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COMPUTERIZED DISPLACEMENT DATA
ANALYSIS IN LASER SPECKLE PHOTOGRAPHY

BY

BIJAN CHITSAZ
B.S.E., University of Central Florida, 1983

RESEARCH REPORT

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ABSTRACT

Laser speckle photography is an experimental technique which provides a non-contact means for direct measurement of in-plane displacements of objects subjected to different loading conditions. It requires a camera system to record two images of the object that are illuminated with laser light on a high resolution film. The double-exposure film (specklegram) is a permanent record of the displacement information of the object. Point-by-point analysis of the specklegram will yield the displacement data, but requires considerable time to complete the data reduction.

An automated data analysis system is developed and described in this report. He-Ne laser and computer-controlled translation stages holding the specklegram represent the first part of the system. A linear diode sensor is used to digitize the generated fringe pattern. Finally, a microcomputer and a spectrum analyzer are used to perform the analysis. The system has been successfully applied to the computation of displacements of a cantilever beam. Comparisons to theoretical results indicate that the system is indeed a viable one and may be used for more complex displacement analysis.

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CHAPTER I

INTRODUCTION

The demands for greater optimization in the design of load resisting structures have created a need for better experimental techniques for accurate measurement of the state of stress in the structure.

A number of experimental methods have been developed over the years, including both full-field methods such as photoelasticity, moire, holographic interferometry, speckle interferometry, etc., and point-by-point methods such as electrical resistance strain gages and speckle photography methods. Some of these methods are briefly explained below.

Photoelasticity Method

Photoelasticity is a method of stress analysis in which a model of the object under design is used. The model is made of special plastic material which possesses desirable strain-optical properties [1]. Photoelasticity depends upon the relationship between the state of stress in a transparent material (the model) and the way in which that material transmits polarized light. The experimentally determined quantity is an observed optical pattern; the observed optical pattern is related to the state of stress (Figure 1a) by using both the optical theory and the theory of elasticity; in

(a)

(b)

Figure 1. a) Fringe formation in a model under stress [1]. b) A circular polariscope.

addition the state of stress in the model must be related to the state of stress in the prototype by using appropriate model theory. Since the model is geometrically similar to the actual structure, the stress distribution in the model indicates the effects of geometry on the stress distribution in the actual structure [1]. Figure 1b shows the arrangement of elements in a circular polariscope.

Moire Method

The word moire is a French name for a fabric known as watered silk, which exhibits patterns of light and dark bands. This moire effect occurs whenever two similar but not quite identical arrays of equidistant lines or dots are arranged so that one array can be viewed through the other.

In stress analysis work, arrays consisting of straight parallel lines (ideally, opaque bars with transparent interspaces of equal width) are most commonly used. Such arrays are frequently referred to as grids or gratings [2]. Such grating must be applied to the area of interest on the object (photographic printing is most often used); another set of grid applied to a transparent sheet will be laid beside the first set. After applying stress to the object, the relative displacement can be measured using a micrometer or a microscope [3].

The moire fringe phenomenon can be explained in terms of the array of lines shown in Figure 2. The linear sets shown in Figure 2a are assumed to be identical; one set S is on the surface to be

Figure 2. a) M and S arrays. b) M and S arrays set beside each other. c) Relative displacement between M and S arrays [3].

studied, the other set M, applied to a transparent sheet (the opaque line width and the transparent space width are equal). Now assume that the master grid, M, is laid beside the S grid with all lines parallel, as in Figure 2b. After applying uniform strain to the surface, S, the two grids will move relative to each other (Figure 2c). In general, the distance, d , between the centers of adjacent lines of maximum density will be given by [4]:

$$d = \frac{P}{\epsilon} (1 + \epsilon) \quad (1)$$

where:

d = the fringe spacing

P = the unstrain grid pitch

ϵ = the strain perpendicular to the grid lines

Or,

$$\epsilon = \frac{P}{d - P} \quad (2)$$

The moire fringe method is a "whole field" method, which means that the strain field can be measured completely [2].

Holographic Interferometry Method

Invention of the laser in 1960 gave a new dimension to the science of optics, and injected practical significance into the study of coherent light [5]. The most important characteristic of laser light, which is used in holography, is its high coherence [6].

Holography is an interference method of recording the light waves diffracted by a subject illuminated with coherent light. The diffracted waves are made to interfere with a phase-related reference wave. If the waves are highly coherent, the relative phase between subject and reference wave remains constant in time producing an observable effect on the intensity distribution of the resulting pattern [5]. Figure 3a shows the recording set-up of an off-axis hologram and figures 3b and 3c show its reconstruction set-up [6].

Through the use of off-axis holography, one can produce three-dimensional images of diffusely reflecting objects which appear to be overlaid by interference fringes that are indicative of deformation, displacement or rotation of the object.

For the purpose of strain measurement, the light scattered by the object is recorded during an initial exposure of an off-axis hologram; after deformation, a second hologram is recorded on the same film plate. Upon reconstruction, the film plate is illuminated by a reference laser light as shown in figures 3b and 3c. Looking through the hologram, a series of dark and bright fringes are observed. Figure 4a shows the normal deformation of a cantilever beam subjected to end transverse force [6]. Next, by assigning fringe order numbers to the bright fringes (Figure 4b), and utilizing the following equation [6]:

$$w(x) = \frac{N\lambda}{2} \quad (3)$$

(a)

(b)

(c)

Figure 3. Off-axis holography. a) System for recording the hologram. b) Reconstruction of the true, virtual image. c) Reconstruction of conjugate, real image [6].

(a)

(b)

Figure 4. Normal deformation of a cantilever beam: a) Side view of the beam. Displacement is in the $+z$ direction, and illumination in the $-z$ direction. b) Fringe pattern observed on the front of the beam [6].

where:

$w(x)$ = deformation of the x location

N = fringe order

λ = wavelength of laser light

Using equation (3), the deformation or displacement at any location of the object can be calculated.

Holographic interferometry is only sensitive to out-of-plane deformation. For in-plane deformation, speckle photography is more sensitive.

Electrical-Resistance Strain Gage Method

Theoretically, an electrical-resistance strain gage operation is based on the principle that the electrical resistance of a conductor changes when it is subjected to mechanical deformation, therefore generating an electric signal. Magnification of this signal is then accomplished by electric means, such as an amplifier. Typically, an electric conductor is bonded to the specimen with an insulating cement under no-load conditions. A load is then applied, which produces a deformation in both the specimen and the resistance element. This deformation is indicated through the use of a strain gage indicator, or a measurement of the change in resistance of the element and a calculation procedure shown below in equation (4) [7]:

$$\epsilon = \frac{1}{F} \frac{\Delta R}{R} \quad (4)$$

where:

ϵ = local strain

F = gage factor

ΔR = change in resistance

R = original resistance of the gage

The important advantage that the electrical resistance type strain gage has is the relative ease with which the output can be amplified, displayed and recorded [2]. Figure 5 shows some of the electrical resistance strain gages currently in use.

This method is a point-by-point method, which means that the strain field of the object cannot be completely measured using only one gage.

Speckle Photography Method

Speckle photography is a technique for making moderately-sensitive measurements of in-plane translation, strain, rotation and vibration [6]. Its principle attractions are the simplicity of the optical system and the relative ease of displaying and interpreting the results. As shown in Figure 6a, the object is illuminated by laser light. It is then photographed twice; once before and once after deformation on the same film plate. A narrow beam of laser light is then directed through the processed film plate (Figure 6b), producing fringes in the back focal plane of the lens (Figure 6c). By knowing the distance between successive fringes, the wavelength of the laser light and the distance between the film plate and the viewing plane,

Figure 5. Configuration of metal-foil strain gages [7].

(a)

(b)

(c)

Figure 6. Two-exposure speckle photography for measurement of in-plane deformation. a) Recording system. b) Set-up for fringe formation. c) Formation of fringe in the back focal plane [6].

the deformation of the object can be calculated using the following equation [6]:

$$U = \frac{\lambda z}{Md} \quad (5)$$

where:

U = in-plane object displacement

λ = wavelength of light used in producing the fringes

z = distance between the specklegram and the viewing plane

d = fringe spacing

M = magnification factor of the recording camera

Also, by knowing the fringe orientation angle, θ (Figure 7), displacement components, U_x and U_y , may be calculated as follows:

$$U_x = U \cdot \sin \theta \quad (6)$$

$$U_y = U \cdot \cos \theta \quad (7)$$

The scope of this research report is to develop an automated method for direct measurement of in-plane displacements of structures subjected to different loading conditions. The speckle photography technique is used. The obtained fringes from the optical Fourier filtering of the processed film plate at a point through the use of a thin laser beam was then digitized using a CCD 133 charge linear diode array. The digitized data is Fourier transformed using a spectrum analyzer and then analyzed by a computer to obtain the in-plane displacement at a point on the surface of the structure.

Figure 7. Diagram of fringe orientation and the respective x and y components of fringe spacing.

Measurement of deformations at different points of the structure is possible using a computer-controlled translation stage.

CHAPTER II

LITERATURE REVIEW

The method of wavefront reconstruction (holography) was first invented by Dennis Gabor in 1948 [8]. Gabor invented this method to improve the resolution in images obtained with an electron microscope. Although unable to demonstrate the validity of his principle with electron waves, he was able to do so with visible light.

Holography, after a decade, seemed destined for obscurity. This brightened in the early 1960s with work carried out at the University of Michigan Institute of Technology. Leith and Upatnieks [9] began publication of a series of reports demonstrating a new approach to optical holography based on communication theory techniques. By 1964, they had convincing proof that holography was practical and that the use of laser light was an important factor [10].

The application of holography to interferometry was first suggested by Horman [11], who described the inclusion of a hologram. Holographic interferometry of diffusely scattering objects was introduced in the context of vibration analysis by Powell and Stetson in March 1965 [12]. The development of two-exposure and real-time holographic interferometry occurred independently in several laboratories, and was reported in papers submitted for publication during the summer of 1965. This work includes that of Burch [13],

Collier, Doherty and Pennington [14]; Stetson and Powell [15]; and Haines and Hildebrand [16] who studied the deformation and displacement of diffusely reflecting objects; and that of Heflinger, Wueker and Brooks [17, 18], who used the method for aerodynamic measurements.

The technique of holographic addition and subtraction was also introduced in 1965 by Gabor et al. [19], and subsequently was noted to be equivalent to holographic interferometry.

In-plane strain measurements were considered by Aleksandrov and Bonch-Brevich [20] and Ennos [21] in 1966 and was used by Wilson [22] in 1967 to measure displacement in a rectangular membrane with a hole in the center subjected to a uniform tensile stress in the longitudinal direction.

In 1967, Barnett [23] presented a sequence of time-average interferograms of vibration of a circular plate with clamped edge. He noted that some of these interferograms appeared to display nodal patterns that were not in agreement with the classical theory of vibrating plates. Molin and Stetson [24] demonstrated that such patterns actually represented combinations of classical modes.

Subsequent analysis and experimentation by Stetson [25], Wilson [26] and their co-workers have produced a detailed description of the formation of fringes in time-average holographic interferometry of objects executing complex motion, particularly multiple vibrational modes.

Introduction of speckle interferometry in 1969 opened new research areas, so that there now exists quite a collection of techniques that are applicable to a wide variety of problems. Any motion on the object surface brings about the motion of speckle pattern, as was explained by Tiziani [27] and Archbold and Ennos [28] in 1970. They concluded that speckles in the image of an object will either shift their locations as the object moves, or they will change their pattern, or both. This conclusion was then carried further, leading to the concept of double-exposure speckle photography. This is the simplest technique in speckle photography and was discussed by Archbold [29], Tiziani [30] and Kopf [31] in 1975.

The double-exposure speckle photography provides information related to the state of strain of the object under consideration. Analysis of such a double-exposure photograph is carried out by directing a narrow laser beam through the photographic film plate at normal incidence to generate in the far field its Fourier transform. This analysis was conducted by Tiziani [30] in 1972. This takes the form of a diffraction halo modulated by a pattern of parallel equispaced fringes, similar to Young's fringes. Fringes are perpendicular to the direction of the displacement and they have spacing inversely proportional to the object displacement.

Stetson [32] has analyzed the apparent motion of speckles due to arbitrary object displacement and deformation, and has concluded that by recording two double-exposed specklegrams from the same observation direction, but with the camera focused on different

planes, the object translation normal to that direction can be extracted.

Adams and Maddux [33] and Boone [34] have discussed the possibility of combining holographic interferometry and speckle photography techniques for use in stress analysis, since the former technique is most sensitive to deformations normal to the object surface and the latter is most sensitive to deformation in the plane of the object surface.

Hudson and Setopoulous [35], in 1974, demonstrated a system for recording sequential pairs of speckle photography in order to measure time-dependent deformations, such as creep.

In 1978, Maddux [36] utilized mechanical scanning of the fringe by a large photodetector. Ineichen [37], in 1979, used a television pick-up system for data acquisition, and also Kaufmann, Ennos, Gale and Pugh [38] used a compact optical system that projected the 1-D Fourier transform of a small area of the specklegram, without distortion, onto a self-scanning linear photodiode array.

Kaufmann [39] used an automated read-out system to directly process the digitized fringe pattern.

In 1981, Ichirou Yamaguchi [40] presented a method based on theoretical investigations of speckle displacement induced by small object deformation. He also used an electronic speckle correlation with a photodiode array to measure speckle displacement. By this method, the strain measurement at a small illuminated area was possible in real-time. In 1982, Yamaguchi [40] used a double-beam arrangement

with a linear sensor of high resolution (square pixels of a size of 15 microns on a side) to convert the intensity data of speckles to an analog-ensembled signal. A data ensemble was then digitized and stored while the object was strained. Then, the image of strained object was digitized and stored. He then cross-correlated the two signals to yield a point of high correlation.

In 1983, Yamaguchi [41] discussed the formation of Young's fringes that are observed in speckle photography. He derived both the shape and the contrast of the fringes by starting from the cross-correlation function of the light intensities to be recorded in a double-exposure specklegram. He also discussed the effect of focusing and defocusing of the specklegram recording which affected the speckle shape, as well as the origin of speckle decorrelation affecting the contrast.

In 1984, A. Muramatsu and M. Lunazzi [42] used correlation techniques between a speckle pattern and its photographic negative to measure lateral displacements and vibrations of rigid objects.

CHAPTER III

THEORY OF FRINGE FORMATION

Fringe formation on the back focal plane of a lens in speckle photography can be explained by Thomas Young's two-slit experiment, as shown in Figure 8. Light waves from slit A reach slit S1 and S2 at the same time and these originate from a single source. Therefore, the secondary wavelengths leaving S1 and S2 are in phase or coherent. Figure 9 shows how the light and dark bands are produced. The bright bands occur whenever the waves arriving from the two slits interfere constructively (the amplitude of resultant wave is greater than the amplitude of either component wave). Dark bands occur when destructive interference (the resultant amplitude is smaller than either wave) is experienced. At point B in the center of the screen, light travels the same distance from each slit. The difference in path length is zero and constructive interference results in a bright central band. At point C, the difference in path length causes the waves to interfere destructively. Another bright band occurs at point D when the waves from each slit again reinforce each other [43].

Theoretical conditions necessary for the production of bright and dark bands are as follows. Consider light reaching point D at a distance y from the central axis AB, as shown in Figure 10. The separation of the two slits is represented by d , and the screen is located at a distance x from the slits. Point D on the screen makes

Figure 8. Illustration of Young's experiment [43].

(a)

(b)

(c)

Figure 9. Origin of light and dark bands in an interference pattern [43].

Figure 10. Theoretical interpretation of the double-slit experiment.

an angle θ with the axes of the system. The line S_2C is drawn so that the distances CD and P_2 are equal. As long as the distance x to the screen is much greater than the slit separation d , P_1 , P_2 and DA may be considered to be perpendicular to the line S_2C . Therefore, the angle $\angle S_1S_2C$ is equal to the angle θ , and the difference ΔP in path length of light coming from S_1 and S_2 is given by:

$$\Delta P = P_1 - P_2 = d \sin \theta \quad (8)$$

Constructive interference will occur at D when this difference in path length is equal to:

$$0, \lambda, 2\lambda, 3\lambda, 4\lambda, \dots, n\lambda$$

where λ is the wave length of light. Therefore, the conditions for bright fringes are given by:

$$d \cdot \sin \theta = n\lambda \quad n = 0, 1, 2, 3, \dots \quad (9)$$

where d is the slit separation and θ is the angle that the fringe makes with the axis.

The condition required for the formation of dark fringes at D will be satisfied when the path difference is:

$$\frac{\lambda}{2}, \frac{3\lambda}{2}, \frac{5\lambda}{2}, \frac{7\lambda}{2}, \dots$$

Under these conditions, destructive interference will cancel the waves. Thus, dark fringes will occur when:

$$d \cdot \sin \theta = n \cdot \lambda/2 \quad n = 1, 3, 5, \dots \quad (10)$$

Equations (9) and (10) may be put into a more useful form by expressing them in terms of the measurable distances x and y . For small angles:

$$\sin \theta \approx \tan \theta = y/x \quad (11)$$

Substituting equation (11) into equations (9) and (10) yields:

$$\text{Bright fringes:} \quad \frac{d(y)}{x} = n\lambda \quad n = 0, 1, 2, 3, \dots \quad (12)$$

$$\text{Dark fringes:} \quad \frac{d(y)}{x} = n \frac{\lambda}{2} \quad n = 1, 3, 5, \dots \quad (13)$$

To find the intensity of light at the plane of fringes, consider the same experiment. Using the electromagnetic theory, the irradiance at the plane of fringes becomes [6]:

$$\begin{aligned} I &= 2 \cdot I_o (1 + \cos \delta) \\ &= 4 \cdot I_o \cdot \cos^2 (\delta/2) \end{aligned} \quad (14)$$

where:

I = irradiance at the fringe plane

I_o = combined irradiance from both slits

δ = phase difference = $(2\pi/\lambda)\Delta l$; where Δl is the difference in distance the light travels from the source S to the observation point at y , and λ is the wavelength of light

From geometry, Δl can be presented as:

$$\begin{aligned} \Delta l = & \{ [x_s^2 + (\frac{d}{2} - y_s)^2]^{\frac{1}{2}} + [x_s^2 + (\frac{d}{2} - y)^2]^{\frac{1}{2}} \} \\ & - \{ [x_s^2 + (\frac{d}{2} + y_s)^2]^{\frac{1}{2}} + [x^2 + (\frac{d}{2} + y)^2]^{\frac{1}{2}} \} \end{aligned} \quad (15)$$

Considering that y_s , y and d are much smaller than x and x_s , equation (15) can be approximated as:

$$\Delta l = - \left(\frac{dy_s}{x_s} + \frac{dy}{x} \right) \quad (16)$$

The irradiance is then:

$$I = 4I_o \cos^2 \left[\frac{\pi d}{\lambda} \left(\frac{y}{x} + \frac{y_s}{x_s} \right) \right] \quad (17)$$

This equation represents parallel fringes (Figure 11) [6].

Local in-plane displacements in the recorded specklegram can be determined by illuminating it with a small laser beam as shown in Figure 12. For the small region of illumination of the specklegram, the displacement is assumed uniform and the region contains pairs of identical speckles displaced by a distance L , the light in the resulting pairs of diffraction cones will interfere to form a diffraction pattern modulated by Young's fringes.

Fringes are perpendicular to the direction of the object displacement $U(x,y)$, and they have a spacing, d , inversely proportional

Figure 11. Photograph of an interference pattern in Young's experiment [43].

Figure 12. Fringe pattern formation by diffraction at a double exposure speckle photograph [38].

to the object displacement, which is given by [6]:

$$U(x,y) = \frac{\lambda z}{Md} \quad (18)$$

where:

λ = wavelength of light source

z = effective distance between the specklegram and the viewing plane

M = magnification of imaging system

d = fringe separation

A Young's fringe pattern is the predominant mode of retrieving the displacement information carried by double-exposure specklegram. The useful parameters are the fringe spacing and the fringe orientation. Since it is a pointwise approach, a great deal of data analysis is involved if one has to analyze a number of specklegrams.

The fringe spacing can be deduced by Fourier transforming the signal obtained from scanning across Young's fringes by a linear photodiode array. The first-order peak (fundamental frequency of the signal) is a representative of the fringe spacing.

The Fourier transform of a function, $g(t)$, is defined by:

$$X(f) = \int_{-\infty}^{+\infty} g(t) e^{-i2\pi ft} dt \quad (19)$$

To demonstrate the above, two examples are discussed. In the first example, a sinewave of 400 Hz frequency was generated by a function generator. This signal was then Fourier transformed using the

spectrum analyzer. Figure 13 shows the time record and the FFT plots of the sinewave, respectively. As shown in Figure 13, the FFT plot, the fundamental frequency is 400 Hz, and it occurs at $1/\text{period}$ of the sinewave. This result was checked by examining another sinewave of 800 Hz frequency. Figure 14 represents the time record and the FFT plots, respectively, for the second example which justifies the result.

Figure 13. Time record and FFT plots of sine wave having frequency of 400 Hz.

Figure 14. Time record and FFT plots of sine wave having frequency of 800 Hz.

CHAPTER IV

COMPUTER-AIDED DATA ACQUISITION SYSTEM HARDWARE AND EXPERIMENTAL SET-UP

In general, automatic processing of Young's fringes consists of three parts: an optical Fourier processor, a fringe pattern digitizer and a fringe pattern analyzer. The first is composed of a low-power laser, a stage to hold the specklegram and a stepping motor to shift the specklegram so that it can be scanned. The second part may be a digitizing TV camera or linear diode sensor. The last part is a computer with appropriate software to do the computational and the controlling tasks.

This chapter presents the hardware used to compute in-plane displacements of objects from double-exposure specklegrams. Figures 15 and 16 illustrate the data acquisition system used in the experimentation. The basic components and their functions are as follows.

Laser

The source of coherent light was a Newport Corporation's He-Ne laser (5 milliwatt output power), with 1.3 millimeter beam diameter and 0.632 micrometer wavelength. Light intensity was controlled by a variable beam splitter. This instrument was placed right after the laser.

Figure 16. Photograph of the actual experimental set up.

Translation Stages

The Klinger Scientific Corporation's translation stages are manual/programmable xyz axes with sensitivity range of 1-65700 micrometer. This type of translation stage was chosen since a high accuracy, as well as remote operation, was required. Remote operation of the stages was done via the HP-IB bus line. The program, "STORDAT," was written in BASIC and was used to drive the stages.

CCD-133D Photodiode Sensor

Data was collected by Fairchild's CCD-133 photodiode array with 1024 pixels of 13x13 microns (Figure 17). This charge-coupled device results in total scan length of 13 millimeters. The photodiode sensor outputs data on two different lines. These data lines, namely A and B, are bus lines which contain the signals from odd and even pixels. This device is operated on 20 volts and 0.3 amperes provided by Kepco Corporation's power supply model SC-32-2.5. Data collected by this array had to be expanded in order to be analyzed on the spectrum analyzer. The approach was to use a pulse generator and two signal generators. The pulse generator used was a Hewlett-Packard Model 222A, and the signal generators were Wavetek Model 182.

Oscilloscope

Hewlett-Packard's Model 1201A oscilloscope was used to view time record data received from the photodiode sensor before filtering.

Figure 17. Photograph of CCD-133D, photodiode sensor.

Spectrum Analyzer

Analog to digital conversion of raw data was possible utilizing the Hewlett-Packard Model 3582A spectrum analyzer. This device not only digitizes the data, but also performs the Fast Fourier Transform (FFT). Data is received from the sensor through the bus lines (A and B) connected to the front panel of the spectrum analyzer. Data is stored in the memory buffer of the analyzer for further analysis. The memory buffer is accessed by the front panel switches or by remote operation through a microcomputer. The HP-3582A spectrum analyzer has three passband shapes available: hanning, uniform and flat top. Each one is best used for different tasks. For example, hanning is used when frequency accuracy is required; uniform is used when maximum frequency is of importance; and flat top is used when best amplitude accuracy is required. For this project, the hanning passband shape was most suitable.

HP-85 Microcomputer

Data collection and storage, remote control of the translation stages and the spectrum analyzer were possible by the Hewlett-Packard Model 85 Microcomputer. Due to the low storage capacity (about 30K byte) of the HP-85, a Hewlett-Packard Model 82901M flexible disk drive was used. This device provided enough storage area to manipulate and store data on a floppy disk. To plot the stored data or the current data, a Hewlett-Packard Model 7470A plotter was used.

CHAPTER V

RESULTS AND DISCUSSION

In order to test and calibrate the CCD-133 photodiode sensor, artificial fringes having different spacing were produced on transparencies as shown in Figure 18. A fringe transparency is placed in the film plate holder and illuminated by white light from a slide projector. Fringes are imaged on the sensor using a lens with magnification ratio $M = 1.54$ (Figure 19). The previous procedure was repeated six times for different fringe spacing sets.

Time record data on the spectrum analyzer appeared to be sinusoidal. These data were Fourier transformed. Figures 20 through 25 represent the time record data, and its corresponding Fourier transform plots, respectively, for the six different cases. As shown in FFT plots, the maximum peak occurs at the fundamental frequency of these waves and is marked with an asterisk. The resultant frequencies were then inverted, tabulated and plotted in Table 1 and Figure 26 against the fringe spacing seen by the sensor. Figure 26 shows that inverse of frequency and fringe spacing has a linear relationship, and by a least squares method, it was found that this relationship had an equation $d' = 46.63 \cdot 1/f + 0.00319$, where f is the frequency in Hz, and d' is the fringe spacing at the plane of sensor in inches. The correlation coefficient for this linear relation was 0.99. This means that if the frequency is 400 Hz, the corresponding fringe spacing will be approximately 0.12 inch.

0.03 in. separation

0.042 in. separation

0.05 in. separation

0.0583 in. separation

0.075 in. separation

0.10 in. separation

Figure 18. Artificial fringes and their respective spacing used in the experiment.

Figure 19. Artificial fringe analysis experimental set up.

Figure 20. Time record and FFT plots of an artificial fringe with 0.03 in. spacing.

Figure 21. Time record and FFT plots of an artificial fringe with 0.042 in. spacing.

Figure 22. Time record and FFT plots of an artificial fringe with 0.05 in. spacing.

Figure 23. Time record and FFT plots of an artificial fringe with 0.058 in. spacing.

Figure 24. Time record and FFT plots of an artificial fringe with 0.075 in. spacing.

Figure 25. Time record and FFT plots of an artificial fringe with 0.100 in. spacing.

Figure 26. Plot of fringe spacing versus inverse of frequency.

TABLE 1
FRINGE SPACING VERSUS INVERSE OF FREQUENCY

FRINGE SPACING (in)	INVERSE OF FREQUENCY (1/Hz)
0.0479	0.0010
0.0666	0.0013
0.0798	0.0017
0.0932	0.0020
0.1198	0.0025
0.1598	0.0033

After the calibration of the sensor, a specklegram of a 1/4 inch thick cantilever beam subjected to transverse-end loading was produced. Material for the beam was plexiglass with $E = 4.56 \times 10^5$ psi and $\nu = 0.3$. The transverse-end load was governed by displacement of the free end, which was 0.005 inch. Figure 27 shows the experimental set-up for recording the double-exposure specklegram. Dimensions of the beam were 5 inches in length and 1 inch in width, with an imaging magnification factor of 0.75. The produced specklegram was then illuminated with an unexpanded He-Ne laser beam. The laser beam was passed through a point on the centerline of the beam resulting in a circular halo modulated by Young's fringes on the plane of the sensor.

Figure 27. Experimental set up for producing double-exposure specklegram of the cantilever beam experiment.

Scanning along the beam centerline was selected since the displacement of any point along the centerline is vertical and this will produce horizontal fringes perpendicular to the sensor orientation. Measurements of displacement of other points was not attempted here since it would be necessary to reorient the sensor.

The specklegram was then displaced using the computer-controlled translation stages until three fringes were observed at the plane of the sensor. The fringe pattern was digitized along a line perpendicular to it using the CCD sensor. This resulted in a record of relative light intensity versus distance, which was converted to a time record by the spectrum analyzer. The time record is stored in the computer and is shown in Figure 28. The noise observed in the time record of the intensity data is due to the speckle effect on the halo. A fourier transform was performed on the time record of the data using the spectrum analyzer and the fundamental frequency (corresponding to the location of the maximum peak) was found to occur at 300 Hz, as shown in Figure 28.

Furthermore, scanning along the centerline of the beam was conducted as controlled by the computer until 4, 5, 6 and 7 fringes were observed. Their time record and corresponding FFT records were plotted in figures 29 through 32.

Table 2 represents the tabulated data for number of fringes versus corresponding frequency in hertz. This relationship was then plotted and approximated by a straight line having the equation

Figure 28. Time record and FFT plots of 3-fringe case.

Figure 29. Time record and FFT plots of 4-fringe case.

Figure 30. Time record and FFT plots of 5-fringe case.

Figure 31. Time record and FFT plots of 6-fringe case.

Figure 32. Time record and FFT plots of 7-fringe case.

$N = 0.01 \cdot f$, with correlation coefficient equal to 0.99, as shown in Figure 33.

TABLE 2
FRINGE NUMBER VERSUS FREQUENCY

FRINGE NUMBER	FREQUENCY (Hz)
3	300
4	400
5	500
6	600
7	700

The previous data was collected from any single scan in a direction perpendicular to the fringes. This data may not include all the information. Therefore, the following experiment was conducted. The photodiode sensor was displaced, four times to the right of the bright spot on the halo and four times to the left of the bright spot. The case of three fringes was chosen for this experiment. Scans were separated by 0.001 inch, as shown in Figure 34. Time record plots and corresponding FFT plots for four scans to the right of bright spot are shown in figures 35 through 38. Figures 39 through 42 represent the time record plots and corresponding FFT plots for four scans to the left of the bright spot. The average of

Figure 33. Plot of fringe number versus frequency.

Figure 34. Scan locations on the fringe halo.

Figure 35. Time record and FFT plots of first scan to the right of bright spot.

Figure 36. Time record and FFT plots of second scan to the right of bright spot.

Figure 37. Time record and FFT plots of third scan to the right of bright spot.

Figure 38. Time record and FFT plots of fourth scan to the right of bright spot.

Figure 39. Time record and FFT plots of first scan to the left of bright spot.

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Figure 40. Time record and FFT plots of second scan to the left of bright spot.

Figure 41. Time record and FFT plots of third scan to the left of bright spot.

Figure 42. Time record and FFT plots of fourth scan to the left of bright spot.

the square of the FFT plots was computed and plotted in Figure 43. As can be seen, the effect of the averaging process has smoothed the FFT plot, but has not affected the location of the peak. This simply was due to the limited resolution of the FFT analyzer in detecting the fundamental frequency. Therefore, it was decided that one scan would be sufficient and will be used in the rest of the experimentation.

Finally, the double-exposure specklegram of the cantilever beam was illuminated again at different points (controlled by the translation stages and the computer) along the beam neutral axis to measure the vertical displacement at various locations. Figure 44 shows the cantilever beam with the sample scan locations separated by 0.26 inch. In this experiment, a camera lens with 8.25 inch focal length was used to image the fringe halo on the plane of the sensor from the viewing plane (ground glass). The fringe size on the viewing plane was smaller than on the sensor plane. The magnification factor used was $M' = 1.2$. The experimental set-up is shown in Figure 45. Fringe images were then digitized and analyzed one at a time by the spectrum analyzer and the computer. Time record and FFT plots for these sample points are presented in figures 46 through 65. The fundamental frequency obtained from FFT plot was then used to calculate the fringe spacing utilizing the relationship obtained for the fringe spacing, d' , and the inverse of frequency, $1/f$:

$$d' = 46.63 \cdot 1/f + 0.00319 \quad (20)$$

Figure 43. Average of eight FFT^2 plots.

Figure 44. Diagram of cantilever beam and locations of various sample points.

Figure 45. Experimental set up for the analysis of the displacements of the cantilever beam.

Figure 46. Time record and FFT plots of point 1.

Figure 47. Time record and FFT plots of point 2.

Figure 48. Time record and FFT plots of point 3.

Figure 49. Time record and FFT plots of point 4.

Figure 50. Time record and FFT plots of point 5.

Figure 51. Time record and FFT plots of point 6.

Figure 52. Time record and FFT plots of point 7.

Figure 53. Time record and FFT plots of point 8.

Figure 54. Time record and FFT plots of point 9.

Figure 55. Time record and FFT plots of point 10.

Figure 56. Time record and FFT plots of point 11.

Figure 57. Time record and FFT plots of point 12.

Figure 58. Time record and FFT plots of point 13.

Figure 59. Time record and FFT plots of point 14.

Figure 60. Time record and FFT plots of point 15.

Figure 61. Time record and FFT plots of point 16.

Figure 62. Time record and FFT plots of point 17.

Figure 63. Time record and FFT plots of point 18.

Figure 64. Time record and FFT plots of point 19.

Figure 65. Time record and FFT plots of point 20.

derived from the artificial fringes experiment. Knowing the fringe spacing, d' (on the sensor plane), laser wavelength, λ , distance, z , between the viewing plane (ground glass) and the specklegram, and the magnification factor, M , used in producing the specklegram, and beam deflection can be calculated using the following equation:

$$v = \frac{\lambda z}{Md} = \frac{\lambda z}{Md' \frac{1}{M'}} = \frac{M'}{M} \frac{\lambda z}{d'} \quad (21)$$

Table 3 represents the computed experimental displacement values and the theoretical displacement values obtained from the beam theory as expressed by [44]:

$$v = \frac{Px^3}{6EI} - \frac{Px l^2}{2EI} + \frac{Pl^3}{3EI} \quad (22)$$

where:

v = vertical deflection

P = applied force

E = modulus of elasticity

I = moment of inertia

l = beam length

for a cantilever beam with an end load applied at the free end. The vertical deflection at the free end was 0.005 inch. Theoretical and experimental values of the vertical displacement of the centerline of the beam are plotted in Figure 66. As shown in the figure, experimental values compare favorably well with the theoretical

TABLE 3

EXPERIMENTAL VERSUS THEORETICAL DISPLACEMENT VALUES
AT DIFFERENT LOCATIONS ALONG CENTERLINE OF THE BEAM

BEAM LENGTH (in)	BEAM THEORY	EXPERIMENTAL (in)
	THEORETICAL (in)	
0.00	0.0050	0.0053
0.26	0.0046	0.0047
0.52	0.0042	0.0047
0.78	0.0038	0.0040
1.04	0.0035	0.0034
1.30	0.0031	0.0034
1.56	0.0027	0.0034
1.82	0.0024	0.0027
2.08	0.0021	0.0021
2.34	0.0018	0.0021
2.60	0.0015	0.0014
2.86	0.0012	0.0014
3.12	0.0009	0.0007
3.38	0.0007	0.0007
3.64	0.0005	0.0007
3.90	0.0003	0.0007
4.16	0.0002	0.0007
4.42	0.0001	0.0007
4.68	0.0000	0.0007
4.85	0.0000	0.0007

Figure 66. Plot of vertical displacement versus beam length.

values, except near the fixed end. Displacements near the fixed end are small and, therefore, the resulted fringe spacing is large which, in turn, yields a small value for the fundamental frequency. Such a small frequency was unresolvable by the spectrum analyzer. Indeed, the spectrum analyzer (HP-3582A) was unable to record and display frequencies between 0 and 100 Hz.

CHAPTER VI

CONCLUSION AND RECOMMENDATIONS

An automated system for direct calculation of object displacement from double-exposure specklegram was developed. He-Ne laser and computer-controlled translation stages holding the specklegram represent the first part of the system, which is the optical Fourier processor. A CCD linear diode sensor is used to digitize the fringe pattern. Finally, a microcomputer and a spectrum analyzer are used to perform the analysis.

Fringe analysis using the Fourier transform method was shown to be effective for displacement measurement. To show the effectiveness of the technique, a series of related experiments were conducted. Among these experiments were the artificial fringe experiments which showed a linear relationship between the fringe spacing and the inverse of frequency. This relationship not only showed that the photodiode sensor was working properly, but also was used to approximate the fringe spacing when frequency was known.

To find the relationship between fringe number and frequency, five different cases (3, 4, 5, 6 and 7 fringes) were tested and showed that the relationship between the number of fringes and the frequency was linear.

Furthermore, average of square FFT records of eight scans on the fringe halo, for the purpose of decreasing speckle noise, showed that the FFT record was somewhat improved, but the location of the peak in the FFT plot did not change, due to the limited resolution of the spectrum analyzer.

Finally, cantilever beam deflection was measured. The procedure followed was to select a point on the beam neutral axis, obtain a time record from fringe digitizing, and then Fourier transform the time record. The resulting frequency is to be substituted into the previously obtained equation for fringe spacing to find the fringe spacing. From such information, beam deflection can easily be calculated. Results showed that the experimental values were very close to the theoretical values. The only non-uniformity noticed was due to the fact that the spectrum analyzer did not display or record the exact value of frequency between 0 and 100 Hz. Therefore, beyond 3.7 inches from the free end, deflection was shown to be 0.0007 inch.

Possible future extensions of this research may include measuring deflection at any location on the beam. Such measurements may include calculation of the angle between x and y components of the displacement. Displacement information may be used in conjunction with numerical techniques such as the boundary element method or the finite element method to yield the stress value at any desired location.

APPENDICES

APPENDIX A

OPERATION OF CC-1 CONTROLLABLE TRANSLATION STAGES

The Klinger Scientific's Model CC-1 programmable stepper motor controller is designed to control stepping motors in response to commands, either from computer or from front panel pushbutton controls. When used in conjunction with Klinger's stepping motor driven positioning stages, they allow for precision single- or dual-axis micropositioning.

The CC-1 controller, when operated from a computer or other data source capable of supplying ASCII code or binary code commands, can perform the following:

1. Establish a home reference position and make all movements relative to this home position.
2. Perform movements relative to the present position in positive or negative direction.
3. Execute movements over a wide speed range (400-2000 Hz) with varying acceleration range (0-0.1 sec).
4. Place a delay of any length between successive movements.
5. Establishes number of steps to be taken in a relative motion (1-65535 microns).

The CC-1 has three programming modes:

1. Command mode
2. Program entry mode
3. Program execution mode

In the command mode, commands are executed as they are received. The CC-1 powers-up in command mode. In program entry mode, a sequence of commands is entered and stored in a program buffer for later execution. There are 48 bytes of memory available for program storage. Table 1 shows the required commands and the number of bytes required for each command. It is impressive to know the length and, correspondingly, the location of each instruction or command to do looping and branching. In program execution mode, there are two commands that enable the entry of this mode. One command, "D↓," starts program execution from location zero of the program storage buffer, and the other, "O↓," starts program execution from the location specified in the command.

The CC-1 allows the set-up of the step rate and acceleration rate in very fine increments (10 microsecond changes). This is easily done through the rate, slope and factor (R, S and F) commands. By proper choice of the R, S and F commands, it is possible to control the starting rate, the number of steps from the starting rate to the slew rate and the final slew rate.

The CC-1 rate equation is:

$$\text{step/second} = \frac{10^6}{(256 - r) \cdot 80 + Z \cdot 10 + 75 \pm 7.5}$$

where:

r = rate parameter as set by the R command

s = slope parameter as set by the S command

f = factor parameter as set by the F command

y = integer equal to $(255 - f)/s$

z = internal factor value

The factor y represents the number of steps required to ramp up from the starting rate to the slew rate, and the number of steps to ramp down again better stepping; and the internal factor, z , changes in value for each step while ramping. When accelerating:

$$Z = 255 - n \cdot s$$

where:

n = step number from the start motion beginning with $n = 1$

When $z = f$ (slew speed), the maximum step rate for any particular value of r and f has been reached. When decelerating:

$$Z = f + n \cdot s$$

where:

n = step number from the start of deceleration

From the above discussion, the starting step rate equation can be deduced plus the final (slew) step rate equation.

Start step rate equation:

$$\text{step/second} = \frac{10^6}{(256 - r) \cdot 80 + (255 - s) \cdot 10 + 75 \pm 7.5}$$

and slew rate equation:

$$\text{step/second} = \frac{10^6}{(256 - r) \cdot 80 + f \cdot 10 + 75 \pm 7.5}$$

For example, for the following commands, "R 253," "S 1," "F 20," "G," the slew rate is:

$$\begin{aligned} \text{step/second} &= 10^6 / (256 - r) \cdot 80 + 10 \cdot f + 75 \\ &= 10^6 / (256 - 253) \cdot 80 + 10 (20) + 75 \\ &= 1914 \end{aligned}$$

The CC-1 is used as a listener on the IEEE-48 bus line. To establish communication, the CC-1 must be properly configured through its dip switches. The dip switches are located on the back panel of the CC-1 controller (for exact location refer to the CC-1 operation manual). They should be set as follows:

S1-1 through S1-5 set UP

S1-6 through SL-10 set DOWN

S2-1 through S2-3 set UP

S2-4 through S2-8 set as device address

S2-9 through S2-10 set UP

APPENDIX B

INSTRUCTIONS ON CCD-133 LINE SCANNER

Basically, a line scan image sensor is composed of a row of image-sensing elements (photosites), two analog transport registers and an output amplifier.

Light energy falls on the photosites and generates charge packets proportional to the light intensity. These charge packets are then transferred in parallel to two analog transport registers, which are checked by 2-phase clocks. The packets are next delivered to an on-chip output amplifier where they are converted to proportional voltage level. A series of pulses, amplitude modulated with the optical information, appear at the output.

Fairchild's charged-couple-device, or CCD, contains 1024 x 1 light sensitive elements of 13 x 13 microns. Its maximum auto rate is 20 MHz with 2500:1 dynamic range, and 3.0 volts per microjoules per centimeter squared, respectively. The 1024 sensing elements of CCD-133 provide a 120-line per inch resolution across an 8-1/2 inch page.

To understand the operation of CCD, refer to figures 67 and 68. Figure 67 is the block diagram and Figure 68 is the timing diagram CCD-133.

Figure 67. Block diagram of CCD-133D.

Image sensor elements or pixels are separated by diffused channel stops, and covered by a silicon dioxide surface passivation layer. Image photons pass through the transparent silicon dioxide layer and are absorbed in the single crystal silicon creating hole-element pairs. The charged-packets accumulated in the image sensor elements are transferred out via the transfer gate to the transport register whenever the transfer gate register goes high. Alternate charge-packets are transferred to the analog transport shift registers. Two registers are on each side of the line of image sensor elements and separated from it by the transfer gate. They are used to move the image generated charge-packets delivered by the transfer gate serially to the two charge-detector/amplifiers. There, the amplifiers allow the output to be delivered as a sample-and-hold waveform.

Figure 68 shows the clocks used in this board. ϕ_x is the transport clock, which is applied to the gates of the CCD transport shift registers to move the charge-packets received from the image sensor elements to the gated charge-detector amplifier, and ϕ_t is the transfer clock, which is the voltage waveform applied to the transfer gate to move the accumulated charge from the image sensor elements to the CCD transport shift registers. The two clocks, V_{oa} and V_{ob} , are used for data transfer activation. They provide adequate support for detecting intensity as low as 300 microwatts. This amount is inadequate compared to 10 microwatts or lower needed in this

experiment. To fix this problem, two function generators and one pulse generator were used, provided that pin 17 of the CCD board was grounded, and pins 3 and 5 connected to the function generators. First function generator was used to derive the pulse generated to account for exposure rate, and the second function generator was used for data rate control. In addition, an external trigger on the HP-3582A spectrum analyzer was needed to expand the time record signals derived from the sensor. Adjustment done on the two function generators and pulse generator was possible by reading data from the charts presented in Figure 69. These adjustments are shown in Figure 70. Figure 71 shows the schematic diagram of set-up.

power supply

pulse generator

signal generator

signal generator

Figure 70. Equipment and their respective adjustments.

Figure 71. Schematic diagram of set up.

APPENDIX C

DATA MANIPULATION PROGRAMS

Programs listed below were used to communicate with the HP-3582A and Klinger Scientific's CC-1 controllers. In their "LISTEN" mode, they are capable of receiving information from a microprocessor (HP-85), and in their "TALK" mode, they are capable of sending information. Both the spectrum analyzer and the translation stage controllers receive and send data in 16-bit, or two-byte words with least significant byte first. Hewlett-Packard microprocessor Model 85 is programmed in the BASIC language and is capable of advance programming through its matrix and memory expansion modules.

These programs are:

1. "STORDAT": This program has a routine to activate both the spectrum analyzer and the translation-stage controllers. In this routine, the operator is capable of scanning along the cantilever beam length every 5 millimeters. This interval can be changed by editing line 350 of this program, and replacing "N 5000" by any integer (0-65,535). Data file name has to be defined at the beginning of the program and it has to be any four-letter word.

2. "AUTOAVG": This routine can be used when the photodiode sensor is mounted on a translation stage. When this program is activated, it sends commands to the translation stage controller to move the sensor a specified distance.

When the motion is completed, it stores the data and moves to a new position. When two consecutive scans are completed, it adds and averages the data in a datafile called "DATA100." Upon completion, the translation stage is moved to a new position collecting another two sets of data which are averaged and stored in a new datafile called "DATA200." These two files are recalled and then averaged, and their averages are stored in a datafile arbitrarily chosen by the operator at the beginning of the program.

3. "AUTOAVG4": Similar to "AUTOAVG," this routine takes the average of four scans to the right of the bright spot in the fringe halo and stores it. Data collected from this program and "AUTOAVG" averaged further utilizing "NEWDATA" program; therefore, resulting average of eight scans.

4. "SCANAVG": Program "SCANAVG" is a modification of "AUTOAVG." In this program, automatic control routine has been removed. Physically, the automatic translation stage is replaced by a manual translation stage. Every time a scan is completed, a message is prompted on the computer screen notifying the operator to move the sensor to a new position.

5. "TRANS1" [45]: Once data is stored on a disk, it can be recalled and viewed. This program was prepared to analyze and view the data. It consists of eight options briefly discussed below.

- a. K1 (DATA ENTRY): This routine allows data entry from the spectrum analyzer, from the datafile or from the keyboard.

- b. K2 (REMOT CONTROL): This option enables the operator to remotely operate the analyzer for data analysis or manipulation.
- c. K3 (TIME RECORD PLOT): This option plots the time record directly from the analyzer CRT, or from the datafile.
- d. K4 (FAST FOURIER TRANSFORM PLOT): This routine Fourier transforms the time record data and then plots it.
- e. K5 (SAVE): Time record data, in binary form, is stored on a disk when this routine is activated.

6. "PLOTING": This program plots the Fourier transform and the time record data. Upon activation, the time record data is zero meaned first and then Fourier transformed. The Fourier transform plot shows the maximum peak occurrence and the object displacement.

7. "DATPLOT": Some times, it is necessary to compare two data points against each other. This program is written especially to plot the Fourier transform and the time record of two different data on the same sheet. Both data are plotted and are zero meaned.

8. "PLOT": This routine was prepared to plot the fringe spacing versus the inverse of frequency. This program plots the data collected from the artificial fringe experiment. It also shows the line representing the best fitted graph along with its equation.

```

10 CLEAR
20 LOCAL 711
30 DISP "*****"
40 DISP
50 DISP "          S T O R D A T
   "
60 DISP
70 DISP "*****"
80 DISP
90 DISP "    AUTOMATIC DATA STOR
   AGE " @ DISP @ DISP "
   PRESS CONT!" @ PAUSE
100 CLEAR
110 COM A(1024),A$(2056),N$(5),T
   $(11),F$(2)
120 FOR J=1 TO 10
130 LOCAL 711
140 CLEAR
150 DISP
160 DISP
170 DISP
180 DISP
190 F$=VAL$(J)
200 IF J=1 THEN 210 ELSE 220
210 LINPUT "Enter file name?",N$
220 G$=N$&F$
230 CLEAR
240 DISP
250 DISP
260 DISP
270 DISP
280 DISP
290 DISP
300 DISP "          SCAN NO. ",J
310 RESET 7
320 CLEAR 7
330 CONTROL 7,16 ; 1
340 OUTPUT 707 USING "K" ; "R 25
   3"
350 OUTPUT 707 USING "K" ; "N 10
   000"
360 S$="-"
370 OUTPUT 707 USING "K" ; S$
380 OUTPUT 707 USING "K" ; "G"
390 OUTPUT 707 USING "K" ; "B"
400 WAIT 1500
410 REMOTE 711
420 OUTPUT 711 USING "14A" ; "LF
   M,70000,1024"
430 IOBUFFER A$
440 TRANSFER 711 TO A$ FHS
450 M$=":D701"
460 T$=G$&M$
470 CREATE T$,1,3000
480 ASSIGN# 1 TO T$
490 PRINT# 1 ; A$
500 ! CHAIN "AUTOAVG"
510 NEXT J
520 DISP "DONE" @ BEEP 8,1000
530 END

```



```

10 CLEAR
20 DISP "*****"
30 DISP ""
40 DISP "          A U T O A V G
"
50 DISP ""
60 DISP "*****"
70 DISP ""
80 COM A(1024),A$(2056),N$(25),
J,D$(25)
90 DISP
100 DISP "    AUTOMATED SCANNING A
LONG THE    FRINGES."
110 DISP
120 DISP "    PRESS CONT WHEN REA
DY!" @ PAUSE
130 CLEAR
140 FOR J=1 TO 2
150 CONTROL 7,16 ; 1
160 OUTPUT 707 USING "K" ; "R 25
3"
170 OUTPUT 707 USING "K" ; "N 50
00"
180 S$="+ "
190 OUTPUT 707 USING "K" ; S$
200 OUTPUT 707 USING "K" ; "G"
210 OUTPUT 707 USING "K" ; "B"
220 WAIT 1500
230 DIM B(1024),F(1024)
240 CLEAR 7
250 RESET 7
260 CLEAR
270 REMOTE 711
280 GOSUB 470
290 GOSUB 390
300 GOTO 570
310 RESET 7
320 CLEAR 7
330 CONTROL 7,16 ; 1
340 OUTPUT 705 USING "K" ; "R 25
3" @ OUTPUT 705 USING "K" ;
"N 500"
350 S$="+ " @ OUTPUT 705 USING "K
" ; S$ @ OUTPUT 705 USING "K
" ; "G"
360 OUTPUT 705 USING "K" ; "B"
370 WAIT 1000
380 RETURN
390 FOR I=0 TO 1023
400 ENTER A$ USING "#,W" ; A(I)
410 NEXT I
420 RETURN
430 FOR I=0 TO 1023
440 ENTER A$ USING "#,W" ; B(I)
450 NEXT I
460 RETURN
470 OUTPUT 711 USING "14A" ; "LF
M,70000,1024"

```



```

480 IOBUFFER A$
490 TRANSFER 711 TO A$ FHS
500 RETURN
510 CLEAR @ DISP "*****
*****"
520 DISP "
"
530 DISP " MOVING TO THE "&T$&"
POSITION "
540 DISP "
"
550 DISP "*****
*****" @ BEEP
560 RETURN
570 T$="SECOND" @ GOSUB 510
580 GOSUB 310
590 LOCAL 711
600 REMOTE 711
610 GOSUB 470
620 GOSUB 430
630 GOSUB 890
640 T$="THIRD" @ GOSUB 510
650 GOSUB 310
660 LOCAL 711
670 REMOTE 711
680 GOSUB 470
690 GOSUB 390
700 T$="FOURTH" @ GOSUB 510
710 GOSUB 310
720 LOCAL 711 @ REMOTE 711
730 GOSUB 470
740 GOSUB 430
750 GOSUB 770
760 GOTO 1010
770 FOR I=0 TO 1023
780 F(I)=(A(I)+B(I))/2
790 NEXT I
800 M$=":D701"
810 D$="TEST200"
820 D$=D$&M$
830 CREATE D$,1,9000
840 ASSIGN# 1 TO D$
850 FOR I=0 TO 1023
860 PRINT# 1 ; F(I)
870 NEXT I
880 RETURN
890 FOR I=0 TO 1023
900 F(I)=(A(I)+B(I))/2
910 NEXT I
920 M$=":D701"
930 D$="TEST100"
940 D$=D$&M$
950 CREATE D$,1,9000
960 ASSIGN# 1 TO D$
970 FOR I=0 TO 1023
980 PRINT# 1 ; F(I)
990 NEXT I
1000 RETURN
1010 D$="TEST100"
1020 M$=":D701"

```

```
1030 D$=D$&M$
1040 ASSIGN# 1 TO D$
1050 FOR I=0 TO 1023
1060 READ# 1 ; A(I)
1070 NEXT I
1080 C$="TEST200"
1090 M$=":D701"
1100 C$=C$&M$
1110 ASSIGN# 1 TO C$
1120 FOR I=0 TO 1023
1130 READ# 1 ; B(I)
1140 NEXT I
1150 FOR I=0 TO 1023
1160 F(I)=(A(I)+B(I))/2
1170 NEXT I
1180 PURGE "TEST100:D701"
1190 PURGE "TEST200:D701"
1200 IOBUFFER A$
1210 M$=":D701"
1220 T$=VAL$(J)
1230 N$="DATA"&T$&M$
1240 CREATE N$,1,3000
1250 ASSIGN# 1 TO N$
1260 CONTROL A$,1 ; 1024*2
1270 PRINT# 1 ; A$
1280 NEXT J
1290 DISP "DONE" @ BEEP 15,8000
1300 CHAIN "DIR"
1310 END
```



```

5 COM H$[25],J,D$[25]
10 CLEAR @ DISP @ DISP @ DISP @
   DISP
20 DISP "          Program TRANS1
   "
30 DISP "          by Reza M. Shei
   khrezai"
40 DISP "          for Theises resea
   rch "
50 DISP "          all rights rese
   rved"
60 DISP @ DISP @ DISP "Press CO
   NT to continue"
70 PAUSE
80 REMOTE 711
90 CFLAG 1 @ CFLAG 2
100 DIM C$[20],A$[2056],B$[20],A
   (1024)
110 INTEGER Z1
120 IOBUFFER A$
130 ON KEY# 1,"D ENTR" GOSUB 230
140 ON KEY# 2,"R.CNT" GOSUB 640
150 ON KEY# 3,"T.R.PL" GOSUB 860
160 ON KEY# 4,"FFT PL" GOSUB 110
   0
170 ON KEY# 5,"SAVE" GOSUB 1300
180 ON KEY# 6,"TRANS2" GOSUB 179
   0
190 ON KEY# 7,"COMBINE" GOSUB 20
   90
200 ON KEY# 8,"TRANS3" GOSUB 256
   0
205 CLEAR
210 KEY LABEL
220 GOTO 210
230 ! DATA ENTRY ROUTINE*****
   *****
   *****
235 CLEAR
240 DISP "*****"
250 DISP "      Use the first 1
   etter  " @ DISP "      to
   choose method of entry  "
260 DISP "*****"
270 DISP @ DISP "          Fi
   le" @ DISP @ DISP "
   Key-board" @ DISP
280 LINPUT "          Analyzer
   ",C$
290 IF C$="F" THEN CLEAR @ GOTO
   1560
300 IF C$="A" THEN CLEAR @ GOSUB
   900
310 IF C$="R" THEN 1710
320 IF C$="K" THEN 350
330 CLEAR
340 GOTO 230
350 DISP "NUMBER OF PTS." @ INPU
   T N1

```



```

360 LINPUT "A PLOT OF INPUT? (Y/
N)",D$
370 IF D$="N" THEN 430
380 LINPUT "USING THE PLOTTER",D
$ @ IF D$="Y" THEN PLOTTER I
S 705
390 INPUT N2@ PEN N2
400 SCALE 0,N1,-1,1
410 MOVE 20,-.9 @ LABEL "#OF PTS
.",N1
420 AXES 100,.1,0,0,1024,1,5
430 FOR I=0 TO N1-1
440 DISP "ENTER POINT #",I @ INP
UT Z2
450 IF D$<>"N" THEN PLOT I,Z2
460 Z2=(2^15-1)*Z2
470 Z1=Z2
480 OUTPUT A$ USING "#,W" ; Z1
490 NEXT I
500 FOR J=1 TO 1023
510 Z1=0
520 OUTPUT A$ USING "#,W" ; Z1
530 NEXT J
540 LINPUT "WANT TO SAVE THE DAT
A? (Y OR N)",D$
550 IF D$="Y" THEN GOSUB 1300
560 ! RETURN OF ALL SENDS*****
*****
*
570 OUTPUT 711 ; "FR1RP0"
580 OUTPUT 711 USING "14A" ; "WT
M,70000,1024"
590 TRANSFER A$ TO 711 FHS
600 CONTROL A$,1 ; 1024*2
610 DISP "DONE" @ BEEP 6,1000
615 CLEAR
620 IF FLAG(2) THEN RETURN
630 GOTO 640
640 ! REMOTE CONTROL ROUTINE****
*****
****
650 CLEAR
660 DISP "*****"
*****
670 DISP " Four control codes h
ere"
680 DISP "*****"
*****
690 DISP " RTN >> return to menu
e"
700 DISP " GO >> send data to an
alyzer"
710 DISP " SAVE >> save time rec
ord"
720 DISP " MRKR >> marker sub ro
utine"
730 DISP " AVG >> Average wrt me
an"
735 DISP " SRQ >> service reques
t recovery"

```

```

736 DISP
740 DISP " All remote control co
      mmands for device 11"
750 DISP @ BEEP 15,500
760 LINPUT "ENTER CONTRL CODE",
      B$
770 IF B$="RTN" THEN CLEAR @ RET
      URN
780 IF B$="AVG" THEN GOSUB 1840
790 IF B$="AVG" THEN 570
800 IF B$="GO" THEN 570
810 IF B$="SAVE" THEN 1300
820 IF B$="MRKR" THEN GOTO 2300
830 IF B$="SRQ" THEN GOSUB 2800
840 OUTPUT 711 ;B$
850 GOTO 750
860 ! DISP TIME RECORD*****
      *****
      ****
865 CLEAR
870 LINPUT "ON PLOTTER?(Y/N)",D$
      @ IF D$="Y" THEN PLOTTER IS
      708
880 DISP "# OF PTS.?" @ INPUT N1
890 GOSUB 900 @ GOTO 940
900 OUTPUT 711 USING "14A" ; "LF
      M,70000,1024"
910 IOBUFFER A$
920 TRANSFER 711 TO A$ FHS
925 CLEAR
930 RETURN
940 !
950 GCLEAR @ LOCATE 20,120,20,90
960 SCALE 0,1024,-1,1
970 LAXES 100,1,0,0,1,1
980 MOVE 512,-1.25 @ LORG 4 @ LA
      BEL "Distance (microns)"
990 MOVE -100,-.2 @ DEG @ LDIR 9
      0 @ LABEL "Relative intensit
      y"
1000 FOR I=0 TO N1-1
1010 ENTER A$ USING "#,M" ; A(I)
1020 A(I)=A(I)/(2^15-1)
1030 PLOT I,A(I)
1040 NEXT I
1050 ALPHA
1060 LINPUT "WANT TO SAVE DATA?(
      Y/N)",D$ @ IF D$="Y" THEN 1
      300
1070 GOTO 1270
1080 RETURN
1090 ! DISP FREQ DATA*****
      *****
      *****700 REM
1095 CLEAR
1100 DIM B(256)
1110 LINPUT "PLOTTER?(Y/N)",D$ @
      IF D$="Y" THEN PLOTTER IS
      708
1120 LOCATE 20,120,20,90

```



```

1130 GCLEAR
1140 SCALE 0,256,0,1
1150 LAXES 20,1,0,0,1,1
1160 DISP "TAKE ANALYZER OUT OF
CALIBRATION THEN PRESS CONT
INUE" @ PAUSE
1170 OUTPUT 711 ; "TA00A1LDS"
1180 MOVE 107,-(.024*10)
1190 DEG @ LDIR 0 @ LOG 4 @ LAB
EL "Spatial Frequency" @ MO
VE -15,.5
1200 ALPHA
1210 LINPUT "ENTER AMP. LABEL",W
1$
1220 LDIR 90 @ LABEL W1$
1230 FOR I=0 TO 254
1240 ENTER 711 USING "#,MZ.DDe,X
" ; B(I)
1250 IF W1$="FFT^2" THEN PLOT I,
B(I)^2 ELSE PLOT I,B(I)
1260 NEXT I
1270 DISP "ENTER LABEL CODE" @ I
NPUT E$ @ MOVE 100,.4
1280 LDIR 0 @ LABEL E$
1285 CLEAR
1290 RETURN
1300 ! TIME RECORD STORAGE*****
*****
*****
1310 DISP "ONLY TIME RECORD IS S
AVED HERE"
1320 LINPUT "WANT KEY SET UP ON
FFT SAVED?(Y/N)",P$ @ IF P$
="Y" THEN GOSUB 1750
1330 GOSUB 1460
1340 GOSUB 900
1350 LINPUT "Have a file?(Y/N)",
Q$ @ GOSUB 1410
1360 ASSIGN# 1 TO D$
1370 IF P$="Y" THEN PRINT# 1 ; A
$,B$ ELSE PRINT# 1 ; A$
1380 ASSIGN# 1 TO *
1385 CLEAR
1390 RETURN
1400 ! SOME DATA MANAGEMENT ROUT
INES*****
*****
1410 LINPUT "Enter file name",D$
1420 D$=D$&M$
1430 IF Q$="Y" THEN RETURN
1440 CREATE D$,1,3000
1450 RETURN
1460 IF FLAG(1) THEN RETURN
1470 SFLAG 1
1480 CLEAR
1490 DISP @ DISP "      Enter;(
0)for tape" @ DISP "
      (1)for disk 1"
1500 DISP "      (2)for d
isk 2" @ INPUT M1

```



```

1510 IF M1=0 THEN M$=":T"
1520 IF M1=1 THEN M$=":D700"
1530 IF M1=2 THEN M$=":D701"
1540 IF M1>2 THEN 1490
1550 RETURN
1560 ! FILE READ ROUTINE*****
*****
1570 CLEAR @ LINPUT "      Does th
e file contain key
      set ups?(Y/N)",D$
1580 CFLAG 1
1590 GOSUB 1460
1600 LINPUT "      File name?",
E$
1610 CLEAR @ DISP @ DISP "*****
*****"
@ DISP "      Reading dat
a
1620 DISP "*****
*****"
1630 E$=E$&M$
1640 ON ERROR GOSUB 1570
1650 ASSIGN# 1 TO E$
1660 OFF ERROR
1670 IOBUFFER A$ @ IOBUFFER B$
1680 IF D$="Y" THEN READ# 1 ; A$
,B$ ELSE READ# 1 ; A$
1690 IF D$="Y" THEN C$=B$ ELSE C
$="PRS"
1700 CLEAR
1710 IF FLAG(2) THEN 570
1720 LINPUT "Want to sort wrt. m
ean?",D$ @ IF D$="Y" THEN G
OSUB 1840
1730 GOTO 570
1740 ! KEY SET UP READ*****
LIST1
1750 IOBUFFER B$
1760 OUTPUT 711 USING "11A" ; "L
FM,77454,5"
1770 TRANSFER 711 TO B$ FHS
1780 RETURN
1790 DISP "*****"
1800 DISP "CHAINING TO TRANS2"
1810 DISP "*****"
1820 CHAIN "TRANS2:D700"
1830 RETURN
1840 ! zero mean routine*****
*****
1850 U1=0
1860 MAT A=ZER
1870 DISP "ENTER LOWER AND UPPER
LIMIT OF DATA TO BE CONSID
ERED"
1880 INPUT C9,C8
1890 FOR I=0 TO 1023
1900 ENTER A$ USING "#,W" ; A(I)
1910 NEXT I

```

```

1920 FOR I=C9 TO C8
1930 U1=U1+A(I)
1940 NEXT I
1950 U1=U1/(C8-C9)
1960 IOBUFFER A$
1970 FOR I=C9 TO C8
1980 A(I)=A(I)-U1
1990 NEXT I
2000 FOR I=0 TO C9
2010 A(I)=0 @ NEXT I
2020 FOR I=C8 TO 1023 @ A(I)=0 @
      NEXT I
2030 FOR I=0 TO 1023
2040 OUTPUT A$ USING "#,W" ; A(I)
      )
2050 NEXT I
2060 CONTROL A$,1 ; 1024*2
2070 PRINT "CK"
2080 RETURN
2090 ! COMBINER ROUTINE
2100 OUTPUT 711 ; "FR01M2RP0"
2110 ! DISP "CONT WHEN READY" @
      PAUSE
2120 ! OUTPUT 711 ; "FR0RP0"
2130 GOSUB 900
2140 OUTPUT 711 ; "IM1AV1RP1"
2150 GOTO 1710
2160 ! AUTOCORELATOR*****
      *****
      *****
2170 CLEAR
2180 DISP "      TURN HP9826 ON"
2190 DISP "BRING UP PROGRAM AUTO
      "
2200 DISP "      ON VOLUME B9826"
2210 DISP "      THEN PRSS CONT"
2220 PAUSE
2230 PASS CONTROL 721
2240 DISP "      NOW TO USE THIS PR
      OGRAM AGAIN "
2250 DISP "      JUST RESET AUTO:B9
      826"
2260 DISP "THEN PRESS CONT ON "
2270 DISP "THIS MACHINE"
2280 PAUSE
2290 RETURN
2300 ! *****MARKER*****
2310 C=0
2320 P=1
2330 OUTPUT 711 ; "MN1MP0"
2340 CLEAR @ DISP @ DISP "Use EN
      D LINE to advance marker"
2350 DISP "and A to retrack it"
2360 DISP
2370 DISP "RTN to leave"
2380 DISP
2390 DISP "P to change the incre
      ment."
2400 DISP "Wait for a beep "
2410 BEEP 50,100

```



```

2420 INPUT A$
2430 IF A$="RTN" THEN 640
2440 IF A$="P" THEN GOSUB 2530
2450 IF A$="A" THEN C=C-P ELSE C
=C+P
2460 IF C>=0 AND C<=255 THEN 248
0
2470 DISP "*ERROR*WRONG MRKR LOC
.*TRY AGAIN" @ C=0 @ GOTO 2
410
2480 Q$="MP"
2490 Q$=Q$&VAL$(C)
2500 DISP Q$
2510 OUTPUT 711 ;Q$
2520 GOTO 2410
2530 DISP "Current inc. is";P
2540 DISP "enter new inc." @ INP
UT P
2550 RETURN
2560 ! ***FRQ AS TR***
2570 GCLEAR
2580 SFLAG 2
2590 DISP "BRING UP THE FIRST TR
ACE" @ GOSUB 230
2600 REDIM B(255)@ DIM G(255)
2610 MAT B=ZER@ MAT G=ZER
2620 OUTPUT 711 ;"TA0SC2AM1AA1LD
S"
2630 FOR I=0 TO 254 @ ENTER 711
USING "#,MZ.DDe,X" ; B(I)@
NEXT I
2640 DISP "*****"
2650 DISP "BRING UP THE REFERENC
E TRACE"
2660 DISP "*****"
2670 GOSUB 230
2680 OUTPUT 711 ;"TA0AA1LDS"
2690 FOR I=0 TO 254 @ ENTER 711
USING "#,MZ.DDe,X" ; G(I)@
B(I)=B(I)-G(I) @ NEXT I
2700 L1=AMIN(B) @ L2=AMAX(B)
2710 LOCATE 20,120,20,100
2720 SCALE 0,255,L1,L2
2730 FRAME
2740 MOVE 0,0
2750 FOR I=0 TO 255
2760 PLOT I,B(I)
2770 NEXT I
2780 CFLAG 2
2790 RETURN
2800 Q=SPOLL(711)
2805 DISP "RESULT OF THE SERIAL
POLL=";Q
2806 B$=" "
2810 RETURN

```



```

5 CLEAR
10 DISP
20 DISP
30 DISP
40 DISP "*****
*****"
50 DISP
60 DISP "          D A T P L O T"
70 DISP
80 DISP "*****
*****"
90 COM A(1024),A$(2056),N$(25),
J,D$(25),B$(2056),L$(25)
110 DISP
120 DISP
130 DISP " VIEW THE DATA BY ENT
ERING THE FILE NAME "
140 DISP
150 DISP " PRESS CONT TO GO
ON" @ PAUSE
155 CLEAR
160 LINPUT "FIRST FILE?",N$
170 LINPUT "SECOND FILE?",D$
180 IF N$="DIR" THEN 1270
190 CLEAR 711
200 RESET 7
210 REMOTE 711
220 IOBUFFER A$
230 M$=":D701"
240 N1$=N$&M$
250 ASSIGN# 1 TO N1$
260 IOBUFFER A$
270 READ# 1 ; A$
280 OUTPUT 711 ; "IM1"
290 OUTPUT 711 ; "FR1RPO"
300 OUTPUT 711 USING "14A" ; "WT
M,70000,1024"
310 TRANSFER A$ TO 711 FHS
320 CONTROL A$,1 ; 1024*2
330 ! GOSUB 1170
340 GOSUB 800
350 M$=":D701" @ D1$=D$&M$ @ ASS.
IGN# 1 TO D1$
360 IOBUFFER A$
370 READ# 1 ; A$
380 OUTPUT 711 USING "14A" ; "WT
M,70000,1024"
390 TRANSFER A$ TO 711 FHS
400 CONTROL A$,1 ; 1024*2
410 J=2
420 ! GOSUB 1170
430 GOSUB 830
440 GOTO 130
450 ! DISP TIME RECORD*****
*****
***
460 CLEAR
470 OUTPUT 711 ; "TA1"
480 PLOTTER IS 708
490 N1=1024

```

```

500 GOSUB 510 @ GOTO 560
510 OUTPUT 711 USING "14A" ; "LF
M,70000,1024"
520 IOBUFFER A$
530 TRANSFER 711 TO A$ FHS
540 CLEAR
550 RETURN
560 !
570 IF J=2 THEN 580 ELSE 610
580 PEN 2
590 LOCATE 65,125,65,95
600 GOTO 620
610 GCLEAR @ LOCATE 65,125,10,40
620 SCALE 0,1024,-1,1
630 LAXES 400,1,0,0,1,1
640 MOVE 512,-1.35 @ LORG 6 @ LA
BEL "Distance (microns)"
650 LORG 4 @ MOVE -90,-0 @ DEG @
LDIR 90 @ LABEL "Relative i
ntensity"
660 FOR I=0 TO N1-1
670 ENTER A$ USING "#,W" ; A(I)
680 A(I)=A(I)/(2^15-1)
690 PLOT I,A(I)
700 NEXT I
710 MOVE 512,.8
720 V$="TIME RECORD PLOT"
730 CSIZE 4
740 DEG @ LDIR 0 @ LORG 5
750 LABEL V$
760 IF J=1 THEN LABEL N$
770 IF J=2 THEN LABEL D$
780 ALPHA
790 RETURN
800 ! DISP FREQ DATA*****
*****
****700 REM
810 CLEAR
820 J=1
830 DIM B(256)
840 IF J=2 THEN 850 ELSE 880
850 PEN 2
860 LOCATE 5,50,65,95
870 GOTO 900
880 PLOTTER IS 708
890 LOCATE 5,50,10,40
900 GCLEAR
910 SCALE 0,50,-0,1.5
920 CSIZE 3
930 LAXES 50,1,0,0,1,1
940 OUTPUT 711 ; "TA00A1LDS"
950 MOVE 15,-.2
960 DEG @ LDIR 0 @ LORG 3 @ CSIZ
E 3 @ LABEL "Spatial Frequen
cy" @ MOVE -4,.6
970 ALPHA
980 W1$="FFT^2"
990 LDIR 90 @ LABEL W1$
1000 L=0
1010 ! MOVE 0,0

```



```

1020 FOR I=0 TO 50
1030 ENTER 711 USING "#,MZ.DDe,X
      " ; B(I)
1040 PLOT I,B(I)^2
1050 ! PRINT I,B(I)^2
1060 IF L>=B(I) THEN 1090
1070 L=B(I)
1080 D=I
1090 NEXT I
1100 IF W1$="FFT^2" THEN MOVE D,
      L^2 ELSE MOVE D,L
1110 IF J=1 THEN PEN 2 ELSE PEN
      1 @ K$="*"
1120 IF J=2 THEN PEN 1 ELSE PEN
      2
1130 LORG 5
1140 K$="*"
1150 LABEL K$
1160 C=D*25500/256
1170 MOVE 15,1.1
1180 L$="Max. value occurs at" @
      L2$=" Hz"
1190 CSIZE 2
1200 DEG @ LDIR 0 @ LORG 3 @ LAB
      EL L$,C,L2$
1210 MOVE 15,1.45
1220 DEG @ LDIR 0 @ LORG 3 @ CSI
      ZE 4 @ LABEL "FFT PLOT" @
      IF J=1 THEN LABEL N$ ELSE
      LABEL D$
1230 IF J=1 THEN GOSUB 450
1240 IF J=2 THEN GOSUB 450
1250 RETURN
1260 ! MEAN ROUTINE
1270 U1=0
1280 MAT A=ZER
1290 FOR I=0 TO 1023
1300 ENTER A$ USING "#,W" ; A(I)
1310 NEXT I
1320 FOR I=0 TO 1023
1330 U1=U1+A(I)
1340 NEXT I
1350 U1=U1/1024
1360 IOBUFFER A$
1370 FOR I=0 TO 1023
1380 A(I)=A(I)-U1
1390 NEXT I
1400 FOR I=0 TO 1023
1410 OUTPUT A$ USING "#,W" ; A(I)
      )
1420 NEXT I
1430 CONTROL A$,1 ; 1024*2
1440 OUTPUT 711 ; "FR1RF0"
1450 OUTPUT 711 USING "14A" ; "W
      TM,70000,1024"
1460 TRANSFER A$ TO 711 FHS
1470 CONTROL A$,1 ; 1024*2
1480 BEEP 9,1000
1490 RETURN
1510 END

```



```

10 DISP
20 DISP
30 DISP
40 DISP
50 DISP
60 DISP "*****"
70 DISP
80 DISP "          P L O T T I N
   G "
90 DISP
100 DISP
110 DISP "*****"
120 COM A(1024),A$(2056),N$(25),
   J,D$(25)
130 DISP
140 DISP
150 DISP "  VIEW THE DATA BY ENT
   ERING THE FILE NAME "
160 DISP
170 DISP "          PRESS CONT TO GO
   ON" @ PAUSE
180 CLEAR
190 LINPUT "FILE NAME?",N$
200 CLEAR 711
210 RESET 7
220 REMOTE 711
230 IOBUFFER A$
240 M$=":D701"
250 N$=N$&M$
260 ASSIGN# 1 TO N$
270 IOBUFFER A$
280 READ# 1 ; A$
290 OUTPUT 711 ; "IM1"
300 OUTPUT 711 ; "FR1RP0"
310 OUTPUT 711 USING "14A" ; "WT
   M,70000,1024"
320 TRANSFER A$ TO 711 FHS
330 CONTROL A$,1 ; 1024*2
340 ! GOSUB 820
350 GOSUB 620
360 LINPUT "TIME RECORD ?",A$
370 IF A$="Y" THEN 420 ELSE 390
380 DISP "DONE" @ BEEP 6,1000
390 END
400 CLEAR
410 !
420 OUTPUT 711 ; "TA1"
430 CLEAR
440 PLOTTER IS 708
450 OUTPUT 711 USING "14A" ; "LF
   M,70000,1024"
460 IOBUFFER A$
470 TRANSFER 711 TO A$ FHS
480 CLEAR
490 !
500 GCLEAR @ LOCATE 20,120,20,90
510 SCALE 0,1024,-1,1
520 LAXES 100,1,0,0,1,1

```

```

530 MOVE 512,-1.25 @ LONG 4 @ LA
    BEL "Distance (microns)"
540 MOVE -100,-.2 @ DEG @ LDIR 9
    @ LABEL "Relative intensit
    y"
550 FOR I=0 TO 1023
560 ENTER A$ USING "#,W" ; A(I+1
    )
570 A(I+1)=A(I+1)/(2^15-1)
580 PLOT I+1,A(I+1)
590 NEXT I
600 ALPHA
610 GOTO 190
620 !
630 CLEAR
640 DIM B(256)
650 PLOTTER IS 708
660 LOCATE 20,120,20,90
670 GCLEAR
680 SCALE 0,50,0,1
690 LAXES 50,1,0,0,1,1
700 OUTPUT 711 ; "TA00A1LDS"
710 MOVE 25,-(.02*10)
720 DEG @ LDIR 0 @ LONG 4 @ LABE
    L "Spatial Frequency" @ MOVE
    -4,.5
730 ALPHA
740 W1$="FFT^2"
750 LDIR 90 @ LABEL W1$
760 L=0
770 FOR I=0 TO 50
780 ENTER 711 USING "#,MZ.DDe,X"
    ; B(I)
790 IF W1$="FFT^2" THEN PLOT I,B
    (I)^2 ELSE PLOT I,B(I)
800 IF L>B(I) THEN 830 ELSE 810
810 L=B(I)
820 D=I
830 NEXT I
840 D1=D*25500/256
850 IF W1$="FFT^2" THEN MOVE D,L
    ^2 ELSE MOVE D,L
860 LONG 5 @ LABEL "*"
870 MOVE 30,.55
880 DEG @ LDIR 0 @ LONG 5 @ LABE
    L "Max value is",D1 @ MOVE 4
    3,.55 @ LABEL "Hz"
890 L$="FFT PLOT" @ MOVE 25,.9
900 DEG @ LDIR 0 @ LONG 5 @ CSIZ
    E 5 @ LABEL L$
910 RETURN
920 !
930 U1=0
940 MAT A=ZER
950 FOR I=0 TO 1023
960 ENTER A$ USING "#,W" ; A(I)
970 NEXT I
980 FOR I=0 TO 1023
990 U1=U1+A(I)
1000 NEXT I

```

```
1010 U1=U1/1024
1020 IOBUFFER A$
1030 FOR I=0 TO 1023
1040 A(I)=A(I)-U1
1050 NEXT I
1060 FOR I=0 TO 1023
1070 OUTPUT A$ USING "#,W" ; A(I)
1080 NEXT I
1090 CONTROL A$,1 ; 1024*2
1100 OUTPUT 711 ; "FR1RPO"
1110 OUTPUT 711 USING "14A" ; "W
    TM,70000,1024"
1120 TRANSFER A$ TO 711 FHS
1130 CONTROL A$,1 ; 1024*2
1140 PRINT "CK"
1150 RETURN
1160 END
```



```

10 CLEAR
20 DISP
30 DISP
40 DISP
50 DISP "*****
*****"
60 DISP
70 DISP "          D A T A V "
80 DISP
90 DISP "*****
*****"
100 DISP
110 DISP " PRESS CONT WHEN READ
Y!" @ PAUSE
120 DIM A$(2056),F(1024)
130 LINPUT "FIRST FILE",N$
140 LINPUT "SECOND FILE",T$
150 LINPUT "FILE TO STORE?",D$
160 IOBUFFER A$
170 N$=N$&M$
180 ASSIGN# 1 TO N$
190 READ# 1 ; A$
200 FOR I=0 TO 1023
210 ENTER A$ USING "#,W" ; F(I)
220 IF I<1023 THEN 280
230 GOSUB 520
240 DIM A(1024)
250 FOR I=0 TO 1023
260 A(I)=F(I)
270 NEXT I
280 NEXT I
290 T$=T$&M$
300 ASSIGN# 1 TO T$
310 READ# 1 ; A$
320 FOR I=0 TO 1023
330 ENTER A$ USING "#,W" ; F(I)
340 IF I<1023 THEN 400.
350 GOSUB 520
360 DIM B(1024)
370 FOR I=0 TO 1023
380 B(I)=F(I)
390 NEXT I
400 NEXT I
410 FOR I=0 TO 1023
420 F(I)=(A(I)+B(I))/2
430 OUTPUT A$ USING "#,W" ; F(I)
440 NEXT I
450 D$=D$&M$
460 CREATE D$,1,3000
470 ASSIGN# 1 TO D$
480 CONTROL A$,1 ; 1024*2
490 PRINT# 1 ; A$
500 BEEP
510 END
520 U1=0
530 MAT F=ZER
540 FOR I=0 TO 1023
550 U1=U1+F(I)
560 NEXT I
570 U1=U1/1024

580 FOR I=0 TO 1023
590 F(I)=F(I)-U1
600 NEXT I
610 RETURN

```

```

10 CLEAR
20 DISP
30 DISP
40 DISP
50 DISP "*****"
   *****"
60 DISP
70 DISP "          S C A N A V G
   "
80 DISP
90 DISP "*****"
   *****"
91 DISP
92 DISP
100 COM A(1024),A$(2056),N$(25),
   J,D$(25)
120 DISP
130 DISP
140 DISP "MANUAL SCAN AVERAGING
   ALONG THE FRINGES "
150 DISP
160 LINPUT "To continue print th
   e FILE NAME to store the ave
   rage.",N$
170 CLEAR
180 DISP
190 DIM B(1024),F(1024)
200 CLEAR 7
210 RESET 7
220 CLEAR
230 REMOTE 711
240 GOSUB 380
250 GOSUB 280
260 GOSUB 1160
270 GOTO 420
280 !
290 FOR I=0 TO 1023
300 ENTER A$ USING "#,W" ; A(I)
310 NEXT I
320 RETURN
330 !
340 FOR I=0 TO 1023
350 ENTER A$ USING "#,W" ; B(I)
360 NEXT I
370 RETURN
380 OUTPUT 711 USING "14A" ; "LF
   M,70000,1024"
390 IOBUFFER A$
400 TRANSFER 711 TO A$ FHS
410 RETURN
420 DISP "MOVE TO SECOND POSITIO
   N" @ DISP "press CONT when y
   ou are ready." @ PAUSE @ BEE
   P 9,1000
430 LOCAL 711
440 REMOTE 711
450 GOSUB 380
460 GOSUB 330
470 GOSUB 1160
480 GOSUB 740

```

```

490 DISP "MOVE TO THIRD POSITION
" @ DISP "Press CONT when yo
u are ready." @ BEEP 9,1000
@ PAUSE
500 LOCAL 711
510 REMOTE 711
520 GOSUB 380
530 GOSUB 280
540 GOSUB 1160
550 DISP "MOVE TO FOURTH POSITIO
N" @ DISP "Press CONT when y
ou are ready." @ BEEP 9,1000
@ PAUSE
560 LOCAL 711 @ REMOTE 711
570 GOSUB 380
580 GOSUB 330
590 GOSUB 1160
600 GOSUB 620
610 GOTO 860
620 FOR I=0 TO 1023
630 F(I)=(A(I)+B(I))/2
640 NEXT I
650 M$=":D701"
660 D$="TEST200"
670 D$=D$&M$
680 CREATE D$,1,9000
690 ASSIGN# 1 TO D$
700 FOR I=0 TO 1023
710 PRINT# 1 ; F(I)
720 NEXT I
730 RETURN
740 FOR I=0 TO 1023
750 F(I)=(A(I)+B(I))/2
760 NEXT I
770 M$=":D701"
780 D$="TEST100"
790 D$=D$&M$
800 CREATE D$,1,9000
810 ASSIGN# 1 TO D$
820 FOR I=0 TO 1023
830 PRINT# 1 ; F(I)
840 NEXT I
850 RETURN
860 D$="TEST100"
870 M$=":D701"
880 D$=D$&M$
890 ASSIGN# 1 TO D$
900 FOR I=0 TO 1023
910 READ# 1 ; A(I)
920 NEXT I
930 C$="TEST200"
940 M$=":D701"
950 C$=C$&M$
960 ASSIGN# 1 TO C$
970 FOR I=0 TO 1023
980 READ# 1 ; B(I)
990 NEXT I
1000 IOBUFFER A$
1010 FOR I=0 TO 1023
1020 F(I)=(A(I)+B(I))/2

```



```

1030 OUTPUT A$ USING "#,W" ; F(I
    )
1040 NEXT I
1050 PURGE "TEST100:D701"
1060 PURGE "TEST200:D701"
1070 M$=":D701"
1080 N$=N$&M$
1090 CREATE N$,1,3000
1100 ASSIGN# 1 TO N$
1110 CONTROL A$,1 ; 1024*2
1120 PRINT# 1 ; A$
1130 DISP "DONE" @ BEEP 15,8000
1140 BEEP 1,2
1150 M$=":D701"
1160 LINPUT "FILE?",T$
1170 M$=":D701"
1180 T$=T$&M$
1190 CREATE T$,1,5000
1200 ASSIGN# 1 TO T$
1210 CONTROL A$,1 ; 1024*2
1220 PRINT# 1 ; A$
1230 RETURN

```

```

10 CLEAR
20 DISP
30 DISP
40 DISP
50 DISP "*****
*****"
60 DISP
70 DISP "          G R I D "
80 DISP
90 DISP "*****
*****"
91 DISP
92 DISP
93 DISP "  PRESS CONT WHEN READ
Y!" @ PAUSE
94 CLEAR
100 PLOTTER IS 700
110 LOCATE 15,35,20,40
120 SCALE 0,55,0,10
130 FOR J=0 TO 25
140 MOVE J,0
150 DRAW J,10
160 NEXT J
170 END

```

```

10 CLEAR
20 DISP
30 DISP
40 DISP
50 DISP "*****
*****"
60 DISP
70 DISP "          P L O T "
80 DISP
90 DISP "*****
*****"
100 DISP
110 DISP "PRESS CONT TO GO ON!"
    @ PAUSE
120 CLEAR
130 PLOTTER IS 700
140 LOCATE 20,125,15,95
150 SCALE 0,65,0,1300
160 LAXES 10,250,0,0,1,1
170 MOVE 25,-100
180 LORG 5
190 LABEL "1/ fringe spacing (1/
    inch)"
200 MOVE -5,725
210 LORG 5
220 DEG
230 LDIR 90
240 LABEL " frequency (Hz.)"
250 MOVE 47.62,1000
260 LABEL "*"
270 MOVE 37.97,800
280 LABEL "*"
290 MOVE 31.7,600
300 LABEL "*"
310 MOVE 27.15,500
320 LABEL "*"
330 MOVE 21.13,400
340 LABEL "*"
350 MOVE 15.87,300
360 LABEL "*"
370 MOVE 25,1115
380 FOR I=0 TO 50
390 PLOT I,22.53*I-81.48
400 NEXT I
410 MOVE 35,1215
420 LDIR 0
430 LORG 5
440 CSIZE 3
450 LABEL " FREQUENCY Vs. IN
    VERSE OF FRINGE SPACING"
460 MOVE 35,300
470 LDIR 0
480 LORG 1
490 CSIZE 3
500 LABEL " * Experimental data
    "
510 MOVE 35,200
520 LABEL " - Least square appr
    oximation"
530 LORG 5
540 MOVE 47,125
550 LABEL "      Y = 22.5*X - 81.
    48"
560 END

```


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