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**Research and Development Entitled Smart
Structures for Fossil Energy Applications**

Final Report

R.O. Claus

December 1990

Work Performed Under Contract No.: DE-AC21-89MC25159

**For
U.S. Department of Energy
Office of Fossil Energy
Morgantown Energy Technology Center
Morgantown, West Virginia**

**By
Virginia Polytechnic Institute
and State University
Blacksburg, Virginia**

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Abstract

The objective of this research program has been to develop optical fiber sensor methods for the nondestructive on-line evaluation of the degradation and damage of ceramic cross flow (CXF) filters.

"Smart" CXF filters have been designed and fabricated which incorporate optical fibers as the sensing elements to determine distributed thermally-induced strain, strain transients which occur during pulse cleaning, particle buildup on the filter tiles, and crack initiation and propagation. These filters were experimentally evaluated in a combustor at Westinghouse in Pittsburgh, PA. The fiber sensor instrumentation has been performed using silica optical fibers, modified to withstand the high temperature and harsh chemical environment of the combustor. Sapphire fiber waveguides for similar measurements have been considered.

Two fiber sensor methods were developed for the final combustor tests, one based on optical intensity changes, the other based on phase changes. The latter, an extrinsic in-line Fabry-Perot interferometer, exhibited displacement resolution on the order of 1 nm, adequate frequency response to detect both quasi-static strain and dynamic acoustic events, wide dynamic range, and little hysteresis over the temperature range investigated.

The major result of this program is that we have demonstrated the feasibility of using optical fiber sensors to measure in situ the dynamic mechanical properties of CXF filters during operation. Secondary results are 1) the feedback of information concerning the operation of the filter elements to potential filter users, 2) the development of potentially useful sensor instrumentation methods, and 3) increased knowledge concerning high temperature fibers, including sapphire fibers.

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1.0. Executive Summary

The objective of this research program has been to develop instrumentation methods to allow in-situ analysis of ceramic cross flow (CXF) filters. Information from such instrumentation is needed to determine how the filters perform during operation, how subsequent filter and combustor designs may be improved based on the knowledge of such performance, and how and where damage and degradation occur.

"Smart" CXF filters have been designed and fabricated which incorporate optical fibers as the sensing elements to determine

- distributed thermally-induced strain,
- strain transients which occur during pulse cleaning,
- particle buildup on the filter tiles, and
- crack initiation and propagation in the filter material.

Fiber sensor-instrumented filters were tested in a combustor at Westinghouse in Pittsburgh, PA. These tests were performed using silica optical fibers modified to withstand the high temperature and harsh chemical environment of the combustor. Sapphire fiber waveguides for similar measurements have also been considered.

Major results of this program have been

- the demonstration of optical fiber sensors for in situ measurements of CXF filters,
- verification of information concerning filter material and structure,
- development of potentially useful sensor instrumentation methods, and
- increased knowledge concerning high temperature optical fibers, including sapphire fibers.

2.0. Introduction

Smart structures are based on the idea that a structure can sense its environment, structural integrity, or other relevant parameters. Upon examining data from sensing elements, the structure is "smart" enough to compute and execute what steps are necessary to adjust itself to perform its job more efficiently. In the case of ceramic Cross Flow Filters (CXF), they could, for example, sense when they are running inefficiently due to particulate buildup and trigger a cleaning pulse. They could also monitor their structural integrity and sound an alarm when they become damaged, or, in some circumstances, sound a warning prior to becoming damaged [1-4].

Fiber optic sensors have been used in the last several years for the measurement of parameters such as strain, temperature, pressure and vibrations. Some of the advantages often cited about fiber sensors are immunity from electromagnetic interference, small size, flexible geometry, high sensitivity to external perturbations and, mainly, the possibility of using them in harsh environments. In fossil energy processes, such as surface coal gasification and coal-fired combustion, fiber sensors can form an integral part of the "smart structure" concept where a structure contains its own sensors, actuators, computation and control hardware.

Fiber sensors work on the principle that when an optical beam propagating through the optical fiber is perturbed by an external perturbation, this effect manifests itself as a change in either the phase, intensity, arrival time, modal content, wavelength or polarization of the output optical signal. Monitoring the specific optical parameter of interest (depending on the type of sensor being used), one can acquire information about the nature and magnitude of the external perturbation.

The specific application to be considered in this project is the use of such sensors in ceramic cross flow filters made out of multiple layers of thin, flat, porous ceramic with grooves which form channels in each layer. The ceramic cross flow filters are analogous to cross-flow heat exchangers, except gas is passed between channels instead of thermal energy. The filters, used for high-temperature, high-pressure particulate collection are periodically flushed with a brief, high pressure cleaning pulse of air or nitrogen to remove the particles that are deposited on the dirty side of the dividing walls within the filter. Thermal shocks, high-temperature and high-pressure environments combined with the brittle nature of the porous ceramic material mandates the need for a continuous, online sensing method that will provide information about the thermal strains that the structure experiences.

Some of the conditions that the fiber is expected to operate under include a direct exposure to 1000° C temperatures and pressures of up to 2500 kPa. Standard silica based optical fibers are not capable of withstanding such temperatures and it is imperative that optical waveguides made of materials other than silica be considered for such applications. Sapphire (Al_2O_3) is a candidate

material that possesses reasonable optical properties, and can potentially perform without significant degradation under the harsh conditions mentioned earlier.

The tasks of this project, therefore, include the development of optical fiber sensors that are capable of measuring thermal and mechanical strains typically experienced by the ceramic cross flow filter and the design and fabrication of sapphire based optical waveguides that can potentially be used for such systems.

3.0. Background

In this section, background information on three different topics is presented. We will briefly discuss the construction of the ceramic cross flow filters, fiber optic sensors and sapphire based optical waveguides. Although a brief review is presented, details can be obtained from the references that are mentioned.

3.1. Ceramic Cross Flow Filters

The ceramic cross flow filter, as mentioned in the introduction, is analogous to cross-flow heat exchangers, except gas is passed between channels instead of thermal energy (heat). The filter element and mounting will be shown in a figure in a subsequent section. Filter elements are constructed of a porous ceramic (alumina or silicon nitride) material. The filter element size of interest is approximately 30 cm high by 30 cm long by 10 cm wide. Particles are removed from the gas stream by direct interception, diffusion, and inertial impaction.

The ceramic filter consists of multiple layers of thin, flat, porous ceramic with grooves which form channels in each layer. Consecutive layers of ceramic are oriented such that the channels formed are perpendicular to each other. One of the sides of the filter element is sealed. Gas enters the filter through the openings of the channel on the two sides that are perpendicular to the sealed end, permeates the porous ceramic, and exits through the openings on the side that is parallel to the sealed end. The filter elements are periodically back flushed with a brief, high-pressure cleaning pulse of air or nitrogen to remove the particles that were deposited on the dirty side of the dividing walls.

3.2. Fiber Optic Sensors

Optical fibers were initially developed for transmission of information and continue to be most predominantly used for that purpose. At the same time, another major use of the optical fibers now shows potential for use in industrial, aerospace, and "smart structure" applications. Fiber optic sensors have emerged as highly sensitive sensors capable of being used in several different applications [5].

There are several ways in which guided light can be modulated by an environmental parameter. However, one can define a general optical fiber sensor as follows: An optical source (typically emitting a constant amplitude of radiation) launches light into an optical fiber which is then carried to the sensing region where one of the properties of the optical wave such as phase, intensity, polarization, or wavelength, is changed because of the external perturbation. There are two basic

classes of fiber optic sensors. The first type is classified as the extrinsic sensor in which the fiber merely serves as a conduit for carrying the light to the sensing region and for bringing back the modulated output from the sensing region to a detector. The modulation takes place externally to the fiber and may be an attenuation imposed by a moving mask or a reflector. These indirect means of modulating the light can include variable-birefringence crystals, chemical absorbers, or phosphorescent and fluorescent elements. The second class of sensor is one in which the measurand interacts directly with the fiber and modulates one of the parameters of propagating light. There are no optical interfaces at the modulator head and any of the aforementioned properties of light can be modulated by designing the optical system in a specific way.

Some of the most sensitive fiber optic sensors operate on the principle of phase-modulation. In such phase-modulated sensors the phase of the electromagnetic wave propagating through the waveguide changes as a result of the external perturbation that is impressed upon the fiber. This change in phase is detected as an intensity variation at the output when the optical beam is made to interfere with a reference beam that is not exposed to the measurand. Although in most sensors, the interference is caused between two beams, one from the reference arm and the other from the sensing arm, it is also possible to extend this sensing technique to include interference between multiple beams.

3.3. Sapphire

Sapphire is single crystal aluminum oxide and has a hexagonal crystalline structure. It exhibits anisotropy in optical and physical properties [6]. Because of its hardness, sapphire can be scratched only by a few substances (such as diamond or boron nitride) other than itself. It is chemically inert and is insoluble in almost anything except at elevated temperatures. Its softening point is 1800° C and has, on an average, a Young's Modulus of 3.7×10^{10} dynes/mm² which is roughly five times higher than that of fused silica. The transmission properties of sapphire are fairly conducive to using it as an optical material and it exhibits a flat transmission response over the entire range of the visible spectrum and in the near-infrared (300 nm to 1500 nm). The transmission of light through sapphire is limited primarily by losses due to surface reflections.

The specific requirements of sapphire fibers are determined by the device applications, but general requirements include composition, length, diameter, defect density and impurity content. Optical attenuation is a key parameter for optical devices such as sensors and is principally controlled by the fiber physical parameters including bulk crystal imperfections, spatial variations in index of refraction, diameter fluctuations and surface defects. For example, it is estimated that a 1 % random variation in diameter can produce a loss on the order of 25 %.

A reduction in diameter fluctuations can be achieved by implementing a closed-loop controller in

the growth apparatus. This approach is essential to reduce the number of fiber guided modes and develop single-mode, single crystal sapphire fibers. Further reductions in surface scattering are only possible by utilizing cladding with the proper index of refraction. The loss reduction resulting from the application of cladding is expected to improve with smaller values of Δn (where Δn is the index difference between cladding and core). Two different methods, namely, i) the outside film deposition method, and ii) the method for the in- or out-diffusion of controlled amounts of dopants, can be used to provide single crystal fibers with a cladding layer.

Either for their use in harsh environments or for their embedment in advanced materials for subsequent materials analysis, the high temperature optical fibers also require protective coatings and/or compliant coatings. The protective coatings minimize the interaction between the fiber and environment and ensure long term stability of the fiber sensor, whereas the compliant layer reduces the chances of fiber cracking during the embedment process..

All these properties make sapphire a potential candidate as a sensing element in harsh conditions such as those experienced in fossil energy processes.

4.0. Methodology

This section describes the methods used to sense the parameters of interest. First, fiber attachment is discussed since it is the mechanism which allows strain to be transferred from the filter to the fibers. We also include a discussion of protecting fibers in the CXF filter environment. Second, an intensity-based microdisplacement sensor is discussed for use as a strain sensor. In the next section, a highly accurate interferometric based microdisplacement sensor is presented. This discussion is followed by a description of a design for a particulate buildup monitor. Finally, a discussion of the development of sapphire fiber and sensors is given.

4.1. Fiber Attachment

For the strain measurement obtained from a sensor to be a faithful replication of the strain that the structure undergoes it is essential that the strain transfer mechanism is as complete as possible. Two high temperature ceramic adhesives were chosen as candidates for attaching sensors: Cotronics #989 and #905.

Cotronics adhesive #989, which has an Al_2O_3 base and a coefficient of thermal expansion similar to that of the filter (approximately 4.5×10^{-6}) was tested first. The adhesive was used to attach several fibers to the cross flow filter, as shown in Figure 1(a). After the ceramic adhesive had cured, the filter was heated to 850°C and then allowed to cool slowly to room temperature. Active monitoring of the fibers during the thermal cycling showed that most of the fibers continued to transmit light. Upon visual inspection, after cool down, several of the fibers were observed to be slightly curved between points of attachment and a small amount of adhesive was found on the portion of the fiber just prior to the inner points of attachment as illustrated in Figure 1(b). This suggests that the fiber pulls through the adhesive during the heating process and bows during the cooling cycle. As a result the strain is not completely transferred from the filter to the fiber implying that Cotronics #989 is not a good choice as an adhesive for fiber attachment.

Cotronics adhesive #905 was tested next. It has an SiO_2 base, a thermal coefficient of expansion similar to the fiber (approximately 10^{-7}), and an operating temperature up to 1400°C . The testing process is identical to that described for the #989 adhesive. In this case all fibers broke prior to reaching 800°C . Upon inspection after cool down there was no fiber between the two adhesive bonds. This implies that strain transfer was good and fiber breakage was due to the order of magnitude difference in the coefficient-of-thermal expansion (CTE) between the filter (approximately 4.5×10^{-6}) and fiber (approximately 5.0×10^{-7}). This adhesive was then tested by affixing fibers to the filter at single points to determine if some other property of the adhesive was causing fiber breakage. The fibers were actively monitored as the filter was heated to temperatures in excess of 900°C and cooled. We observed that no fibers experienced breakage.

Therefore, the Cotronics #905 was chosen for adhering fiber optic strain sensors.

In determining the choice of adhesive it became apparent that the strain experienced by the sensing fibers must be kept to a minimum. With the order of magnitude difference in the coefficients of thermal expansion and the extreme temperatures, mechanical creep in the fibers became a concern. The problem here is that if a sensing fiber were to deform during the heating process, the data obtained after cooling may not be a true representation of the strains experienced. For these reasons, sensors requiring only one point of adhesion per contiguous fiber were examined in great detail.

4.1.1. Fiber Lead Protection

While the handling and placement of silica fiber optic sensors is managed with relative ease in a laboratory environment, "real world" applications may require special care. In this particular instance, fragile fibers would have to be inserted into a high temperature and high pressure vessel. In addition, such factors as high flow turbulent air currents and particulate matter could adversely affect the integrity of sensor leads. To combat these potential problems stainless steel tubing used as a protective sheath was examined. The tubing was annealed at 900° C to relieve any residual strain induced during the manufacturing process. This also resulted in greater flexibility of the tubing and allowed greater ease in handling.

Several configurations were tested to determine which one would allow the greatest ease of attachment while providing the maximum protection to the fiber. The arrangement that seemed to work best was attaching a short length, large diameter stainless steel tube to be used as a guide. Once the guide was attached to the filter, the stainless steel tubing used as a protective sheathing could be inserted through it and permanently attached to the filter with ceramic adhesive, both #989 and #905. The two adhesives are used to provide protection at both room and high temperatures. The #905 adhesive provides high strength bonding capabilities at high temperatures, but is inadequate at room temperature. The #989 provides the necessary bonding strength for handling the stainless steel tubing and filter at room temperature. This gave the advantage of being able to attach sensors to the filter first, followed by attaching a protective sheath without risk of losing control of a two meter stainless steel tube and breaking the sensor.

The stainless steel tubing/sheathing effectively solved the problems of protecting the fibers; however, two other problems were observed. First, the polymer protective coating for the fibers would melt and stick to the tubes causing the fiber to break during heating due to the expansion of the stainless steel tubing. To prevent this, several different coatings were examined. For laboratory conditions, fibers could simply be stripped of their coating and used, but the fiber proved to be far too brittle to use in an in situ test. We then examined chemically deposited silver

as a coating. This increased the strength marginally, but failed to protect the fiber at temperatures above 500° C. The next attempt used chemically deposited nickel. This coating provided excellent protection, but at very high temperatures the fiber became more brittle, and uniform and complete coatings could not be attained. Commercially available metallic coatings were also examined. Aluminum coated single-mode fiber was obtained from NOI (pre-production run only) and proved to be inadequate. A military grade polymer coating (polyimide) was tested and gave good results for temperatures below 420° C. A special order for single-mode fiber coated with polyimide was placed with Polymicro Corporation, and the fiber proved to be acceptable for in-situ testing.

The second problem created by the stainless steel tubing was the introduction of air leaks from the pressure vessel. This created difficulties since the combination of fibers with no coating and the combustor byproduct of steam caused the fibers to break. Attempts were made to reduce air leaks by reducing the diameter of the input holes of the stainless steel tubes to approximately 10 μm larger than the diameter of the fiber. This was accomplished by sealing a small glass tube in the stainless steel tube. This does not prevent air leaks, but limits them substantially while allowing the fiber the freedom of movement that is required. Since leaks are only reduced, it is also very important that fiber coating remains intact since any defect will result in a deterioration of mechanical strength in the fiber due to the high temperature steam. This, in combination with the small bending radius required for CXF applications, can result in fiber breakage. A diagram of the final sheathing and attachment scheme may be seen in Figure 2.

4.2. Intensity Based Sensor

4.2.1. Motivation

Sapphire fibers that show promise of being available in the near term will consist of single crystal rods coated with a material of a lower index of refraction, hence they will have a large core, a large numerical aperture and will propagate many modes. To simulate these conditions, fiber sensors utilizing large core fibers were investigated. Unfortunately these sensor schemes are primarily based on intensity variations due to changing loss factors, as opposed to the more sensitive Fabry-Perot sensors based on a phase-modulated interference.

4.2.2. Principle of Operation

An intensity-based sensor comprised of two 100 μm core diameter, 140 μm cladding diameter graded index fibers placed inside a hollow core tube is shown in Figure 3. When an external perturbation acts on the sensor, it leads to a longitudinal misalignment between the two fibers facing each other, resulting in a decrease in the output intensity. Any induced strain on the two-fiber system will lead to a gap separation s and can be shown to result in a drop in the output

intensity given by [6]

$$\text{Loss (dB)} = 10 \log_{10} \left[\frac{d/2}{(d/2) + s \tan \left(\sin^{-1} \left(\frac{NA}{n_0} \right) \right)} \right]^2, \quad (2)$$

where d is the diameter of the fiber (100 μm), NA is the numerical aperture of the fiber given by $[n_1^2 - n_2^2]^{1/2}$, and n_0 is the refractive index of the surrounding medium ($n_0 = 1$). By plotting the variation of the optical intensity versus gap separation and knowing the sensor gauge length, one can obtain strain information from the sensor.

4.2.3. Sensor System Design

Since the sensor is based on intensity-modulation the amount of noise present must be kept to an absolute minimum. Unfortunately from an optical viewpoint, the operating environment tends to be noisy. Interior fluorescent lighting causes excess noise, and infrared radiation becomes a concern due to the high temperature environment. To reduce the noise from these exterior sources a chopper and a lock-in amplifier were used. The lock-in amplifier locks in on and reports the intensity of a signal with a particular frequency and phase. The chopper sets the phase and frequency of the signal. The use of a chopper and a lock-in amplifier effectively decreased the effect of external noise sources and improved signal-to-noise ratios.

A second source of noise was due to fluctuations in the source. Initially a HeNe laser operating at 633 nm was used. The configuration consisted of mounting the laser on an optical rail and projecting the beam through a chopper and a microscope objective, and finally injecting it into the fiber. While the power from the laser was quite stable, it was observed that the output of the sensor seemed to be quite noisy. It was determined that since the fiber was highly multimode, injection conditions from a linear polarized, single wavelength source were the cause of the noise. This was corrected by using a low cost light emitting diode which operated at 780 nm ± 50 nm. In addition the chopper could be removed and the source intensity varied electronically. To further remove noise which might result from slow intensity changes in the output of the source, a fraction of the light was sampled and monitored as a reference.

Several sensors were constructed by inserting two 140 μm diameter fibers in a 145 μm inner diameter hollow tube so that their ends were butted against each other. Great care was taken in preparing the ends so they were flat, as the quality of the end affects the performance of the sensor. One fiber was designated as the input fiber and one as the output fiber. The spacing between the fiber ends was then varied to determine the power loss curve versus separation shown in Figure 4. This curve was determined experimentally since it is dependent on reflections from the tube

providing longitudinal alignment. Having determined that the sensor has its a linear range with a gap separation varying between 100 μm and 300 μm , the gauge length for the sensor was determined by taking the product of the maximum separation distance of 350 μm and dividing by the maximum temperature and the estimated coefficient of thermal expansion. This gave approximately a 10 cm gage length for temperatures up to 1000° C.

Tests showed that a sensor with this gauge length gave good results when the material was expanding, but gave poor results during contraction. Visual inspection of sensors showed that the fibers were curved (or bowed) and were not returning to their original position as the material contracted. Smaller diameter fibers were first tried as a solution, but failed to work as they did not maintain transversal alignment to the degree necessary to provide meaningful data. Mechanical guides were then tried in the hopes of limiting fiber bowing. These guides consisted of short lengths of large diameter glass tubing adhered to the filter and are shown in Figure 5. The original sensor was then guided by the tubes during contraction periods, thereby preventing large bowing. This worked fairly well but lags in sensor response were seen during testing. Figure 6 shows for an example of sensor lag when the filter begins to cool.

In order to use the equipment most efficiently the system was automated. By first using an 8×8 coupler prior to the sensors, multiple sensors could be powered by a single source and one of the outputs from the coupler could provide a reference power measurement. In addition, a computerized switch was used to electronically switch signals received from individual sensors to the lock-in amplifier, where intensities could be monitored by the computer. This system, shown in Figure 7, allowed the monitoring of up to seven sensors and one source power reference, as well as time and temperature information.

4.2.4. Characterization

Tests were conducted to determine the exact relation between power loss and gap separation. A sensor was spliced onto an output fiber from the coupler. The air gap was increased, using a micrometer, in 10 micrometer increments starting with a gap of zero and ending with a gap of 600 micrometers. At each incremental step the optical power was measured 10 times and averaged. Five sets (a set being all data points from zero to 600 micrometers) of data were taken for each of two sensors. All ten sets of data were averaged and then plotted as seen in Figure 4. An equation describing the optical output intensity versus the gap separation was obtained using a curve fit routine. The equation shown in Figure 4 is used with the intensity versus time data obtained during filter testing to give an experimentally obtained strain versus time plot. A predicted strain versus time plot can be obtained using the gage length of the sensor, the coefficient of thermal expansion of the filter and the temperature versus time data.

4.3. Fabry-Perot Strain Sensor

4.3.1. Motivation

In the near term, only multimode sapphire optical fibers will be available; at the same time; single-mode sapphire fibers can be expected to be developed in the long term. This requires the manufacture of small diameter single crystal rods coated with a material having only a slightly lower index of refraction. The existence of such fiber would allow highly sensitive phase-modulated based fiber optic sensors to be implemented. We have constructed phase-modulated sensors using silica fibers which are applicable to high temperature CXF filter analysis.

4.3.2. Principle

Several types of Fabry-Perot sensors have been described in the past [8-11]. Fabry-Perot sensors that are based on the principle of multiple beam interference are now introduced. A reflective cavity is formed at the end of a fiber and an optical beam is propagated down the fiber to the cavity. The signal returning from the cavity consists of multiple reflections which interfere with each other. The expression for a typical N-beam interference intensity can be shown to be given by

$$I \propto \frac{\sin^2(N\phi/2)}{\sin^2(\phi/2)}, \quad (3)$$

where ϕ , the phase difference between two consecutive beams, is equal to $(2\pi)2d/\lambda$, where λ is the wavelength of light and d is the length of the cavity. This means that any strain induced in the fiber will lead to a change in the phase ϕ and hence result in an intensity modulation of the output signal.

4.3.3. Construction

In this section, we describe an optical fiber extrinsic Fabry-Perot interferometer that will be used as a sensor of microdisplacements and thus strain. The interferometer is classified as extrinsic because the Fabry-Perot cavity is formed as an air-gap between two fiber ends and changes in the physical properties of the input and output fibers do not result in a variation in the sensor output.

The extrinsic Fabry-Perot interferometer is constructed by placing two fiber ends in a hollow silica tube as shown in Figure 8. A single mode fiber ($\lambda_0 = 1300$ nm), acting as the input/output fiber, and a multimode fiber, used purely as a reflector, form an air-gap that is a low-finesse Fabry-Perot cavity. The far end of the multimode fiber is shattered to prevent reflections from the far end adding to the detector noise. The Fresnel reflection from the glass/air interface at the front of the

air-gap (reference reflection) and the reflection from the air/glass interface at the far end of the air-gap (sensing reflection) interfere in the input/output fiber. The first reflection is equivalent to the field in the reference arm, and the second reflection is equivalent to the field in the sensing arm, of a classical two-wave interferometer. Using the indices of refraction for the fibers and air, the reflections at both the fiber ends are calculated to be approximately four percent. Although multiple reflections occur within the air-gap, the effect of reflections subsequent to the ones described above can be shown to be negligible. We thus model the sensor as a low-finesse Fabry-Perot cavity, with $N = 2$. The two fibers are allowed to move in the silica tube and changes in the air-gap length cause changes in the phase difference between the reference reflection and the sensing reflection. This changes the intensity of the light monitored at the output arm of a fused biconical tapered coupler.

4.3.4. Principle of operation

We will evaluate the interference of the two-wave interferometer in terms of a plane-wave approximation. A coherent, approximately-plane wave detected at the output of the sensor can be represented in terms of its complex amplitude $U_i(x, z, t)$, given by

$$U_i(x, z, t) = A_i \exp(j\phi_i), \quad i = 1, 2, \quad (4)$$

where the variable A_i can be a function of the transverse coordinate x and the distance traveled, z , and the subscripts $i = 1, 2$ stand for the reference and the sensing reflections, respectively. Assuming that the reference reflection coefficient $A_1 = A$, the sensing reflection coefficient A_2 can be written as

$$A_2 = A \left[\frac{ta}{a + 2s \tan(\sin^{-1}(NA))} \right], \quad (5)$$

where a is the fiber core radius, t is the transmission coefficient of the air-glass interface (≈ 0.98), s is the end separation and NA is the numerical aperture of the single-mode fiber, given by $NA = (n_1^2 - n_2^2)^{1/2}$. The terms n_1 and n_2 are the refractive indices of the core and the cladding, respectively. The observed intensity at the detector is a superposition of the two amplitudes and is given by

$$I_{\text{det}} = |U_1 + U_2|^2 = A_1^2 + A_2^2 + 2 A_1 A_2 \cos(\phi_1 - \phi_2), \quad (6a)$$

which can be rewritten as

$$I_{\text{det}} = A^2 \left[1 + \frac{2ta}{a + 2s \tan[\sin^{-1}(NA)]} \cos\left(\frac{4\pi s}{\lambda}\right) + \left(\frac{ta}{a + 2s \tan[\sin^{-1}(NA)]} \right)^2 \right], \quad (6b)$$

where we have assumed that $\phi_1 = 0$ and $\phi_2 = 2s(2\pi/\lambda)$, and λ is the wavelength of operation in free space. Note that we have ignored the contributions due to multiple reflections. For a displacement sensor, it is useful to plot the detected intensity versus gap-separation s , as shown in Figure 9. We see that the fringe contrast drops as the displacement increases; this is to be expected since the relative intensity of the sensing reflection starts dropping with respect to the reference reflection.

The number of fringes resulting from the sensor attached to the filter undergoing thermally induced strain can be predicted by

$$\# \text{ of fringes} = \frac{2L(\Delta T)\alpha_{\text{filter}}}{\lambda}, \quad (7)$$

where L is the gage length of the sensor, ΔT is the change in temperature, α_{filter} is the thermal expansion coefficient of the filter ($4.3 \times 10^{-6} / ^\circ\text{C}$) and λ is the wavelength of light (1300 nm). To test the calibration of the sensor, a micropositioner was used to create a known displacement between the two fiber ends that form the Fabry-Perot cavity. For a comparison with the theoretical results, an oscilloscope trace of the continuously monitored output intensity of the sensor for a starting gap of zero to a final gap of 203 micrometers is shown in Figure 10. (The trace should be seen inverted in order to compare it with the theoretically predicted behavior.) The experimentally counted number of fringes for the displacement was 301.5 which corresponds to a displacement of 202 micrometers.

4.3.5. Quadrature Phase Shifted Operation

Quadrature phase shifted operation of the sensor is needed if one intends to measure a dynamically varying quantity that changes direction (or polarity) with time. The principle of operation of a quadrature phase-shifted, dual-mode interferometric sensor is now described. Figure 11 shows a typical sinusoidal variation of the output intensity with respect to changes in the phase difference between the reference and the sensing reflections. If the phase difference ϕ varies sinusoidally with time and the peak-to-peak variation is large enough to push the sensor out of its linear range, we observe fringes at the output of the detector as shown in the figure. The basic principle of operation of the detection scheme for a dynamic strain measurement system can now be described by considering two sinusoidal transfer functions out of phase by 90° . Assuming that the transfer function for the first detector (D_1) leads that of the second (D_2), we find that the output waveform for D_1 leads that of D_2 until time t_1 . At time t_1 , the phase ϕ changes direction (because of a change in direction of the strain) and the output waveforms switch their lead-lag properties. We see that the output from D_2 now leads that of D_1 until time t_2 when the strain changes direction again. Keeping track of the lead-lag phenomenon between the two detectors gives us

unambiguous information about the relative direction of the strain.

If we had used only one detector, the switch in direction would not be noticeable if the strain changed direction at a peak of the transfer function curve. Since we now have two signals out of phase by 90° , if the direction change occurs at one peak (of either D_1 or D_2), the other transfer function curve will provide information about the direction change.

Practical methods of obtaining two signals 90° out of phase with respect to one another are shown in Figures 12 (a) and (b). In Figure 12 (a), two single-mode fibers are inserted into one hollow silica tube and the gap-separations for the two fibers are adjusted actively by moving the fibers in and out of the tube until a 90° phase shift is achieved at the output. Note that two different sources are used in order to avoid interference effects between the two signals returning to the coupler if only one source was used to launch light into the single-mode fibers. It may, however, be possible to use a single source and using two different lengths of lead fibers for the two sensors such that the difference in the lengths is greater than the coherence length of the laser. Figure 12 (b) is a slight variation of the earlier scheme; here, we use two different silica tubes and, once again, adjust the quadrature phase-shift actively. Since the two tubes have external diameters on the order of a few hundred micrometers, the two sensors monitor almost the same environmental perturbations.

We have assembled and packaged two complete support systems for the Fabry-Perot strain sensors in an effort to make them more rugged, portable, and able to use the quadrature-phase-shifted operation described earlier. A diagram of one of the ruggedized Fabry-Perot support systems can be seen in Figure 13. The design uses three fiber optic couplers configured to allow two separate sensing fibers with only one optical source.

4.3 . Particulate Buildup Monitor

4.4.1. Motivation

Particulate build up is a concern in the cross flow operating environment since loading beyond a limit causes a noticeable loss in efficiency. Optical intensity based sensors provide a good way to measure a buildup of fly ash which absorbs and scatters light.

4.4.2. Design

A diagram of a particulate loading sensor using optical fiber and lenses attached to filter can be seen in Figure 14 (a). The graded index (GRIN) lenses are used to collimate the light from the input fiber and refocus it into the output fiber. The initial optical power level was recorded with clean lenses. Particulate matter (obtained from Westinghouse) was placed between the lenses and then blown clean with compressed air. The optical power was recorded at each step.

A plot of the results from loading and cleaning the sensor can be seen in Figure 15. The normalized optical power during the loaded condition was always less than 1% of the initial value while the value after blowing the sensor clean was about 95% of the initial value. The smooth surface of the lens allows the particulate to be almost completely cleaned. It is understood that these experiments do not simulate actual loading and pulse cleaning conditions, but they do give an indication of which sensor designs should be pursued.

Figure 14 (b) is a diagram of an initial test set-up for a sensor that could be implemented from the clean side of the filter. The objective of this experiment was to test the feasibility of placing the optics inside two clean channels and detecting optical transmission through two layers of filter material and one dirty channel full of particulate. A HeNe laser was directed at a piece of filter material with only one row of channels intact, as seen in the figure. The initial optical power was recorded with the "clean" filter. The channel was then packed with particulate and the power was again recorded. Compressed air was used to clean the filter channel. The optical power after cleaning was about 50% of the initial value. Figure 16 is a plot of the results for this experiment.

4.5. Sapphire Fiber Sensor Development

4.5.1. Motivation

Extremely high temperatures are experienced in actual on line use of CFX filters. In order to provide on line testing and monitoring, durable sensors must be provided. Sapphire provides an excellent opportunity for such sensors since it can withstand high temperatures and is impervious to most chemical attacks. Commercially available single crystal rods are examined as potential waveguides. They must first be clad with a material of a lower index of refraction to form an optical waveguide.

4.5.2. Approach

Cladding on single crystal sapphire fibers can be applied by two different methods: 1) deposition of an external layer, and ii) in- and out-diffusion of controlled amounts of dopant. Since very little information is available about the dopant effects on refractive index changes for sapphire and YAG materials the cladding choices are very limited. Furthermore, only two high temperature stable ceramics with a lower refractive index lower than sapphire ($n = 1.75$) are available. In addition to having lower refractive index than the core, the cladding material should also be thermodynamically compatible with the fiber core. The resulting possible cladding choices for the selected materials are i) Film deposition: $\text{Al}_2\text{O}_3/\text{SiO}_2$ ($\Delta n=0.30$), $\text{Al}_2\text{O}_3/\text{Mullite}$ ($\Delta n=0.12$), $\text{YAG}/\text{Al}_2\text{O}_3$ ($\Delta n=0.06$), and ii) In- & Out-Diffusion: $\text{Cr}-\text{Al}_2\text{O}_3/\text{Al}_2\text{O}_3$ ($\Delta n=0.006$), $\text{Al}_2\text{O}_3/\text{Al}_2\text{O}_{3-x}\text{F}_{2x}$ ($\Delta n=0.10$), and $\text{Ti}-\text{Al}_2\text{O}_3/\text{Al}_2\text{O}_3$ ($\Delta n=0.003$).

The choice of a protective coating for the sapphire sensor fiber depends upon the intended specific application. For example, for sensing the failure of ceramic cross flow filters, mullite or ZrO_2 coatings will be preferable protective coatings. In general, the protective coatings, if needed, will be deposited by a process called the metalorganic chemical vapor deposition (MOCVD) process or by sputtering.

In the MOCVD reactor configuration, the reaction chamber is a quartz tube with a uniform temperature zone 300 mm long and 100 mm inside diameter supported by stainless-steel, water cooled flanges at both ends. Temperature is maintained by resistive heating with a three-zone furnace. Low pressures are achieved by a root blower which is backed by a mechanical pump. Source materials are packaged in all-welded, Teflon-coated, stainless-steel bubblers which are connected to the front end of the reactor by stainless-steel lines with a manual valve. The desired depositing pressure is controlled by manipulating the valves on either side of the reactor: one at the pump and one at the source. Pressure is monitored by a pressure transducer. Flow rate is calibrated by sending N_2 through a flowmeter at the desired pressure before opening the source valve.

In the film deposition procedure, SiO_2 has been proposed as one of the possible cladding coatings on sapphire optical fibers. Tetraethoxysilane (TEOS) has been used as the source to deposit SiO_2 films. TEOS is a volatile liquid at room temperature. The first step in the process consists of loading the fibers and the silicon wafer into the reactor and pumping down the chamber pressure to better than 10^{-3} torr. The chamber temperature is raised to 680 °C. The silicon wafer is used to measure the film thickness and refractive index. Before the start of deposition, the flow rate is calibrated and set to 5 standard cubic centimeter per minute (sccm) at a pressure of 2.7 kPa. Deposition is started by opening the source valve. During the deposition, the pressure and temperature are maintained at 2.7 kPa and 680 °C, respectively. After four hours of deposition (the film thickness is 1 μm) the samples are annealed at 1000 °C for one hour in order to avoid film cracking. When the temperature is lowered to room temperature, the chamber is backfilled with air and the coated silicon wafer is replaced with a new one. The procedure is repeated a second time to obtain the total film thickness of approximately 2 μm .

ZrO_2 has been proposed as one of the possible protective coatings on sapphire optical fibers in harsh environmental use. ZrO_2 films deposited on silicon substrates have been carried out by MOCVD using zirconium acetylacetonates or zirconium trifluoroacetylacetonate at temperatures ranging from 350 °C to 500 °C. The optical properties, structure, microstructure, and composition of these films can be characterized by ellipsometer, x-ray diffraction, scanning electron microscopy (SEM) and electron spectroscopy for chemical analysis (ESCA), respectively.

Silica Coatings: The appearance of the deposited silica film on the silicon wafer is mirror-like and

very uniform. The uniformity, film thickness and refractive index (at a wavelength of 632.8 nm) are measured by ellipsometry on the testing silicon wafers. Five points were measured on each wafer. The average thicknesses for the two runs were 1.062 μm and 1.105 μm , respectively. The average refractive index was 1.458 at 632.8 nm.

Zirconia Coatings: The films deposited below 400°C using zirconium acetylacetonate as a precursor were amorphous to x-ray diffraction, while the films deposited above 450 °C were cubic. The chemical analysis of the films showed the presence of carbon in an amount equal to 15 % by atomic content. Annealing at 1000 °C in oxygen converted cubic zirconia film to monoclinic. Stabilization of high temperature forms of zirconia at low temperatures generally involves the substitution of cations having larger ionic radius which increase the mean diameter of the cations in the zirconia. We attribute the stabilization of cubic modification of zirconia in our film to the incorporation of the carbon into the lattice. This stabilization mechanism by carbon impurity may be significantly different from the stabilization by metal oxides, and possibly may involve the formation of Zr-C and Zr-O-C bonds.

Because of the relative low vapor pressure of the precursor and the formation of carbon contained films, the zirconium acetylacetonate was abandoned and we switched to zirconium trifluoroacetylacetonate for further studies. The deposition rate of zirconia films as a function of reagent partial pressure, for a deposition temperature of 400 °C, is illustrated in Figure 17, which shows that the deposition rate is increased with increasing reagent partial pressure. Since the exponent to the partial pressure is close to one (0.94) the pyrolysis may be a first order reaction. Figure 18 shows the variation of deposition rate as a function of deposition temperature. The reagent partial pressure was kept constant at 6.4 kPa. As can be seen from Figure 18, the deposition rate increased with increasing temperature at 400 °C and above that the deposition rate decreased significantly with increasing reaction temperature.

The thickness nonuniformity factor (TN) for the reactor is defined as follows:

$$\text{TN \%} = (\text{DR}_3 - \text{DR}_1) * 100 / [(\text{DR}_1 + \text{DR}_3)/2] , \quad (8)$$

where DR_1 and DR_3 are the deposition rates for the specimens placed at the beginning and at the end of the uniform temperature zone of the reactor, respectively. The variation of thickness nonuniformity with deposition temperature is shown in Figure 19. The low deposition rates and negative values for thickness, for deposition temperature greater than 400°C indicate a mass transfer control for the deposition. The increase in deposition rate down the reactor (positive values of thickness nonuniformity) at temperature lower than 400 ° C indicate the presence of a gas phase reaction in addition to the surface reaction.

To further improve the deposition characteristics, the fabrication of zirconia films using zirconium trifluoroacetylacetonate was also investigated at lower pressures (2.7 to 4.0 kPa). Some properties of zirconia films at low pressures and 400 °C are : deposition rate is 6.6 nm/min, thickness nonuniformity is 2.5 %, refractive index is 2.0, dielectric constant is 18 and resistivity is 5000 ohm.cm. The SEM studies showed that grain size of zirconia films increased from roughly 20 nm to 80 nm with high temperature heat treatment. The x-ray diffraction studies identified both monoclinic and tetragonal forms of zirconia in films subjected to high temperature heat treatments.

Optical tests: The SiO₂-clad sapphire rods were used in an intensity-based sensor configuration (similar to the all silica fiber intensity-based sensor) and test data was obtained. The results are shown in Figure 20. This preliminary curve shows that the intensity based sensor with the multimode sapphire fiber may be the best initial try at sapphire based fiber sensors. The clad sapphire rod was tested for spectral attenuation measurements and the results are shown in Figure 21. The numerical aperture of the sapphire clad with silica was found to vary from 0.55 to 0.83; this high numerical aperture is to be expected since the refractive indices of sapphire and silica are quite different.

5.0. Results and Discussion

5.1. Strain measurements

5.1.1. Methods

Strain can be measured by two of the sensors presented: the intensity based sensor and the extrinsic Fabry-Perot fiber sensor.

5.1.2. Intensity based strain sensing

The in-situ testing performed at the Westinghouse facility with the intensity-based sensor used an early version of the system described in the methodology section. This system used the HeNe laser and was not automated. Hence some noise was associated with the laser and data points are spaced rather widely. The major goal of the first tests conducted at the Westinghouse facility was to demonstrate the feasibility of instrumenting a CXF filter with optical fibers. The following is a summary of this test.

All sensor leads were coated with silver and placed inside stainless steel protective tubing. The sensors were attached to the filter using the Cotronics 905 adhesive. The stainless steel tubing was attached using both Cotronics 905 and 989. The adhesives were left to dry overnight.

At the start of the test, the filter vessel temperature was 27.2° C. The filter vessel preheaters were turned on and after 96 minutes the flame in the vessel was lit with a gas flow of 20 kg/hour at low pressure. The temperature in the filter vessel began to rise quickly and 24 minutes later, the filter vessel temperature was 260° C. The opening of the stainless steel tubing inside the vessel could not be sealed for this test because of the sensor design (this problem was corrected for future testing). Attempts were made to seal the outside opening of the tubes with vacuum grease. During the test, air began to flow through the tubes and soon after moisture began to build up in the tubes until water began to drip continuously from the end of the tubing. All of the fiber leads broke during testing due to the sharp bends in the fibers and because of the moisture and the poor quality of the chemically deposited silver coating.

However, data was taken for both intensity-based sensors. Figures 22 and 23 are plots of the normalized optical power versus the temperature of the filter vessel. Sensor 1 had a gauge length of 10.67 cm and a starting gap of 80 micrometers. Sensor 2 had a gauge length of 10.57 cm and a starting gap of 20 micrometers. Neither sensor had a starting gap large enough to allow the intensity to start in the linear range. The leads of sensor 1 broke at 443° C while the leads of sensor 2 broke at 338° C. At 427° C the gap for sensor 1 is calculated to be 310 micrometers

which from the calibration curve in Figure 4 corresponds to a power drop to about 67 %. As seen in Figure 22 sensor 1 had dropped to about 63 %. Sensor 2 has similar results to within a few percent of the predicted values. Increased accuracy can be achieved with computer controlled data acquisition, averaging schemes and an LED as a source.

At a FEORC laboratory at Virginia Tech the completed sensing system described earlier was tested. Fiber sensors were attached to the filter and heated in a pottery kiln. The results presented should be taken in the context of a laboratory setting since the filter was surrounded by electrical heaters and it was not possible to direct air flow through the filter on a continuous basis. The results are meant to show the feasibility of the sensor being used and give some indication of the measured thermal strain of the filter material.

Figure 23 is a plot from an intensity-based (I-B) sensor during thermal cycling. Notice the time lag for the response of the sensor. This time lag is due to the sensing fibers bending as the material contracts and straightening as the material begins to expand again. Figures 24 a-d are the results from a test of the final version of the data acquisition and display system. Figures 24 a-d are a series of plots from one I-B sensor during one test up to 600° C. Figure 24a is a plot of the temperature (from a conventional thermocouple) in the testing kiln versus time. Figure 24b is a plot of the measured strain from the I-B fiber optic strain sensor and to the predicted values of thermally induced strain versus temperature. A plot of the measured and predicted strain versus time is shown in Figure 24c. Predicted values of strain are determined by multiplying the change in temperature from the starting temperature with the coefficient of thermal expansion of the material. The plot in Figure 24d is the normalized optical power versus time. Note the abrupt change in optical power at approximately 40 minutes. This abrupt change is often observed and is due to fiber slippage which is inherent to the I-B sensor due to the long (5.5 cm) gage length that is required.

5.1.3. Fabry-Perot Based Strain Sensing

Several laboratory experiments were performed to measure thermally induced strains in the ceramic cross flow filters. The main purpose of these experiments was to show the validity of the sensing method as well as to provide some information of the filter material. A summary of the results is given below.

i) Two sensors were attached to the filter with only a few micrometers between them. The gauge lengths of the two sensors were 0.955 cm and 0.934 cm. The expected values for the number of fringes are 39 and 38 for sensor 1 and sensor 2, respectively. The actual values were measured to be 36 and 35, respectively, as seen from Figures 25 and 26. The difference in the actual and predicted values could be due to inaccuracies in knowing the exact attachment points of the fiber to

the filter. These inaccuracies arise because one side of the sensor the alignment tube is attached to the filter and it is difficult to determine exactly where the fiber is attached. This problem was eliminated in subsequent experiments. The steady increase in the dc level is due to the detector amplifier circuit. The irregular fringes for sensor 1 in Figure 25 at about 400° C are due to an intentional decrease in laser power to keep the signal in the range of the data acquisition system. The irregular fringes throughout the plot in Figure 26 are due to a poor signal-to-noise ratio for sensor 2.

ii) The sensor was attached to the filter with a gage length of 1.0 cm. Approximately 38 fringes (intensity peaks) were expected for an increase in temperature from 25° C to 500° C. During the actual test, 39 fringes were counted from the data taken by hand. While the filter was at 500° C, a 45 second blast of 25° C air was directed at the filter. The sensor output went through approximately five fringes as seen in the oscilloscope trace in Figure 27. Although it is understood that the actual cleaning pulse is a fraction of a second, this result demonstrates the sensor's ability to react to a cooling pulse from a small copper tube which cools the filter much slower than the actual cleaning pulse through the entire filter.

iii) The results from a test with a sensor gage length of 0.871 cm can be seen in Figure 28. 37 fringes were observed from 25-510° C. The calculated number of fringes for this test is 34.20. A separate test with a gage length of 1.3 cm resulted in 56 fringes from 25-600° C, shown in Figure 29. The predicted number of fringes for this sensor is 60.50. The error in fringe count could be due to the expansions of the fiber or the adhesive, both of which have a coefficient of thermal expansion (CTE) that is an order of magnitude less than the filter.

iv) A quadrature-phase shifted sensor like the one described in the methodology section was constructed and attached to a micro-positioner to produce a known displacement. The two sensing fibers can use the same source in this configuration because the separate alignment tubes prevent any unwanted interference between the two sensing fibers. Figure 30 is a typical oscilloscope trace of the outputs from the two sensing fibers.

The two quadrature phase shifted sensor designs were first tested on a titanium cantilever beam. The construction of the sensors was changed often before an optimum fabrication method was achieved, the cantilever beam allowed us to save time in testing instead of performing actual filter tests each time. Once the optimum design was obtained, the sensor was attached to the filter and placed in the kiln. A temperature history plot is shown in Figure 31. As seen in the figure, there are three points where the sensor experiences a change in direction of displacement. An oscilloscope trace of the optical outputs of the two Fabry-Perot interferometers, that make up the sensor, versus time can be seen in Figure 32. We notice that the envelopes of the fringes gives an indication of increasing and decreasing displacement. The large spikes in the two traces are

temperature markers. Figure 33 shows an expansion of the two traces when the kiln changed from increasing temperature to decreasing temperature at 600° C. The top trace leads the bottom trace in phase until the thermal strain changes from positive to negative at which time the top trace begins to lag the bottom trace in phase. These two outputs are functions of time; when channel #1 is plotted versus channel #2, an ellipse is formed as is expected from our experience with Lissajous figures. Figure 34 is an expansion of the two traces when the kiln changed from increasing temperature to decreasing temperature at 500° C, with channel #1 plotted versus channel #2. The change from increasing strain to decreasing strain can be seen as change in the direction of rotation of the ellipse. We were able to detect all three directional changes in the thermal strain using this method. A table of the experimentally counted number of fringes and the predicted number can be seen in Figure 35.

5.1.4. In-Situ Testing Using the Fabry-Perot Based Strain Sensor

The first in situ test was conducted at Westinghouse Electric Corporation during the testing of the intensity based sensor. All sensor leads were coated with silver and placed inside stainless steel protective tubing. The sensors were attached to the filter using the Cotronics 905 adhesive. The stainless steel tubing was attached using both Cotronics 905 and 989. The adhesives were left to dry overnight.

The test procedure was exactly as that described for the intensity-based sensors described earlier. We identified problems in splicing fibers together as well as in the failure of detectors failing; however an indication that the sensors were functioning was obtained. Corrective action was taken by ruggedizing the coupling and detector systems.

The second in-situ test was performed at Westinghouse and good results were obtained. A summary of the results follows.

The fibers used in these experiments were coated with a polyimide by Polymicro Inc. from a preform supplied by FEORC. The operating temperatures are restricted to around 420 °C and for future use it may be more practical to obtain gold coated fibers from FiberGuide or aluminum coated fiber available from Hughes and NOI (Canada). We obtained data from several Fabry-Perot sensors during heating to 420° C, pulse cleaning and cool-down. Figure 2 shows the method used to seal the stainless steel tubing during the tests. This attachment method was tested in the FEORC facilities. During testing at Westinghouse several of the input fibers to the sensors broke. All of the breaks occurred between the stainless steel tubing bond and the first sensor bond. However, none of the sensor fibers broke during testing.

A diagram of the placement of each of the eight F-P strain sensors can be seen in Figure 36. The

gage length of sensor #1 was over a crack between two dirty channel laminates. Sensor #2 was over a crack between two clean channel laminates. The other sensors (#'s 3-8) were not positioned over any visible filter defects. Sensor #4 was a dual-fiber quadrature phase shifted sensor to allow unambiguous detection of change in direction of strain. Stainless steel tubing guides were attached with Cotronics 905 high temperature adhesive. The stainless steel tubing was ground longitudinally to its axis to reduce bending in the optical fiber at the attachment point.

During the first Westinghouse tests, pressure leaks through the stainless steel tubing allowed moisture to build up in the tubes which contributed to the optical fiber leads breaking during testing. To reduce this problem the lead fiber was placed in a hollow silica tube with an inner diameter of 145 micrometers. An adhesive was then used to seal the stainless steel protective tubing without attaching the lead fiber to the filter. If the fiber is attached to the filter in more than one place it will experience plastic deformation at high temperatures. This method reduces the flow of air significantly but still allows some air to pass between the 125 μm outer diameter fiber and the 145 μm inner diameter hollow silica tube. All eight fiber sensors were fabricated on-site and then the leads were threaded into the stainless steel protective tubing and the sensor attached using Cotronics 989. The support optics and electronics allowed the monitoring of four sensors at any one time. All eight sensors were attached and were left overnight to ensure a proper drying of the adhesive.

The stainless steel protective tubes were placed in one direction and tied together with masking tape to aid in threading them through the opening in the filter vessel. The filter was then loaded into the filter holder. Lead bricks were used to press the filter into the holder as shown in Figure 37. Several steel washers were placed between the bricks and the filter to prevent the bricks from damaging the sensors. Sensors #2 and #7 were monitored while the bolts in the filter clamp were tightened. Figure 38 is the output of sensor #2 during the bolt tightening. The peak phases difference recorded correspond to strain levels of 3.5 μstrain . The fibers were threaded through the opening in the filter vessel wall. The filter was then lowered slowly until the stainless steel tubing was threaded through the opening. After lowering the filter completely into the filter vessel, a specially drilled Conax fitting (supplied by Westinghouse) was used to seal the filter vessel. The Conax fitting was drilled for eight stainless steel tubes and one conventional thermocouple. After installing the Conax fitting but before capping the filter vessel we heated the filter vessel to about 60° C to check the sensor outputs. Sensor #1 appeared to be broken and sensor #'s 2, 4 (both fibers), 6 and 7 showed excellent fringe contrast. The filter vessel was capped and left to cool down.

At the beginning of the tests the filter was still warm (37° C) from the heating process it underwent the previous night. The filter vessel was pressurized to 30 psi to check for leaks in the stainless steel protective tubing. Small leaks were detected in tubes 1, 3, 4, and 8; no other leaks were

detected. During the pressurization, both fibers in sensor #4 were monitored. The trace was started when pressurization began. The oscilloscope ground trace was recorded (to provide marks in the trace) when the vessel reached 30 psi. The signal recorded corresponds to a strain of 7.3 μ strain for the induced differential pressure of 30 psi. The electric heaters were turned on to provide a slow warming of the filter which is normally done to prevent thermal shock to the filter. Sensors #2, #4 (both fibers) and #7 were chosen to be monitored during testing. Both fibers from sensor #4 were monitored throughout the entire test. Figure 39a is a plot of strain and temperature versus time from one of the fibers in sensor #4 during the following stages: i) electric heater warm-up, ii) cool-air to the back plate to start torch, iii) cool air increase, iv) flame on, v) flame out, vi) flame on again and, finally, vi) closed bypass valve to induce rapid heating. Each of these stages is clearly noticeable on the plot in the expanded view shown in Figure 39b. At 420° C the torch was tuned off and the filter vessel was allowed to cool. During cooling several pulse cleanings were recorded, they will be discussed in a later subsection. As the filter begins cool the thermal strain in the filter starts decreasing and this is depicted in Figure 40. Figure 41 shows a comparison between the experimental and the theoretical values.

During the cool air cycle it was noticed that sensor #7 detected filter contraction before sensors #4 and #6. This could be due to the filter contracting around the dirty channels first and then to the top and sides later.

5.2. Pulse Cleaning Transient Strains

At the second Westinghouse in-situ testing thermally induced strain was observed with the Fabry-Perot based sensor during cleaning pulses. The fiber sensor output can be seen in Figure 42 a) with an expanded view in Figure 42 b). This signal was obtained with the oscilloscope ac-coupled. The signals recorded correspond to displacements on the order of 70 nm with a typical frequency spectrum centered around approximately 2.0 kHz. These signals are likely to be caused by an acoustic wave generated by thermal shock.

The ability of the extrinsic Fabry-Perot sensor to detect acoustic signals generated by acoustic shocks or crack growth has been demonstrated at the Fiber & Electro-Optics Research Center. The results, as yet unpublished, will be presented at the SPIE Conference on Smart Structures and Skins, to be held in Boston in September 1991.

Testing was subsequently conducted to determine the ability of the Fabry-Perot sensor to measure such acoustic emissions on the filter material. A sensor was attached to a small piece of filter material as in the in-situ testing. The filter was fractured under load and the detected signal resembled that observed during pulse cleaning. It is for these reasons that we believe the observations made during pulse cleaning were caused by an acoustic wave most probably

generated by thermal shock.

5.3. Particulate Buildup Monitor

Preliminary testing was conducted for particulate buildup monitoring (see methodology section) and represents an approach to implement such a sensor. The test results were obtained at FEORC laboratories. The results of the preliminary tests were promising and show considerable potential for in-situ testing.

5.4. Crack Displacement Measurement

Crack opening displacement measurements in the filter material were attempted at in house laboratory facilities. The filter was heated to 1000° C and then quickly cooled to form a small crack on the surface of the filter. A Fabry-Perot sensor was placed over the crack while another sensor was attached nearby on a solid piece of filter. The two sensors were then monitored during heating of the filter to 500° C. A sample of the data is shown in Figure 43. The bottom trace shows that six fringes (each fringe corresponds to 651 nanometers of displacement) were counted from 280° C to 350° C for the sensor not over the crack, which is within one fringe of the expected value. The output fringes were very smooth and could easily be counted knowing that the filter was constantly experiencing a rise in temperature; however, the output fringes for the sensor over the crack were full of spikes. These spikes could be due to sudden changes in displacement or just a change in direction of displacement.

While exact displacement could not be measured since a quadrature phase shifted sensor was not placed over the crack, it is quit easy to determine a crack has occurred due to the erratic nature of the output when compared to the predictable output from the nearby sensor.

6.0. Conclusion

In this project, two different fiber optic sensors were considered for use in ceramic cross flow filters. The intensity-based sensor was tested with a great degree of success. Even with a computerized data acquisition system, the intensity-based sensor was unable to achieve the resolution of the Fabry-Perot sensor. The intensity-based sensing method is considered to be the best first approach for sapphire fiber sensors, due to the availability of multimode sapphire rods only. Another drawback of the intensity sensor is the hysteresis behavior observed over cyclic variation of temperature.

We have determined that extrinsic Fabry-Perot fiber optic sensors can be used to measure thermal strains in ceramic cross-flow filters with accuracies of $0.1 \mu\text{m/m}$. The single ended approach of the reflective Fabry-Perot sensors is well suited for high thermal strain measurements; the results obtained show that the output of the fiber sensor tracks the temperature changes exactly as expected and shows no noticeable time lag between the measurand and the output signal.

Sapphire fibers were manufactured with silica claddings and their spectral attenuation was measured. An intensity based sensor using sapphire fibers was fabricated and its performance calibrated. The move toward single-mode sapphire fibers will pave the way toward their use in phase-modulated sensors.

The success of the Fabry-Perot sensor has proved that such fiber optic sensors are ideally suited for "smart structures" in fossil energy applications.

7.0. Future Directions

The research performed during the duration of this project has laid the foundation for a fiber optic sensor based smart structure system for ceramic cross flow filters that can lead to improved coal processing techniques in future fossil energy applications. Specific improvements and modifications that can lead to advanced thermal strain mapping of CXF filters are given below.

7.1. Intensity Based Sensors

The intensity based sensor can readily be adapted to multimode sapphire fiber based systems for high temperature applications. The technology thrust should concentrate on the development of new techniques for the fabrication of high optical quality sapphire fibers. The fabrication methods would have to eliminate surface defects and reduce optical propagation losses in the waveguide. This development would allow the use of long lengths of sapphire sensor heads that can be operated in the high temperature environments with standard silica fibers carrying optical power to and from the sapphire sensors. As low loss optical quality sapphire fibers become available, novel sensing techniques that modify the existing methods for silica based fiber sensors can be developed. The advantageous features of sapphire, such as immunity to harsh environments and high temperatures, along with the simplicity of the signal processing techniques for the intensity based sensor will make this sensor an excellent option for inexpensive, reliable and long-lasting sensing demands.

7.2. Fabry-Perot Sensors

The extrinsic Fabry-Perot sensor presented in this report offers great promise for future applications. Since it is based on the phase-modulation principle, the F-P sensor is among the most sensitive of fiber sensors and can meet the high-accuracy, high-resolution demands that one would typically envision to be encountered in advanced smart structures. Modifications in sensor designs, such as the use of two wavelengths simultaneously, would allow unambiguous tracking of a dynamically varying parameter with higher accuracies. Improved data-acquisition techniques that use dedicated signal processing chips or sophisticated software can lead to higher sensitivities and the elimination of manual fringe counting techniques, thus reducing delay times between the sensing process and the decision-making process in a smart structure that houses both sensors and actuators.

The success of this sensing scheme in a variety of other applications (vibration sensing on F-15 aircraft, damage and stress concentration measurements in composite laminates, etc.) underscores

the versatile nature of this sensor to meet stringent demands in different environments. The individual sensing elements can be used in a multiplexed fashion to measure thermally induced strains at several different locations on a CXF filter and thus lead to optimization of filter manufacturing, processing and operation. The advantages of multiplexed fiber optic sensors have been exploited by researchers in several different applications in the past. The Fabry-Perot nature of the sensor eliminates the need for complex stabilization schemes typically encountered in other phase-modulated fiber optic sensors. The use of a single source and detector to effectively run a host of sensors that acquire data from various locations in a coal fired power generation plant will allow for economic monitoring of system elements such as fluidized-bed combustors.

7.3. Particulate Build-Up Sensors

The relatively simple intensity based sensor demonstrated in a laboratory environment can also be adapted for use with sapphire fibers. The promising results from the experiments conducted during the duration of this project indicate a high potential for the implementation of such sensing elements at several locations for acquiring particulate build-up information. Modifications and future efforts will be dictated by the quality of results obtained from future in-situ tests.

8.0. Figures

Figure 1. Fibers attached to filter. a) Attachment configuration before temperature cycling. b) Fiber pulls out of the adhesive at high temperature.

Figure 2. . A diagram of the attachment method that allows the stainless steel tubing to be sealed. The hollow silica tube prevents the sensing fiber from being bonded in more than one location. If the fiber is bonded in more than one location it will experience plastic deformation at high temperatures.

Figure 3. Intensity based air gap splice strain sensor.

$$y = 1.0020 - 3.0237e-4x - 1.4866e-5x^2 + 4.6489e-8x^3 - 5.3330e-11x^4 + 2.2174e-14x^5$$

Figure 4. Calibration curve for the intensity based sensor.

Figure 5. a) Air-gap sensor design (X indicates placement of adhesive).
b) Expanded view of air-gap sensor.

Figure 6. a) Temperature vs. time. b) Normalized intensity output of sensor vs. time.

Figure 7. Experimental setup for testing of fiber optic air-gap strain sensor

Figure 8. The Fabry-Perot sensor setup.

Figure 9. Therotical output vs. Gap separation

Figure 10. Continuously monitored output of a Fabry-Perot sensor with large displacement.

Figure 11. Quadrature phase shifted theory.

Figure 12. Quadrature phase shifted sensors.

Figure 13. Diagram of the support system for the Fabry-Perot sensors.

Figure 14. Particulate loading sensors. a) Optical transmission system attached to the filter.
b) Optical transmission system that could be implemented with optical system on clean side of the filter.

Figure 15. Particulate loading sensor data for the sensor described in Figure 14a. The lenses and filter were clean at the beginning and then particulate was placed between the lenses and blown clean seven times.

Figure 16. Particulate loading sensor data for the sensor described in Figure 14b. The filter was clean at the beginning and then particulate was placed in the filter channel and then blown clean twice.

Figure 17. Deposition rate of ZrO₂ films as a function of reagent partial pressure.

Figure 18. Deposition rate of ZrO₂ films as a function of deposition temperature.

Figure 19. Variation of thickness nonuniformity in the reactor with deposition temperature.

Figure 20. Normalized output intensity vs. displacement for two sapphire intensity based displacement sensors.

Figure 21. Spectral attenuation of sapphire clad with silica.

Figure 22. Normalized optical power of intensity-based strain sensor versus temperature of filter vessel at Westinghouse.

Figure 23. Normalized optical power of intensity-based strain sensor.

Figure 24a. Temperature versus time plot for an intensity-based strain sensor.

Figure 24b. Strain (experimental and predicted) versus temperature plot for an intensity-based strain sensor.

Figure 24c. Strain (experimental and predicted) Versus time plot
for an intensity based strain sensor.

Figure 24d. Normalized optical output versus time for an intensity based strain sensor.

Figure 25. Trace of output vs. temperature for sensor 1.

Figure 26. Trace of output vs. temperature for sensor 2.

Figure 27. Response of Fabry-Perot sensor to a 45 second cool air blast.

Figure 28. Oscilloscope trace of the output voltage of the Fabry-Perot based strain sensor with a gauge length of 0.871 cm versus temperature of the filter.

Figure 29. Oscilloscope trace of the output voltage of the Fabry-Perot based strain sensor with a gauge length of 1.3 cm versus temperature of the filter.

Figure 30. O-scope trace of the outputs from two Fabry-Perot strain sensors 90° out of phase.

Figure 31. Temperature history of Fabry-Perot test.

Time in minutes

Figure 32. Oscilloscope trace of the two Fabry-Perot sensors.

Figure 33. Expanded traces at the point where the kiln went from increasing temperature to decreasing temperature at 600° Celsius.

Figure 34. Expanded traces at the point where the kiln went from increasing temperature to decreasing temperature at 500° Celsius. The top figure is a trace of channel 1 versus channel 2.

Temperature range in degrees C	<u>Number of fringes</u>	
	Experimental	Predicted
23 - 500	70	60
500 - 400	12.5	12.4
400 - 600	24	24.8
600 - 250	55	43.4

Figure 35. Table of experimentally counted number of fringes and predicted number of fringes.

Figure 36. Diagram of fiber optic F-P strain sensor placement. The filter back was defined after clamping filter into holder, the back of the filter was on the clean air plenum side.

Figure 37. Lead bricks on top of the filter to provide comperssion during mounting.

Figure 38. Lead bricks on top of the filter to provide compression during mounting.

Figure 39a. Strain and temperature versus time for sensor 4 during heat-up.

Figure 39b. Strain and temperature versus time for sensor 4 during heat-up.

Figure 40. Differential microstrain and temperature versus time for sensor 4 during cool-down.

Figure 41. Measured and predicted strain versus time during cool-down.

a)

Time
.5 sec / div

b)

Time

Figure. 42. a) Typical data received during a pulse cleaning. b) An expanded view of the data received during a pulse cleaning.

Figure 43. Oscilloscope trace of two interferometric sensors. The top trace is the output from the sensor over a crack in the filter and the bottom trace is from the sensor not over the crack.

9.0. References

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10.0. List of Abbreviations

°C	Centigrade
CXF	Cross Flow Filter
cm	Centimeter
dB	Decibels
ESCA	Electron Spectroscopy for Chemical Analysis
F-P	Fabry-Perot
HeNe	Helium Neon
I-B	Intensity Based
LASER	Light Amplification by Stimulated Emission of Radiation
LED	Light Emitting Diode
mm	Millimeter
MOCVD	Metallorganic Chemical Vapor Deposition
NA	Numeric Aperture
nm	Nanometer
TEOS	Tetraethoxysilane
μm	Micrometer
YAG	Yttrium Aluminum Garnet

11.0. Appendix:

11.1. Computer programs for data acquisition systems:

- 1) NORMA.BAS-----Searches through data files taken during the intensity-based sensor tests and finds the maximum value. The data is then divided by the maximum to give a normalized quantity.
- 2) SPXA.BAS-----Used to determine spectral attenuation characteristics. It controls a spectrometer to allow wave length selection, and also reads values from a lock-in amplifier so power loss may be determined.
- 3) DOEPROG.BAS-----Used to collect data from intensity based sensors. Data taken includes time, temperature, and optical power.
- 4) CALNORM.BAS----Normalizes data taken when calibrating the intensity-based sensor.
- 5) STRAIN.BAS-----Calculates the theoretical and experimental strain from data taken during testing.
- 6) NEWDAT.BAS-----Operates on data taken during from the intensity-based sensor. Data is broken into two files: time vs. temperature and time vs. optical power.
- 7) MICRON2.BAS-----Collects data for generating the calibration curve for the intensity based sensor. (i.e. it collects intensity vs. separation
- 8) MAIN.BAS-----Collects data for the Fabry-Perot system. Data includes time, temperature, and voltage readings form sensors.
- 9) MODPOINT.BAS----Searches through the Fabry-Perot data to determine peaks and valleys of fringes.
- 10) POINTCNT.BAS---Counts the number of peaks and valleys. (i.e. a discrete representation of the displacement related to time and temperature is given.

```

10 '      NORMA.BAS      by A. Plante
20 '
30 ' THIS PROGRAM WILL NORMALIZE THE DOE DATA FILES GENERATED
40 ' FROM THE DOEPROG.BAS PROGRAM.
50 '
55 '*****
60 '
70 CLS
80 PRINT:PRINT"This program will normalize the DOE data files generated from the DOEPROG.BAS  program.
90 '
100 PRINT:PRINT:PRINT"What is the name of the data file to be normalized?
110 INPUT "FILE NAME ";FILES$
120 PRINT:PRINT"What is the name of the new normalized data file?
130 INPUT "NEW FILE NAME ";NFILES$
140 CLS
150 PRINT:PRINT:PRINT"BE PATIENT. THIS PROGRAM MAY TAKE A WHILE. "
160 '
170 DIM X(3000),Y(3000),Z(3000),NORM(3000)
180 '
190 ' * * * COUNTS THE NUMBER OF COLUMNS IN A FILE * * *
200 '
210 OPEN FILES$ FOR INPUT AS #1
220 IF EOF(1) THEN 260
230 INPUT #1, X,Y,Z  'TIME,TEMP,OUTPUT VOLTAGE mVOLTS
240 NUM=NUM + 1
250 GOTO 220
260 CLOSE #1
270 '
280 ' * * * VALUES PUT INTO ARRAY * * *
290 '
300 OPEN FILES$ FOR INPUT AS #1
310 COUNT = COUNT + 1
320 INPUT #1, X,Y,Z
330 X(COUNT) = X 'TIME
340 Y(COUNT) = Y 'TEMP
350 Z(COUNT) = Z 'OUTPUT VOLTAGE mVOLTS
360 IF COUNT=NUM THEN 380
370 GOTO 310
380 CLOSE #1
390 '
400 ' * * * FINDS THE LARGEST VALUE OF Z * * *
410 '
420 COUNT = 0
430 BIG = Z(1)
440 FOR COUNT = 1 TO NUM
450 IF Z(COUNT+1) > BIG THEN BIG=Z(COUNT+1)
460 NEXT COUNT
470 '
480 ' * * * WRITES THE NORMALIZED VALUE TO A FILE * * *
490 '
500 OPEN NFILES$ FOR OUTPUT AS #2
510 FOR COUNT = 1 TO NUM

```

520 NORM(COUNT) = Z(COUNT)/BIG
530 PRINT #2, X(COUNT), Y(COUNT), NORM(COUNT)
540 NEXT COUNT
550 CLOSE #2
560 CLS
570 PRINT:PRINT:PRINT"THE NEW NORMALIZED FILE IS "NFILES\$
580 '
590 END


```

10 '      SPXA.BAS      by J. Greene
20 '
30 ' THIS PROGRAM USES THE 488 GPIB INTERFACE TO CONTROL A COMPUDRIVE TO SCAN A
40 ' RANGE OF WAVELENGTHS WITH A SPEX MONOCHROMOTOR. THE OUTPUT FROM THE
50 ' MONOCHROMOTOR IS AMPLIFIED USING A LOCK-IN AMPLIFIER(COMPUTER CONTROLLED).
60 ' THE PROGRAM RUNS FIRST A REFERENCE SCAN, AND THEN A DATA SCAN. DURING
70 ' EACH SCAN, THE OUTPUT FROM THE LOCK-IN IS STORED TO THE DISK (IN mV)
80 ' ALONG WITH ITS CORRESPONDING WAVELENGTH (IN NANOMETERS).
90 '
91 ' *****
92 '
93 '
100 ' ***** "Decl.Bas" & MUST PRECEDE ANY GPIB APPLICATION PROGRAM *****
101 '
110 CLEAR ,60000! : IBINIT1=60000! : IBINIT2=IBINIT1+3 : BLOAD "bib.m",IBINIT1
120 CALL IBINIT1(IBFIND,IBTRG,IBCLR,IBPCT,IBSIC,IBLOC,IBPPC,IBBNA,IBONL,IBRSC,
    IBSRE,IBRSV,IBPAD,IBSAD,IBIST,IBDMA,IBEOS,IBTMO,IBEOT,IBRDF,IBWRTF,IBTRAP,IBDEV,IBLN)
130 CALL IBINIT2(IBGTS,IBCAC,IBWAIT,IBPOKE,IBWRT,IBWRTA,IBCMD,IBCMDA,IBRD,IBRDA,
    IBSTOP,IBRPP,IBRSP,IBDIAG,IBXTRC,IBRDI,IBWRTI,IBRDIA,IBWRTIA,IBSTA%,IBERR%,IBCNT%)
140 '
150 ' ***** ESTABLISH THE LOCK-IN & COMPUDRIVE AS DEV4% & DEV10%, RESP. *****
160 '
170 BDNAME$ = "DEV4"
180 CALL IBFIND(BDNAME$,DEV4%)
190 IF DEV4% < 0 THEN 2330
200 KEY OFF
210 SCANS = "reference"
220 BDNAME$ = "DEV10"
230 CALL IBFIND(BDNAME$,DEV10%)
240 IF DEV10% < 0 THEN 2350
250 CLS
260 '
270 ' ***** SET-UP THE OPENING SCREEN *****
280 '
290 GOSUB 2410
300 LOCATE 7,11,0,1,13
310 PRINT "This program is to be used for experiments using the SPEX C2DB"
320 PRINT TAB(11)"Compudrive and the EG&G Lock-in Amplifier. The program runs a"
330 PRINT TAB(11) "scan of wavelengths using the SPEX, and reads measurements from"
340 PRINT TAB(11) "the lock-in."
350 PRINT
360 PRINT
370 PRINT TAB(11) "The program will perform two scans. The first will be"
380 PRINT TAB(11) "a refernce scan, and the second will be the data scan."
390 PRINT
400 PRINT
410 PRINT TAB(26)"<PRESS ANY KEY TO CONTINUE>"
420 A$=INKEY$:IF A$="" THEN 420
430 '
440 ' ***** REQUEST SCAN PARAMETERS FOR THE COMPUDRIVE FROM USER *****
450 '
460 CLS

```

```

470 B$=CHR$(3)+CHR$(13)
480 GOSUB 2410
490 LOCATE 7,11,1,1,13:PRINT TAB(5)"The scan parameters(start position, end position, and burst increment)
must be
500 PRINT "entered in nanometers, and include a decimal point."
510 PRINT:PRINT
520 PRINT TAB(7)"Enter the start position[8 characters max.]:";
530 INPUT START$
540 PRINT
550 PRINT TAB(7)"Enter the end position for the scan[8 characters max.]:";
560 INPUT ENDD$
570 PRINT
580 PRINT TAB(7)"Enter the burst increment value[6 characters max.]:";
590 INPUT BIS
600 GOSUB 2410: LOCATE 10,11,0,1,13:PRINT "Please Wait ... about 30 s ... while
the CompuDrive moves to the start position."
610 '
620 ' ***** SEND SCAN INFO TO THE COMPUDRIVE *****
630 '
640 FLAG = 0
650 WRT$ = CHR$(2)+"ST"+START$+B$
660 GOSUB 1930
670 WRT$ = CHR$(2)+"EN"+ENDD$+B$
680 GOSUB 1930
690 LOCATE 11,11,0,0,0
700 WRT$ = CHR$(2)+"BI"+BIS+B$
710 GOSUB 1930
720 WRT$ = CHR$(2)+"TYB"+BIS+B$
730 GOSUB 1930
740 WRT$ = CHR$(24)+"T"+B$
750 GOSUB 1930
760 GOSUB 1390: ' READ POSITION DATA FROM COMPUDRIVE
770 CLS
780 GOSUB 2410:LOCATE 5,14,0,1,13:PRINT "The Lock-In is now performing an Auto-Measure routine.";
790 WRT$="ASM"+C$
800 GOSUB 2060: ' LOCK-IN AUTO-MEASURE
810 GOSUB 1460
820 GOSUB 1660: ' FIND CURRENT SENSITIVITY OF LOCK-IN
830 PRINT
840 '
850 '
860 ' ***** START TAKING MEASUREMENTS AND STORE THEM IN
870 ' A FILE AS SUCH: WAVELENGTH (nm), VOLTAGE (mV) *****
880 '
890 '
900 GOSUB 2410:LOCATE 10,7,0,1,13:PRINT "Please enter the name of the data file for the "SCAN$" scan:";
910 INPUT FILE$
920 OPEN FILE$ FOR OUTPUT AS #1
930 '
940 GOSUB 2410:LOCATE 10,7,0,1,13:PRINT "Scan in progress ";
950 LOOP = (VAL(ENDD$)-VAL(START$))/VAL(BIS)
960 FOR LOOP1 = 0 TO LOOP

```

```

970 LOCK1 = 0
980 '
990 ' ***** 20 VALUES FROM LOCK-IN ADDED AND NAMED LOCK1 *****
1000 '
1010 FOR LOOP2 = 1 TO 20
1020 WRT$="OUT"+C$
1030 GOSUB 2120
1040 LOCK1 = LOCK1 + VAL(ANSWER$)/20
1050 NEXT LOOP2
1060 '
1070 '
1080 ' ***** LOCK2 IS THE AVERAGE OF LOCK1 AND IS A PERCENTAGE *****
1090 '
1100 '
1110 LOCK2=LOCK1/100
1120 VOLT = X*LOCK2/100
1130 WAVELGTH = VAL(START$) + (LOOP1*VAL(BI$))
1140 WRITE #1,WAVELGTH,VOLT
1150 PRINT ". ";
1160 IF LOOP1 = LOOP THEN 1230
1170 GOSUB 1970 : ' TRIGGER SCAN INCREMENT
1180 WRT$="AS"+C$
1190 GOSUB 2060
1200 GOSUB 1460
1210 GOSUB 1660 : ' SENSITIVITY CALIBRATION
1220 NEXT LOOP1
1230 GOSUB 1390
1240 IF INCR=1 THEN GOTO 1500
1250 CLOSE #1
1260 CLS
1270 GOSUB 2410:LOCATE 10,18,0,1,13:PRINT "The computer is ready to do the second scan."
:PRINT:PRINT:PRINT
1280 PRINT TAB(26)"<PRESS ANY KEY TO CONTINUE>"
1290 A$=INKEY$:IF A$="" THEN 1290
1300 INCR = 1
1310 CLS
1320 SCANS$ = "data"
1330 GOTO 600 : ' RETURN TO THE BEGINNING FOR SECOND SCAN
1340 '
1350 ' ***** SUBROUTINE: READ POSITION DATA FROM
1360 '          COMPUDRIVE UNTIL SCAN IS DONE *****
1370 '
1380 '
1390 CALL IBRSP(DEV10%,S%)
1400 IF S% < 128 THEN FLAG = 0
1410 IF (S%=128) AND (FLAG = 1) THEN RETURN
1420 IF (S% = 128) AND (FLAG = 0) THEN FLAG = 1
1430 TALK$ = SPACES$(10)
1440 CALL IBRD(DEV10%,TALK$)
1450 GOTO 1390
1460 CALL IBRSP(DEV4%,S%)
1470 FINISH = S% AND 32:PRINT ". ";

```

```

1480 IF FINISH = 0 THEN RETURN
1490 GOTO 1460
1500 CLS
1510 CLOSE #1
1520 GOSUB 2410:LOCATE 10,7,0,1,13: PRINT "Do you wish to run another 2-scan set['y' or 'n']?";INPUT A$
1530 IF A$ = "y" THEN INCR=0:SCAN$="reference":GOTO 460: ' Start program again
1540 IF A$ = "n" THEN GOTO 1560
1550 GOTO 1520
1560 CLS:KEY ON:END
1570 '
1580 '
1590 '***** SUBROUTINE: READ SENSITIVITY FROM LOCK-IN AS
1600 '          VARIABLE "SEN". "SEN" IS AN INTEGER
1610 '          0-15 CORRESPONDING TO A SENSITIVITY IN mV *****
1620 '
1630 ' VARIABLE X
1640 '
1650 '
1660 WRT$="SEN"+C$
1670 CALL IBWRT(DEV4%,WRT$)
1680 ANSWER$=SPACES(10)
1690 CALL IBRD(DEV4%,ANSWER$)
1700 SEN=VAL(ANSWER$)
1710 IF SEN = 0 THEN X=.0001
1720 IF SEN = 1 THEN X=.0003
1730 IF SEN = 2 THEN X=.001
1740 IF SEN = 3 THEN X=.003
1750 IF SEN = 4 THEN X=.01
1760 IF SEN = 5 THEN X=.03
1770 IF SEN = 6 THEN X=.1
1780 IF SEN = 7 THEN X=.3
1790 IF SEN = 8 THEN X=1
1800 IF SEN = 9 THEN X=3
1810 IF SEN = 10 THEN X=10
1820 IF SEN = 11 THEN X=30
1830 IF SEN = 12 THEN X=100
1840 IF SEN = 13 THEN X=300
1850 IF SEN = 14 THEN X=1000
1860 IF SEN = 15 THEN X=3000
1870 RETURN
1880 '
1890 '
1900 '***** SUBROUTINE: WRITE A COMMAND TO THE SPEX *****
1910 '
1920 '
1930 CALL IBWRT(DEV10%,WRT$)
1940 RETURN
1950 '
1960 '***** SUBROUTINE: TRIGGERS THE SPEX TO INCREMENT THE SCAN *****
1970 '
1980 '
1990 WRT$ = CHR$(24)+ "E"+CHR$(3)+CHR$(13)

```

```

2000 CALL IBWRT(DEV10%,WRT$)
2010 RETURN
2020 '
2030 ' ***** SUBROUTINE: WRITE A COMMAND TO THE LOCK-IN *****
2040 '
2050 '
2060 CALL IBWRT(DEV4%,WRT$)
2070 RETURN
2080 '
2090 ' ***** SUBROUTINE: READ OUTPUT FROM THE LOCK-IN *****
2100 '
2110 '
2120 CALL IBWRT(DEV4%,WRT$)
2130 ANSWER$=SPACES(10)
2140 CALL IBRD(DEV4%,ANSWER$)
2150 RETURN
2160 '
2170 ' ***** SUBROUTINE: CHECK TO SEE IF THE POWER IS STILL
2180 '           IN THE LINEAR RANG OF THE DETECTOR *****
2190 '
2200 '
2210 '
2220 IF POWER <= THEN 2260
2230 IF POWER <= THEN 2260
2240 IF POWER <= THEN 2260
2250 IF POWER <= THEN 2260
2260 PRINT "THE NEXT FILTER NEEDS TO BE PLACED IN THE CONFIGURATION"
2270 INPUT "PRESS ENTER WHEN READY TO CONTINUE";NEXTFILT
2280 ' GOTO SCAN AGAIN
2290 '
2300 '
2310 ' ***** FLAG THE USER THAT THERE'S A HARDWARE PROBLEM *****
2320 '
2330 PRINT "THE COMPUTER CAN'T FIND THE LOCK-IN AMPLIFIER"
2340 GOTO 2360
2350 PRINT "THE COMPUTER CAN'T FIND THE COMPUDRIVE"
2360 END
2370 '
2380 ' ***** SUBROUTINE: SETS UP THE SCREEN FORMAT *****
2390 '
2400 '
2410 CLS:PRINT
"*****"
2420 LOCATE 22,1,0,1,13:PRINT
"*****"
2430 RETURN

```

```

10 '      DOEPROG.BAS      by A. Plante
20 '
30 '
40 '
50 ' THIS PROGRAM WILL COLLECT THE TEMP, TIME, AND THE NORMALIZED
60 ' (OUTPUT/REF) OUTPUT FOR UP TO FIVE SENSORS. A LOCK-IN AMPLIFIER,
70 ' A COMPUTER CONTROLLED BNC SWITCHING DEVICE, AND A THERMOCOUPLE
80 ' ARE NEEDED TO RUN THE PROGRAM. THE LENGTH OF EACH SENSOR, THE
90 ' INITIAL MAX READING, AND THE READING OF THE SENSOR AFTER THE
100 ' GLUE DRIES SHOULD BE RECORDED BY HAND. THIS DATA WILL BE NEEDED
110 ' TO COMPUTE THE STRAIN IN THE STRAIN.BAS PROGRAM.
120 '
130 '*****
140 '
150 KEY OFF
160 CLEAR ,60000! : IBINIT1=60000! : IBINIT2=IBINIT1+3 : BLOAD "bib.m",IBINIT1
170 CALL IBINIT1(IBFIND,IBTRG,IBCLR,IBPCT,IBSIC,IBLOC,IBPPC,IBBNA,IBONL,IBRSC,
    IBSRE,IBRSV,IBPAD,IBSAD,IBIST,IBDMA,IBEOS,IBTMO,IBEOT,IBRDF,IBWRTF,IBTRAP,IBDEV,IBLN)
180 CALL IBINIT2(IBGTS,IBCAC,IBWAIT,IBPOKE,IBWRT,IBWRTA,IBCMD,IBCMDA,IBRD,IBRDA,
    IBSTOP,IBRPP,IBRSP,IBDIAG,IBXTRC,IBRDI,IBWRTI,IBRDIA,IBWRTIA,IBSTA%,IBERR%,IBCNT%)
190 BDNAME$ = "GPIB0"
200 CALL IBFIND(BDNAME$,GPIB0%)
210 IF GPIB0% < 0 THEN PRINT "ERROR":END
220 BDNAME$ = "DEV4"
230 CALL IBFIND(BDNAME$,DEV4%)
240 IF DEV4% < 0 THEN PRINT "ERROR":END
250 '
260 OUT &H303,&H80 : ' CONFIGURATION OF RELAY CARD
270 '
280 CLS
290 PRINT "BEFORE RUNNING THIS PROGRAM, IT IS NECESSARY TO RE-BOOT BASICA WITH"
300 PRINT "THE COMMAND  BASICA/F:5"
310 PRINT
320 PRINT "THIS PROGRAM IS TO BE USED TO STORE NORMALIZED SENSOR READINGS TO A"
330 PRINT "DATA FILE. THE SENSOR READINGS ARE NORMALIZED BY DIVIDING THEIR "
340 PRINT "VALUE BY A REFERENCE. UP TO FIVE SENSORS CAN BE MONITORED."
350 PRINT "EACH SENSOR IS CONNECTED TO THE LOCK-IN AMPLIFIER BY A COMPUTER"
360 PRINT "CONTROLLED BNC SWITCHING DEVICE."
370 PRINT
380 PRINT "NOTE: IT IS IMPOTANT TO CONNECT THE SENSORS IN SEQUENTIAL ORDER FROM
390 PRINT "    RIGHT TO LEFT."
400 PRINT "    Also, record by hand the length of each sensor, the
410 PRINT "    max reading, and the reading of the sensor after the
420 PRINT "    glue dries. This information will be needed to compute
430 PRINT "    the strain in the STRAIN.BAS program.
440 PRINT "PRESS ENTER TO CONTINUE"
450 '
460 IF INKEY$ = "" THEN 450
470 CLS
480 TIME$="00:00:00" TIME SET TO 0
490 INPUT "How many sensors will be used ";AA
500 CLS

```

```

510 NUMBER = 2*AA
520 NOISE=0 'TURNS OFF THE BEEP ON THE AUTOMEASURE
530 '
540 '* * * * * OPEN OUTPUT DATA FILES * * * * *
550 '
560 FOR FF = 1 TO AA
570 PRINT "Please input name for data file from sensor"FF
580 INPUT "File name ";FILES$
590 OPEN FILES$ FOR OUTPUT AS #FF
600 CLS
610 NEXT FF
620 '
630 PRINT
640 '
650 '* * * * * INITIALIZES SENSOR AND REF SENSITIVITY * * * * *
660 '
670 FOR INITIAL = 1 TO NUMBER
680 CLS
690 PRINT"AUTO MEASURE IN PROGRESS
700 '
710 J=INT(INITIAL/2):K=INT((INITIAL+1)/2)
720 Q=J-K 'CHECKS TO SEE IF REF OR SENSOR ON
730 '
740 IF INITIAL = 1 THEN 760
750 IF Q<0 THEN 800 'REF ON WHEN Q<0
760 COUNT=COUNT + 1
770 OUT &H301,2^(COUNT-1)
780 GOSUB 1940 'AUTOMEASURE
790 SNS(COUNT) = SNS
800 NEXT INITIAL
810 '
820 CLS
830 PRINT
840 NOISE=1 'TURNS ON BEEP IN AUTOMEASURE
850 COUNT=1
860 LOCATE 1,5
870 PRINT"? TO QUIT"
880 LOCATE 1,20
890 PRINT"! TO TURN OFF A SENSOR"
900 XXX$=INKEY$
910 IF XXX$ = "?" THEN 1310 'JUMPS TO END AND CLOSES FILES
920 '
930 '* * * MAIN LOOP: RECORDS TIME,TEMP,AND NORM OF REF AND SENSORS * * * * *
940 '
950 FOR II = 2 TO AA+1
960 IF FLG(II)=1 THEN 1250 'SENSOR TURNED OFF WHEN FLG SET TO 1
970 HOLDC = COUNT
980 '* * * REF OUPUT * * *
990 COUNT = 1 'COUNT=1 FOR ALL REF
1000 OUT &H301,1
1010 GOSUB 2840 'RECALL INITIAL SENSITIVITY
1020 GOSUB 2130 'LOCK-IN AMP OUTPUT

```

```

1030 GOSUB 2560 'SENSITIVITY PUT IN TERMS OF mV
1040 GOSUB 1410 'CHECK OUTPUT
1050 IF CHECK = 1 THEN 1010 'NEW OUTPUT FOUND USING ADJUSTED SENSITIVITY
1060 OUT &H301,2^(II-1)
1070 FOR P = 1 TO 200:NEXT P
1080 REF = X*LOCK2/1000
1090 '
1100 '***** SENSOR OUTPUT *****
1110 '
1120 COUNT = HOLDC + 1
1130 GOSUB 2840 'RECALL SENSITIVITY
1140 GOSUB 2130 'LOCK-IN AMP OUTPUT
1150 IF FLG(II)=1 THEN 1250 'SENSOR TURNED OFF WHEN FLG=1
1160 GOSUB 1410 'CHECK OUTPUT
1170 IF FLG(II)=1 THEN 1250 'SENSOR TURNED OFF WHEN FLG=1
1180 IF CHECK = 1 THEN 1130 'RE-EVALUATE OUTPUT FOR ADJUSTED SENSITIVITY
1190 GOSUB 2560 'SENSITIVITY PUT IN TERMS OF mV
1200 SENSOR = X*LOCK2/1000
1210 '
1220 GOSUB 3030 'TEMPERATURE
1230 GOSUB 3360 'TIME
1240 GOSUB 1620 'OUTPUT
1250 NEXT II
1260 '
1270 XXX$=INKEY$
1280 IF XXX$ = "?" THEN 1310 '? ENDS PROGRAM
1290 GOTO 830 'TAKES ANOTHER SET OF READINGS
1300 '
1310 FOR FF = 1 TO AA
1320 CLOSE #FF
1330 NEXT FF
1340 OUT &H301,0
1350 LOCATE 20,1
1360 PRINT:PRINT"THE PROGRAM HAS BEEN STOPPED, AND THE DATA HAS BEEN WRITTEN
1370 PRINT"TO THE DESIGNATED FILES.
1380 END
1390 '
1400 '
1410 '----- SUBROUTINE: CHECK SENSITIVITY -----
1420 '
1430 '
1440 WRT$ = "N" 'N CHECKS FOR AN OVERLOAD
1450 CALL IBWRT(DEV4%,WRT$)
1460 ANSWER$=SPACES$(10)
1470 CALL IBRD(DEV4%,ANSWER$)
1480 N=VAL (ANSWER$)
1490 CHECK = 0 ' THIS CHECKS WHEN THE AUTOMEASURE IS REPEATED
1500 IF N=0 THEN 1560 'N > 0 THEN THERE IS AN OVERLOAD
1510 DUMMY$=INKEY$
1520 IF DUMMY$="!" THEN 3220 '! TURNS OFF A SENSOR
1530 IF FLG(II)=1 THEN 1590 'FLG = 1 THEN SENSOR TURNED OFF
1540 GOSUB 1940 'AUTOMEASURE

```



```

1550 IF CHECK=1 THEN 1580
1560 IF LOCK1 > 2100 THEN 1590
1570 GOSUB 2920 'SENSITIVITY CHANGED BY ONE STEP
1580 SNS(COUNT) = SNS
1590 RETURN
1600 '
1610 '
1620 '----- SUBROUTINE: OUTPUT -----
1630 '
1640 '
1650 IF (II-1) = 1 THEN PRINT #1,MIN,TEMP,SENSOR/REF
1660 IF (II-1) = 2 THEN PRINT #2,MIN,TEMP,SENSOR/REF
1670 IF (II-1) = 3 THEN PRINT #3,MIN,TEMP,SENSOR/REF
1680 IF (II-1) = 4 THEN PRINT #4,MIN,TEMP,SENSOR/REF
1690 IF (II-1) = 5 THEN PRINT #5,MIN,TEMP,SENSOR/REF
1700 IF (II-1) = 6 THEN PRINT #6,MIN,TEMP,SENSOR/REF
1710 IF (II-1) = 7 THEN PRINT #7,MIN,TEMP,SENSOR/REF
1720 TRACK = TRACK + 1
1730 IF TRACK = (II-1) THEN 1780 'SKIPS FIRST COLUMN AFTER INITIAL READING
1740 'INITIAL READING PUT IN FIRST COLUMN
1750 X=3:Y=40
1760 GOTO 1790
1770 '
1780 X=3:Y=7
1790 XX = (II-1)*3 + 2
1800 LOCATE X,Y:PRINT " "
1810 LOCATE X,Y:PRINT "TEMP (C) "TEMP
1820 X=XX
1830 LOCATE X,Y:PRINT " "
1840 LOCATE X,Y:PRINT "REF "(II-1)REF
1850 X=XX+1
1860 LOCATE X,Y:PRINT " "
1870 LOCATE X,Y:PRINT "SENSOR"(II-1)SENSOR
1880 X=XX+2
1890 'OCATE X,Y:PRINT " "
1900 LOCATE X,Y:PRINT "NORM "(II-1)SENSOR/REF
1910 RETURN
1920 '
1930 '
1940 '----- SUBROUTINE: AUTOMEASURE -----
1950 '
1960 '
1970 CHECK = 1 'DOCUMENTS AUTOMEASURE
1980 WRT$="AS"
1990 CALL IBWRT(DEV4%,WRT$)
2000 PRINT"HIT * WHEN RED AUTO LIGHT TURNS OFF
2010 IF NOISE = 0 THEN 2030
2020 BEEP:FOR P=1 TO 800:NEXT P
2030 IF INKEY$="*" THEN 2050
2040 GOTO 2030
2050 WRT$="SEN"
2060 CALL IBWRT(DEV4%,WRT$)

```

```

2070 ANSWER$=SPACES$(10)
2080 CALL IBRD(DEV4%,ANSWER$)
2090 SNS=VAL (ANSWER$)
2100 RETURN
2110 '
2120 '
2130 '----- SUBROUTINE: LOCK-IN AMP -----
2140 '
2150 '
2160 WRT$="OUT"
2170 CALL IBWRT(DEV4%,WRT$)
2180 ANSWER$=SPACES$(10)
2190 CALL IBRD(DEV4%,ANSWER$)
2200 FOR P=1 TO 200:NEXT P
2210 LOCK2 = 0
2220 WRT$="AQN"
2230 CALL IBWRT(DEV4%,WRT$)
2240 FOR P=1 TO 300:NEXT P
2250 FOR CHRIS=1 TO 5
2260 DUMMY$=INKEY$
2270 IF DUMMY$="!" THEN GOSUB 3220 '! TURNS OFF A SENSOR
2280 IF FLG(II)=1 THEN 2530
2290 LOCK2A=0
2300 FOR I = 1 TO 10
2310 WRT$="OUT"
2320 CALL IBWRT(DEV4%,WRT$)
2330 ANSWER$=SPACES$(10)
2340 CALL IBRD(DEV4%,ANSWER$)
2350 LOCK1=VAL(ANSWER$)
2360 LOCK2A=LOCK2A+LOCK1/100
2370 NEXT I
2380 DUMMY$=INKEY$
2390 IF DUMMY$="!" THEN 3220
2400 LOCK2=0
2410 FOR I = 1 TO 10
2420 WRT$="OUT"
2430 CALL IBWRT(DEV4%,WRT$)
2440 ANSWER$=SPACES$(10)
2450 CALL IBRD(DEV4%,ANSWER$)
2460 LOCK1=VAL(ANSWER$)
2470 LOCK2=LOCK2+LOCK1/100
2480 NEXT I
2490 CK = ABS(LOCK2-LOCK2A)/LOCK2
2500 IF CK < .01 THEN CHRIS = 5
2510 NEXT CHRIS
2520 RETURN
2530 '
2540 '
2550 '
2560 '----- SUBROUTINE: TAKE THE SENSITIVITY AND PUT
2570 ' IT IN TERMS OF mV AS VARIABLE X -----
2580 '

```

```

2590 '
2600 WRT$="SEN"
2610 CALL IBWRT(DEV4%,WRT$)
2620 ANSWER$=SPACE$(10)
2630 CALL IBRD(DEV4%,ANSWER$)
2640 SEN=VAL(ANSWER$)
2650 IF SEN = 0 THEN X=.0001
2660 IF SEN = 1 THEN X=.0003
2670 IF SEN = 2 THEN X=.001
2680 IF SEN = 3 THEN X=.003
2690 IF SEN = 4 THEN X=.01
2700 IF SEN = 5 THEN X=.03
2710 IF SEN = 6 THEN X=.1
2720 IF SEN = 7 THEN X=.3
2730 IF SEN = 8 THEN X=1
2740 IF SEN = 9 THEN X=3
2750 IF SEN = 10 THEN X=10
2760 IF SEN = 11 THEN X=30
2770 IF SEN = 12 THEN X=100
2780 IF SEN = 13 THEN X=300
2790 IF SEN = 14 THEN X=1000
2800 IF SEN = 15 THEN X=3000
2810 RETURN
2820 '
2830 '
2840 '----- SUBROUTINE: RECALL AUTOMEASURED SENSITIVITY -----
2850 '
2860 '
2870 WRT$="SEN"+STR$(SNS(COUNT))
2880 CALL IBWRT(DEV4%,WRT$)
2890 RETURN
2900 '
2910 '
2920 '----- SUBROUTINE: SENSITIVITY CHANGED BY ONE STEP -----
2930 '
2940 '
2950 CHECK=1 ' KEEPS TRACK OF WHEN OUTPUT ADJUSTED
2960 DECR=SNS(COUNT)-1
2970 WRT$="SEN"+STR$(DECR)
2980 CALL IBWRT(DEV4%,WRT$)
2990 SNS=DECR
3000 RETURN
3010 '
3020 '
3030 '----- SUBROUTINE: TEMPERATURE RECORDED -----
3040 '
3050 '
3060 SUM = 0
3070 FOR X=1 TO 10
3080 OUT &H220,0
3090 A=0
3100 A=INP (&H220)

```

```

3110 IF A > 127 THEN 3120 ELSE 3100
3120 B = INP(&H221)
3130 C = INP(&H221)
3140 N = 16*B + C/16
3150 N = 10*N/4096 - 5
3160 SUM = SUM + N
3170 NEXT X
3180 TEMP = SUM*100
3190 RETURN
3200 '
3210 '
3220 '----- SUBROUTINE: SENSOR TURNED OFF -----
3230 '
3240 '
3250 LOCATE 20,1
3260 INPUT"WHAT SENSOR WILL BE TURNED OFF";SR
3270 LOCATE 20,1:PRINT "
3280 XX=3 + SR*3
3290 X=XX:Y=60
3300 LOCATE X,Y
3310 PRINT"SENSOR"(SR)"OFF"
3320 FLG(SR+1)=1
3330 RETURN
3340 '
3350 '
3360 '----- SUBROUTINE: TIME -----
3370 '
3380 '
3390 SECONDS=VAL(RIGHT$(TIMES$,2))
3400 MINUTES=VAL(MID$(TIMES$,4,2))
3410 HOURS=VAL(LEFT$(TIMES$,2))
3420 MIN=SECONDS/60 + MINUTES + HOURS*60
3430 LOCATE 1,55 :PRINT"
3440 LOCATE 1,55
3450 PRINT MIN "MINUTES"
3460 RETURN

```

```

10 '      CALNORM.BAS      by A. Plante
20 '
30 ' THIS PROGRAM WILL NORMALIZE A DOE DATA FILE GENERATED FROM
40 ' THE MICRON2.BAS PROGRAM. THE DATA FILE CONTAINS THE LENGTH
50 ' OF THE AIR GAP AND THE OUTPUT VOLTAGE IN mV.
60 '
63 '*****
66 '
70 CLS
80 PRINT:PRINT"This program will normalize a DOE data file generated from the MICROM2.BAS  program."
90 PRINT:PRINT:PRINT"What is the name of the data file to be normalized?"
100 INPUT "FILE NAME ";FILES$
110 PRINT:PRINT"What is the name of the new normalized data file?"
120 INPUT "NEW FILE NAME ";NFILES$
130 CLS
140 DIM X(3000),Y(3000),Z(3000),NORM(3000)
150 '
160 ' * * * COUNTS THE NUMBER OF COLUMNS IN A FILE * * *
170 '
180 OPEN FILES$ FOR INPUT AS #1
190 IF EOF(1) THEN 230
200 INPUT #1, X,Y
210 NUM=NUM + 1
220 GOTO 190
230 CLOSE #1
240 '
250 ' * * * VALUES PUT INTO ARRAY * * *
260 '
270 OPEN FILES$ FOR INPUT AS #1
280 COUNT = COUNT + 1
290 INPUT #1, X,Y
300 X(COUNT) = X
310 Y(COUNT) = Y
320 IF COUNT=NUM THEN 340
330 GOTO 280
340 CLOSE #1
350 '
360 ' * * * FINDS THE LARGEST VALUE OF Y * * *
370 '
380 COUNT = 0
390 BIG = Y(1)
400 FOR COUNT = 1 TO NUM
410 IF Y(COUNT+1) > BIG THEN BIG=Y(COUNT+1)
420 NEXT COUNT
430 '
440 ' * * * WRITES THE NORMALIZED VALUE TO A FILE * * *
450 '
460 OPEN NFILES$ FOR OUTPUT AS #2
470 FOR COUNT = 1 TO NUM
480 NORM(COUNT) = Y(COUNT)/BIG
490 PRINT #2, X(COUNT),NORM(COUNT)
500 NEXT COUNT

```

510 CLOSE #2
520 CLS
530 PRINT:PRINT:PRINT"THE NEW NORMALIZED FILE IS "NFILES\$
540 '
550 END

```

10'          STRAIN.BAS    by A. Plante
20'
30'  THIS PROGRAM WILL TAKE A DOE FILE GENERATED FROM THE DOEPROG.BAS
40'  PROGRAM AND CALCULATE THE THEORETICAL AND EXPERIMENTAL STRAIN.
50'  IT WILL THEN PUT THESE CALCULATED VALUES INTO TWO FILES CONTAINING
60'  STRAIN AND TIME SO THAT PLOTS OF THE THEORETICAL AND EXPERIMENTAL
70'  VERSUS TIME CAN BE OBTAINED.
80'
90' *****
100'
110 CLS:KEY OFF
120'
130 PRINT"THIS PROGRAM WILL TAKE A DOE FILE AND CALCULATE THE EXPERIMENTAL AND
THEORETICAL STRAIN.
140 PRINT:PRINT:PRINT:INPUT "WHAT IS THE NAME OF THE FILE";FILES
150'
160 OPEN FILES FOR INPUT AS #1
170 DIM X(2000),Y(2000),Z(2000),NORM(2000),TSTRAIN(2000),ESTRAIN(2000),GAP(2000)
180'
190 GOSUB 330 'NORMALIZES INTENSITY
200 CLS
210 PRINT:INPUT "WHAT WAS THE LENGTH OF THE SENSOR";LENGTH
220 INPUT "WHAT WAS THE INTIAL MAXIMUM READING OF THE SENSOR";IMAX
230 INPUT "WHAT WAS THE READING OF THE SENSOR AFTER THE GLUE";GLUE
240 PRINT:INPUT "WHAT WILL THE EXPERIMENTAL STRAIN VS TIME FILE BE CALLED";EFILES
250 INPUT "WHAT WILL THE THEORETICAL STRAIN VS TIME FILE BE CALLED";TFILES
260'
270 GOSUB 680 'THEORETICAL STRAIN
280 GOSUB 810 'EPERIMENTAL STRAIN
290 END
300'
310'----- NORMALIZATION OF INTENSITY -----
320'
330' * * * COUNTS THE NUMBER OF COLUMNS IN A FILE * * *
340'
350 IF EOF(1) THEN 390
360 INPUT #1, X,Y,Z 'TIME, TEMP, INTENSITY
370 NUM=NUM + 1
380 GOTO 350
390 CLOSE #1
400'
410' * * * VALUES PUT INTO ARRAY * * *
420'
430 OPEN FILES FOR INPUT AS #1
440 COUNT = COUNT + 1
450 INPUT #1, X,Y,Z
460 X(COUNT) = X
470 Y(COUNT) = Y
480 Z(COUNT) = Z
490 IF COUNT=NUM THEN 510
500 GOTO 440
510 CLOSE #1

```

```

520 '
530 ' * * * FINDS THE LARGEST VALUE OF Z * * *
540 '
550 COUNT = 0
560 BIG = Z(1)
570 FOR COUNT = 1 TO NUM
580 IF Z(COUNT+1) > BIG THEN BIG=Z(COUNT+1)
590 NEXT COUNT
600 '
610 ' * * * PUTS NORMALIZED INTENSITY INTO AN ARRAY * * *
620 '
630 FOR COUNT = 1 TO NUM
640 NORM(COUNT) = Z(COUNT)/BIG
650 NEXT COUNT
660 RETURN
670 '
680 '----- THEORETICAL DETERMINATION OF STRAIN -----
690 '
700 FOR LOOP1 = 1 TO NUM
710 TSTRAIN(LOOP1) = 4.53E-06 * (Y(LOOP1)-Y(1)) 'Y IS TEMP Y1 IS INITIAL
720 NEXT LOOP1
730 OPEN TFILES FOR OUTPUT AS #1
740 FOR LOOP2 = 1 TO NUM
750 PRINT #1,X(LOOP2),TSTRAIN(LOOP2)
760 NEXT LOOP2
770 CLOSE #1
780 RETURN
790 '
800 '
810 '----- EXPERIMENTAL DETERMINATION OF STRAIN -----
820 '
830 OPEN EFILES FOR OUTPUT AS #1
840 NN = NORM(1)*IMAX/GLUE
850 IGAP=5517.2-40376!*NN+125090!*NN^2-192230!*NN^3+144740!*NN^4-42742!*NN^5
860 FOR LOOP3 = 1 TO NUM
870 N = NORM(LOOP3)
880 GAP(LOOP3)=5517.2-40376!*N+125090!*N^2-192230!*N^3+144740!*N^4-42742!*N^5
890 ESTRAIN(LOOP3) = (GAP(LOOP3)-IGAP)/LENGTH
900 PRINT #1,X(LOOP3),ESTRAIN(LOOP3)
910 NEXT LOOP3
920 CLOSE #1
930 RETURN

```



```

10 '      NEWDAT.BAS      by A. Plante
20 '
30 ' THIS PROGRAM WILL CONVERT A DOE NORMALIZED FILE INTO TWO
40 ' SEPARATE FILES. ONE OF THE TWO NEW FILES WILL CONTAIN TIME
50 ' AND TEMPERATURE DATA, AND THE OTHER WILL CONTAIN TIME AND
60 ' NORMALIZED DATA. THE PROGRAMS DOEPROG.BAS AND NORMA.BAS
70 ' SHOULD BE RUN PRIOR TO USING THIS PROGRAM.
80 '
90 '*****
100 '
110 CLS:KEY OFF
120 DIM X(3000),Y(3000),Z(3000)
130 '
140 PRINT:PRINT"This program will convert a DOE normalized file into two separate files.
      One of the two new files will contain time and temperature data, and the other will
      contain time and normalized data.
150 PRINT:PRINT"If you have not run the program: NORMA.BAS you must stop the
      program and run it first.
160 PRINT:PRINT:PRINT
170 INPUT "WHAT IS THE NAME OF THE NORMALIZED FILE TO BE SEPARATED";FILES
180 INPUT "TMP FILE";FILEAS
190 INPUT "NOR FILE";FILEBS
200 OPEN FILE$ FOR INPUT AS #1
210 COUNT = COUNT + 1
220 INPUT #1, X,Y,Z
230 X(COUNT)=X:Y(COUNT)=Y:Z(COUNT)=Z
240 IF EOF(1) THEN 260
250 GOTO 210
260 CLOSE #1
270 '
280 OPEN FILEAS FOR OUTPUT AS #3
290 OPEN FILEBS FOR OUTPUT AS #2
300 FOR LOOP = 1 TO COUNT
310 PRINT #3,X(LOOP),Y(LOOP)
320 PRINT #2,X(LOOP),Z(LOOP)
330 NEXT LOOP
340 CLOSE #3
350 CLOSE #2
360 PRINT:PRINT:PRINT:PRINT"THE TWO NEW FILES HAVE BEEN NAMED " FILEAS " AND " FILEBS
370 END

```

```

1'      MICRON2.BAS      A. Plante  2 September 1990
5'
6'
30'
32'  This program is to be used to calibrate an intensity-based sensor.
33'  Normalized sensor readings and the length of the air gap will be
34'  stored in a data file. The sensor readings are normalized by
35'  dividing their value by a reference. The sensor should be assembled
36'  on a linear micro-positioner with the ends butted together (zero gap)
37'  prior to running this program. The sensor should also be connected
38'  to a lock-in amplifier.
40'
50'
60'
70  CLEAR ,60000! : IBINT1=60000! : IBINT2=IBINT1+3 : BLOAD "bib.m",IBINT1
80  CALL IBINT1(IBFIND,IBTRG,IBCLR,IBPCT,IBSIC,IBLOC,IBPPC,IBBNA,IBONL,IBRSC,IBSRE,IBRSV,
    IBPAD,IBSAD,IBIST,IBDMA,IBEOS,IBTMO,IBEOT,IBRDF,IBWRTF,IBTRAP,IBDEV,IBLN)
90  CALL IBINT2(IBGTS,IBCAC,IBWAIT,IBPOKE,IBWRT,IBWRTA,IBCMD,IBCMDA,IBRD,IBRDA,IBSTOP,
    IBRPP,IBRSP,IBDIAG,IBXTRC,IBRDI,IBWRTI,IBRDIA,IBWRTIA,IBSTA%,IBERR%,IBCNT%)
100 BDNAMES$ = "GPIB0"
110 CALL IBFIND(BDNAMES,GPIB0%)
120 IF GPIB0% < 0 THEN PRINT "ERROR":END
130 BDNAMES$ = "DEV4"
140 CALL IBFIND(BDNAMES,DEV4%)
150 IF DEV4% < 0 THEN PRINT "ERROR":END
160 '
170 OUT &H303,&H80 : ' *** This line configures the relay card ***
180 '
190 CLS
220 PRINT
230 PRINT "THIS PROGRAM IS TO BE USED TO STORE NORMALIZED SENSOR READINGS TO A"
240 PRINT "DATA FILE. THE SENSOR READINGS ARE NORMALIZED BY DIVIDING THEIR "
250 PRINT "VALUE BY A REFERENCE. THE SENSOR SHOULD BE ASSEMBLED ON "
255 PRINT "A LINEAR MICRO-POSITIONER WITH THE ENDS BUTTED TOGETHER (ZERO GAP). "
260 PRINT "THE SENSOR SHOULD BE CONNECTED TO THE LOCK-IN AMPLIFIER."
280 PRINT
310 PRINT
320 PRINT "PRESS ENTER TO CONTINUE"
330 '
340 IF INKEY$ = "" THEN 330
350 CLS
360 PRINT "TO QUIT THE PROGRAM AT ANY TIME, TYPE ?"
365 PRINT:PRINT"TO ENTER THE TEMPERATURE, TYPE +"
370 PRINT:PRINT
380 PRINT "PRESS ENTER TO CONTINUE"
390 '
400 IF INKEY$ = "" THEN 390
410 CLS
420 INPUT "How many sensors will be calibrated ";AA
430 CLS
440 NUMBER = 2*AA
450 NOISE=0

```

```

460 FOR FF = 1 TO AA
470 PRINT "Please input name for the calibration data file for sensor"FF
480 INPUT "File name ";FILES$
490 OPEN FILES FOR OUTPUT AS #FF
500 CLS
510 NEXT FF
520 PRINT
530 FOR INITIAL = 1 TO NUMBER
540 CLS
550 PRINT"AUTO MEASURE IN PROGRESS
560 J=INT(INITIAL/2):K=INT((INITIAL+1)/2)
570 Q=J-K
580 IF INITIAL = 1 THEN 600
590 IF Q<0 THEN 650
600 COUNT=COUNT + 1
610 OUT &H301,2^(COUNT-1)
620 GOSUB 1330
630 SNS(COUNT) = SNS
645 FOR P=1 TO 600:NEXT P
650 NEXT INITIAL
660 FOR P=1 TO 500:NEXT P:CLS
670 PRINT
680 NOISE=1
690 COUNT=1
700 FOR II = 2 TO AA+1
705 INPUT "HOW MUCH WAS THE MICROMETER MOVED";MICR
707 MEAS=MICR + MEAS
710 HOLDC = COUNT
720 COUNT = 1
730 OUT &H301,1
750 GOSUB 1900 'RECALL SENSITIVITY SUBROUTINE
760 GOSUB 1490 'LOCK-IN AMP SUBROUTINE
770 GOSUB 1620 'SENSITIVITY PUT IN TERMS OF mV SUBROUTINE
780 GOSUB 1020 'CHECK OUTPUT
790 IF CHECK = 1 THEN 750
800 OUT &H301,2^(II-1)
810 FOR P = 1 TO 200:NEXT P
820 REF = X*LOCK2/1000
830 COUNT = HOLDC + 1
840 GOSUB 1900 'RECALL SENSITIVITY SUBROUTINE
850 GOSUB 1490 'LOCK-IN AMP
860 GOSUB 1020 'CHECK OUTPUT
870 IF CHECK = 1 THEN 840
880 GOSUB 1620 'SENSITIVITY PUT IN TERMS OF mV
890 SENSOR = X*LOCK2/1000
895 GOSUB 2200
900 GOSUB 1200 'OUTPUT
910 NEXT II
912 XXX$=INKEY$
915 IF XXX$ = "?" THEN 940
930 GOTO 670
940 FOR FF = 1 TO AA

```

```

950  CLOSE #FF
960  NEXT FF
970  OUT &H301,0
980  PRINT:PRINT"THE PROGRAM HAS BEEN STOPPED, AND THE DATA HAS BEEN WRITTEN
990  PRINT"TO THE DESIGNATED FILES.
1000 END
1010 '
1020 '--- CHECK SENSITIVITY SUBROUTINE ---
1030 '
1040  WRT$ = "N" 'N CHECKS FOR AN OVERLOAD
1050  CALL IBWRT(DEV4%,WRT$)
1060  ANSWERS$=SPACES$(10)
1070  CALL IBRD(DEV4%,ANSWERS$)
1090  N=VAL (ANSWERS$)
1100  CHECK = 0 ' THIS CHECKS WHEN THE AUTOMEASURE IS REPEATED
1110  IF N > 0 THEN 1140
1120  IF LOCK1 > 2100 THEN 1180
1130  GOSUB 2000
1135  IF LOCK1 > 2100 THEN 1150
1140  GOSUB 1330
1150  SNS(COUNT) = SNS
1160  CHECK = 1 'KEEPS TRACK OF WHEN AUTOMEASURE IS REPEATED
1180  RETURN
1190 '
1200 '--- OUTPUT SUBROUTINE ---
1210 '
1214  PRINT"AIR GAP "MEAS "MICRONS
1215  PRINT"AT "TEMP" C"
1220  PRINT "Reference"REF,"Sensor"(II-1)SENSOR,"Norm "SENSOR/REF
1230  IF (II-1) = 1 THEN PRINT #1,MEAS,SENSOR/REF
1240  IF (II-1) = 2 THEN PRINT #2,MEAS,SENSOR/REF
1250  IF (II-1) = 3 THEN PRINT #3,MEAS,SENSOR/REF
1260  IF (II-1) = 4 THEN PRINT #4,MEAS,SENSOR/REF
1270  IF (II-1) = 5 THEN PRINT #5,MEAS,SENSOR/REF
1280  IF (II-1) = 6 THEN PRINT #6,MEAS,SENSOR/REF
1290  IF (II-1) = 7 THEN PRINT #7,MEAS,SENSOR/REF
1300  RETURN
1310 '
1320 '
1330 '--- AUTO MEASURE SUBROUTINE ---
1340 '
1350  WRT$="AS"
1360  CALL IBWRT(DEV4%,WRT$)
1370  PRINT"HIT * WHEN RED AUTO LIGHT TURNS OFF
1380  IF NOISE = 0 THEN 1400
1390  BEEP:FOR P=1 TO 800:NEXT P
1400  IF INKEY$="*" THEN 1410
1405  GOTO 1400
1410  WRT$="SEN"
1420  CALL IBWRT(DEV4%,WRT$)
1430  ANSWERS$=SPACES$(10)
1440  CALL IBRD(DEV4%,ANSWERS$)

```

```

1450 SNS=VAL (ANSWERS)
1460 RETURN
1470 '
1480 '
1490 --- LOCK-IN AMP SUBROUTINE ---
1500 '
1501 WRT$="OUT"
1502 CALL IBWRT(DEV4%,WRT$)
1503 ANSWER$=SPACES(10)
1504 CALL IBRD(DEV4%,ANSWERS)
1505 FOR P=1 TO 200:NEXT P
1510 LOCK2 = 0
1520 FOR I = 1 TO 10
1530 WRT$="OUT"
1540 CALL IBWRT(DEV4%,WRT$)
1550 ANSWER$=SPACES(10)
1560 CALL IBRD(DEV4%,ANSWERS)
1570 LOCK1=VAL(ANSWER$)
1580 LOCK2=LOCK2+LOCK1/100
1590 NEXT I
1600 RETURN
1610 '
1620 --- THIS SUBROUTINE TAKES THE SENSITIVITY
1630 ' AND PUTS IT IN TERMS OF mV AS VARIABLE X ---
1640 '
1650 WRT$="SEN"
1660 CALL IBWRT(DEV4%,WRT$)
1670 ANSWER$=SPACES(10)
1680 CALL IBRD(DEV4%,ANSWERS)
1690 SEN=VAL(ANSWERS)
1700 IF SEN = 0 THEN X=.0001
1710 IF SEN = 1 THEN X=.0003
1720 IF SEN = 2 THEN X=.001
1730 IF SEN = 3 THEN X=.003
1740 IF SEN = 4 THEN X=.01
1750 IF SEN = 5 THEN X=.03
1760 IF SEN = 6 THEN X=.1
1770 IF SEN = 7 THEN X=.3
1780 IF SEN = 8 THEN X=1
1790 IF SEN = 9 THEN X=3
1800 IF SEN = 10 THEN X=10
1810 IF SEN = 11 THEN X=30
1820 IF SEN = 12 THEN X=100
1830 IF SEN = 13 THEN X=300
1840 IF SEN = 14 THEN X=1000
1850 IF SEN = 15 THEN X=3000
1880 RETURN
1890 '
1900 --- RECALL AUTOMEASURED SENSITIVITY ---
1910 '
1940 WRT$="SEN"+STR$(SNS(COUNT))
1960 CALL IBWRT(DEV4%,WRT$)

```

```

1970 RETURN
1980 '
1990 '
2000 '--- SENSIVITY CHANGED BY ONE STEP ---
2010 '
2020 PRINT"NOW IN STEP CHANGE SUB
2110 DECR=SNS(COUNT)-1
2120 WRT$="SEN"+STR$(DECR)
2122 CALL IBWRT(DEV4%,WRT$)
2123 ANSWER$ = SPACES(10)
2125 CALL IPRD(DEV4%,ANSWER$)
2126 PRINT ANSWER$
2130 PRINT"GOING TO CHECK OUTPUT WITH SEN-1
2140 GOSUB 1490
2170 SNS=DECR
2180 RETURN
2190 '
2200 '--- TEMPERATURE RECORDED ---
2210 '
2215 SUM = 0
2220 FOR X=1 TO 10
2250 OUT &H220,0
2280 A=0
2290 A=INP (&H220)
3000 IF A > 127 THEN 3010 ELSE 2290
3010 B = INP(&H221)
3020 C = INP(&H221)
3030 N = 16*B + C/16
3040 N = 10*N/4096 - 5
3050 SUM = SUM + N
3060 NEXT X
3070 TEMP = SUM*100
3080 RETURN

```

MAIN.BAS by C. KOOB
 LANGUAGE: QUICK BASIC

PROGRAM READS DATA FROM THE ANALOGUE TO DIGITAL CARD AND
 STORES IT FOR LATER USE. TIME IS ALWAYS RECORDED AND
 TEMPERATURE RECORDING IS OPTIONAL. UP TO FIVE NODES MAY
 BE MONITORED WITH A .15 VOLT NOISE THRESHOLD.

INITIALIZATION

```
DECLARE SUB CHANNELREAD (ADCHANNEL!, ADGAIN!, VOLTS!)
DECLARE SUB ETIME (TIMES!)
DIM SHARED GAIN(5)
DIM OLDVOLTS(7)
COMMON SHARED BASE.ADDRESS, COMMAND.REGISTER, STATUS.REGISTER,
DATA.REGISTER
COMMON SHARED COMMAND.WAIT, WRITE.WAIT, READ.WAIT, CCLEAR, CADIN, CSTOP
COMMON SHARED BASE.FACTOR, BASE.CHANNELS
' DEFINE SOME VARIABLES USED IN THE READ CHANNEL ROUTINE
```

```
BASE.ADDRESS = &H2EC
COMMAND.REGISTER = BASE.ADDRESS + 1
STATUS.REGISTER = BASE.ADDRESS + 1
DATA.REGISTER = BASE.ADDRESS
COMMAND.WAIT = &H4
WRITE.WAIT = &H2
READ.WAIT = &H5
```

```
CCLEAR = &H1
CADIN = &HC
CSTOP = &HF
```

```
BASE.FACTOR = 4096
BASE.CHANNELS = 16
GAIN(0) = 1
GAIN(1) = 2
GAIN(2) = 4
GAIN(3) = 8
TIMES$ = "0:00"
```


 #####

MAIN PROGRAM TO READ AND COLLECT DATA FROM THE AD-BOARD

#####

THIS SETS THE PARAMATERS IN THE PROGRAM

```
CLS
INPUT "Do you want to read the temperature "; NOTEMP$
IF NOTEMP$ = "N" THEN GOTO CHANNELSETUP
IF NOTEMP$ = "n" THEN GOTO CHANNELSETUP
CLS
PRINT "Connect the thurmocouple to channel 0"
INPUT "Press a return to continue"; NONSCENCE
CLS
ADCHANNEL = 0
ADGAIN = 0
CALL CHANNELREAD(ADCHANNEL, ADGAIN, VOLTS)
TEMP = VOLTS * 1000
PRINT "THE TEMPERATURE IS "; TEMP; " DEGREES"
```


THIS PART ASKS HOW MANY SENSORS YOU WANT TO HOOK UP

CHANNELSETUP:

```
PRINT
PRINT
INPUT "How many sensors do you want (1-5) "; NUMBSENSE
PRINT
PRINT
PRINT "PRESS CONTROL BREAK TO END"
DATA$ = "DOE"
DATB$ = ".DAT"
FOR X# = 1 TO NUMBSENSE
FILES$ = DATA$ + RIGHT$(STR$(X#), 1) + DATB$
PRINT FILES$
OPEN FILES$ FOR OUTPUT AS #X#
OLDVOLTS(X#) = 0
NEXT X#
```

```
IF NOTEMP$ = "N" GOTO LOOPNOTEMP
IF NOTEMP$ = "n" GOTO LOOPNOTEMP
```

```

*****
*****
*****

```

```

THIS PART LOOPS COLLECTING DATA

```

```

LOOPTEMP:

```

```

    ADCHANNEL = 0
    CALL CHANNELREAD(ADCHANNEL, ADGAIN, VOLTS)
    TEMP = VOLTS * 1000
    CALL ETIME(TIMES)

```

```

    FOR X = 1 TO NUMBSENSE
    CALL CHANNELREAD(X, ADGAIN, VOLTS)
    IF ABS(VOLTS - OLDVOLTS(X)) < .15 THEN GOTO SKIP
    OLDVOLTS(X) = VOLTS
    WRITE #X, TIMES, VOLTS, TEMP

```

```

SKIP:    NEXT X
        GOTO LOOPTEMP

```

```

*****
*****
*****

```

```

THIS PART LOOPS COLLECTING DATA AND NO TEMPERATURE

```

```

LOOPNOTEMP:

```

```

    TEMP = VOLTS * 1000
    CALL ETIME(TIMES)

```

```

    FOR X = 1 TO NUMBSENSE
    CALL CHANNELREAD(X, ADGAIN, VOLTS)
    IF ABS(VOLTS - OLDVOLTS(X)) < .15 THEN GOTO SKIPPY
    OLDVOLTS(X) = VOLTS
    WRITE #X, TIMES, VOLTS

```

```

SKIPPY:  NEXT X
        GOTO LOOPNOTEMP

```

```

END

```

```

*****
*****

```

CHANNELREAD

Subroutine to read a/d channel

Variables passed (adchannel, adgain, volts)

SUB CHANNELREAD (ADCHANNEL, ADGAIN, VOLTS) STATIC

SHARED GAIN()

SHARED BASE.ADDRESS, COMMAND.REGISTER, STATUS.REGISTER, DATA.REGISTER

SHARED COMMAND.WAIT, WRITE.WAIT, READ.WAIT, CCLEAR, CADIN, CSTOP

SHARED BASE.FACTOR, BASE.CHANNELS

'Stop and clear the dt2801 series board

OUT COMMAND.REGISTER, CSTOP

TEMP = INP(DATA.REGISTER)

WAIT STATUS.REGISTER, WRITE.WAIT, WRITE.WAIT

WAIT STATUS.REGISTER, COMMAND.WAIT

OUT COMMAND.REGISTER, CCLEAR

'WAIT UNTILL THE DT2801 SERIES BOARD DATA IN FULL FLAG IS CLEAR

'AND READY FLAG IS SET, THEN WRITE THE READ A/D IMMEDIATE COMAND

'BYTE TO THE COMMAND REGISTER.

WAIT STATUS.REGISTER, WRITE.WAIT, WRITE.WAIT

'WAIT STATUS.REGISTER, COMMAND.WAIT

OUT COMMAND.REGISTER, CADIN

'WAIT UNTILL THE DT2801 SERIES BOARD DATA IN FULLL FLAG IS CLEAR, THEN

'WRITE THE A/D GAIN BYTE TO THE DATA IN REGISTER.

WAIT STATUS.REGISTER, WRITE.WAIT, WRITE.WAIT

OUT DATA.REGISTER, ADGAIN

'WAIT UNTIL THE DT2801 SERIES BOARD DATA IN FULL FLAG IS CLEAR, THEN

'WRITE THE A/D CHANNELBYTE TO THE DATA IN REGISTER.

WAIT STATUS.REGISTER, WRITE.WAIT, WRITE.WAIT

OUT DATA.REGISTER, ADCHANNEL

'READ TWI BYTES IF A/D DATA FROM THE DATA OUT REGISTER, WAITING FOR A

'A SET DATA OUT READY (OR READY) FLAG BEFORE EACH READ AND COMBINE

THE

TWO BYTES INTO ONE WORD.

WAIT STATUS.REGISTER, READ.WAIT
LOW = INP(DATA.REGISTER)
WAIT STATUS.REGISTER, READ.WAIT
HIGH = INP(DATA.REGISTER)
DATA.VALUE = HIGH * 256 + LOW

WAIT UNTILL THE DT2801 DATA IN FULL FLAG IS CLEAR AND READY FLAG IS
SET, INDICATING COMMAND COMPLETION, THEN CHECK THE STATUS REGISTER
ERROR FLAG

WAIT STATUS.REGISTER, WRITE.WAIT, WRITE.WAIT
WAIT STATUS.REGISTER, COMMAND.WAIT
STATUS = INP(STATUS.REGISTER)
IF (STATUS AND &H80) THEN GOTO 970

CALCULATE AND THE A/D READING IN VOLTS.

FACTOR = (10 / BASE.FACTOR) / GAIN(ADGAIN)
UNI.VOLTS = DATA.VALUE * FACTOR
VOLTS = (UNI.VOLTS * 2 - (10 / GAIN(ADGAIN)))

GOTO 1030

970 ERROR

PRINT
PRINT "ERROR in A-D BOARD"

1030
END SUB

ETIME

Subroutine to read the time that has elapsed

Variable (times)

SUB ETIME (TIMES) STATIC

TEMP\$ = TIMES
SECONDS = VAL(RIGHT\$(TEMP\$, 2))
MINUTES = VAL(MID\$(TEMP\$, 4, 2))
HOURS = VAL(LEFT\$(TEMP\$, 2))
TIMES = SECONDS / 60 + MINUTES + HOURS * 60
END SUB

```

MODPOINT.BAS by C. KOOB
LANGUAGE: QUICK BASIC
PROGRAM ALLOWS THE USER TO SET THRESHOLDS FOR PEAKS AND VALEYS,
THEN THE PROGRAM FINDS THE PEAKS AND VALEYS THAT QUALIFY AND
STORE THERE TIME AND TEMPERATURE IN A FILE CALLED TEMPER.DAT

*****
START OF PROGRAM
GATHER FILE NAME DATA
10 CLS
20 PRINT "ENTER THE NAME OF THE FILE THAT YOU WISH TO FIND PEAKS AND VALEYS
FOR"
30 PRINT "THE .DAT EXTENTION IS ASSUMED."
40 PRINT
50 PRINT "File Name: "
60 INPUT B$
70 C$ = ".dat"
80 D$ = B$ + C$
90 PRINT "ENTER THE UPPER BOUND FOR THE PEAK SERCH ALGORITHM"
100 PRINT "Peak Threshold: "
110 INPUT MAXTHRESH
120 PRINT "ENTER THE LOWER BOUND FOR THE VALEY SERCH ALGORITHM"
130 PRINT "Min Threshold "
140 INPUT MINTHRESH
150 CLS
160 PRINT "THE SOURCE FILE IS "; D$
170 PRINT "THE MAXIMUM THRESHOLD IS "; MAXTHRESH
180 PRINT "THE MINIMUM THRESHOLD IS "; MINTHRESH
190 OPEN D$ FOR INPUT AS #1
200 OPEN "TEMPER.DAT" FOR OUTPUT AS #2
210 COUNT = 0
220 COUNT = COUNT + 1
230 IF EOF(1) THEN END
240 INPUT #1, time, VALUE, TEMP
*****
READ FIRST VALUE OF THE FILE TO DETERMINE WEATHER TO LOOK FOR A VALEY OR
PEAK
*****

250 IF VALUE > MAXTHRESH THEN GOTO 290
260 IF VALUE < MINTHRESH THEN GOTO 430
270 GOTO 220
*****
280 ' LOOK FOR PEAK
*****
290 MAXVALUE = VALUE
291 mtime = time
292 MTEMP = TEMP
300 WHERE = COUNT

```

```

310 COUNT = COUNT + 1
320 IF EOF(1) THEN GOTO 380
330 INPUT #1, time, VALUE, TEMP
340 IF VALUE > MAXVALUE THEN WHERE = COUNT
350 IF VALUE > MAXVALUE THEN MAXVALUE = VALUE
351 IF VALUE > MAXVALUE THEN mtime = time
352 IF VALUE > MAXVALUE THEN MTEMP = TEMP
360 IF VALUE > MINTHRESH THEN GOTO 310
*****
'IF VALUE GREATER THAN MIN THRESHOLD CONTINUE TO LOOK FOR A PEAK, ELSE
TAKE
'WHAT YOU HAVE STORE IT AND BEGIN LOOKING FOR A VALEY.
*****
370 GOTO 390
380 IF WHERE > (COUNT - 2) THEN END
390 PRINT #2, 0, WHERE, MAXVALUE, mtime, MTEMP
400 PRINT 0, WHERE, MAXVALUE, mtime, MTEMP
410 IF EOF(1) THEN GOTO 570
420 'valley find
430 MINVALUE = VALUE
431 mtime = time
432 MTEMP = TEMP
440 WHERE = COUNT
450 COUNT = COUNT + 1
460 IF EOF(1) THEN GOTO 520
470 INPUT #1, time, VALUE, TEMP
480 IF VALUE < MINVALUE THEN WHERE = COUNT
490 IF VALUE < MINVALUE THEN MINVALUE = VALUE
491 IF VALUE < MINVALUE THEN mtime = time
492 IF VALUE < MINVALUE THEN MTEMP = TEMP
500 IF VALUE < MAXTHRESH THEN GOTO 450
*****
'IF VALUE LESS THAN MAX THRESHOLD CONTINUE TO LOOK FOR A VALEY, ELSE TAKE
'WHAT YOU HAVE STORE IT AND BEGIN LOOKING FOR A PEAK.
*****
510 GOTO 530
520 IF WHERE > (COUNT - 2) THEN END
530 PRINT #2, 1, WHERE, MINVALUE, mtime, MTEMP
540 PRINT 1, WHERE, MINVALUE, mtime, MTEMP
550 IF EOF(1) THEN GOTO 570
560 GOTO 290
570 END

```

```

POINTCNT.BAS  by C. KOOB
LANGUAGE:      QUICK BASIC
PROGRAM ALLOWS THE USER TO SET THE NAME OF A DATA FILE TO WHICH
THE TIME, NUMBER OF FRINGES, AND TEMPERATURE WILL BE WRITTEN.
DATA IS OBTAINED FROM THE TEMPER.DAT FILE AND THE CREATED FILE WILL
HAVE AN EXTENTION OF .FNG

```

```

*****

```

```

START OF PROGRAM
  GATHER FILE NAME DATA

```

```

CLS
PRINT "ENTER THE FILE NAME TO HAVE DATA ( NUMBER OF FRINGES) STORED IN IT."
PRINT "THE .FNG EXTENTION IS ASSUMED AND NEED NOT BE ENTERED."
PRINT " "

```

```

INPUT "FILE NAME", file$
DATB$ = ".FNG"
OPEN "TEMPER.DAT" FOR INPUT AS #1
OPEN file$ + DATB$ FOR OUTPUT AS #3

```

```

*****

```

```

' INPUT THE FIRST VALUE AND GIVE IT A FRINGE COUNT OF 0

```

```

*****

```

```

  tab$ = CHR$(9)
  INPUT #1, PEAK1, COUNT, VALUE1, time, TEMP
  PRINT #3, time;tab$;0;TAB$;TEMP
  PRINT time,0,TEMP
  counter = 0

```

```

*****

```

```

' INPUT THE NEXT VALUE AND INCRIMENT THE FRINGE COUNT BY +.5

```

```

' IF END OF FILE THEN END, AND LOOP UNTIL END OF FILE

```

```

*****

```

```

20 IF EOF(1) THEN GOTO 200
  INPUT #1, PEAK1, COUNT, VALUE1, time, TEMP
  counter = counter + .5
  PRINT #3, time;tab$;counter;TAB$;TEMP
  PRINT time,counter,TEMP
  GOTO 20

```

```

200 END

```

END

DATE FILMED

07 / 03 / 91