would act as the alignment tube. The bulky nature of this component may be reduced by grinding away the part of the sapphire rods not needed for alignment purposes.

4.3.2: Room Temperature Test

After modifying the WSFMI assembly to incorporate the proposed design improvements, the modified WSFMI system is fitted with a sensing head consisting solely of a sapphire step-index multimode reference fiber. With adjustment of the position of the singlemode fiber in the sensing arm, the fundamental mode may be preferentially excited, as seen in the middle trace of Figure 4.3.1. The top trace is a detail of the dominant fringe group and the bottom trace records the voltage driving the actuator in the measurement arm.

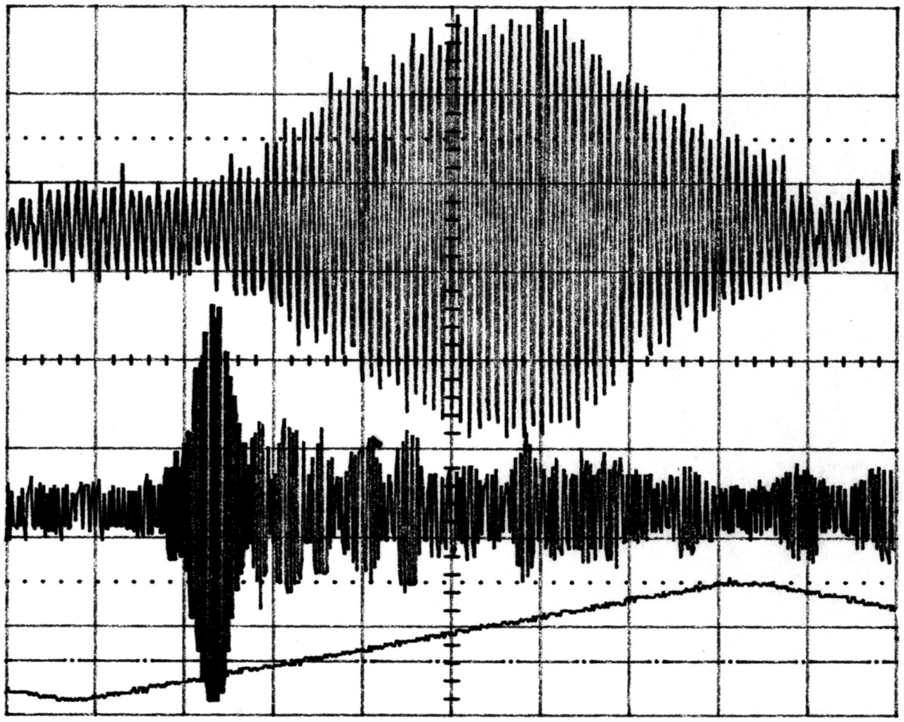

Figure 4.3.1: Optimized Interferogram Generated Using a Sapphire Reference Fiber in the Sensing Head of the Modified WSFMI System

It can be easily seen that although the fundamental fringe group is preferentially excited, other non-fundamental low order modes are partially excited, resulting in a jumble of fringes to the right of the dominant mode in Figure 4.3.1. The center portion of this fringe group has a signal to noise ratio of approximately 9.2 decibels. This raises the concern that when a sensing head consisting of both a reference and a sensing fiber is used, the fundamental mode reflecting from the sensing fiber would be not be of a great enough amplitude to be distinguished from the non-fundamental low order modes associated with the reference fiber end reflection. The signal attenuation caused by the beam traversing the gap between the two fiber ends is also a concern.

These concerns are explored by assembling a sensing head consisting of a sapphire reference fiber and a silica fiber with an aluminum coated endface. The endface of the silica fiber is coated with 42 angstroms and is used as the sensing fiber because the reflection from the metal coated endface is expected to be between 25 and 30 percent, while reflection from a sapphire fiber endface is 7 percent. Results obtained using this sensing head show easily identifiable fringe groups corresponding to each of the two fiber endfaces in the sensing head. This is shown in the middle trace of Figure 4.3.2, for a gap separation of approximately 1740 microns. The top trace is a detail of the fundamental fringe group associated with the sensing fiber and the bottom trace records the voltage driving the actuator in the measurement arm. The fundamental fringe groups corresponding to the reference and sensing fiber endfaces are denoted R and S, and have maximum signal to noise ratios of approximately 16.0 and 7.8 decibels, respectively. When the fiber endfaces are separated by approximately 877 microns the measurement repeatability is 16 microns (2 sigma). The relative error for the repeatability measurements is 1.82 percent. Comparing the amplitudes of the reference and sensing fiber endface interferograms reveal that the returned signal from the sensing fiber end is below 10 percent, which is much less than the expected 25 to 30 percent; sapphire fiber has a reflectivity of 7 percent.

It was discovered that because the aluminum coated fibers had been stored in air, the coating had degraded, although visual inspection was not able to reveal this. It is apparent that good results were obtained for two reasons: improvements to the alignment methods decrease the number and the amplitude of the unwanted fringe groups, and the two fiber endfaces are separated by a large enough gap that the lower order non-fundamental fringe groups corresponding to the reference fiber end do not interfere with the fundamental mode fringe group corresponding to the sensing fiber endface.

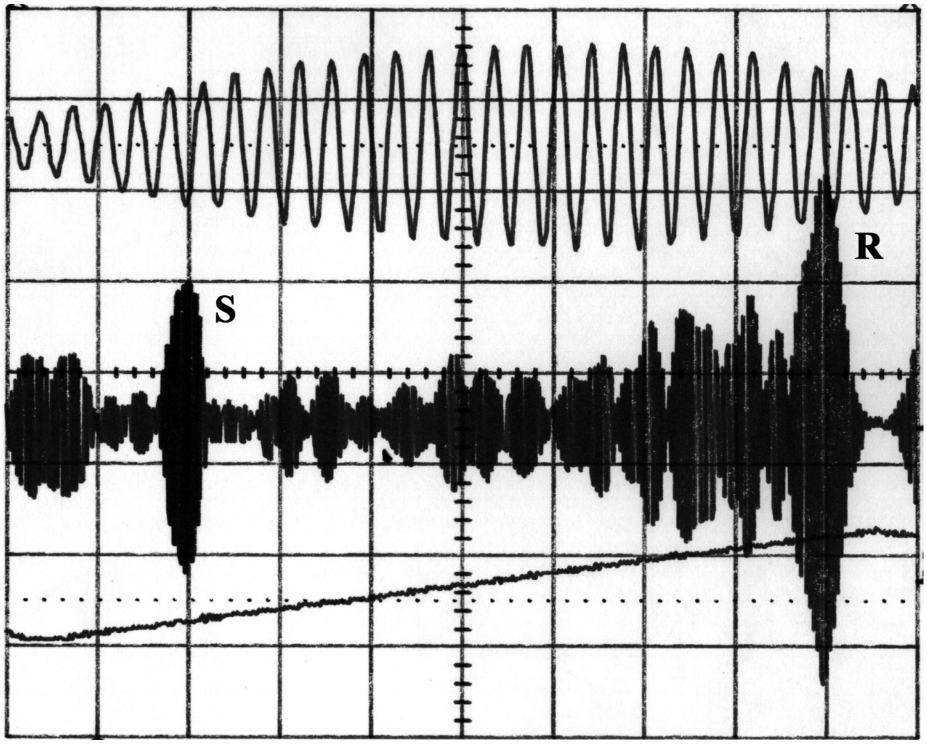

Figure 4.3.2: Optimized Interferogram Generated Using a Sapphire Reference Fiber and an Aluminum Coated Sensing Fiber in the Sensing Head of the Modified WSFMI System

Encouraged by the high amplitude of the sensing fiber interferograms obtained using the degraded aluminum coated endface, combined with access to electronics that were developed to increase the scanning range of the mirror, the substitution of an uncoated sapphire fiber for the aluminum coated sensing fiber was made. The reflectivity of the two endfaces are about the same; a polished sapphire fiber endface has a 7 percent reflectivity, while the aluminum coated endface is estimated to have less than a 10 percent reflectivity. This substitution is attractive because the uncoated endface would eliminated potential problems of coating degradation in operating environments.

Using the sapphire fiber sensing head consisting of both a reference and a sensing fiber endface and electronics that increase the scanning range from about 1.2 millimeters to about 6.4 millimeters, the results represented by Figure 4.3.3 were obtained for cases in which the sapphire fiber was held straight and the endface separation is approximately 5.02 millimeters. The middle trace is the detected interferogram, the top trace is a detail of the fundamental fringe group associated with the sensing fiber, and the triangular waveform corresponds to the voltage driving the actuator. As can be inferred from this trace and was observed in the laboratory, the amplitude of the fringe groups associated with the sensing fiber endface suffer negligible reduction of signal amplitude when the sensing fiber is positioned 6.4 millimeters from the reference fiber endface.

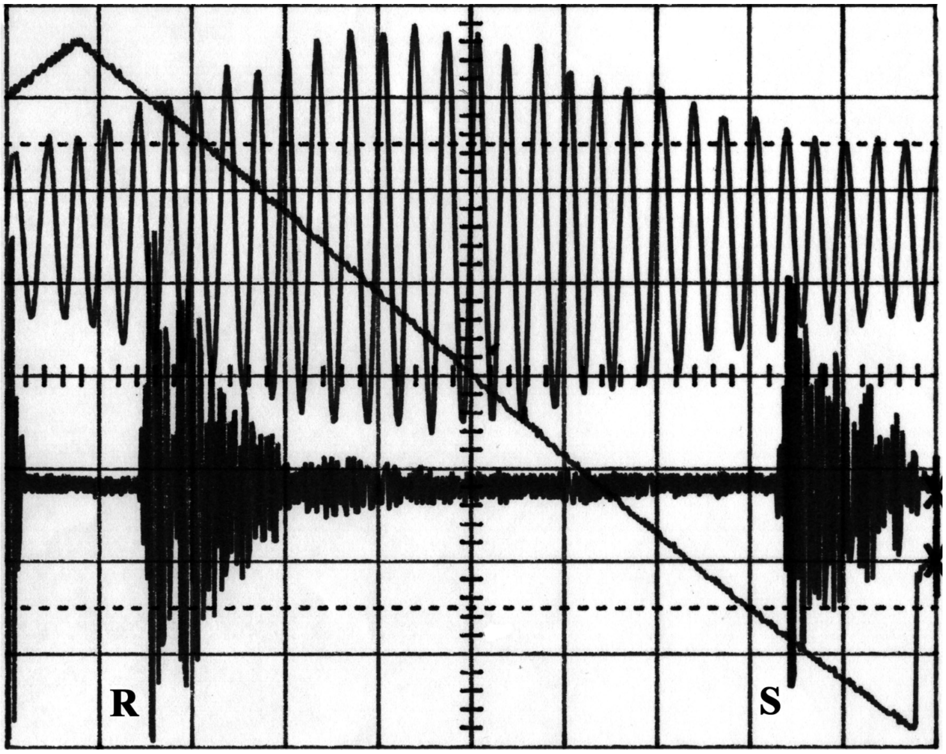

Figure 4.3.3: Typical Optimized Interferogram Obtained Using a Sapphire Fiber Sensing Head in the Modified WSFMI System at Room Temperature

This system is used to perform displacements by correlating the current driving the actuator located in the measurement arm with the generation of the zero-order fringe.

When the gap length is held at 800 micrometers, ten successive measurements of the gap using the WSFMI system gives a measurement repeatability of 3 micrometers (2σ). Position data, plotted in Figure 4.3.4, is obtained over 1.65 millimeters and shows good agreement with the transverse stage demarcations. Discrepancies between measured and transverse stage demarcation data stem from a slightly nonlinear voltage driving the actuator, difficulty in choosing the fringe with the greatest amplitude in the fundamental fringe groups, and errors in positioning the transverse stage.

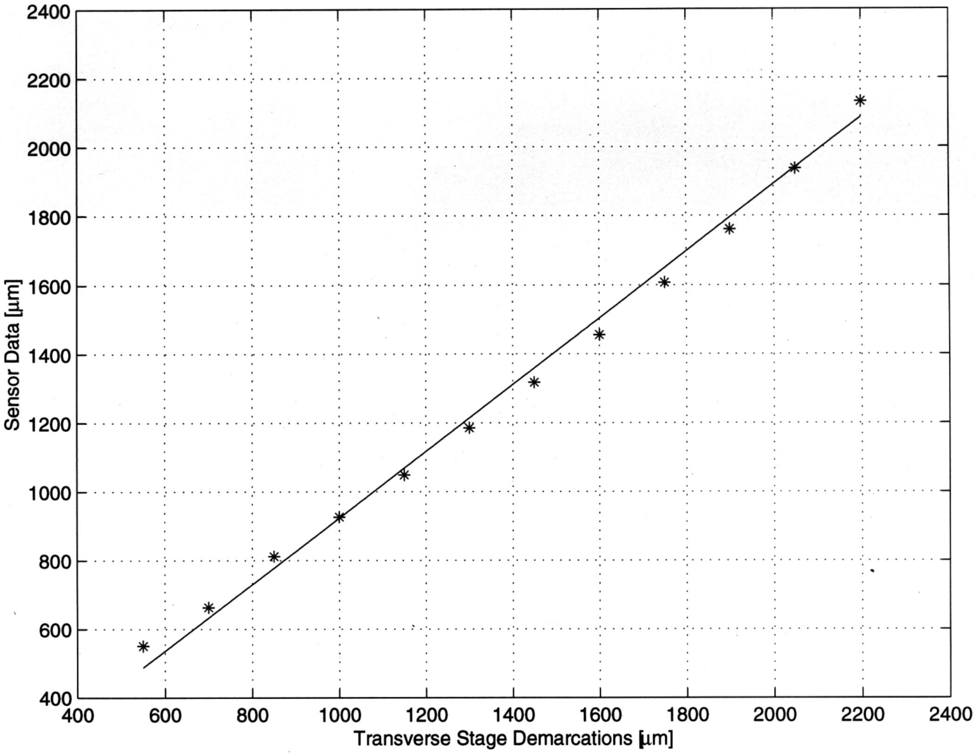

Figure 4.3.4: Measured Gap Length Plotted Against the Indicated Transverse Stage Demarcations

Perturbing the sapphire fiber, after the silica fiber input to the GRIN lens has been aligned so that the fundamental mode is dominant, will degrade the quality of the fundamental fringe group. With enough perturbation, the fundamental fringe group can become indistinguishable from the other non-fundamental low order modes. Although the it is detrimental to the SNR to perturb the sapphire after the fundamental mode has been preferentially excited, it is possible to bend the fiber into a desired position and then, through alignment adjustments between the GRIN lens and corresponding sapphire fiber end, make the fundamental mode dominant. The fundamental mode can be made dominant for bends in the sapphire of 20, 30, 55, 60, and 90 degrees. The results are comparable to the straight fiber case for each. The middle trace of Figure 4.3.5 is a plot of the signal detected when the sapphire reference fiber is bent 90 degrees for a gap separation of approximately 1.64 millimeters.

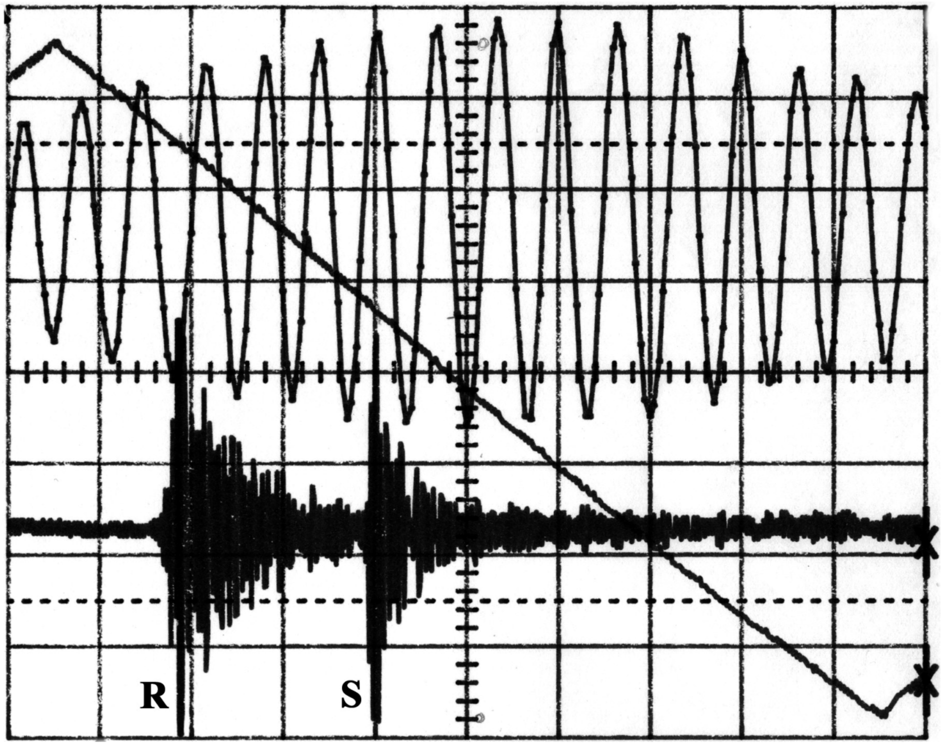

Figure 4.3.5: Optimized Interferogram Obtained Using a Sapphire Fiber Sensing Head in the Modified WSFMI System at Room Temperature. There is a Bend of 90 Degrees in the Reference Fiber.

The fundamental fringe group corresponding to the reference fiber endface has a maximum signal to noise ratio of approximately 14.6 decibels, while the fundamental fringe group corresponding to the sensing fiber endface has a maximum signal to noise ratio of approximately 10.3 decibels. The top trace is a detail of fundamental fringe group associated with the reference fiber, and the triangular waveform is a record of the voltage driving the actuator. The ability to bend the fiber into a desired position and achieve good results helps to make it a candidate for use in high temperature extensometer design.

4.3.3: High Temperature Test 1

As was mentioned, the fringe contrast achieved at room temperature is not as large as is expected. Upon examining the fiber ends for scratches, dirt, and other possible defects, it is noted that the endfaces were smooth, but microvoids can be seen existing slightly beneath the surface of the fiber endface. In order to eliminate the possibility that these microvoids near the surface of the fiber interfere with the ability of the endface to reflect light, the fibers are repolished so that only 2 to 3 microvoids, near the outer diameter of the fiber, remain. This procedure does not improve the detected fringe contrast.

Despite the fact that the fringe contrast is not as large as desired, a high temperature test is performed to examine the effect of temperature on the quality of the output signal. The sensor assembly, with both sapphire fibers held straight, is placed in a kiln, and temperature is elevated in steps of 100 degrees Celsius. The sensing fiber is mounted on a translation stage, to allow the size of the gap between the sensing and reference endfaces to be easily adjusted. Few measures are taken to isolate the sensor from vibrations, and the sensor is not well supported inside of the kiln. The maximum possible temperature that this test can achieve is 800 degrees Celsius because of the softening temperature of the fused silica tube. At a temperature of 500 degrees Celsius the fundamental mode is difficult to excite and is not stable. At 600 degrees Celsius the fringes can be seen to modulate the noise, but they are too small to be of practical use. A room temperature plot is shown in Figure 4.3.6 for a gap separation of approximately 1318 microns, and a plot at 500 degrees Celsius is shown in Figure 4.3.7 for a gap separation of approximately 1144 microns. In both figures the middle trace is the detected interferogram and the bottom trace is a record of the voltage signal driving the actuator. In Figure 4.3.6, the top trace is a detail of the fundamental fringe group associated with the sensing fiber endface. The maximum signal to noise ratios of the