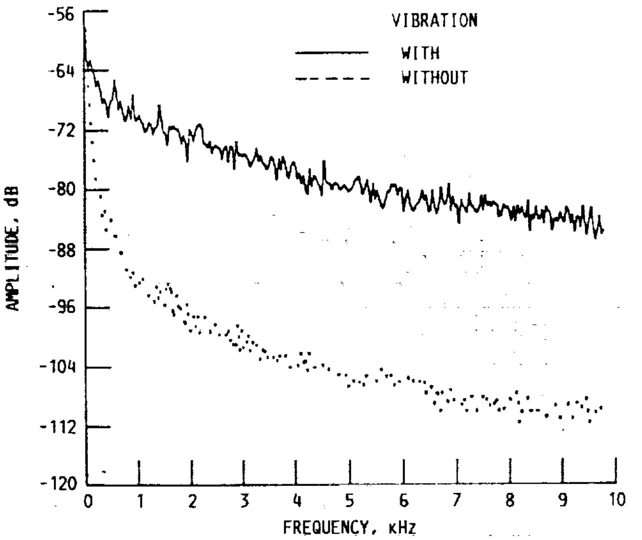

FIGURE 7. - AMPLITUDE VERSUS FREQUENCY OF THE DETECTOR OUTPUT WHEN LASER LIGHT IS SENT THROUGH AN SMA CONNECTOR UNDER TRANSVERSE VIBRATIONS.

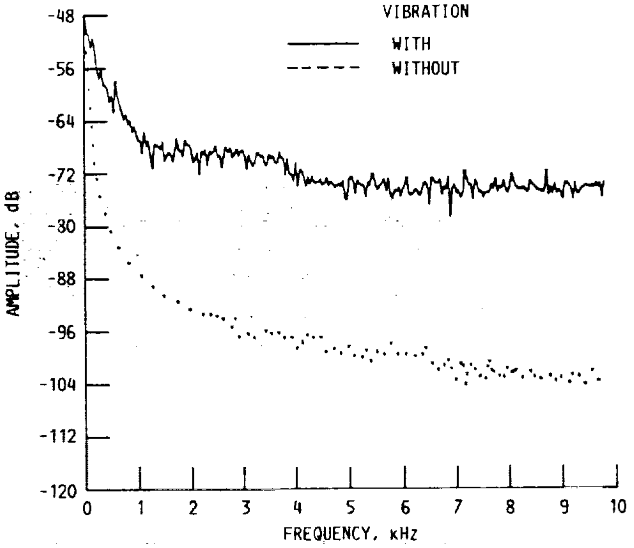

FIGURE 8. - AMPLITUDE VERSUS FREQUENCY OF THE DETECTOR OUTPUT WHEN LASER LIGHT IS SENT THROUGH AN SMA CONNECTOR UNDER LONGITUDINAL VIBRATIONS.

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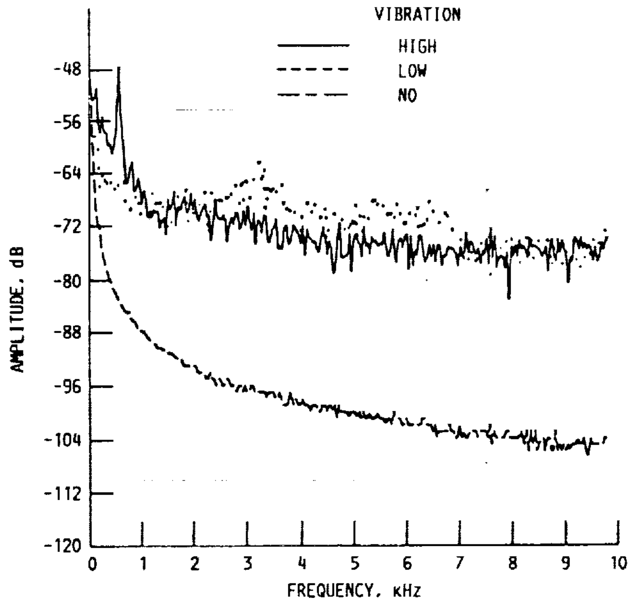

FIGURE 9. - AMPLITUDE VERSUS FREQUENCY FOR LASER LIGHT THROUGH AN SMA CONNECTOR AT NO, LOW, AND HIGH LEVELS OF VIBRATIONAL FORCE. THE FREQUENCIES OF VIBRATION WERE HELD CONSTANT.

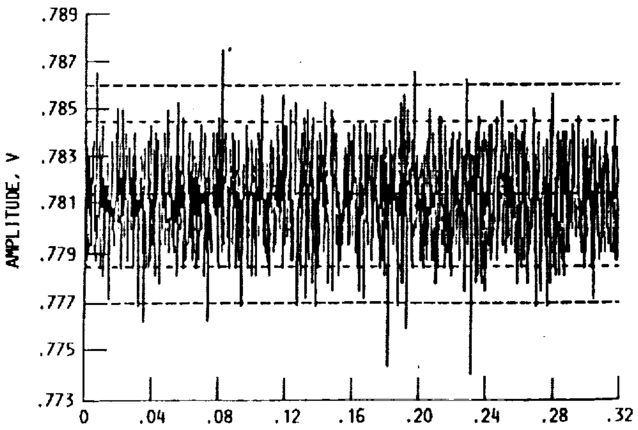

FIGURE 10. - AMPLITUDE VERSUS TIME OF THE DETECTOR OUTPUT FOR A VIBRATED LED SIGNAL. HORIZONTAL LINES CORRESPOND TO THE MEAN AND ONE-, TWO- AND THREE-SIGMA BANDS FOR AN UNVIBRATED SIGNAL.

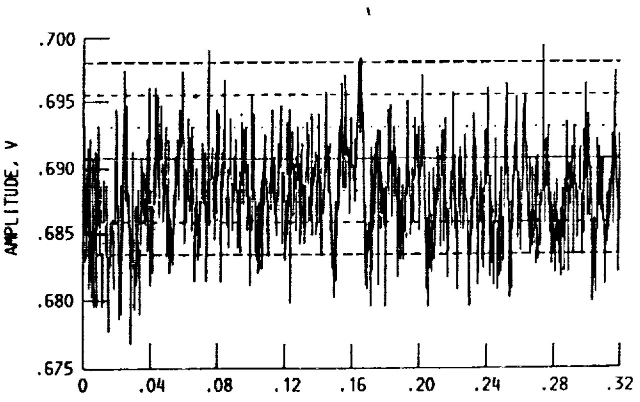

FIGURE 11. - AMPLITUDE VERSUS TIME OF THE DETECTOR OUTPUT FOR A VIBRATED LASER SIGNAL. HORIZONTAL LINES CORRESPOND TO THE MEAN AND ONE-, TWO AND THREE-SIGMA BANDS FOR AN UNVIBRATED SIGNAL.

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16. Abstract

An experimental study was performed to determine the effects of vibration on the propagation of light through SMA- and ST-type fiber-optic connectors. A multimode, fiber-optic link was vibrated from 0 to 10,000 Hz at a constant peak acceleration along the connector transverse and longitudinal axes. All other environmental parameters were ambient. Transfer characteristics through the connection were examined as a function of vibrational frequency using both laser and LED light to illuminate the system. Slight differences in operation between the SMA and ST connectors were observed with no appreciative attenuation as a result of vibration. Vibration did cause the constant-amplitude input light to be modulated in the connector; however, the amplitude of vibration-induced noise was less than 3 standard deviations from the mean.

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