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ABSTRACT

The capability of a computer program which can be part of a larger computer program for a fully automated multiaxial testing facility is described. This computer program is designed to process test data from tubular or flat specimens made from isotropic or anistropic materials including high modulus fiber composites. The program can receive data from a large number of strain gages and combinations of applied loads. Options are provided for single element, 90-degree, rectangular or Delta rosettes, or any combinations of these types of strain gages. Options are provided for strain gage transverse sensitivities. The program outputs include: structural axes strains and stresses, initial and strain dependent elastic constants, shift of principal strain direction with load, and local curvatures from back-to-back strain gages, and either calcomp or microfilm plots. The computer program is described with respect to its flow chart, input/output, embedment or linking with other programs and its possible utility in a fully automated testing system.

Key words: Computer program, testing data reduction, automated testing, strain gage data, angle shift, local curvatures, fiber composites, stress analysis, computer plotting.

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INTRODUCTION

In fully automated testing for characterization of materials in general and in particular fiber composites, a computer program is required. It is the function of the computer program to: receive input signals from the testing machine, convert them to engineering data, perform the necessary computations, carry out the comparisons with the predetermined test-program-profiles, and issue new commands for the next testing step. Thus, the computer program together with the predetermined test-program-profile can control the testing and make fully automated testing a practicality. Fully automated testing will be of great utility in testing of advanced fiber composites where the load path effects, load rate, multitude of load conditions and their history of application must be precisely controlled and recorded. Specific cases of automated testing are described in [1][1] and [2].

The subject of this paper is to describe the capability of a computer program which can be a part of a larger computer program for a fully automated multiaxial testing facility. However, the computer program described herein has not been used in such a facility as yet. This computer program is designed to process test data from tubular or flat specimens made from isotropic or anisotropic materials including high modulus fiber composites. The program can receive data from a number of strain gages and combinations of applied loads. Options are provided for single element, 90-degree, rectangular or Delta rosettes, or any combinations of these types of strain gages. Options are provided for strain gage transverse sensitivities.

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[1]The italic number in the brackets refer to the list of references appended to this paper.

The inputs to the computer program are digital strain gage and load cell data. The program outputs include: structural axes strains and stresses, initial and strain dependent elastic constants, next load increment extrapolated strains, extrapolated failure strains and shift of principle strain direction with load. The program has provisions for analysis of data from back-to-back strain gages at a point and the computation of local curvatures at this point. Plotting options of the output are also provided.

The capability of this computer program is described with respect to its flow chart, input/output, and its embedment or linking with a laminate analysis. Its possible utility in fully computer controlled testing is discussed.

CAPABILITY OF COMPUTER PROGRAM

The computer program is organized as is depicted in the flow chart in Figure 1. A brief description of the functions of the various boxes in the Flow Chart (Fig. 1) follows.

Input Data

The input data for the program consists of the specimen parameters listed in Table 1, the test parameters and options listed in Table 2, and the strain gage raw data. The strain gage raw data, as used in this program, consists of digital strain readings on paper tape. The data from the paper tape is punched on cards in a format acceptable to the program. The input data is read in as depicted in the first three blocks of the Flow Chart (Fig. 1).

Convert Input Data to Stress and Apparent Strain

The portion of the program represented by block (4) in the Flow Chart

(Fig. 1) converts the strain gage scaled digital strain readings to apparent strains. The average stress in the specimen is computed using the load cell reading input and the specimen cross section dimensions.

In this portion of the program, a table of input data information is constructed and the raw strain gage data is converted to apparent strains. This table serves two purposes: (1) it facilitates subsequent computations, and (2) it serves as a standard for the input data in cases which have different data input formats than the one presently used and described in the previous section.

Compute Actual Strains

The apparent strains are corrected for transverse sensitivity in the portion of the computer program denoted by block 5 in the Flow Chart (Fig. 1). Two sets of equations are used for these corrections. The number of constants required for the transverse sensitivity corrections depend on both the type of gage and the supplier. For example, for the case of three element rosettes, one option requires three constants and the Poisson's ratio of the material on which the manufacturer's gage factor was measured [3]. The other option requires only one constant. In either case, the constants are provided by the gage manufacturer. The corrected strains are stored in a table and are available for subsequent computations.

Transformation of Actual Strains to Structural Axes

The actual strains described in the previous section are determined with respect to a local gage axes, that is, the longitudinal and transverse gage axes. For useful engineering data, the strains need to be transformed to the structural axes of the specimens. The structural axes of the specimen, or any component for that matter, refer to the overall specimen geometry and usually coincide with the principal external loading directions.

The transformation of the strains is accomplished in the portion of the program represented by block 6 in the Flow Chart (Fig. 1). The transformation is performed using the well known rotation transformation relations [4] and the input gage orientation with respect to structural axes (load direction) information.

The structural axes strains are stored in a table and are available for subsequent computations and for input to the Multilayered Fiber Composites Analysis Computer Code [5] for the laminate stress analysis as will be described later. The data transfer takes place in the part of the computer program denoted by block 7 in the Flow Chart (Fig. 1).

Shift of Principal Strain Axes with Load

Several factors contribute to changes in angle between gage axes and structural axes. Some of the important ones are: gage misalignment, load eccentricity, fiber misalignment and fiber relative rotation during loading. So far as the gage is concerned, the combined effect of these factors is reflected as increments in the input gage orientation angle.

This angular increment can be readily determined by satisfying known conditions of the strain state on the structural axes. For the case of coincident axial load and fiber direction, for example, the known strain condition on the structural axes is that the shear strain should be zero. Using this condition, the change in the angle can be obtained from the strain transformation equations and the structural axes strains. Corresponding conditions for other loadings are derivable from the rotation transformation equations.

The angular shift is computed in the portion of the program indicated by block 8 in the Flow Chart (Fig. 1). The results are stored in a table and are available for subsequent laminate stress analysis computations.

Smoothing Routines for Extrapolation,
Interpolation and Plotting

The structural strain gage data is fitted with a smooth curve which can be used for interpolation, extrapolation, plotting and for computing derivatives at desired points. The smooth piecewise function is generated in the part of the computer program denoted by block 9 in the Flow Chart (Fig. 1).

In these computations, the structural axes longitudinal strain (E_{xx}) is taken as the independent variable in generating the piecewise smoothing function for curve fitting. The dependent variables are stress, the structural axes transverse strain (ε_{yy}), and the structural axes shear strain (ε_{xy}).

Engineering Constants and Failure Load
Extrapolated Values

Engineering constants (moduli, Poisson's ratio, etc.), and failure load parameters (stress and strains) are readily computed from the piecewise smooth functions described in the last section. The longitudinal modulus (ε_{xx}) equals the slope of the function longitudinal stress (σ_{xx}) versus longitudinal strain (ε_{xx}) evaluated at the desired strain (ε_{xx}). The major Poisson's ratio ν_{xy} equals the slope of the function transverse strain (ε_{yy}) versus longitudinal strain (ε_{xx}) evaluated at ε_{xx}. The coupling term between longitudinal strain and shear strain equals the slope of the function shear strain (ε_{xy}) versus ε_{xx} evaluated at ε_{xx}. Other stress-strain or strain-stress relationships can be obtained in a similar fashion. These computations are performed in the portion of the program designated by block 10 in the Flow Chart (Fig. 1).

The values for the failure strains for each gage are obtained by extrapolation when only the failure load is known. The corresponding failure strains are calculated using the smoothing function (block 11, Flow Chart in Fig. 1).

The results of these computations are stored in a table and are available for laminate analyses with load dependent stress-strain or strain-stress relationships. The computations for interpolated slope values are performed in the part of the program denoted by block 14 and block 15 in the Flow Chart (Fig. 1).

Plotting Routines

The computer program has options for plotting the data reduction results. The plotting is accomplished using the smoothing functions described previously in conjunction with available plotting routines. This is accomplished in the part of the computer program denoted by blocks 12 and 13 in the Flow Chart (Fig. 1).

The plotting can be done either on the calcomp or on microfilm. Samples of calcomp plots are shown in figures 2, 3, and 4 for stress, transverse strain (ε_{yy}), and shear strain (ε_{xy}) versus longitudinal strain (ε_{xx}).

Displacement Matrix

Bending in the test specimens is measured by back-to-back rosettes. Values read from these gages can be used to compute reference plane strains and local curvatures if the assumption is made that plane sections before and after deformation remain plane. In this computer program, these computations are performed in the part of the program denoted by block 16 in the Flow Chart (Fig. 1). Subsequently, they are used as input data for the laminate stress analysis. See block 17 Flow Chart (Fig. 1).

Computer Program Output

The output of the computed results described previously is printed in the part of the program denoted by block 18. Here, several tables are printed out. The headings of these tables are listed in Table 3.

LINK WITH MULTILAYER FIBER COMPOSITE ANALYSIS

The laminate stress analysis using the strain gage data is performed by the Multilayer Fiber Composite Analysis Computer Code [5]. The linking between the two programs is simply accomplished through the aid of temporary storage (block 19, Flow Chart, Fig. 1).

Laminate stresses are computed either for all or for selected gage values by transferring the desired strain values from temporary storage to multilayered fiber composite analysis code. The additional input data required, the mechanics of the computer code for laminate stress analysis, and the output are described in detail in [5].

DISCUSSION ON COMPUTERIZED CONTROLLED TESTING

The computer program described herein has been used extensively in the reduction of the strain gage data reported in [6]. It became evident in that effort that a computer program of this type has great utility.

In general, coupling data reduction programs with multilayered laminate analysis programs to control fiber composite testing requires a real-time operation. This means either instantaneous access to time sharing systems or a small computer [2] attached to and used only with the testing machine.

Real time programming of small computers [7] is a highly specialized profession and can be quite expensive. It usually results in rigid format software which can only be modified by real-time programmers. This leads to the following two distinct disadvantages:

1. Operator does not have control of the program beyond that provided by the rigid format.

2. Limited flexibility in carrying out computations required for fiber composite laminate stress analysis.

One alternative to the previously described disadvantages is a cross-compiler [8]. The cross-compiler translates a FORTRAN IV program, for example, into the machine language acceptable to the smaller computer. Programming for computer controlled testing can be done in FORTRAN, or any other high level language, and then translated and loaded in the smaller computer.

With either the availability of cross-compilers or an instantaneous access to a time sharing system, the linked system of programs described herein could supply the major portion of all the software required to control automated testing.

CONCLUDING REMARKS

The results of this investigation lead to the following statements.

1. An operational computer program has been generated to reduce the strain gage data generated in manual or automated testing of fiber composites.

2. This computer program can handle readily a large number (greater than one-hundred) and various types of strain gages, their transverse sensitivity, different specimen geometries, and isotropic or anistropic material.

3. The changes in local curvatures are computed from back-to-back strain gages. The change in fiber direction with load is computed via suitable strain transformation.

4. This computer program is designed to provide engineering data in terms of tables, calcomp plots, or microfilm.

5. This computer program can be linked with an available multilayered fiber composite computer code [5]. In this form the package can be used with an on-line computerized testing facility.

REFERENCES

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TABLE 1--Specimen parameters.

Type of specimen	-	flat or tube
Type of material	-	isotropic, anisotropic
Transverse sensitivity	-	one or four gage manufacturer constants
Specimen gage section	-	diameter or width
Specimen gage section	-	thickness

TABLE 2--Test parameters and options.

Number of gage positions

Number of load increments

Type of gage and orientation

Failure load

Back-to-back gage positions

Positions to be interpolated

Positions to be plotted

TABLE 3--List of output table headings.

Input data

Apparent strains

Actual strains

Structural axes strains

Strain principal axes

Extrapolated strains to failure load

Slope values - engineering constants evaluated at load increments

Interpolated slope values - engineering constants evaluated at any point

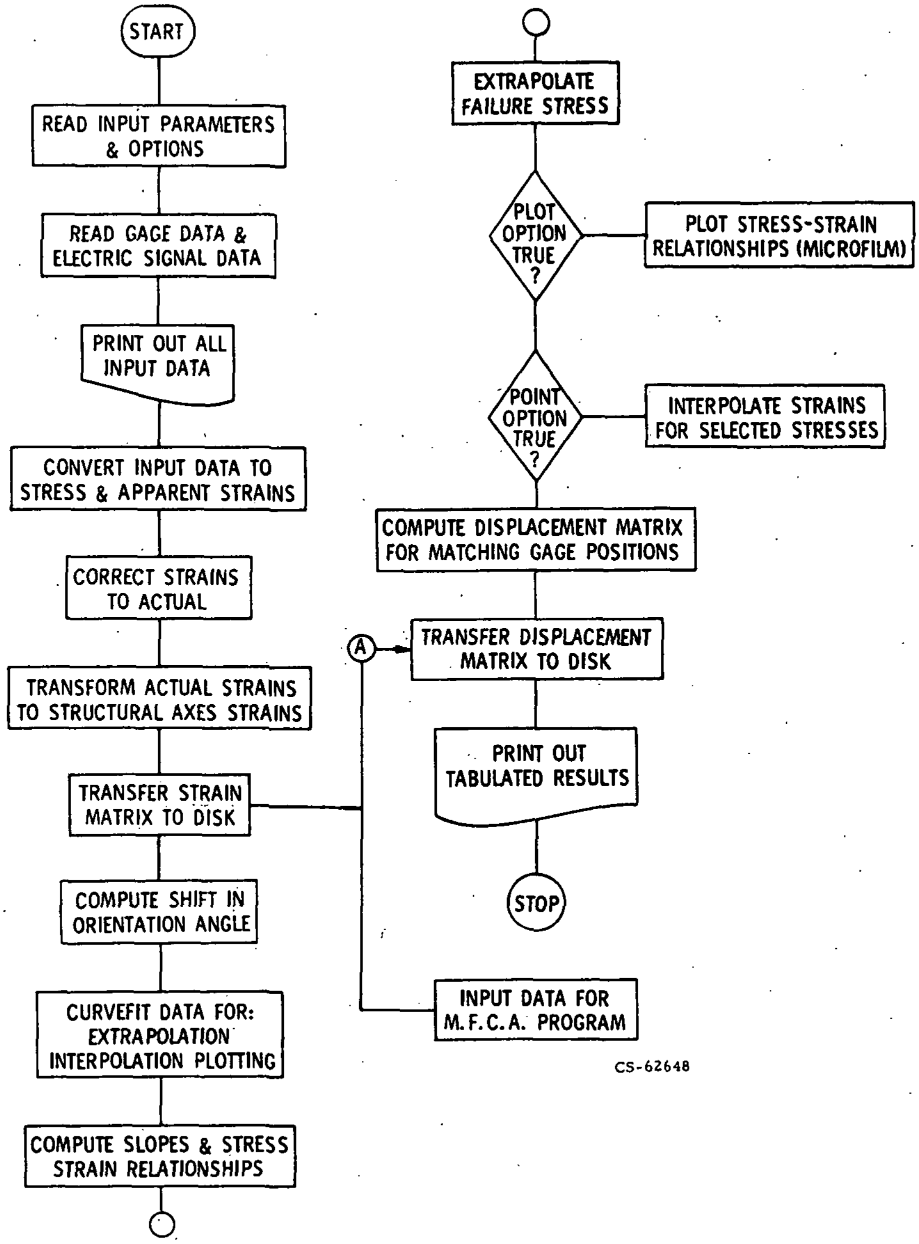

Figure 1. - Strain gage data reduction computer program flow chart.

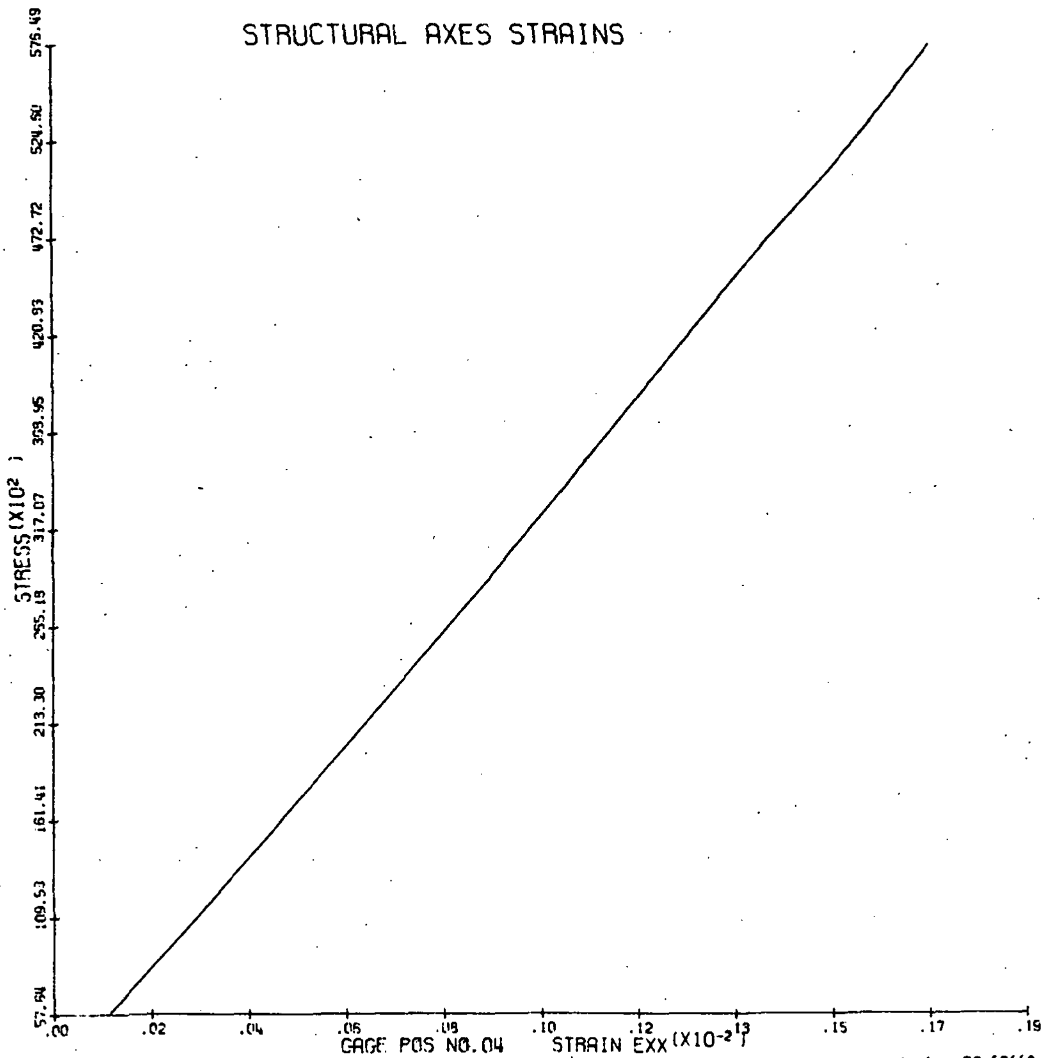

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Figure 2. - Structural axes strains.

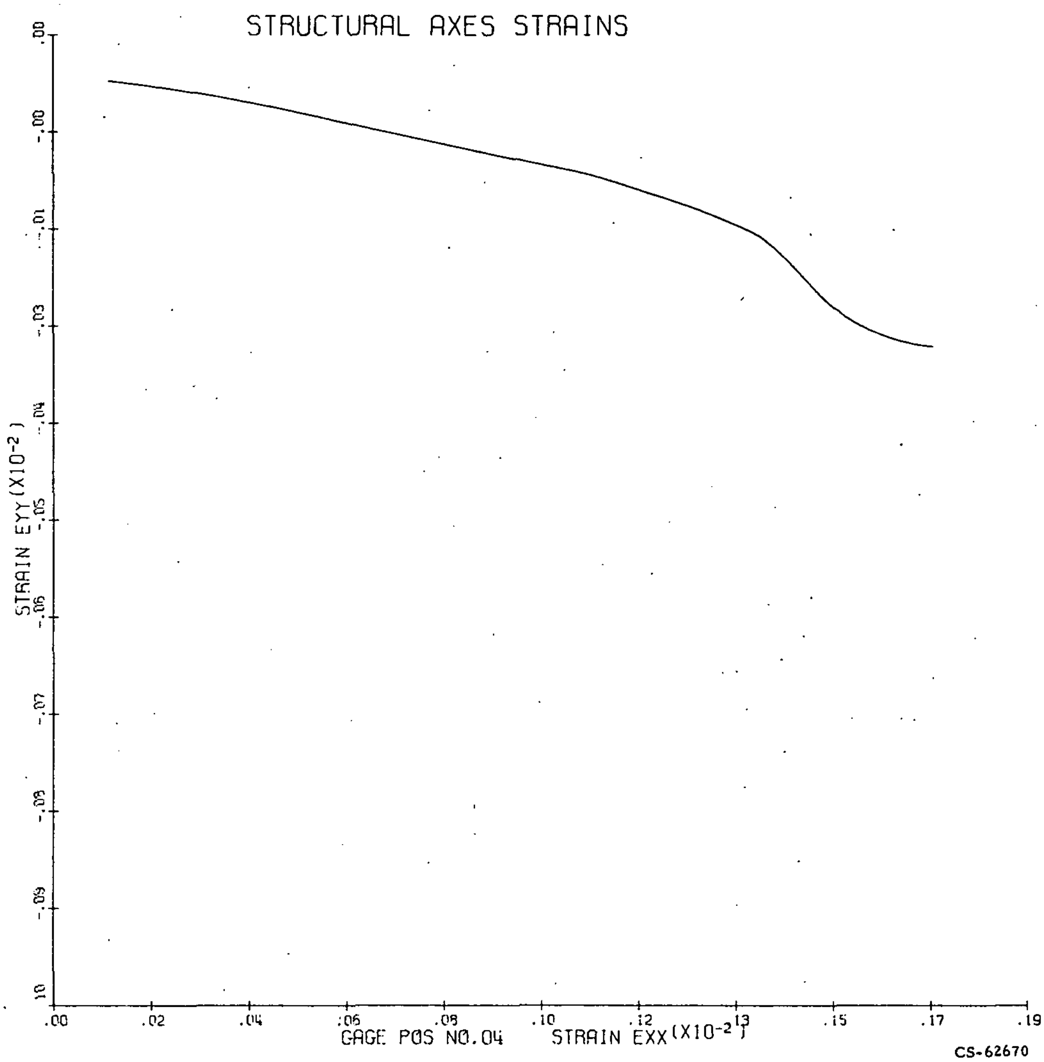

Figure 3. - Structural axes strains.

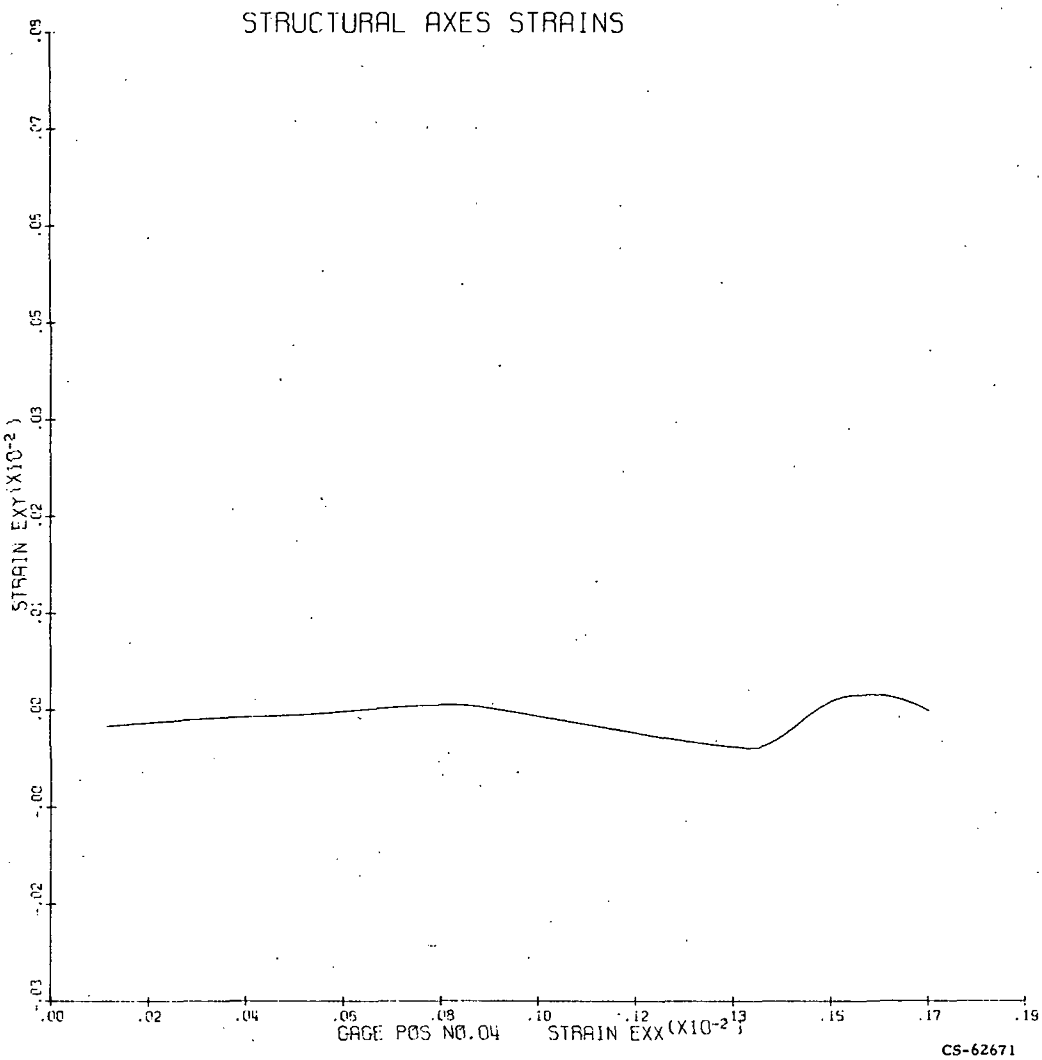

Figure 4. - Structural axes strains.