NBS MEASUREMENT SERVICES

Special Publication 250–26

NBS PHASE ANGLE CALIBRATION SERVICES

R. S. Turgel, J. M. Mulrow, and D. F. Vecchia



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NBS MEASUREMENT SERVICES: NBS Phase Angle Calibration Services

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Calibrations and related measurement services of the National Bureau of Standards (NBS) provide the means for industry, government agencies, academia, and others to relate the measurements they make to national standards and, by extension, to the measurement systems of other countries throughout the world. It is of crucial importance to improving U.S. productivity, efficiency, and quality -- in short our competitive stance -- that measurements of appropriate accuracy can be made at all stages of product development, production, and marketing and that it is possible to refer the results of these measurements to each other in a meaningful way. NBS services provide essential support for satisfying these needs, as well as measurement needs arising from societal concerns such as health, safety, natural resources, and defense. The requirements of NBS clientele range from the highest levels of accuracy realizable from advanced science and technology to the practical levels of accuracy needed to support routine production. A reference-level measurement may be the result of days of painstaking individual effort or may be provided by a semi-automatic measuring system in minutes. The variation in customer needs and hence in NBS services responsive to those needs is great.

The more than 300 different calibration services, measurement assurance services, and special tests that are offered by NBS are described in NBS Special Publication 250, <u>NBS Calibration Services Users Guide</u>. The <u>Guide</u> provides essential technical details of NBS calibration and related measurement services, such as levels of accuracy provided by NBS and the requirements to be met by customers' transfer standards. It also provides information needed for placing orders for these services and identifies technical and administrative contacts for each service.

Technical descriptions in the <u>Users Guide</u> are intended to be restricted to the material needed by a potential customer to decide if a given service will meet that customer's needs. Frequently, a customer may be interested in more detailed and extensive information, such as the way in which the errors associated with a measurement are assessed. Beginning in 1987, NBS established a Special Publication 250 series which supplements the <u>Guide</u>. Each publication in this series provides a detailed technical description of a specific NBS calibration service, or closely related set of services, and includes:

- o specifications for the service
- o design philosophy and theory
- o description of NBS measurement system used to provide service
- NBS operational procedures
- o measurement uncertainty assessment, including error budget, identification of systematic and random errors
- o NBS internal quality control procedures

Special Publication 250-26, NBS Phase Angle Calibration Services, describes special-test service offered under NBS Test Number 55110S by the Electronic Instrumentation and Metrology Group in the Electrosystems Division. Service 55110S is part of a series of services offered by the Division that are intended to support the application of modern electronic techniques to measurement problems.

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NBS PHASE ANGLE CALIBRATION SERVICE

Abstract

The National Bureau of Standards (NBS) offers a calibration service for audio-frequency phase meters. The calibrations are based on a phase angle standard developed at NBS that generates two sinusoidal signals displaced relative to one another by a precisely known phase angle over a frequency range of 2 hertz to 50 The signal amplitudes are independently kilohertz. adjustable on each channel from 0.5 volts to 100 volts. The angular resolution is better than 0.002° at the low end of the frequency range and decreases to 0.005° at the high end. The uncertainty of the phase angle between the two signals generated by the standard varies from 0.005° to 0.04°, depending on frequency and amplitude.

Using the phase angle standard, phase meter readings are obtained at selected test points. From the calibration data, the phase meter response characteristic is determined and is compared to that of an ideal meter having a linear characteristic. If the phase meter response conforms to the linear model, a straight-line calibration curve is derived from the data and serves to calculate corrected readings. From the statistical parameters associated with the calibration curve, it is possible to estimate the limits of offset between the calibrated meter and the calibration standard. By extension, the uncertainty of readings of the phase meter in the user's laboratory can be estimated.

Key Words: Calibration, Calibration Curve, Linear Model, Phase Meter, Phase Standard, Uncertainty.

1. INTRODUCTION

The measurement of phase angle is important in many applications encompassing diverse areas such as power systems, navigation, satellite tracking, and servo circuit design. Modern phase meters are capable of resolution of 0.01 degrees, so that the process of checking their calibration is far from trivial.

Phase angles, like voltage ratio, are dimensionless quantities and, in theory at least, can be reproduced at any time without reference to physical standards. In practice, however, doing so is a difficult task and prone to cumulative errors. It is, therefore, highly desirable and convenient to use a phase angle standard for phase meter calibrations to assure consistency of measurements.

The National Bureau of Standards (NBS) is providing a calibration service for audio frequency phase meters to make consistent and traceable phase measurement possible. This Technical Note describes the phase meter calibration procedure used at NBS and provides some of the statistical background for evaluating the accuracy of the calibrations.

2. DESCRIPTION OF SERVICE

NBS provides phase meter calibrations over a frequency range from 2 Hz to 50 kHz. The nominal frequency resolution of the test signal is 1 Hz up to 5 kHz and 10 Hz from 5 to 50 kHz. The frequency stability of the signal provided is of the order of 10 parts per million, and the accuracy of the frequency is limited by the synthesizer adjustment as described in [1]. The phase angle of the standard is insensitive to the exact frequency value and is not affected by frequency drifts.

The amplitudes of the two signals applied to the phase meter can be varied independently over a useful range from 0.5 to 100 volts, or 0.5 to 5 amperes with a special transconductance amplifier [2]. Since phase meters are generally not very sensitive to amplitude, no attempt is made to regulate the magnitude of the output voltages (or currents) precisely. The amplitude values are adjusted to within a few tenths of a percent, but should be regarded as nominal values only.

3. DESIGN PHILOSOPHY

Phase meter calibrations can be carried out by comparing the reading of the phase meter under test with that of a reference phase meter. For such a procedure to be valid, the signal source, although uncalibrated, must be well characterized. Frequency and phase stability, as well as spectral purity, of the test signals must have sufficiently tight tolerances so that the waveform will not influence the response of the phase meter. Rather than develop such a precision phase meter and a suitable signal source, it seemed preferable to

1

combine their attributes and develop a phase-calibrated signal source. The reasons for choosing this particular implementation, which is embodied in the NBS Phase Angle Standard, are discussed in [1].

4. DESCRIPTION OF THE SYSTEM

The NBS Phase Angle Standard, described in detail in [1], [3], [4], and [5] is a signal source that provides two sinusoidal voltage outputs displaced relative to each other by a known phase angle. To calibrate a phase meter, the meter is generally connected directly to the two outputs of the Phase Angle Standard. If one of the inputs to the phase meter requires a current, a specially designed transconductance amplifier [2] is connected between the Phase Angle Standard and the phase meter to be calibrated. The amplifier furnishes a current proportional to the Phase Angle Standard output voltage with a known and generally negligible additional phase offset. Further details can be found in [1] and [3].

5. CALIBRATION PROCEDURE

The calibration procedure is controlled from an instrument controller via a General Purpose Interface Bus (GPIB)¹. If the instrument under test is also bus compatible, then the calibration can proceed almost completely automatically. In most cases, however, the phase meter output will have to be read from its own display and manually entered into the controller (computer).

Wherever possible, a second precision phase meter, used as a check standard, is connected in parallel with the instrument under test. Since the characteristics of the check standard are well-known, the measurement results obtained from it provide additional reassurance that the system is operating properly. The indicated phase angles are then recorded from the readouts of the phase meter under test and the check standard meter. The readings are entered into a computer (instrument controller) keyboard, or transferred directly to the controller via the GPIB, if provided.

The usual procedure consists of selecting 12 phase angles spanning the interval from 0° to 360° (or other intervals specifically requested by the customer) for each set of input voltage (current) and frequency conditions. Normally, four replicate readings are taken at each selected phase angle. The order of measurements is chosen at random such that one set of 12 phase angle measurements is completed before the next one is started and is arranged so that the same angle is never measured twice in succession. Because some phase meters have appreciable settling times, a variable delay is provided by the controller between setting the Phase Angle Standard and recording the reading. If the delay required to obtain consistent readings is longer than five seconds, the time interval is reported in the calibration report.

¹ IEEE Standard 488-1978

All readings are recorded on magnetic tape or disk, whether entered manually or automatically via the bus. For the purposes of calculation, angles lying between 359 and 361 degrees are converted to corresponding values in the range of -1 to +1 degrees. On phase meters having more than one readout range, readings are taken on the 0 to 360 degree range whenever possible.

Each specified set of conditions of frequency and input voltages or currents is designated as a "Range," and phase angle data for each Range are treated independently. An exception is made if it is deemed necessary to retest a Range and if the results of both sets of measurements appear to come from the same (statistical) population. In that case the results of both Ranges are combined.

Immediately after completing the set of readings on a particular Range, a plot of differences between the phase meter readings and the corresponding phase angle settings on the Phase Angle Standard is obtained. This plot helps in checking for outliers or possible errors in the data entered. By superimposing a similar plot of the differences obtained from the check standard, similarities between the two sets of data can be examined. Normally, these two sets can be expected to be uncorrelated, and any obvious similarity may indicate an equipment malfunction.

After all the calibration data have been collected and have been given a preliminary check, as indicated above, the statistical procedures outlined below are applied to the data.

6. SYSTEMATIC ERRORS IN PHASE ANGLE STANDARD

The uncertainty of the phase angle between the two output signals generated by the Phase Angle Standard is a function of frequency as well as signal amplitude. The values of estimated uncertainty components are shown in Table 1. The values in this table are based on experimental data reported in [3] and measurements made during the development of the system. These values apply only for the Phase Angle Standard itself. For those calibrations requiring an output voltage in excess of 100 volts rms or an output current instead of a voltage, external amplifiers must be used. The phase shifts caused by these amplifiers, which may be of the order of degrees, must be compensated by an adjustment of the Phase Angle Standard. While the phase shifts in the external amplifiers are relatively stable with time, they do lead to an increased uncertainty of the phase angle of the system. The additional uncertainty component is assigned on the basis of phase stability determined by monitoring the system output with a bridge circuit [1]. The bridge circuit measures the phase error at a nominal 180-degree phase angle. Typically, for test parameters of 120 V, 5 A, and 60 Hz, the sum of the systematic uncertainty components due to the external amplifiers is increased to 0.025 degrees.

| | 60 Hz | 400 Hz | 5 kHz | 15 kHz | 30 kHz | 50 kHz |
|-------------------|----------|-----------|------------|-------------|--------|--------|
| | | (U | nits of Mi | llidegrees) | | |
| Auto-Zero Corr.* | 1 | 2 | 5 | 6 | 12 | 20 |
| Linearity | 2 | 2 | 3 | 10 | 15 | 20 |
| 7:1 Voltage Ratio | 1 | 2 | 3 | 10 | 20 | 40 |
| *The uncertainty | y due to | frequency | adjustment | is include | d. | |

Table 1. Estimated Phase Angle Uncertainty

The correction determined by the auto-zero procedure can be verified experimentally from time-to-time using the bridge technique described in [1] and [2]. Experience gained so far seems to indicate that the residual error after the auto-zero correction is applied will not vary by more than one or two millidegrees over periods of a month or so. Stability of the auto-zero correction itself can be ascertained easily by noting the value for the correction displayed on the readout of the Phase Angle Standard. The value determined is recorded with the phase meter calibration data to obtain a history of the performance of the standard.

7. CALIBRATION CURVE

As outlined above, calibration of phase meters is achieved by intercomparison of readings from the phase meter under test with the corresponding values assigned to the NBS Phase Angle Standard. A functional relationship is then established between the phase meter measurements and the phase angle values of the standard, and the corrected readings of the user's phase meter are derived based on this functional relationship.

An illustration of such a simple relationship is shown in Figure 1, where the solid straight line represents the calibration curve fitted to all measurements. To make measurements with the user's phase meter, the observed values are related to the NBS values by means of the calibration curve which brings the corrected measurement results into close agreement with the standard. Schematically, for a future phase meter value, y, a dotted line is drawn through y parallel to the x-axis. At the point where it intersects the calibration curve, another dotted line is drawn parallel to the y-axis, and its point of intersection with the x-axis, x, is the corresponding calibrated value relative to NBS. The reader is referred to reference [6] for a more detailed discussion on the use of linear calibration curves.





7.1 Simple Linear Model

The procedures and analyses discussed below are appropriate for calibrating phase that have an essentially meters linear response characteristic. A phase meter that has a linear response relative to the NBS Phase Angle Standard will exhibit the following behavior. An observed phase angle, y, will be related to the phase angle, x, assigned to the signals generated by the NBS Phase Angle Standard, plus random noise which in the linear expression is designated by a term, e.

y = a + bx + e.

For an ideal meter the slope, b, will equal 1, the intercept, a, will equal zero, and the scatter of random measurement errors will be sufficiently small for the measurement system.

To examine the relationship between the values of the NBS Phase Angle Standard and the observations from an actual user's phase meter, the observed phase angles are first fitted to a simple linear function of the NBS values, and then the adequacy of the straight-line fit is tested. If the linearity is acceptable, the statistical significance of differences of the estimated slope and intercept from their respective ideal values is checked.

If these statistical tests show that the user's phase meter offset is not negligible, thus indicating a need for correction of the phase meter readings, the fitted curve becomes the calibration curve for the user's phase meter. The uncertainty of the corrected values obtained from the calibration curve is then estimated using the procedure discussed below in sections 7.5 and 7.6.

7.2 Least Squares Fit

Given phase meter measurements y_{ij} corresponding to NBS phase angle values x_i , where i is the index of the selected phase angle and j denotes the repetition, a simple model to describe the phase meter behavior is given by:

$$y_{ij} = a + b x_i + e_{ij}$$
,
 $\begin{cases} i = 1, ..., k \\ j = 1, ..., n \end{cases}$

where the random measurement errors, e_{ij} , are typically assumed to have a Gaussian distribution with mean value zero and standard deviation σ , to be estimated.

Using a caret (^) to denote estimated parameter values, the leastsquares estimates of the slope and intercept are:

$$\hat{\mathbf{b}} = \frac{\sum_{i=1}^{k} \sum_{j=1}^{n} (y_{ij} \cdot \overline{\mathbf{y}}) (x_i \cdot \overline{\mathbf{x}})}{\sum_{i=1}^{k} (x_i \cdot \overline{\mathbf{x}})^2}$$
$$\hat{\mathbf{a}} = \overline{\mathbf{y}} \cdot \hat{\mathbf{b}} \cdot \overline{\mathbf{x}}$$

where

$$\overline{y} = \frac{\sum_{i=1}^{k} \sum_{j=1}^{n} y_{ij}}{nk}$$
, and $\overline{x} = \frac{\sum_{i=1}^{k} x_{i}}{k}$

The residuals from the fit are:

$$c_{ij} = y_{ij} - \hat{a} - \hat{b} x_i$$

and the residual standard deviation, which estimates σ , is:

$$s = \left(\begin{array}{cc} k & n \\ \frac{\sum\limits_{i=1}^{k} \sum\limits_{j=1}^{r} r_{ij}^{2}}{\frac{1}{2}} \\ \frac{1}{2} \\ \frac{1$$

Two sample data sets will be used to illustrate the phase meter calibration computations. Figures 2A and 2B show examples of data from two meters. The plots are of the differences $(y_{ij}-x_i)$ versus x_i . For Example 1, three repetitions (n=3) of the phase meter measurements were obtained at 12 phase angle settings (k=12) on the NBS Phase Angle Standard. For Example 2, four repetitions (n=4) of the phase meter measurements were obtained at the same 12 phase angle settings (k=12) as in Example 1. Also, note that if the phase meter is in agreement with the NBS standard, the plot of the differences

should be randomly distributed about a horizontal line through zero as in Figure 2B. Thus the phase angle measurements in Figure 2A show that a slope of the calibration curve different from one (b \neq 1) will be necessary to correct the phase meter readings.

Plotting the differences between the observed phase angles and the corresponding NBS values against the NBS values will disclose any aberrant or systematic behavior of the user's phase meter. For example, oscillatory behavior of the data would suggest that the simple linear relationship does not represent the system. Example 3, shown in Figures 3A and 3B, illustrates this type of behavior. Figure 3A is a plot of y vs. x, and no noticeable nonlinearities are apparent. The same data are replotted in Figure 3B as the (y-x) differences vs. x, and a nonlinear pattern is now apparent. A statistical test for detecting such nonlinearity is discussed below.



Figure 2A. Differences Between Measured Phase Angles and Corresponding NBS Values, Plotted Against NBS Values (Example 1).



Figure 2B. Differences Between Measured Phase Angles and Corresponding NBS Values, Plotted Against NBS Values (Example 2).



Figure 3A. Measured Phase Angles Plotted Against Corresponding NBS Values (Example 3)



Figure 3B. Differences Between Measured Phase Angles and Corresponding NBS Values, Plotted Against NBS Values (Example 3).

7.3 Test of Model Adequacy

Before proceeding with the tests for the slope and intercept, it is confirmed that a simple linear function is adequate to relate phase meter measurements to the assigned values of the NBS Phase Angle Standard. A plot of the deviations from the linear fit provides insight into the model adequacy. A formal statistical test to decide whether or not a simple linear function of the phase meter measurements is an appropriate calibration curve is based on the information in the repeated measurements at each phase angle (see [7], page 33). The <u>lack-of-fit</u> test is obtained when the fitted value for each phase angle,

$$\hat{y}_{i} = \hat{a} + \hat{b} x_{i}$$
, $i = 1, ..., k$

is compared to the average of the repeat measurements at corresponding phase angles:

$$\overline{y}_{i} = \frac{\int_{j=1}^{n} y_{ij}}{n}$$

Close agreement between the fitted values and these averages is evidence that the simple linear function is reasonable. Using the F statistic as a criterion, the calibration data are not consistent with a straight line model if:

$$F' = \frac{S_{L}^{2}}{S_{e}^{2}} > F_{0.01} \{k-2, k(n-1)\}$$

where,

$$S_{L}^{2} = \frac{n}{k-2} \sum_{i=1}^{k} (\hat{y}_{i} - \overline{y}_{i})^{2}$$
$$S_{e}^{2} = \frac{1}{k(n-1)} \sum_{i=1}^{k} \sum_{j=1}^{n} (y_{ij} - \overline{y}_{i})^{2}$$

and F_{α} {k-2, k(n-1)} is the upper one-percent point (for $\alpha = 0.01$) of the F distribution with k-2 degrees of freedom in the numerator and k(n-1) degrees of freedom in the denominator (see [7], page 37). Use of a small significance level ($\alpha = 0.01$) in the lack-of-fit test implies that we are only interested in detecting very substantial departures from linearity in the phase meter under test.

Generally, in statistical tests a convention exists in using α of 0.05, 0.01 or smaller. Alternatively, because the selection of a particular α level is somewhat arbitrary, it is common to report an attained significance level corresponding to the calculated value of a test statistic. A computed significance level near zero corresponds to a high degree of confidence that the associated hypothesis is not tenable. For instance, in the lack-of-fit test, a computed significance level for F' of 0.004 would lead to the conclusion that the observed departure from linearity was statistically significant at the 0.004 level of probability.

7.4 Tests of Slope and Intercept

If the linear model is found to be adequate, the next step is to determine the test statistics, t_1 and t_2 , to check if the intercept a is zero and if the slope b is one. The test statistics are as follows [7, page 26]:

$$t_1 = \frac{a}{\hat{S(a)}}$$
; $t_2 = \frac{b-1}{\hat{S(b)}}$

where

$$S(\hat{a}) = \left(\begin{array}{c} \frac{k}{\sum\limits_{i=1}^{k} x_i^2} \\ \frac{1}{\sum\limits_{i=1}^{k} (x_i - \overline{x})^2} \\ i = 1 \end{array}\right)^{\frac{k}{2}} \cdot s \text{ and } S(\hat{b}) = \left(\begin{array}{c} 1 \\ \frac{1}{\sum\limits_{i=1}^{k} (x_i - \overline{x})^2} \\ \frac{1}{\sum\limits_{i=1}^{k} (x_i - \overline{x})^2} \end{array}\right)^{\frac{k}{2}} \cdot s .$$

A value of $|t_1| > t_{\alpha/2}(nk-2)$ indicates that the intercept is significantly different from zero, and a value of $|t_2| > t_{\alpha/2}(nk-2)$ indicates that the slope is significantly different from one.² The value of $t_{\alpha/2}(nk-2)$ can be found in a table of Student's t distribution, where α is the significance level of the test (typically, $\alpha = 0.05$) and (k-2) is the number of degrees of freedom in the residual standard deviation (see, for example, Appendix A).

Alternatively, attained significance levels can be computed using each calculated value of t_1 or t_2 . Computed significance levels near zero correspond to high confidence in asserting that the intercept and slope are significantly different from zero and one, respectively. For example, a computed significance level for t_2 of 0.05 or less indicates that the slope is probably different from one.

² The parameters a and b are tested separately so that the nature of systematic offset (relative to the standard) can be ascertained. If the intercept differs appreciably from zero, but the slope is not significantly different from its ideal value, a simple additive constant would be sufficient to reduce this source of error. If the slope is significantly different from its ideal value, then there is a need to calculate individual corrections for every data point. However, the use of these two separate t-tests is not optimal if we actually wish to test simultaneously if a = 0 and b = 1. See [7, page 94] for a discussion of the best statistical procedure for simultaneous evaluation of the slope and intercept.

7.5 Offset in Corrected Values

The following procedure can be thought of as a determination of the practical, rather than the statistical, significance of the offset of a phase meter from the NBS assigned values. For example, tests on the slope and intercept may be statistically significant, but the consequences of ignoring one or both of these can be practically insignificant relative to the required accuracy or resolution of the phase meter.

To assess the overall disagreement between the user's phase meter and the NBS assigned values, statistical confidence limits can be computed for the offset (systematic error) in the expected reading of the phase meter relative to the NBS value. The term "expected reading" may be thought of either as the value produced by the phase meter in the absence of random measurement errors or, equivalently, as the limiting mean of a large number of repeat measurements corresponding to a fixed phase angle. For phase meters having a linear response relative to the NBS Phase Angle Standard, the expected reading at a given phase angle x, denoted by E(y|x), is:

$$E(y|x) = a + bx.$$

Then, the offset between the phase meter and the NBS standard at phase angle x is given by:

$$\Delta_{x} = E(y|x) - x = a + (b - 1)x.$$
(1)

Note that Δ_x is actually the systematic offset of an uncorrected reading on the phase meter. As we show below, with the calibration data obtained following the procedure described in section 5 and the computations given in section 7.2, the user can account for part or all of the offset by applying various corrections to the readings and then computing "bounds to offset," that depend on the respective corrections that are considered. These bounds represent a component of the overall measurement uncertainty.

In the calibration report, limits to offset from the NBS Phase Angle Standard are listed for phase meter corrections at three levels of complexity:

- (1) NO CORRECTION: use the observed reading;
- (2) CONSTANT CORRECTION: add a constant to the observed reading;
- (3) FULL CORRECTION: use the complete calibration curve correction.

When the required accuracy of the phase meter is specified a priori, the computed limits to offset for levels (1) and (2) may be used for comparison to decide if a simple correction (or no correction) is sufficient to achieve the user's required accuracy. Error limits associated with the full correction represent the smallest bound to offset that is available and are non-zero only because of the random uncertainty in the calibration data used to compute the estimated calibration curve.

It is clear from equation (1) that the offset in a phase meter reading depends on the particular phase angle x that is measured. In general, however, we require the error limits over the whole range of the calibration

curve, not merely for the expected offset corresponding to a single phase angle. Therefore, the initial step toward estimating offsets for <u>any</u> phase angle x is to compute statistical confidence bands appropriate for the whole calibration curve over the entire range from 0° to 360° (or other intervals requested by the customer). For the straight line as a whole, confidence curves [7, page 31] are given by the equations:

and

$$\ell(\mathbf{x}_t) = \mathbf{a} + \mathbf{b}\mathbf{x}_t - \mathbf{R}(\mathbf{x}_t)$$

$$\mathbf{u}(\mathbf{x}_t) = \hat{\mathbf{a}} + \hat{\mathbf{b}}\mathbf{x}_t + \mathbf{R}(\mathbf{x}_t)$$
(2)

where

$$R(x_{t}) = s \sqrt{2 F_{0.05}(2, k-2)} \begin{bmatrix} 1 & (x_{t} - \overline{x})^{2} \\ -\frac{1}{nk} & + \frac{(x_{t} - \overline{x})^{2}}{\sum_{i=1}^{k} (x_{i} - \overline{x})^{2}} \end{bmatrix}^{\frac{1}{2}}.$$
 (3)

In the equations, x_t denotes the "true," or NBS, phase angle $(0^\circ \le x_t \le 360^\circ)$ and F is an appropriate upper percentage point of the F distribution (as an illustration we have used the upper 5 percent point).

Figure 4 is a diagram of a calibration curve with the corresponding confidence bands sketched about it. For any given phase angle setting of the NBS Phase Angle Standard, the true reading on the phase meter is expected to



Figure 4. Calibration curve for a phase meter with corresponding confidence bands

be situated within the bands. Note that distance between the curves, $d(x_t) =$

 $u(x_t) - l(x_t)$, is different for each value of x_t , but the largest distance occurs at $x_t = 0^\circ$ or $x_t = 360^\circ$.

To estimate the offset of a phase meter, the calculations for each level of correction involve simple algebraic expressions derived from equation (2) by determining the limiting values for the whole calibration curve. For convenience, the largest value of the estimated offset over the whole range of x is listed in the calibration report. Thus, the computed limit in each case should be interpreted as an upper bound to offset over the whole range of phase angles measured.

LEVEL 1. NO CORRECTION: Offset in Uncorrected Values.

Lower and upper limits to the offset in a phase meter reading y_t corresponding to a "true" phase angle x_t , when there are no corrections applied to y_t , are given by:

and

$$L(x_{t}) = a + (b - 1)x_{t} - R(x_{t})$$
$$U(x_{t}) = \hat{a} + (\hat{b} - 1)x_{t} + R(x_{t})$$

where $R(x_t)$ is given in equation (3). The largest limits occur at either $x_t = 0^\circ$ or $x_t = 360^\circ$. (If another interval is requested by the customer, the endpoints of that interval are substituted for 0° and 360° where appropriate.)

The magnitude of the largest estimated offset for uncorrected values is:

$$\Delta_{\text{LEVEL1}} = \text{maximum of} \{ |L(0^{\circ})|, |U(0^{\circ})|, |L(360^{\circ})|, |U(360^{\circ})| \} .$$
(4)

The value of Δ_{LEVEL1} is an estimated upper bound to the offset between an uncorrected phase meter reading and the corresponding NBS assigned value. If y denotes a phase meter reading and \hat{x} denotes the associated "corrected"³ value derived from y to bring a reading into agreement with the NBS Phase Angle Standard, then taking $\hat{x} = y$ indicates that no correction is applied. Other levels of correction in the discussion below are indicated by similar equations. Thus, $\hat{x} = y + A$ indicates that a constant correction is applied, and $\hat{x} = By + A$ indicates that a linear correction is applied, where A and B are computed constants.

To decide if the agreement of an uncorrected phase meter reading with the corresponding phase angle supplied by the NBS standard is acceptable for practical purposes, $\hat{\Delta}_{\text{LEVEL1}}$ may be compared to an a priori accuracy specification, δ , if given. Then, provided $\hat{\Delta}_{\text{LEVEL1}} \leq \delta$, it is sufficient to let $\hat{x} = y$ to bring the result of the measurement into the desired agreement with the standard. However, it is important to note that this comparison ignores random measurement error in the phase meter reading. A procedure for including the user's limits to random error in a combined uncertainty estimate is given in section 7.6.

 $[\]hat{x}$ represents an estimate of the value the Phase Angle Standard would have to be set to in order to make the phase meter read a value y.

<u>LEVEL 2</u>. CONSTANT CORRECTION: Offset in $(y + A_2)$.

If we ignore the possible difference in the slope of the calibration curve from its ideal value {b = 1; therefore, we set B_2 (= 1/b) = 1}, but correct for the displacement of the line, estimated by $A_2 = \bar{x} - \bar{y}$, then the corrected phase meter reading is given by:

$$\hat{\mathbf{x}} = \mathbf{y} + (\overline{\mathbf{x}} - \overline{\mathbf{y}}) \\ = \mathbf{y} + \mathbf{A}_2$$

where \overline{x} and \overline{y} are the sample means from the calibration data (see section 7.1). Lower- and upper-limits on the offset in a measurement corrected this way are:

and

$$L(x_{t}) = (\hat{a} + A_{2}) + (\hat{b} - 1)x_{t} - R(x_{t})$$

$$U(x_{t}) = (\hat{a} + A_{2}) + (\hat{b} - 1)x_{t} + R(x_{t})$$
(5)

where $R(x_t)$ is defined in equation (3). Note that the limits are calculated simply by adding A₂ to the corresponding limits for uncorrected values.

An estimated upper bound, $\hat{\Delta}_{\text{LEVEL2}}$, to the magnitude of the offset in values corrected by adding $A_2 = (\overline{x} - \overline{y})$ to observed readings is obtained from equation (4), but substituting the new limits at 0° and 360° given above in equation (5). The value $\hat{\Delta}_{\text{LEVEL2}}$ may be compared to an a priori limit δ , if appropriate.

<u>LEVEL 3.</u> FULL CORRECTION: Offset in $(B_3 \cdot y + A_3)$.

If no correction, or a constant correction, is deemed inadequate to bring the phase meter reading into agreement with the NBS standard, then the full calibration curve should be used for correction. To estimate the phase angle of the NBS standard that corresponds to the phase meter reading, y, the following equation is used:

$$\hat{\mathbf{x}} = \frac{\mathbf{y} - \hat{\mathbf{a}}}{\hat{\mathbf{b}}}$$
$$= \mathbf{B}_3 \mathbf{y} + \mathbf{A}_3$$

where $B_3 = 1/b$, $A_3 = -\hat{a}/\hat{b}$, and \hat{a} , \hat{b} are the least-squares estimates of the intercept and slope obtained from the fitted calibration curve. Lower and upper limits on the offset in a measurement corrected via the calibration curve are:

$$L(x_t) = -\frac{R(x_t)}{\hat{b}}$$
 and $U(x_t) = +\frac{R(x_t)}{\hat{b}}$

where $R(x_{+})$ is given in equation (3). An estimated upper bound to the

magnitude of the offset is:

 $\hat{\Delta}_{\text{LEVEL3}} = \text{maximum of } \{ |R(0^{\circ})/\hat{b}|, |R(360^{\circ})/\hat{b}| \}$.

Results of the calculations discussed in this section are illustrated in two sample Reports of Calibration given in Appendix B. In the first example, a comparison of the three offsets suggests that a full correction is probably appropriate for the phase meter under test. Offsets for the phase meter in the second example show that very little is gained by correcting observed measurements.

7.6 Calculation of Phase Meter Uncertainty

Regardless of the type of correction applied to phase meter readings, the procedure described above provides only one component of the overall uncertainty in a corrected measurement. That is, the computed bound $\hat{\Delta}$ may be thought of as an estimate of the possible offset, or systematic error, in a phase meter reading relative to the NBS standard *if the random error in the phase meter could be made negligible*. Statistical methods are used to obtain $\hat{\Delta}$ because the functional relationship between a phase meter and the NBS standard is not known exactly, but is estimated by a series of repeated measurements (so the calibration curve has an associated imprecision).

To estimate the overall uncertainty in a phase meter reading, information obtained by the user about the variability of repeated measurements on the phase meter may be combined with the estimated offset as follows. Data obtained from the user's measurement process may be used to compute an estimate, s_p , of the standard deviation of phase meter random errors under normal laboratory test conditions. Then a bound, E, to the overall disagreement between phase meter readings and the NBS assigned values for each type of phase meter correction may be calculated by:

(1) NO CORRECTION: $E_{\text{LEVEL1}} = \hat{\Delta}_{\text{LEVEL1}} + s_p \cdot t_{\alpha/2}(\nu_p)$

(2) CONSTANT CORRECTION: $E_{LEVEL2} = \hat{\Delta}_{LEVEL2} + s_p \cdot t_{\alpha/2}(\nu_p)$

```
(3) FULL CORRECTION: E_{LEVEL3} = \hat{\Delta}_{LEVEL3} + B \cdot s_p \cdot t_{\alpha/2}(\nu_p)
```

where respective values of $\hat{\Delta}$ are given in Section 7.5, B = 1/ \hat{b} is computed from the estimated slope of the calibration curve, and ν_p is the degrees of freedom associated with s_p . Tabled values from the Student's t distribution for $\alpha = 0.05$ and $\alpha = 0.01$ may be found in Appendix A. When sufficient data is used to compute s_p , e.g., if $\nu_p \geq 30$, then for $\alpha = 0.05$, t is approximately equal to 2.00.

The standard deviation that is used to calculate the phase meter uncertainty must have sufficient degrees of freedom to provide a realistic measure of phase meter precision. As a general rule, 15 degrees of freedom is a minimum for the initial computation of the standard deviation. As more repeat measurements are obtained, the standard deviation may be recomputed to take advantage of the increased data base, and assuming that the measurement procedure is stable, this will assure a more reliable value of the estimated standard deviation.

A standard deviation based on as few as two data points can be combined with other similar estimates that have been obtained on separate occasions or at different phase angles to calculate what is called a "pooled" standard deviation. If the individual standard deviations are s_1, s_2, \ldots, s_k with degrees of freedom $\nu_1, \nu_2, \ldots, \nu_k$, respectively, then the pooled standard deviation is:

$$s_{p} = \left(\frac{\nu_{1}s_{1}^{2} + \nu_{2}s_{2}^{2} + \dots + \nu_{k}s_{k}^{2}}{\nu_{1} + \nu_{2} + \dots + \nu_{k}} \right)^{\frac{1}{2}}$$

The degrees of freedom associated with s_p is $\nu_p = \nu_1 + \nu_2 + \ldots + \nu_k$. Each of the individual standard deviations is assumed to be calculated from the usual formula for the estimated standard deviation,

$$s_2 = \sum (y_1 - \overline{y})^2 / (n - 1)$$

with (n-1) degrees of freedom. The sequence of repeat measurements y_1, y_2, \ldots, y_n used to calculate an individual s_i may be obtained by taking n independent readings on the phase meter for any fixed input signal. Estimates for various phase angles may be combined using the formula above.

8. LIMITATIONS OF THE CALIBRATION CURVE

Phase meters are normally designed to have a linear response characteristic, and the data obtained from them are sufficiently repeatable to make the steps outlined above for obtaining a linear calibration curve and estimation of error limits a valid procedure. In isolated cases, however, the assumptions underlying this procedure do not hold. The significant sources of error that may cause this condition are summarized below.

8.1 Lack of Precision

Lack of precision is the inability to repeat measurements accurately with the same phase meter under similar operating conditions which therefore increases the random error in the measurement. The calibration curve, however, is designed to reduce the systematic error and so cannot help to reduce the random error component. To obtain better precision, it is usually necessary to improve the physical components of the measurement system or their interaction.

8.2 Nonlinearity of the Calibration Curve

The assumption of linearity is essential for the calibration procedure described to be valid. A possible source of a nonlinear systematic error is the cross coupling of input signals within the phase meter. An example is shown in Figure 3B. If a portion of one of the input signals is coupled to the other through a mutual inductance, the resulting phase error will be greatest when the coupled signal component is out of phase, at a nominal phase angle of 0° or 180° and least when the coupled component is in phase at 90° and 270° as shown in the figure.

Another type of nonlinearity can arise if the digital readout of the phase meter is not linear. The calibration curve could then be represented by a second or third order polynomial. In practice, however, it is more likely that such nonlinearities are small and masked by the random error of the meter.

8.3 Differences Among Repetitions

Several repeat measurements are made at each phase angle during a calibration. As mentioned, a set of readings is taken in a random order at all selected phase angles before a repeat set is started. When significant changes are apparent from set to set, possibly indicating short-term drifts, a calibration curve will not yield satisfactory results. Errors of this type can be checked by plotting differences between observed and standard phase angles for each set, as shown in Figure 5 (where there are no major visible changes). A formal statistical test for differences in calibration curves can be found in [6, page 43].



Figure 5. Changes in calibration curve from repetition to repetition

9. REFERENCES

- Turgel, R. S.; Oldham, N. M.; Stenbakken, G. N.; Kibalo, T. H.; "NBS Phase Angle Calibration Standard," Nat. Bur. Stand. (U.S.) Technical Note 1144, July 1981.
- [2] Laug, O. B., "A Wide-Band Transconductance Amplifier for Current Calibrations," IEEE Transactions on Instrumentation and Measurement, IM-34, No. 4, December 1985.
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- [4] Turgel, R. S.; Oldham, N. M.; "High-Precision Audio-Frequency Phase Calibration Standard," *IEEE Trans.Instrum. Meas.*, vol. IM-27, no. 4, December 1978.
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- [6] Croarkin, C. M.; Varner, R. N.; "Measurement Assurance for Dimensional Measurement on Integrated-Circuit Photomasks," Nat. Bur. Stand. (U.S.) Technical Note 1164, August 1982.
- [7] Draper, N. R.; Smith, H.; Applied Regression Analysis, 2nd Edition, Wiley and Sons Inc., New York, 1981.

APPENDIX A. Critical values of Student's t Distribution

Table A-1

Critical Values $t_{\alpha/2}(\nu)$ of Student's t Distribution

| ν | α=0.05 | α=0.01 | ν | α=0.05 | α= 0.01 |
|----|---------------|--------|-----|--------|----------------|
| | | | | - | |
| 2 | 4.303 | 9.925 | 62 | 1.999 | 2.657 |
| 4 | 2.776 | 4.604 | 64 | 1.998 | 2.655 |
| 6 | 2.447 | 3.707 | 66 | 1.997 | 2.652 |
| 8 | 2.306 | 3.355 | 68 | 1.995 | 2.650 |
| 10 | 2.228 | 3.169 | 70 | 1.994 | 2.648 |
| 12 | 2.179 | 3.055 | 72 | 1.993 | 2.646 |
| 14 | 2.145 | 2.977 | 74 | 1.993 | 2.644 |
| 16 | 2.120 | 2.921 | 76 | 1.992 | 2.642 |
| 18 | 2.101 | 2.878 | 78 | 1.991 | 2.640 |
| 20 | 2.086 | 2.845 | 80 | 1.990 | 2.639 |
| 22 | 2.074 | 2.819 | 82 | 1.989 | 2.637 |
| 24 | 2.064 | 2.797 | 84 | 1.989 | 2.636 |
| 26 | 2.056 | 2.779 | 86 | 1.988 | 2.634 |
| 28 | 2.048 | 2.763 | 88 | 1.987 | 2.633 |
| 30 | 2.042 | 2.750 | 90 | 1.987 | 2.632 |
| 32 | 2.037 | 2.738 | 92 | 1.986 | 2.630 |
| 34 | 2.032 | 2.728 | 94 | 1.985 | 2.629 |
| 36 | 2.028 | 2.719 | 96 | 1.984 | 2.628 |
| 38 | 2.024 | 2.712 | 98 | 1.983 | 2.627 |
| 40 | 2.021 | 2.704 | 100 | 1.983 | 2.626 |
| 42 | 2.018 | 2.698 | 102 | 1.983 | 2.625 |
| 44 | 2.015 | 2.692 | 104 | 1.982 | 2.624 |
| 46 | 2.013 | 2.687 | 106 | 1.982 | 2.623 |
| 48 | 2.011 | 2.682 | 108 | 1.981 | 2.622 |
| 50 | 2.009 | 2.678 | 110 | 1.981 | 2.621 |
| 52 | 2.007 | 2.674 | 112 | 1.981 | 2.620 |
| 54 | 2.005 | 2.670 | 114 | 1.981 | 2.620 |
| 56 | 2.003 | 2.667 | 116 | 1.981 | 2.619 |
| 58 | 2.002 | 2.663 | 118 | 1.980 | 2.618 |
| 60 | 2.000 | 2.660 | 120 | 1.980 | 2.617 |
| | | | ω | 1.960 | 2.576 |
| | | | | | |

 ν = number of degrees of freedom in the total standard deviation.

APPENDIX B. Sample Calibration Reports

The results of an NBS calibration are reported to the customer in a form similar to the examples shown in this appendix. There is some variation in the way the test is conducted and the results are reported depending on the design of the phase meter being calibrated.

The report identifies the customer, the instrument (by make, model, and serial number), the customer order number, the date, and ambient temperature during the test. For each set of current, voltage, and frequency conditions, the report provides an equation which can be used to correct the phase meter readings and lists in the appendix to the reort the estimated limit to offset from the NBS Phase Angle Standard that is associated with corrected values. Summary tables for each set of test conditions give adjusted values obtained from the correction equation for selected values of phase meter readings. Additional tables show the actual unprocessed calibration data. Coefficients parameters associated with and statistical the correction equation (calibration curve) are given in an appendix.

The data are taken using a computer program named " ϕ CAL6." This program allows the operator to specify the phase angles test points, the number of readings at each, and all of the housekeeping information needed to document the measurement. This information includes the test date, file name under which the information and calibration data are stored on disk or tape, as well as the make, model, and serial number of the instrument under test and of the check standard phase meter (if used). While the calibration parameters associated with the calibration curve and the corrections derived from it are not stored, these can be recalculated by the program from the stored data, if needed.

A second program named "REPORT" calculates and formats the data and prints the calibration report using some of the subprograms associated with " ϕ CAL6."

Two sample Reports of Calibration are shown in this appendix. In the first example, a comparison of the estimated offsets associated with uncorrected, partially corrected, and fully corrected phase meter readings (see section 7.5) suggests that a full correction is probably appropriate for the phase meter under test. Offsets for the phase meter in the second example show that very little is gained by correcting observed measurements. In fact, the summary table of adjusted values is suppressed in the calibration report since the adjustment obtained from the full correction equation is less than 0.01° for any observed reading on the phase meter.

U.S. DEPARTMENT OF COMMERCE NATIONAL BUREAU OF STANDARDS GAITHERSBURG, MD 20899

REPORT OF CALIBRATION

Phase Meter Model , Serial No.

Submitted by



The phase meter was tested in April 1987 using the NBS Phase Angle Calibration Standard.⁴ The ambient temperature was $23 \pm 2^{\circ}$ C. The phase meter under test, as well as the Phase Angle Calibration Standard, were under power for more than 3 hours before readings were taken.

For the specified current, voltage, and frequency conditions, three readings were taken at 12 test points (phase angles) selected in a random order. The NBS Phase Angle Standard was set to the desired phase angle, and the digital readout of the phase meter under test was read and recorded. The time constant in the response of the phase meter required a timed delay of 30 seconds before taking readings to obtain consistent results.

No adjustments of the phase meter were made at any time. The range switch provided on the phase meter was operated so that readings fell into an interval from -1 to 359 degrees wherever possible. Readings in the interval from 359 to 360 degrees were converted to an interval from -1 to 0 degrees for purposes of computation.

During the tests the test signal frequencies was maintained at constant values with a frequency stability better than 10 parts per million and with an uncertainty of less than ± 0.01 Hz if below 5 kHz and ± 0.1 Hz from 5 to 50 kHz.

⁴ NBS Technical Notes 1144 (July 1981) and 1220 (April 1986)

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The systematic uncertainty in the value of the NBS Phase Angle Standard is estimated to be less than 0.003 degrees at the currents, voltages, and frequencies used in this test. For the present data, based on replication readings, the limit to offset from the values provided by the NBS Phase Angle Calibration Standard for a corrected phase angle using the equation below, is estimated to be less than 0.020 degrees. The overall uncertainty of corrected phase angle measurements depends on the variability of repeat measurements on the phase meter under normal laboratory test conditions. The estimated standard deviation of repeat measurements at NBS was 0.022 degrees. Under similar operating conditions, the overall disagreement between a corrected phase meter reading and the NBS standard would be estimated to be less than 0.064 degrees⁵.

For the Director National Engineering Laboratory

Barry A. Bell, Group Leader Electronic Instrumentation and Metrology Electrosystems Division Test No. 722-Order No. Date: April, 1987

⁵ NBS Technical Note XXXX, p. yy

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Reference Signal Voltage:30.00 VVariable Phase Signal Voltage:30.00 VFrequency:60 Hz

Corrected Phase Angle:* x'= - 0.019407 + 1.000251 y

Table of Corrected Phase Angles (x') in Degrees*

| OBSERVED | CORRECTED | OBSERVED | CORRECTED |
|-------------|-------------|-------------|-------------|
| PHASE ANGLE | PHASE ANGLE | PHASE ANGLE | PHASE ANGLE |
| (Degrees) | (Degrees) | (Degrees) | (Degrees) |
| | | | |
| 0 | -0.02 | 180 | 180.03 |
| 10 | 9.98 | 190 | 190.03 |
| 20 | 19.99 | 200 | 200.03 |
| 30 | 29.99 | 210 | 210.03 |
| 40 | 39.99 | 220 | 220.04 |
| 50 | 49.99 | 230 | 230.04 |
| 60 | 60,00 | 240 | 240.04 |
| 70 | 70.00 | 250 | 250.04 |
| 80 | 80.00 | 260 | 260.05 |
| 90 | 90.00 | 270 | 270.05 |
| 100 | 100.01 | 280 | 280.05 |
| 110 | 110.01 | 290 | 290.05 |
| 120 | 120.01 | 300 | 300.06 |
| 130 | 130.01 | 310 | 310.06 |
| 140 | 140.02 | 320 | 320.06 |
| 150 | 150.02 | 330 | 330.06 |
| 160 | 160.02 | 340 | 340.07 |
| 170 | 170.02 | 350 | 350.07 |

* Calculated values based on linear model (see appendix) ·

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Unprocessed Calibration Data for Range:

| Reference Signal Voltage: | 30.00 | V |
|--------------------------------|-------|----|
| Variable Phase Signal Voltage: | 30.00 | V |
| Frequency: | 60 | Hz |

| NBS STANDARD | METER UNDER TEST | NBS STANDARD | METER UNDER TEST |
|--------------|------------------|--------------|------------------|
| (Degrees) | (Degrees) | (Degrees) | (Degrees) |
| | | | |
| 0.00 | 0.03 | 180.00 | 179.97 |
| 0.00 | 0.02 | 180.00 | 179.98 |
| 0.00 | 0.01 | 180.00 | 179.95 |
| 30.00 | 30.03 | 210.00 | 209.95 |
| 30.00 | 30.01 | 210.00 | 209.97 |
| 30.00 | 30.01 | 210.00 | 209.98 |
| 60.00 | 59.99 | 240.00 | 239.94 |
| 60.00 | 60.01 | 240.00 | 239.96 |
| 60.00 | 60.01 | 240.00 | 239.96 |
| 90.00 | 90.01 | 270.00 | 269.99 |
| 90.00 | 90.01 | 270.00 | 269.96 |
| 90.00 | 89.96 | 270.00 | 269.86 |
| 120.00 | 119.99 | 300.00 | 299.94 |
| 120.00 | 119.98 | 300.00 | 299.96 |
| 120.00 | 120.00 | 300.00 | 299.92 |
| 150.00 | 150.00 | 330.00 | 329.95 |
| 150.00 | 149.99 | 330.00 | 329.96 |
| 150.00 | 149.99 | 330.00 | 329.96 |
| | | | |

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<u>Appendix</u>

The calibration of this phase meter provides an equation to correct the reading obtained from the phase meter so that the result of the measurement will be close in agreement with the corresponding value supplied by the NBS Phase Angle Standard. These corrections are calculated from the unprocessed calibration data obtained during the test, which are shown on separate pages.

Because random fluctuations tend to mask the limiting mean of the phase meter response at any particular test point, the corrections calculated are based on predicted values. These values are obtained by fitting the unprocessed data (y) for each set of current, voltage, and frequency conditions to an equation which models the average response of the phase meter to phase angles (x) supplied by the NBS standard.

| Reference Signal Voltage: | 30.00 V | | |
|---|---|----------------------------|------------------------|
| Variable Phase Signal Voltage: | 30.00 V | | |
| Frequency: | 60 Hz | | |
| Predicted value y' = Standard errors of coefficients Significance levels ⁶ | 0.019402 + 0.9 (0.006952) (0.0 (0.009) (0.0 | 99749 · x 00036) 00) | (degrees) (degrees) |
| Residual standard deviation Lack-of-fit Significance level ⁷ | s = 0.022188 F'= 0.466 (0.895) | 2s = 0.04436 | (degrees) |
| Estimated limits of systematic of | offset from NBS: | | |

| without corrections | (x' = y) | 0.091 | (degrees) |
|-----------------------------|--------------------|-------|-----------|
| with a constant correction | (x' = y + 0.262) | 0.070 | (degrees) |
| using the fitted linear equ | uation (see above) | 0.020 | (degrees) |

⁶ Significance levels are derived using statistical tests (Student's t-distribution) to decide if the intercept and slope of the fitted straight line are different from their ideal values, zero and one, respectively. A level near zero (less than or equal to 0.05) shows that the associated parameter is probably different from the ideal value.

⁷ The significance level of F' is associated with an objective statistical test for the adequacy of a linear model relating the user's phase meter response and the NBS assigned values. Significance levels near zero (less than or equal to 0.01) indicate that the assumption of a straight line as a model for the phase meter response may be incorrect. However, if the variability of the repeat readings is of the same order as the resolution of the meter, and the data points are therefore not normally distributed, the table of values on which this test is based are not applicable.

U.S. DEPARTMENT OF COMMERCE NATIONAL BUREAU OF STANDARDS GAITHERSBURG, MD 20899

REPORT OF CALIBRATION

Phase Meter Model , Serial No.

Submitted by

Street

The phase meter was tested in August 1982 using the NBS Phase Angle Calibration Standard.⁸ The ambient temperature was $23 \pm 2^{\circ}$ C. The phase meter under test, as well as the Phase Angle Calibration Standard, were under power for more than 3 hours before readings were taken.

For the specified current, voltage, and frequency conditions, four readings were taken at 12 test points (phase angles) selected in a random order. The NBS Phase Angle Standard was set to the desired phase angle, and the digital readout of the phase meter under test was read and recorded. The time constant in the response of the phase meter required a timed delay of 30 seconds before taking readings to obtain consistent results.

No adjustments of the phase meter were made at any time. The range switch provided on the phase meter was operated so that readings fell into an interval from -1 to 359 degrees wherever possible. Readings in the interval from 359 to 360 degrees were converted to an interval from -1 to 0 degrees for purposes of computation.

During the tests the test signal frequencies was maintained at constant values with a frequency stability better than 10 parts per million and with an uncertainty of less than ± 0.01 Hz if below 5 kHz and ± 0.1 Hz from 5 to 50 kHz.

⁸ NBS Technical Notes 1144 (July 1981) and 1220 (April 1986)
Phase Meter Model Serial No.

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The systematic uncertainty in the value of the NBS Phase Angle Standard is estimated to be less than 0.004 degrees at the currents, voltages, and frequencies used in this test. For the present data, based on replication readings, the limit to offset from the values provided by the NBS Phase Angle Calibration Standard for a corrected phase angle using the equation below, is estimated to be less than 0.011 degrees. The overall uncertainty of corrected phase angle measurements depends on the variability of repeat measurements on the phase meter under normal laboratory test conditions. The estimated standard deviation of repeat measurements at NBS was 0.008 degrees. Under similar operating conditions, the overall disagreement between a corrected phase meter reading and the NBS standard would be estimated to be less than 0.027 degrees⁹.

For the Director National Engineering Laboratory

Barry A. Bell, Group Leader Electronic Instrumentation and Metrology Electrosystems Division Test No. 722-Order No. Date: August, 1982

9 NBS Technical Note XXXX, p. yy



- 3 -

Reference Signal Voltage:5.00 VVariable Phase Signal Voltage:100.00 VFrequency:60 Hz

No correction is needed to bring the observed phase angle reading into agreement with the NBS standard.

Phase Meter Model Serial No.

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Unprocessed Calibration Data for Range:

| Reference Signal Voltage: | 5.00 | V |
|--------------------------------|--------|----|
| Variable Phase Signal Voltage: | 100.00 | V |
| Frequency: | 60 | Hz |

| NBS STANDARD | METER UNDER TEST | T NBS STANDARD | METER UNDER TEST |
|--------------|------------------|----------------|------------------|
| (Degrees) | (Degrees) | (Degrees) | (Degrees) |
| | | | |
| 0.00 | 0.00 | 180.00 | 179.99 |
| 0.00 | 0.00 | 180.00 | 179.99 |
| 0.00 | 0.01 | 180.00 | 180.01 |
| 0.00 | 0.00 | 180.00 | 179.99 |
| 30.00 | 29.99 | 210.00 | 210.00 |
| 30.00 | 30.00 | 210.00 | 210.01 |
| 30.00 | 29.99 | 210.00 | 210.00 |
| 30.00 | 30.00 | 210.00 | 210.01 |
| 60.00 | 60.00 | 240.00 | 240.01 |
| 60.00 | 60.00 | 240.00 | 240.01 |
| 60.00 | 60.01 | 240.00 | 240.00 |
| 60.00 | 59.99 | 240.00 | 240.01 |
| 90.00 | 89.98 | 270.00 | 270.00 |
| 90.00 | 89.99 | 270.00 | 269.99 |
| 90.00 | 90.00 | 270.00 | 270.00 |
| 90.00 | 90.00 | 270.00 | 270.02 |
| 120.00 | 119.99 | 300.00 | 300.01 |
| 120.00 | 120.00 | 300.00 | 300.00 |
| 120.00 | 120.00 | 300.00 | 300.00 |
| 120.00 | 120.01 | 300.00 | 300.00 |
| 150.00 | 150.01 | 330.00 | 330.00 |
| 150.00 | 150.01 | 330.00 | 330.00 |
| 150.00 | 150.00 | 330.00 | 330.01 |
| 150.00 | 149.98 | 330.00 | 329.99 |
| | | | |

Phase Meter Model Serial No.

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Appendix

The calibration of this phase meter provides an equation to correct the reading obtained from the phase meter so that the result of the measurement will be close in agreement with the corresponding value supplied by the NBS standard. These corrections are calculated from the unprocessed calibration data obtained during the test, which are shown on separate pages.

Because random fluctuations tend to mask the limiting mean of the phase meter response at any particular test point, the corrections calculated are based on predicted values. These values are obtained by fitting the unprocessed data (y) for each set of current, voltage, and frequency conditions to an equation which models the average response of the phase meter to phase angles (x) supplied by the NBS standard.

| Reference Signal Voltage: | 5.00 V | | |
|--|---|---------------------------------------|------------------------|
| Variable Phase Signal Voltage: | 100.00 V | | |
| Frequency: | 60 Hz | | |
| Predicted value y' = - Standard errors of coefficients Significance levels ¹⁰ | 0.002581 + (0.002324) ((0.273) (| 1.000020 · x (0.000012) (0.100) | (degrees) (degrees) |
| Residual standard deviation Lack-of-fit Significance level ¹¹ | s = 0.00854 F'= 0.811 (0.620) | 2s = 0.01708 | (degrees) |

Estimated limits of systematic offset from NBS:

| without corrections | $(\mathbf{x'} = \mathbf{y})$ | 0.011 | (degrees) |
|-----------------------------|------------------------------|-------|-----------|
| with a constant correction | (x' = y + 0.262) | 0.010 | (degrees) |
| using the fitted linear equ | uation (see above) | 0.007 | (degrees) |

Significance levels are derived using statistical tests (Student's t-distribution) to decide if the intercept and slope of the fitted straight line are different from their ideal values, zero and one, respectively. A level near zero (less than or equal to 0.05) shows that the associated parameter is probably different from the ideal value.

¹¹ The significance level of F' is associated with an objective statistical test for the adequacy of a linear model relating the user's phase meter response and the NBS assigned values. Significance levels near zero (less than or equal to 0.01) indicate that the assumption of a straight line as a model for the phase meter response may be incorrect. However, if the variability of the repeat readings is of the same order as the resolution of the meter, and the data points are therefore not normally distributed, the table of values on which this test is based are not applicable.

APPENDIX C

Computer Program for Phase Meter Calibration

A computer program has been developed to implement the procedures and calculations given in this NBS Technical Note. The program sets the NBS Phase Standard to the desired operating conditions and records the readings of the phase meter under test. The computer (instrument controller) can receive the readings directly from the phase meter, if the meter has a GPIB interface, otherwise the digital display of the phase meter is read and the data are entered manually via the keyboard. The data can be stored on disk for future recall, and after all the data for a range have been collected, the program attempts to fit the data to a straight line, using the phase angle settings of the NBS standard as an independent variable. Finally, the corrected phase meter readings and the statistical parameters resulting from the fit are printed out as the calibration report using the second section of the program.

This appendix contains a complete listing of the main program sections and the sub-programs which are written in BASIC for the Hewlett-Packard¹² Model 85 configured with 32K of RAM, the Advanced Programming ROM, the Mass Storage ROM, and the I/O ROM. The code may require modification if the program is to be used on another computer. Minor modification may also be required to interface to a different phase angle standard, or if a printer other than the Qume Sprint 11 Plus with a RS-232-C Model 1 Interface¹2 is used.

The listing incorporates two main programs. The first program called " ϕ CAL6" controls the operation of the NBS Phase Angle Standard, the test procedure, and performs the statistical analysis. The second program, called "REPORT," formats and prints the calibration report. The structure of these two programs is shown in figures C-1 and C-2. The programs invoke various subprograms which comprise the remainder of the listing. Because of the limited memory available, the subprograms are swapped in and out of memory as needed. Despite the memory limitation, the programs contain many explanatory comments which will assist in understanding the program procedures. Lists of cross references and descriptions of variables are also provided.

To calibrate a phase meter several steps have to be followed. First, the Phase Meter Calibration Program (ϕ CAL6) is loaded and run. Then, a new test is initialized by selecting the "New Test" option in the menu. This step includes entering administrative information about the customer and the phase meter to be tested. Next, using the "Test Points" selection from the main menu, the range parameters and the phase angles to be tested are set up. Using the "Enter Data" option more information about the number of readings per test point, the time allowed for the meter to settle, the peripheral bus addresses, etc. are set up. The actual calibration data is then taken either fully automatically using the GPIB or entered manually for test points selected in a random order by the program.

¹² To describe the system discussed adequately, commercial equipment and parts are identified by the manufacturer's name and model number. In no case does such identification imply a recommendation or endorsement by the National Bureau of Standards, nor does it imply that the material or equipment identified is necessarily the best available for the purpose.

After all the readings for one range have been taken, the data are stored with the "Save" selection from the menu. An optional error plot can then be obtained to check for outliers or errors in data entry. If the data seem satisfactory, the "Fit" option can be used to provide statistical information on how well the data fit the linear model. Corrected phase meter readings are then calculated using the linear equation.

To print the calibration report, the program "REPORT" is loaded and run. This program recovers the calibration data from the disk storage and calculates the numerical information needed. The report can then be printed with a format that allows some flexibility by exercising options from the menu.

ACKNOWLEDGEMENT.

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```
100 ! Phase Meter Calibration Program
105 !
110 ! This program sets the date and time and dispatches the user
115 ! from the main menu to the calibration routines. JUL 87
120 !
125 ON KEY# 1, "MENU" GOTO 225
130 OPTION BASE 1@ INTEGER B1(100), B2(100)
135 COM C$[60],R(10,4),C(100,8),D(100,8),A(5),T0$[100]
140 DIM I2$[20], I3$[20], M1$[160], M2$[40], Z(1)
145 SARRAY M1$,M2$,T0$ @ C$[60]=" "
150 !
155 ! Prompt user for date and time.
160 !
165 ! R(1,1)=0 to skip prompt concerning saving of previous file.
170 R(1,1)=0 @ CLEAR @ DISP "Phase Meter Calibration Program" @ DISP
175 DISP " < k1 > returns you to menu." @ DISP
180 CALL "QUERY" ( "Enter date (MM/DD/YYYY).",R,Y,D$ ) @ ON R GOTO 185,200,225
185 DISP @ CALL "QUERY" ( "Enter time (HH:MM:SS).",R,Y,T$ )
190 ON R GOTO 195,185,225
195 D=VAL(D$[9,10])*1000+MDY(D$)-MDY("12/31/"&VAL$(VAL(D$[7,10])-1)) @ SETTIME H
MS(T$),D
200 ! S1$=date; TIME$=time
205 S$=DATE$ @ S1$=S$[4,6]&S$[7,8]&"/19"&S$[1,2] @ M=2
210 !
215 ! Main menu.
220 !
225 SLET M1$(1) = "Stored File"
230 SLET M1$(2) = "New File"
235 SLET M1$(3) = "Edit File"
240 SLET M1$(5) = "Range List"
245 SLET M1$(6) = "Test Data"
250 SLET M1$(7) = "Check Data"
255 SLET M1$(9) = "Enter Data"
260 SLET M1$(10) = "Test Points"
265 SLET M1.$(11) = "Init Check"
270 SLET M1$(12) = "Find Fit"
275 SLET M1$(13) = "Plot Test"
280 SLET M1$(14) = "Plot Check"
285 SLET M1$(15) = "Save Data"
290 CLEAR @ C=0 @ KO=0 @ CALL "MENU" ( M,M1$,C ) @ M=15
295 ON C GOTO 315,345,385,100,395,430,450,100,485,520,525,580,610,635,655
300 !
305 ! Load stored file.
310 !
315 GOSUB 680 @ ON R GOTO 225,320,225
320 CALL "LOAD" ( C$,A(),R(,),D(,),C(,),B1(),B2(),DO$,TO$ )
325 SCRATCHSUB "LOAD" @ GOTO 225
330 !
335 ! Start new file.
340 !
345 GOSUB 680 @ ON R GOTO 225,350,225
          "INITAR" ( A(),B1(),B2(),C(,),D(,),R(,),TO$ ) @ SCRATCHSUB "INITAR"
350 CALL
355 C$=" " @ C$[60]=" " @ C$[2]=C$
360 CLEAR @ CALL "HEADER" ( C$,S1$,R1,R(,),1,N1,M0,T0$,D0$ )
365 SCRATCHSUB "HEADER" @ GOTO 225
```

```
370 !
375 ! Edit header, ranges, auto-zero data, test data, and check data.
380 !
385 CALL "EDITFI" ( C$,A(),B1(),B2(),C(,),D(,),D0$,M0,N$,R(,),S1$,T0$ )
390 SCRATCHSUB "EDITFI" @ GOTO 225
395 !
400 ! List range parameters.
405 !
410 DISP "Range R(,)" @ DISP @ FOR A=1 TO 8
415 DISP USING 420 ; A,R(A,1),R(A,2),R(A,3),R(A,4) @ NEXT A
420 IMAGE 3D, 2X, 3D, 2X, 3D. D, 2X, 3D. D, 2X, 5D
425 DISP @ DISP "Press <CONT> to continue." @ PAUSE @ GOTO 225
430 !
435 ! Observe test data.
440 !
445 CALL "DATA" ( D(,),B1(),N$ ) @ SCRATCHSUB "DATA" @ GOTO 225
450 !
455 ! Observe check data.
460 !
465 CALL "DATA" ( C(,),B2(),N$ ) @ SCRATCHSUB "DATA" @ GOTO 225
470 !
475 ! Begin or continue test.
480 !
485 CALL "GET PARAMS" ( R,A(),T1,T0$,A1,A2,A3,F2,F3,I2$,I3$,P2,P3 )
490 SCRATCHSUB "GET PARAMS" @ IF FLAG(5) THEN GOTO 225
495 CALL "GET DATA" ( R,B1(),B2(),T1,A1,A2,A3,F2,F3,I2$,I3$,P2,P3,S1$,D0$,Z )
500 SCRATCHSUB "GET DATA" @ IF Z=1 THEN 225
505 !
510 ! Initialize ranges.
515 !
520 CALL "GETRNG" ( A(),C(,),D(,),R(,),B1(),B2() ) @ SCRATCHSUB "GETRNG" @ GOTO
225
525 !
530 ! Initialize check standard.
535 !
540 CLEAR @ DISP "Is a check standard being used for this test?"
545 CALL "YESNO" ( R ) @ ON R GOTO 555,550,225
550 CFLAG 1 @ GOTO 225
555 SFLAG 1 @ CALL "HEADER" ( C$,S1$,R1,R(,),2,N1,M0,T0$,D0$ )
560 SCRATCHSUB "HEADER" @ GOTO 225
565 !
570 ! Invoke fit routines.
575 !
580 ALPHA 1 @ CLEAR @ C=O @ KO=O
585 SLET M2$(1) = "Fit Test Data" @ SLET M2$(2) = "Fit Check Data"
590 CALL "MENU" ( 2,M2$,C ) @ ON C GOTO 595,600
595 CALL "FIT" (`C$,R(,),D(,),B1(),S1$,TO$,DO$,1 ) @ GOTO 605
600 CALL "FIT" ( C$,R(,),C(,),B2(),S1$,TO$,DO$,O )
605 SCRATCHSUB "FIT" @ GOTO 225
610 !
615 ! Plot test data.
620 !
625 CALL "PLOT" ( C$,D(,),R(,),B1(),R1,S1$,1,T0$,D0$ )
630 SCRATCHSUB "HEADER" @ SCRATCHSUB "PLOT" @ GOTO 225
```

```
635 !
640 ! Plot check data.
645 !
650 CALL "PLOT" ( C$,C(,),R(,),B2(),R1,S1$,O,TO$,DO$ ) @ GOTO 630
655 !
660 ! Save file.
665 !
670 CALL "STORE" ( C$,A(),R(,),D(,),C(,),B1(),B2(),D0$,T0$ )
675 SCRATCHSUB "STORE" @ GOTO 225
680 !
685 ! Warn user about pending loss of data.
690 !
695 ! Skip warning if no data has been entered.
700 IF R(1,1)=0 THEN R=2 @ RETURN
705 CLEAR @ DISP "Should previous file be saved?"
710 CALL "YESNO" ( R ) @ RETURN
```

| VAR B1() | OCCURS IN LINE 130 ,320 ,350 ,385 445 ,495 ,520 ,595 | no. of readings at each point of the test meter |
|------------------------|--|--|
| 82() | 625 ,670 130 ,320 ,350 ,385 465 ,495 ,520 ,600 | no. of readings at each point of the check meter |
| С\$ | 650,670 135,145,320,355 355,355,355,360 385,555,595,600 | this string contains information about the test that is extracted from the table of contents. C\$[1,30]=customer name; C\$[31,40]= |
| R (,) | 625 ,650 ,670 135 ,170 ,320 ,350 360 ,385 ,415 ,415 415 ,415 ,520 ,555 595 ,600 ,625 ,650 670 ,700 | <pre>test date; C\$[41,50]=serial no.; C\$[60]=folder no. array of parameters for each of the 8 ranges. R(r,1)=no. of first test point of range; R(r,2)=reference channel voltage (or current if negative); R(r,3)=variable channel voltage or current: R(r,4)=frequency</pre> |
| С (,) | 135 ,320 ,350 ,385 465 ,520 ,600 ,650 670 | <pre>check meter data. lst subscript=point no.; C(p,1)=ideal reading; C(p,2-7)=repeat readings; C(p,8)=average of readings</pre> |
| D (,) | 135 ,320 ,350 ,385 445 ,520 ,595 ,625 670 | test meter data. (described in C(,) above) |
| A () | 135 ,320 ,350 ,385 485 ,520 ,670 | A(1)=next available test point; A(2)=present range; A(3)=no. of readings to take; A(4)=reading on. |
| 10\$ | 135 ,145 ,320 ,350 360 ,385 ,485 ,555 595 ,600 ,625 ,650 670 | TO\$(1),TO\$(2),TO\$(3)=manufacturer, model, serial no. of test meter; TO\$(4),TO\$(5),TO\$(6)= manufacturer, model, serial no. of check meter. |
| I 2\$ I 3\$ M1\$ | 140 ,485 ,495 140 ,485 ,495 140 ,145 ,225 ,230 235 ,240 ,245 ,250 255 ,260 ,265 ,270 275 ,280 ,285 ,290 | instructions to set up test meter for auto reading. instructions to set up check meter for auto reading. array of strings of main menu options |
| M2\$ | 140 ,145 ,585 ,585 590 140 | array of strings of fit menu options. used to select whether to fit test or check data. |
| R Y | 180 ,180 ,185 ,190 315 ,345 ,485 ,495 545 ,545 ,700 ,710 180 ,185 | used for two purposes; gives information:about user's reply and is a temporary register for the present range. dummy variable |
| D \$ T \$ D | 180 ,195 ,195 ,195 185 ,195 195 ,195 | string into which user enters the date string into which user enters the time Julian value of date |
| \$ \$1\$ | 205 ,205 ,205 ,205 205 ,360 ,385 ,495 555 ,595 ,600 ,625 650 | string copy of Julian date mm/dd/yyyy format of date |
| M C | 205 ,290 ,290 290 ,290 ,295 ,580 590 ,590 | no. of options in menu passed to MENU routine no. of selected menu option |
| KO DO\$ | 290 ,580 320 ,360 ,385 ,495 555 ,595 ,600 ,625 650 ,670 | unused variable date of test. loaded tests may have dates differing from the present date |
| R1 N1 | 360 ,555 ,625 ,650 360 ,555 | dummy variable dummy variable |
| N\$ A | 360,385,555 385,445,465 410,415,415,415 415,415,415 | dummy variable dummy string loop control |
| T1 A1 A2 | 485,495 485,495 485,495 | WAIT between readings address of phase standard address of test meter |
| A3 | 485,495 | address of check meter |
| FZ F3 | 405,495 | test meter multiplier for automatic readings |
| P2 | 485,495 | position of reading in test meter input |
| P3 Z | 485 ,495 495 ,500 | position of reading in check meter input |

```
100 SUB "A-ZERO" (A,R,D(,),F)
105 !
110 ! This program takes auto-zero samples to find the span and
115 ! average. At user's request it will record the span and
120 ! the last correction. JUL 87
125 !
130 ! INPUT: D(,)=data, F=flag to skip initial prompt.
135 !
140 OPTION BASE 10 SFLAG 5 0 IF F THEN GOTO 155
145 CLEAR @ DISP "Do you want an auto-zero sample?" @ CALL "YESNO" ( K )
150 ON K GOTO 155,240,245
155 CLEAR @ S=D(92,R) @ DISP USING "D,30A"; S," of 4 samples have been taken."
160 ! L=smallest correction, H=highest corr., T=sum of corrs.,
165 ! C=no. of corrs. in T.
170 L=361 @ H=-361 @ T,C=0 @ S=S+1 @ IF S=5 THEN S=1
175 DISP USING "41A,D,A"; "Next stored sample will occupy position ",S,"." @ D
ISP
180 ! Do auto-zero.
185 D$="LRFAQLFQLFFQR" @ Q=3 @ CALL "TALK" ( A,D$,Q )
190 IF Q<>-1 THEN DISP "Auto-zero was UNSUCCESSFUL." @ WAIT 1500 @ GOTO 145
195 Q=VAL(D$[8,16]) @ L=MIN(L,Q) @ H=MAX(H,Q) @ T=T+Q @ C=C+1
200 DISP USING 205 ; H-L,T/C @ DISP
205 IMAGE "running span =",2DZ.3D / "running average =",2DZ.3D
210 ! Increase sample size on user request.
215 DISP "Do you want another reading?" @ CALL "YESNO" ( K ) @ ON K GOTO 185,225
,245
220 !
225 DISP @ DISP "Do you want to store this" @ DISP " sample?"
230 CALL "YESNO" ( K ) @ ON K GOTO 235,145,245
235 D(92,R)=S @ D(92+R,S*2-1)=H-L @ D(92+R,S*2)=Q
240 CFLAG 5
245 SCRATCHSUB "TALK" @ SUBEXIT
VAR
       OCCURS IN LINE
А
       100,185
                                 address of phase standard
       100 ,155 ,235 ,235
R
                                 present range
       235
       100 ,155 ,235 ,235
                                 test meter data. (see main program xref)
D (,)
       235
F
       100,140
                                 flag to skip "Do you want an auto-zero?" prompt
Κ
       145 ,150 ,215 ,215
                                 reply to yes or no prompt
       230,230
S
       155 ,155 ,170 ,170
                                 no. of samples taken
       170 ,170 ,175 ,235
       235,235
       170 ,195 ,195 ,200
                                 smallest auto-zero correction
L
       235
Н
       170 ,195 ,195 ,200
                                 highest auto-zero correction
       235
Т
       170 ,195 ,195 ,200
                                 sum of corrections in present sample
       170 ,195 ,195 ,200
                                 no. of auto-zeros taken for sample
С
                                 correction read from standard
       185 ,185 ,195
D $
                                 multi-purpose variable. passes no. of queries
       185 ,185 ,190 ,195
Q
       195,195,195,235
                                   to TALK and returns with -1 if TALK succeeded.
                                   on line 195 Q is the read correction
```

100 SUB "CHKRNG" (Z,A(),R(,))
105 !
110 ! This program will delete the present range if its test
115 ! points overflow the data arrays. JUL 87
120 !
125 OPTION BASE 1
130 Z=1 @ IF A(1)<=91 THEN SUBEXIT
135 Z=0 @ A(1)=R(A(2),1) @ R(A(2),2),R(A(2),3),R(A(2),4)=0
140 CLEAR @ DISP "Maximum number of test points reached. RANGE DELETED."
145 DISP @ DISP "Press <CONT>." @ PAUSE
150 SUBEXIT

| OCCURS IN LINE | |
|--------------------|---|
| 100 ,130 ,135 | set if there isn't room for the range |
| 100 ,130 ,135 ,135 | A(1)=next available test point; A(2)=present |
| 135 ,135 ,135 | range |
| 100 ,135 ,135 ,135 | array of range parameters. (see xref in |
| 135 | main program) |
| | OCCURS IN LINE 100 ,130 ,135 100 ,130 ,135 ,135 135 ,135 ,135 100 ,135 ,135 ,135 135 |

```
100 SUB "DATA" (D(,),B(),N$) ! JUL 87
105 !
110 ! This program displays phase angle and auto-zero data.
115 !
120 N$="" @ OPTION BASE 1@ DIM M$[40]
125 !
130 ! Have user select which data to see.
135 !
140 SARRAY M$ @ SLET M$(1) = "Angle Data" @ SLET M$(2) = "Auto-Zero Data"
145 CALL "MENU" ( 2,M$,C ) @ IF C=2 THEN 345
150 !
155 ! View phase angle data.
160 !
165 ! Prompt user for test points to see.
170 CLEAR @ CALL "QUERY" ( "Enter first test point to be seen.", C, A2, Z$ )
175 IF A2<1 OR A2>91 THEN DISP "Data out of range." @ DISP @ GOTO 170
180 ON C GOTO 190,170,185
185 N$=CHR$(128) @ SUBEXIT
190 DISP @ CALL "QUERY" ( "Enter last test point to be seen.",C,A3,Z$ )
195 IF A3<1 OR A3>91 THEN DISP "Data out of range." @ DISP @ GOTO 190
200 ON C GOTO 215,190,205
205 N$=CHR$(128) @ SUBEXIT
210 ! Function to keep angle within range of -1 to 359.
215 DEF FND(X) = X-360*(X>359 \text{ AND } X<361)
220 ! Now show the data.
225 S=0 @ N=0
230 FOR A=A2 TO A3
235 IF B(A)=0 THEN DISP USING 240 ; A;D(A,1) @ GOTO 285
240 IMAGE /3D,1X,3D.3D," *** NO DATA ***"
245 DISP USING 250 ; A;D(A,1);B(A);D(A,8);D(A,2);D(A,3);D(A,4);D(A,5);D(A,6);D(A
,7)
250 IMAGE / 3D, 1X, 3D. 3D, 2X, 3D, 2X, 3D. 3D, 2(/3X, 2(3D. 3D, 3X), 3D. 3D)
255 D8 = FND(D(A, 8))
260 IF B(A)<2 THEN 285
265 \text{ FOR } B=2, \text{ TO } B(A)+1
270 S=S+(FND(D(A,B))-D8)©2
275 NEXT B
280 N=N+B(A)-1
285 NEXT A @ IF N=0 THEN 315
290 ! Show the statistical info.
295 DISP USING 300 ; SQR(S/N)
300 IMAGE //"standard deviation = ",DZ.4D/"[replication]"
305 DISP USING 310 ; 3*SQR(S/N),N
310 IMAGE " 3s = ",17DZ.4D/" degrees of freedom = ",5D
315 DISP @ DISP @ DISP "Press <CONT> to continue.
320 PAUSE
325 SUBEND
330 !
335 ! Display auto-zero info for a given range.
340 !
345 CLEAR @ CALL "QUERY" ( "Enter range to examine.",C,R,Z$ )
350 IF R<1 OR R>8 THEN 345
```

355 ON C GOTO 360,345,185 360 IF D(92,R)=O THEN DISP @ DISP "NO DATA AVAILABLE FOR THAT RANGE" @ WAIT 2000 @ GOTO 185 365 CLEAR @ DISP USING 370 ; R 370 IMAGE / "Range ",D," Auto-Zero Data" //" Sample Span Final Corr." // 375 FOR I=1 TO 4 @ DISP USING 380 ; I,D(92+R,I*2-1),D(92+R,I*2) @ NEXT I @ GOTO 315 380 IMAGE 5D,7DZ.3D,5DZ.3D

| VAR | OCCURS IN LINE | |
|-------|--|---|
| D (,) | 100 ,235 ,245 ,245 245 ,245 ,245 ,245 245 ,245 ,255 ,270 | any meter data. (see main program xref) |
| | 360,375,375 | |
| В (,) | 100 ,235 ,245 ,260 265 ,280 | no. of readings at each point of either meter |
| N \$ | 100 ,120 ,185 ,205 | contains CHR\$(128) to request main menu |
| M \$ | 120 ,140 ,140 ,140 145 | array of strings of menu options |
| С | 145 ,145 ,170 ,180 190 ,200 ,345 ,355 | contains no. of menu option selected or value of user's request on QUERY |
| A2 | 170 ,175 ,175 ,230 | first test point to be seen |
| Ζ\$ | 170 ,190 ,345 | dummy string |
| A3 | 190 ,195 ,195 ,230 | last test point to be seen |
| S | 225 ,270 ,270 ,295 305 | standard deviation |
| N | 225 ,280 ,280 ,285 295 ,305 ,305 | no. of readings used to calculate deviation |
| А | 230 ,235 ,235 ,235 | test point no. and loop control |
| | 245,245,245,245 | |
| | 245,245,245,245 | |
| | 265 270 280 285 | |
| D8 | 255 270 | average reading at point A |
| B | 265,270,275 | reading no. loop control |
| R | 345,350,350,360 | range no. |
| | 365 ,375 ,375 | |
| Ι | 375 ,375 ,375 ,375 375 | loop control |
| | | |

```
100 SUB "EDIT" (R(,),D(,),B(),N$,J)
105 !
110 ! This program allows the user to change ranges and test and
115 ! check data. JUL 87
120 !
125 ! INPUT: J=1 to edit ranges; J=2 to edit data points.
130 !
135 OPTION BASE 1
140 N=0
145 ON J GOTO 165,230
150 !
155 ! Edit user-specified range.
160 !
165 CLEAR @ CALL "QUERY" ( "Enter range to be edited.", X, R, Y$ )
170 ON X GOTO 175,165,275
175 IF R<1 OR R>8 THEN 165
180 CLEAR @ GOSUB 285
185 DISP @ DISP "Make corrections, then press CONT> to continue." @ PAUSE
190 IMAGE A,"(",2D,",",D ,")= ",M2DZ.2D
195 CLEAR @ GOSUB 285
200 IMAGE /, "Are data OK now?"
205 DISP USING 200 ;
210 CALL "YESNO" ( X ) @ ON X GOTO 275,175,275
215 !
220 ! Edit user-specified data point.
225 !
230 CLEAR @ DISP "Enter data point to be edited." @ IF N#O THEN DISP N;" is the
default."
235 CALL "QUERY" ( "",X,N,Y$ )
240 ON X GOTO 245,230,275
245 IF N<1 OR N>91 THEN 230
250 GOSUB 320
255 DISP @ DISP "Make corrections, then press <CONT> to continue." @ PAUSE
260 CLEAR @ GOSUB 320
265 DISP USING 200 ;
270 CALL "YESNO" (X) @ ON X GOTO 275,230,275
275 SUBEXIT
280 !
285 ! Routine to display range information.
290 !
295 FOR I=1 TO 4
300 DISP USING 190 ; "R",R,I,R(R,I)
305 NEXT I
310 RETURN
315 !
320 ! Routine to display data points.
325 !
330 S=0
335 FOR I=1 TO 8
340 IF I>1 AND I<=B(N)+1 THEN S=S+D(N,I)-360*(D(N,I)>359 AND D(N,I)<361)
345 IF I=8 AND B(N)<>0 THEN D(N,8)=S/B(N)
350 DISP USING 190 ; "D", N, I, D(N, I)
355 NEXT I
360 IF B(N) <>0 THEN D(N,8) = S/B(N)
365 DISP USING 370 ; N,B(N)
370 IMAGE "B(",DD,")= ",2D
375 RETURN
380 SUBEND
```

| VAR | OCCURS IN LINE | |
|-------|--------------------|--|
| R (,) | 100,300 | array of range parameters. (see main program) |
| D (,) | 100,340,340,340 | test or check meter data. (see main program |
| ()) | 345 ,350 ,360 | xref) |
| В (,) | 100 ,340 ,345 ,345 | no. of readings at each point of test or check |
| | 360 ,360 ,365 | meter |
| N \$ | 100 | unused |
| J | 100 ,145 | J=l to edit ranges; J=2 to edit data |
| Ν | 140 ,230 ,230 ,235 | no. of data point to edit |
| | 245,245,340,340 | |
| | 340,340,345,345 | |
| | 345,350,350,360 | |
| | 360,360,365,365 | |
| Х | 165 ,170 ,210 ,210 | numerical value of the user's request |
| | 235 ,240 ,270 ,270 | |
| R | 165 ,175 ,175 ,300 | range no. |
| | 300 | |
| Y \$ | 165 ,235 | dummy string |
| I | 295,300,300,305 | loop control |
| | 335 ,340 ,340 ,340 | |
| | 340 .340 .345 .350 | |
| | 350 355 | |
| S | 330,340,340,345 | sum of readings at a data point |
| | 360 | |

```
100 SUB "EDITFI" (C$,A(),B1(),B2(),C(,),D(,),D0$,M0,N$,R(,),S1$,T0$) ! JUL 87
105 !
110 ! This program dispatches control to the routines that allow
115 ! the user to edit test data and information. JUL 87
120 !
125 OPTION BASE 10 DIM M$[80]
130 !
135 ! Have user select data to change.
140 !
145 SARRAY M$ @ SLET M$(1) = "Edit Header" @ SLET M$(2) = "Edit Range"
150 SLET M$(3) = "Edit Test Data" @ SLET M$(4) = "Edit Check Data"
155 SLET M$(6) = "Main Menu" @ CALL "MENU" ( 6,M$,R ) @ ON R GOTO 160,175,180,18
5,100,190
160 CALL "HEADER" ( C$,S1$,A(2),R(,),1,1,M0,T0$,D0$ ) @ WAIT 1500
165 CALL "HEADER" ( C$,S1$,A(2),R(,),2,0,M0,T0$,D0$ )
170 CALL "HEADER" ( C$,S1$,A(2),R(,),3,1,M0,T0$,D0$ ) @ GOTO 190
175 CALL "EDIT" ( R(,),D(,),B1(),N$,1 ) @ GOTO 190
180 CALL "EDIT" ( R(,),D(,),B1(),N$,2 ) @ GOTO 190
185 CALL "EDIT" ( R(,),C(,),B2(),N$,2 )
190 SCRATCHSUB "HEADER" @ SCRATCHSUB "EDIT" @ SUBEND
```

| VAR | OCCURS IN LINE | |
|-------|--------------------|--|
| C \$ | 100 ,160 ,165 ,170 | test info from TOC (see main program xref) |
| A () | 100 ,160 ,165 ,170 | A(2)=no. of present range |
| B1(,) | 100 ,175 ,180 | readings/test point (see main program xref) |
| B2(,) | 100 ,185 | readings/check point(see main program xref) |
| C (,) | 100 ,185 | check meter data. (see main program xref) |
| D (,) | 100 ,175 ,180 | test meter data (see main program xref) |
| DO\$ | 100 ,160 ,165 ,170 | test date |
| MO | 100 ,160 ,165 ,170 | dummy variable |
| N \$ | 100 ,175 ,180 ,185 | dummy string |
| R (,) | 100 ,160 ,165 ,170 | array of range parameters (see main program |
| | 175 ,180 ,185 | xref) |
| S1\$ | 100 ,160 ,165 ,170 | present date |
| TO\$ | 100 ,160 ,165 ,170 | test and check meter info (see main program) |
| M \$ | 125 ,145 ,145 ,145 | array of strings of menu options |
| | 150 ,150 ,155 ,155 | |
| R | 155 ,155 | selected menu option |

```
100 SUB "ENTER" (R(,),D(,),B1(),S(),N,K,A,B,X,Y,S,S1,S2,T1,T2,F1,R1)
105 !
110 ! "ENTER" computes fitted intercept a-hat, fitted slope b-hat,
115 ! standard deviation of readings s, goodness of fit F', intercept
120 ! test statistic t1 and slope test statistic t2 for the data
125 ! of the range or ranges that the user specifies. last modified
130 ! 6-30-87, 2:51.
135 !
140 ! INPUT: R(,)=ranges, D(,)=test or check data, B1()=no. of readings
145 ! at test points, S()=intermediate sums; OUTPUT: N=nk, K=k,
150 ! A=a-hat, B=b-hat, X=av. ideal reading, Y=av. actual reading,
155 ! S=s, S1=S(a-hat), S2=S(b-hat), T1=t1, T2=t2, F1=F', R1=last
160 ! range specified
165 !
170 OPTION BASE 10 DIM C1(10)
175 SCRATCHSUB "READAT"
180 !
185 ! store ranges to process in C1()
190 !
195 CLEAR @ CALL "QUERY" ( "Enter no. of ranges to combine.", R, L, Z$ )
200 IF L<1 OR L>8 THEN 195
205 ON R GOTO 210,195,405
210 FOR C=1 TO L
215 CLEAR @ CALL "OUERY" ( "Enter range.", R, R1, Z$ )
220 IF R1<1 OR R1>8 THEN 215
225 ON R GOTO 230,215,405
230 IF R(R1,2)=0 THEN DISP "Data not present for range ";R1 ELSE GOTO 240
235 WAIT 2000 @ GOTO 195
240 C1(C)=R1 @ NEXT C
245 !
250 CLEAR @ DISP "Computing -- please wait."
255 ! FND(Z)=Z changed to values between -1 and 159 inclusive
260 \text{ DEF FND}(Z) = Z-360*(Z>359 \text{ AND } Z<361)
265 S(1),S(2),S(3),S(4),S(5),S(6),S(7),S(8),S(9),N,K=0
270 !
275 ! loop to find averages
280 !
285 ! S(1)=n_{\Sigma}^{\Sigma}x; S(2)=n^{\Sigma}x^{2}; x=ideal reading
290 ! S(3)= 'y; y=actual reading
295 FOR C=1 TO L @ R1=C1(C) @ FOR I=R(R1,1) TO R(R1+1,1)-1 @ K=K+1 @ FOR J=2 TO
B1(I)+1
300 S(1)=S(1)+D(I,1) @ S(2)=S(2)+D(I,1)*D(I,1) @ S(3)=S(3)+FND(D(I,J)) @ N=N+1 @
 NEXT J @ NEXT I
305 NEXT C @ X=S(1)/N @ Y=S(3)/N
310 !
315 ! loop to find b-hat and a-hat
320 !
325 ! S(4) = \frac{2}{(y-Y)(x-X)}; S(5) = n^{2}(x-X)^{2}
330 ! S(6) = SSE = \Sigma [y - (av. x at point)]^2
335 FOR C=1 TO L @ R1=C1(C) @ FOR I=R(R1,1) TO R(R1+1,1)-1 @ FOR J=2 TO B1(I)+1
340 S(4)=S(4)+(FND(D(I,J))-Y)*(D(I,1)-X) @ S(5)=S(5)+(D(I,1)-X)^2
345 S(6)=S(6)+(FND(D(I,J))-D(I,8))<sup>2</sup> @ NEXT J @ NEXT I @ NEXT C @ B=S(4)/S(5) @
A = Y - B * X
```

```
350 !
355 ! loop to find SSR
360 !
365 ! S(7)=SSR= <sup>∑</sup>[y-(fitted y)]^2
370 FOR C=1 TO L @ R1=C1(C) @ FOR I=R(R1,1) TO R(R1+1,1)-1 @ FOR J=2 TO B1(I)+1
375 S(7)=S(7)+(FND(D(I,J))-(A+B*D(I,1)))^2 @ NEXT J @ NEXT I @ NEXT C
380 !
385 ! compute s, S(a-hat), S(b-hat), t1, t2, F'
390 !
395 S=SQR(S(7)/(N-2))
400 S1=SQR(S(2)/(N*S(5)))*S @ S2=SQR(1/S(5))*S
405 T1=ABS(A/S1) @ T2=ABS((B-1)/S2) @ F1=ABS((N-K)/(K-2)*(S(7)-S(6))/S(6))
410 SUBEND
```

| VAR | OCCURS IN LINE | |
|--|---|---|
| R (,) | 100 ,230 ,295 ,295 | array of range parameters. (see main program |
| D (,) | 335,335,370,370 100,300,300,300 | test or check data. (see main program xref) |
| | 300,340,340,340 | |
| B1() S () | 100 ,295 ,335 ,370 100 ,265 ,265 ,265 265 ,265 ,265 ,265 265 ,265 ,300 ,300 300 ,300 ,300 ,300 305 ,305 ,340 ,340 340 ,340 ,345 ,345 345 ,345 ,375 ,375 | readings/data point (see main program xref) array of intermediate sums. $S(1)=n\Sigma x$; $S(2)=n\Sigma x^2$ (x=ideal reading); $S(3)=\Sigma\Sigma y$ (y= actual reading); $S(4)=\Sigma\Sigma(y-Y)(x-X)$; $S(5)=n\Sigma(x-X)^2$; $S(6)=SSE=\Sigma\Sigma[y-(av. x at point)]^2$; $S(7)=SSR=\Sigma\Sigma[y-(fitted y)]^2$ |
| | 405,405,405 | |
| N | 100 ,265 ,300 ,300 305 ,305 ,395 ,400 405 | nk (no. or readings at each test point times no. of test points) |
| К | 100 ,265 ,295 ,295 | no. of test points |
| А | 100 ,345 ,375 ,405 | â (fitted y-intercept) |
| В | 100 ,345 ,345 ,375 405 | b (fitted slope) |
| Х | 100 ,305 ,340 ,340 345 | average ideal reading |
| Y S S1 S2 T1 T2 F1 R1 | 100 ,305 ,340 ,345 100 ,395 ,400 ,400 100 ,400 ,405 100 ,400 ,405 100 ,405 100 ,405 100 ,405 100 ,405 100 ,215 ,220 ,220 | average actual reading standard deviation S(â) S(b) tl t2 F' range no. |
| 01() | 230 ,230 ,240 ,295 295 ,295 ,335 ,335 335 ,370 ,370 ,370 | |
| C1() | 1/0 ,240 ,295 ,335 370 | list of range numbers to use in calculations |
| R L | 195 ,205 ,215 ,225 195 ,200 ,200 ,210 295 ,335 ,370 | numerical value of user's request no. of ranges to combine |
| Ζ\$ | 195,215 | dummy string |
| С | 210 ,240 ,240 ,295 295 ,305 ,335 ,335 345 ,370 ,370 ,375 | Cl() subscript loop control |
| I | 295 ,295 ,300 ,300 300 ,300 ,300 ,335 335 ,340 ,340 ,340 345 ,345 ,345 ,370 370 ,375 ,375 ,375 | data point no. loop control |
| J | 295 ,300 ,300 ,335 340 ,345 ,345 ,370 375 ,375 | reading no. loop control |

```
100 SUB "FIT" (C$,R(,),D(,),B1(),S1$,T0$,D0$,H1)
105 !
110 ! This program dispatches control to various programs that
115 ! analyze data. JUL 87
120 !
125 OPTION BASE 1 ! JUL 07-87
130 SCRATCHSUB "READAT"
135 SCRATCHSUB "ENTER"
140 DIM S(10)
145 DIM M3$[109]
150 SARRAY M3$ @ GOTO 260
155 !
160 ! Allow user to select a function.
165 !
170 ALPHA 1 @ CLEAR
175 C=0 @ M=10
180 SLET M3$(1) = "Enter Range"
185 SLET M3(3) = "Print Header"
190 SLET M3$(4) = "Print Par"
195 SLET M3$(5) = "Print Data"
200 SLET M3$(7) = "Reg. Est. "
205 SLET M3$(8) = "Sel. Est. "
210 SLET M3$(10) = "Main Menu"
215 CALL "MENU" ( M,M3$,C )
220 SCRATCHSUB "MENU"
225 SCRATCHSUB "DATA"
230 SCRATCHSUB "PLOT"
235 SCRATCHSUB "HEADER"
240 ON C GOTO 260,100,400,270,365,100,305,335,100,440
245 !
250 ! Enter range and calculate fit.
255 !
260 CALL "ENTER" ( R(,),D(,),B1(),S(),N,K,A,B,X,Y,S,S1,S2,T1,T2,F1,R1 )
265 SCRATCHSUB "ENTER" @ GOTO 170
270 DISP "Please wait..." @ GOSUB 420
275 CALL "STAT" ( S(),N,K,A,B,X,Y,S,S1,S2,T,T1,T2,F,F1,1 )
280 SCRATCHSUB "STAT"
285 GOTO 170
290 !
295 ! Print regular fit estimates of phase angle.
300 !
305 CALL "REG" ( A,B )
310 SCRATCHSUB "REG"
315 GOTO 170
320 !
325 ! Print fit estimates for selected phase angles.
330 !
335 CALL "SEL" ( A,B )
340 SCRATCHSUB "SEL"
345 GOTO 170
```

```
350 !
355 ! Print all data.
360 !
365 DISP "Please wait..." @ GOSUB 420
370 CALL "PDATA" ( R(,),D(,),B1(),A,B,R1 )
375 SCRATCHSUB "PDATA"
380 GOTO 170
385 !
390 ! Print the header.
395 !
400 GOSUB 420 @ GOTO 170
405 !
410 ! Routine to print the header.
415 !
420 CALL "HEADER" ( C$,S1$,R1,R(,),3,H1,M0,T0$,D0$ )
425 SCRATCHSUB "HEADER"
430 RETURN
435 !
440 SUBEND
```

| VAR | OCCURS IN LINE | |
|-------|--------------------|--|
| C \$ | 100 ,420 | test info from TOC (see main program xref) |
| R (,) | 100 ,260 ,370 ,420 | range parameters (see main program xref) |
| D (,) | 100,260,370 | test or check data. (see main program xref) |
| B1(,) | 100,260,370 | readings/data point (see main program xref) |
| S1\$ | 100,420 | present date |
| T0\$ | 100,420 | test and check meter info (see main program) |
| D0\$ | 100,420 | test date |
| H1 | 100,420 | set if fitting test data |
| S () | 140,260,275 | intermediate sums. (see ENTER xref) |
| M3\$́ | 145 ,150 ,180 ,185 | array of strings of menu options |
| | 190,195,200,205 | |
| | 210 ;215 | |
| С | 175,215,240 | selected menu option |
| М | 175 ,215 | no. of options in menu |
| Ν | 260,275 | nk (see ENTER xref) |
| К | 260 ,275 | no. of data points |
| А | 260 ,275 ,305 ,335 | â (fitted y-intercept) |
| | 370 | Α |
| В | 260 ,275 ,305 ,335 | b (fitted slope) |
| | 370 | |
| Х | 260 ,275 | average ideal reading |
| Y | 260 ,275 | average actual reading |
| S | 260 ,275 | standard deviation |
| S1 | 260 ,275 | S(â) |
| S2 | 260 ,275 | S(b) |
| Τ1 | 260 ,275 | tl |
| 12 | 260 ,275 | |
| F1 | 260,275 | F. |
| K1 | 260 ,370 ,420 | range no. |
| 1 | 2/5 | Student's t |
| F | 2/5 | upper 1% point of F distribution |
| MU | 420 | dummy variable |
| | | |

100 SUB "F TABL" (A,V1,V2,F) 105 ! 110 ! This program calculates the F-statistic through a binary 115 ! search of table values figured in the INV F program. JUL 87 120 ! 125 ! INPUT: A=upper percent points; V1, V2=degrees of freedom in 130 ! numerator, denominator. JUL 87 135 ! 140 ! F1,F2=low, high approximations for F. 145 F1,F2=1 150 ! Find a too high approximation for F. 155 CALL "INV F" (F2, V1, V2, P) @ IF P>A THEN F1=F2 @ F2=F2*2 @ GOTO 155 160 ! F=value halfway between the too high and too low values. 165 ! P=resultant % points. If P is too low then F is too high, 170 ! so change too high value to F. If P is too high then F 175 ! is too low, so change too low value to F. 180 F=(F1+F2)/2 @ CALL "INV F" (F,V1,V2,P) @ IF P-A<-.001 THEN F2=F @ GOTO 180 185 IF P-A>.001 THEN F1=F @ GOTO 180 190 ! P is just right, within an accuracy of .001. 195 SCRATCHSUB "INV F" @ SUBEND

| A LUL | | |
|-------|--------------------|--------------------------------------|
| А | 100 ,155 ,180 ,185 | upper percentage points |
| V1 | 100 ,155 ,180 | degrees of freedom in numerator |
| ٧2 | 100 ,155 ,180 | degrees of freedom in denominator |
| F | 100 ,180 ,180 ,180 | F-statistic |
| | 185 | |
| F1 | 145 ,155 ,180 ,185 | low approximation for F |
| F2 | 145,155,155,155 | high approximation for F |
| | 155 ,180 ,180 | |
| Ρ | 155 ,155 ,180 ,180 | percentage points corresponding to F |
| | 185 | |

OCCUPS IN LINE

VAD

```
100 SUB "GET DATA" (R,B1(),B2(),T1,A1,A2,A3,F2,F3,I2$,I3$,P2,P3,S1$,D0$,Z)
105 !
110 ! "GET DATA" initializes the standard phase meter to a given
115 ! range, optionally records auto-zero sample data, automatically
120 ! selects and sets the meter to each angle of the test, and
125 ! records the read or user-entered angles of the meters. JUL 87
130 !
135 OPTION BASE 1
140 COM C$[60],R(10,4),C(100,8),D(100,8),A(5),T0$[100]
145 DIM I$[20]
150 !
155 ! Function to reduce voltage over 100 by factor of 40 to
160 ! compensate for the standard's step-up.
165 !
170 DEF FNV$(Q)
175 Q=ABS(R(R,Q)) @ IF Q>100 THEN Q=Q/40
180 FNV$=VAL$(Q) @ FN END
185 !
190 ! Function to keep angles within range of -1 to 359.
195 !
200 \text{ DEF FND}(0) = 0-360*(0>359 \text{ AND } 0<361)
205 !
210 ! Set the standard and the phase meters that are to be read
215 ! automatically. Also display the range parameters for the
220 ! user to verify.
225 !
230 CLEAR @ IF FLAG(2) THEN OUTPUT A2 ;12$
235 IF FLAG(3) THEN OUTPUT A3 ; I3$
240 CALL "TALK" ( A1, "LRC"&VAL$(R(R,4))&".DO"&FNV$(2)&".000D1"&FNV$(3)&".000C0D0
OD10",3)
245 WAIT 4000
250 !
255 ! Allow user to take auto-zero samples.
260 !
265 CFLAG 5 @ CALL "A-ZERO" ( A1,A(2),D(,),O )
270 SCRATCHSUB "A-ZERO" @ IF FLAG(5) THEN 720
275 !
280 ! Get ready to get phase meter data.
285 !
290 CALL "HEADER" ( C$,S1$,A(2),R(,),3,1,M0,T0$,D0$ ) @ SCRATCHSUB "HEADER"
295 ! A(4)=no. of readings already taken.
300 A(4)=0 @ FOR I=R(A(2),1) TO R(A(2)+1,1)-1 @ A(4)=A(4)+B1(I) @ NEXT I
305 ! Sl=no. of test points in range, Il=last test point taken.
310 \text{ S1}=R(A(2)+1,1)-R(A(2),1) @ I1=0
315 !
320 ! Head of loop to get phase meter data.
325 !
330 ! Increment no. of readings, and exit if average no. of
335 ! readings S2= wanted no. of readings.
340 A(4)=A(4)+1 @ S2=INT((A(4)-1)/S1) @ IF S2>=A(3) THEN Z=0 @ GOTO 725
345 ! Find a reading that hasn't been taken and doesn't repeat
```

```
350 ! the last angle. I is the test point of that reading.
355 I=IP(S1*RND)+R(A(2),1) @ IF B1(I)>S2 THEN 355
360 IF I=I1 THEN 355 ELSE I1=I
365 !
370 ! Show the present test point.
375 !
380 PRINT USING 390 ; I,B1(I),D(I,1),A(4)
385 CLEAR @ DISP S1$;" ";TIME$ @ DISP USING 390 ; I,B1(I),D(I,1),A(4)-A(3)*S1
390 IMAGE "TEST PT", 3D, "-", D, X, "PHASE", M3D. 3D, 2X, M2D
395 !
400 ! Set and retrieve phase angle.
405 !
410 CALL "TALK" ( A1, "A"&VAL$(D(I,1)+.0001)&"LRAQ",1 )
415 !
420 ! Wait for meter(s) to settle.
425 !
430 ON KYBD K, "A"&CHR$(128) GOTO 730 @ ON TIMER# 1,T1 GOTO 445
435 FOR T2=1 TO 180 @ WAIT 1000 @ BEEP 20,2
440 NEXT T2 @ DISP "Timing failure. Press <CONT>." @ PAUSE
445 OFF TIMER# 1 @ OFF KYBD
450 IF NOT FLAG(2) OR FLAG(1)>FLAG(3) THEN BEEP 100,80 @ BEEP 50,80 @ BEEP 25,10
0
455 !
460 ! Get automatic readings.
465 !
470 IF FLAG(2) THEN A=A2 @ F=F2 @ P=P2 @ Z$="TEST" @ GOSUB 675 @ D2=Q
475 IF FLAG(3) THEN A=A3 @ F=F3 @ P=P3 @ Z$="CHECK" @ GOSUB 675 @ D3=Q
480 !
485 ! Get test meter reading from user.
490 !
495 IF FLAG(2) THEN 535
500 CALL "QUERY" ( "Enter test data.", R, D2, Z$ )
505 IF Z$[1,1]="A" THEN 730
510 ON R GOTO 515,495,720
515 Q=D2 @ GOSUB 760 @ ON Y GOTO 500,535,720
520 !
525 ! Store test reading and new average, and update reading count.
530 !
535 D(I,B1(I)+2)=D2 @ Q=0
540 FOR K=2 TO 7 @ Q=Q+FND(D(I,K)) @ NEXT K
545 B1(I)=B1(I)+1 @ D(I,8)=Q/B1(I)
550 !
555 ! Get check meter reading.
560 !
565 IF NOT FLAG(1) THEN 340
570 IF FLAG(3) THEN 635
575 CALL "QUERY" ( "Enter check data.", R, D3, Z$ )
580 IF Z$[1,1]<>"A" THEN 610
585 ! Erase last test point so that test and check data will correspond.
590 B1(I)=B1(I)-1 @ D(I,B1(I)+2)=0
595 IF NOT B1(I) THEN D(I,8)=0 @ GOTO 730
600 \text{ Q}=\text{Q}+\text{FND}(D(I,K)) \text{ @ NEXT K}
```

605 D(I,8)=Q/B1(I) @ GOTO 730 610 ON R GOTO 615,575,720 615 Q=D3 @ GOSUB 760 @ ON Y GOTO 575,635,720 620 ! 625 ! Store check reading and new average, and update reading count. 630 ! 635 C(I,B2(I)+2)=D3 @ Q=0 640 FOR K=2 TO 7 @ Q=Q+FND(C(I,K)) @ NEXT K 645 B2(I)=B2(I)+1 @ C(I,8)=Q/B2(I) @ GOTO 340 650 ! 655 ! This routine reads a meter and returns the result in Q. 660 ! It is internal to avoid the delay caused by the initial 665 ! the initial loading of a CALLed program. 670 ! 675 SET TIMEOUT 7;5000 @ ON TIMEOUT 7 GOTO 695 680 ENTER A ; Z\$@ Q=VAL(Z\$[P])*F 685 IF ABS(FND(Q)-D(I,1))>1 THEN PRINT " **** INCONSISTENT DATA ****" 690 RETURN 695 CLEAR @ DISP "No response from ";Z\$;" meter." 700 DISP 70,100 @ BEEP 100,150 @ BEEP 70,150 705 DISP @ DISP "Do you want to try again?" 710 CALL "YESNO" (Y) @ ON Y GOTO 675,720,720 715 ! 720 Z=1 725 SCRATCHSUB "TALK" @ SUBEXIT 730 IF K=128 THEN 720 735 SCRATCHSUB "TALK" @ CALL "A-ZERO" (A1,2,D(,),1) 740 SCRATCHSUB "A-ZERO" @ IF FLAG(5) THEN 720 ELSE 385 745 ! 750 ! This routine checks to see whether the data is consistent. 755 ! 760 IF ABS(FND(Q)-D(I,1))<=1 THEN Y=2 @ RETURN 765 BEEP 70,100 @ BEEP 100,150 @ BEEP 70,150 770 DISP @-DISP "The data is inconsistent." @ DISP 775 DISP "Do you want to change the data?" @ CALL "YESNO" (Y) 780 IF Y=2 THEN 685 ELSE DISP @ RETURN

| VAR R | OCCURS IN LINE 100 ,175 ,240 ,500 | no of range to fill |
|---------------|--|---|
| D1 () | 510 ,575 ,610 | No. of lange to fill |
| BI(,) | 100 ,300 ,355 ,380 385 ,535 ,545 ,545 545 ,590 ,590 ,590 595 605 | no. of readings at each point of test meter |
| B2(,) | 100 ,635 ,645 ,645 | no. of readings at each point of check meter |
| T1 A1 | 100 ,430 100 ,240 ,265 ,410 | WAIT between readings bus address of phase standard |
| ۸2 | 735 | hus address of test server |
| A3 | 100,235,475 | bus address of check meter |
| F2 | 100,470 | test meter automatic reading multiplier |
| 125 125 | 100,475 | check meter automatic reading multiplier |
| 13\$ | 100 ,235 | instructions to setup check meter for auto reading |
| P2 | 100,470 | position of reading in test meter input |
| P3 S1\$ | 100,475 | position of reading in check meter input |
| DO\$ | 100,290 | date of test |
| Z | 100 ,340 ,720 | set when aborting to main menu |
| C \$ R (.) | 140,290 | test into from TOC (see main program xref) |
| . ()) | 300 ,300 ,310 ,310 | array of fange parameters (see main program vier) |
| C () | 355 | abook mater data (ave main preason wref) |
| D(.) | 140,265,380,385 | test meter data. (see main program xref) |
| (, , | 410 ,535 ,540 ,545 | |
| | 590,595,600,605 | |
| A () | 140,265,290,300 | A(1)=next available test point; A(2)=present |
| • • • | 300 ,300 ,300 ,300 | range; A(3)=no. of readings to take; |
| | 310,310,340,340 | A(4)=reading on. |
| | 385,385 | |
| T0\$ | 140 ,290 | test and check meter info (see main program xref) |
| 1 \$ MO | 145 290 | unused |
| I | 300 ,300 ,300 ,355 | no. of data point being taken |
| | 355,360,360,380 | |
| | 385,410,535,535 | |
| | 540 ,545 ,545 ,545 | |
| | 545,590,590,590 | |
| | 605,605,635,635 | |
| | 640 ,645 ,645 ,645 | |
| \$1 | 645,685,760 310 340 355 385 | no of test points in range |
| 11 | 310 ,360 ,360 | last test point taken |
| S2 | 340 ,340 ,355 | average no. of readings taken in each data point |
| ĸ | 430,540,540,540 | interrupting programmed key, also is a loop |
| | 640 ,730 | control |
| T2 | 435,440 | loop control for ticking during wait between readings |
| F | 470,475,680 | reading multiplier for test or check meter |
| Ρ | 470 ,475 ,680 | position of reading in test or check meter input |
| Ζ\$ | 470,475,500,505 | multi-purpose variable. |
| | 695 | |
| D2 | 470 ,500 ,515 ,535 | test meter reading |
| Q | 4/0,4/5,515,535 | multi-purpose variable. contains test of check meter reading. also is sum of readings at a |
| | 600 .605 .615 .635 | test point. |
| | | |
| | 640 ,640 ,645 ,680 | |
| D3 | 640 ,640 ,645 ,680 685 ,760 475 ,575 ,615 ,635 | check meter reading |
| D3 Y | 640 ,640 ,645 ,680 685 ,760 475 ,575 ,615 ,635 515 ,615 ,710 ,710 | check meter reading multi-purpose variable. numerical value of user's |

```
100 SUB "GET PARAMS" (R,A(),T1,T0$,A1,A2,A3,F2,F3,I2$,I3$,P2,P3)
105 !
110 ! This program prompts the user for the parameters needed
115 ! to conduct a test and take data. JUL 87
120 !
125 ! INPUT: TO$()=test and check meter info; OUTPUT: R,A(2)=range
130 ! to fill; A(3)=readings/point; T1=WAIT time between readings;
135 ! A1, A2, A3=bus address for standard, test meter, check meter;
140 ! F2,F3=factor by which automatic meter readings are multiplied;
145 ! I2$,I3$=instruction code to query test, check meter; P2,P3=
150 ! byte of beginning of reading in string returned by test,
155 ! check meter; FLAG(2), FLAG(3)=1 if test, check meter is to
160 ! be read; FLAG(5)=1 if user requests main menu.
165 !
170 OPTION BASE 10 DIM I$[20],M$[400]
175 INTEGER F(10),L(10)
180 !
185 CLEAR @ DISP "Enter range you want to fill."
190 CALL "QUERY" ( " Range "&VAL$(A(2))&" is the default.",R,Z,Z$ )
195 ON R GOTO 200,210,565
200 A(2)=Z @ IF Z<1 OR Z>8 THEN A(2)=1 @ GOTO 185
205 !
210 CLEAR @ R=A(2) @ IF A(3)=0 THEN A(3)=4
215 DISP "Specify 1 to 6 readings per"
220 CALL "QUERY" ( " testpoint. "&VAL$(A(3))&" is the default.",Y,Z,Z$ )
225 DISP @ ON Y GOTO 230,240,565
230 IF Z<1 OR Z>6 THEN 215 ELSE A(3)=Z
235 !
240 T1=20 @ DISP "Specify wait of at least 2"
245 CALL "QUERY" ( " seconds. 20 is the default.", Y, T1, Z$ )
247 ON Y GOTO 250,250,565
250 IF T1<2 THEN 240 ELSE T1=T1*1000-1999
255 !
260 ! Get meter query instructions from disk.
265 !
270 ON ERROR GOTO 285 @ ASSIGN# 1 TO "METERS:D700" @ OFF ERROR
275 READ# 1 ; N,M$,F(),L()@ GOTO 300
280 ! The file doesn't exist yet, so make it.
285 OFF ERROR @ CREATE "METERS:D700",3,256
290 FOR I=1 TO 10 @ F(I),L(I)=1 @ NEXT I @ M$[400]=" " @ N=0
295 ASSIGN# 1 TO "METERS:D700" @ PRINT# 1 ; N,M$,F(),L()
300 ASSIGN# 1 TO *
305 !
310 ! Get bus addresses from user and see if readings are to be
315 ! taken via bus. If user wants automatic reading then see
320 ! whether the querying instructions for the meter(s) is(are)
325 ! already stored on disk. If not then get the info and add
330 ! it to the METERS file.
335 !
340 CLEAR @ DISP "Enter address of PHASE STANDARD."
345 A1=1 @ CALL "QUERY" ( " 1 is the default.", Y, A1, Z$ )
 347 ON Y GOTO 350,350,565
 350 A1=A1+716 @ IF A1<717 OR A1>731 THEN 340
```

```
355 ! Initialize FLAGs. 2 and 3 are described at the beginning of
360 ! this program. 4 will be set by end of prompts if additions
365 ! are made to the meter info file.
370 CFLAG 2 @ CFLAG 3 @ CFLAG 4
372 A2.A.M.P=0
375 F=2 @ I$="TEST" @ GOSUB 430 @ A2=A @ F2=M @ I2$=I$ @ P2=P
380 ! FLAG(1)=1 if test will use a check meter.
385 IF FLAG(1) THEN F=3 @ I$="CHECK" @ GOSUB 430 @ A3=A @ F3=M @ I3$=I$ @ P3=P
390 !
395 ! Save additions to METERS, if any.
400 !
405 IF FLAG(4) THEN ASSIGN# 1 TO "METERS:D700" @ PRINT# 1 ; N,M$,F(),L() @ ASSIG
N# 1 TO *
410 CFLAG 5 @ SUBEXIT
415 !
420 ! This info gathering routine is called once per meter.
425 !
430 CLEAR @ DISP "Do you want the "&I$&" meter to" @ DISP " be read via bus?"
435 SFLAG F @ CALL "YESNO" ( Y ) @ ON Y GOTO 445,440,565
440 CFLAG F @ RETURN
445 !
450 CLEAR @ CALL "QUERY" ( "Enter address of "&I$&" meter.", Y, A, Z$ )
455 ON Y GOTO 460,450,565
460 A=A+700 @ IF A<700 OR A>731 OR A=A1-16 OR A=A2 THEN 450
465 ! See whether METERS already has info about this meter.
470 I=F*3-5 @ I$[1,10]=GET$(T0$(I)) @ I$[11,20]=GET$(T0$(I+1))
475 FOR L=1 TO 361 STEP 40 @ IF M$[L,L+19]=I$ THEN 545
480 NEXT L
485 ! Meter not found. Prompt user for info.
490 DISP @ CALL "QUERY" ( "Enter the instruction code for setting up this mete
r.", Y, Z, I$)
495 ON Y GOTO 500,490,565
500 DISP @ DISP "At which byte of the returned"
505 CALL "QUERY" ( " string does the reading begin?", Y, P, Z$ )
510 ON Y GOTO 515,500,565
515 DISP @ DISP "By what factor must the reading" @ M=1
520 CALL "QUERY" ( " be adjusted. 1 is the default.", Y, M, Z$ )
525 ON Y GOTO 530,530,565
530 L=N*40+1 @ N=N+1 @ F(N)=M @ L(N)=P @ M$[L,L+9]=GET$(TO$(I))
535 M$[L+10,L+19]=GET$(T0$(I+1)) @ M$[L+20,L+39]=I$ @ SFLAG 4 @ RETURN
540 ! Meter found. Copy info.
545 FOR I=L+39 TO L+20 STEP -1 @ IF M$[I,I]<>" " THEN 555
550 NEXT I
555 I$=M$[L+20,I] @ I=INT(L-1)/40+1 @ M=F(I) @ P=L(I) @ RETURN
560 !
565 SFLAG 5 @ SUBEND
```

VAR OCCURS IN LINE R 100 ,190 ,195 ,210 no. of range to fill A () 100 ,190 ,200 ,200 A(2)=present range; A(3)=no. of readings to 210 ,210 ,210 ,220 take 230 T1 100 ,240 ,245 ,250 WAIT between readings 250,250 **TO\$** 100,470,470,530 test and check meter info (see main program 535 xref) A1 100,345,345,350 bus address of phase standard 350 ,350 ,350 ,460 A2 100,372,375,460 bus address of test meter A3 100,385 bus address of check meter F2 100,375 test meter automatic reading multiplier F3 100,385 check meter automatic reading multiplier 100,375 I2\$ instructions to set up test meter I3\$ 100,385 instructions to set up check meter P2 100,375 position of reading in test meter input P3 100,385 position of reading in check meter input I \$ 170,375,375,385 multi-purpose string. initially contains the 385,430,450,470 type of meter being set up. returning from 470,475,490,535 the routine at line 420 it contains the 555 instructions to set up the given meter. M \$ 170 ,275 ,290 ,295 meter information string. M\$[0,0+9]=manufac-405,475,530,535 turer; M\$[o+10,o+19]=model no.; M\$[o+20,o+39]= 535,545,555 instruction string to set up meter 175 ,275 ,290 ,295 F () array of automatic reading multipliers --405,530,555 gives multiplier for each meter in METERS file 175,275,290,295 array of positions of readings in meter input --L () 405,530,555 gives position for each meter in METERS file Ζ 190,200,200,200 user's numerical input 220,230,230,230 490 Ζ\$ 190 ,220 ,245 ,345 dummy string 450,505,520 Y 220,225,245,247 numerical value of user's request 345,347,435,435 450,455,490,495 505,510,520,525 N 275,290,295,405 number of meters in the METERS file 530,530,530,530 530 Ī 290,290,290,290 multi-purpose variable. serves as loop control, 470,470,470,530 and in lines 470, 530, and 535, as an index 535,545,545,545 into the TO\$() array 550,555,555,555 555 372,375,385,450 address of meter to be considered in the routine А 460,460,460,460 at line 420 460,460 372 ,375 ,385 ,515 М test or check meter reading multiplier, used to 520,530,555 adjust readings that are taken via bus Ρ 372,375,385,505 position of reading in test or check meter input 530,555 F 375,385,435,440 flag to set if meter considered by routine at 470 line 420 is to be read automatically L 475 ,475 ,475 ,480 location in M\$ of information about meter being 530,530,530,535 considered 535,535,535,545 545,555,555,545

```
100 SUB "GETRNG" (A(),C(,),D(,),R(,),B1(),B2())
105 !
110 ! This program initializes ranges and ideal readings for
115 ! their data. AUG 87
120 !
125 ! Determine range to set up.
130 !
135 OPTION BASE 1
140 !
145 ! Find a free range, if any.
150 A(2)=0 @ IF R(1,1)=0 THEN A(1)=1
155 IF A(2)=8 THEN CLEAR @ DISP "No free ranges." @ WAIT 2000 @ SUBEXIT
160 A(2)=A(2)+1 @ IF R(A(2),2)<>0 THEN 155
165 A(1) = R(A(2), 1)
170 ! Automatically use range 1 if no ranges have been used.
175 IF A(2)=1 THEN GOTO 265
180 ! See if user wants to restart a range.
185 CLEAR @ DISP "Enter range to setup."
190 CALL "QUERY" ( " Range "&VAL$(A(2))&" is the default.",Y,R,Z$ )
195 ON Y GOTO 200,265,440
200 IF R<1 OR R>8 THEN 185
205 A(2) = R @ A(1) = R(A(2), 1)
210 ! Parameters can be changed without changing readings.
215 DISP @ DISP "Do you want to discard old data?"
220 CALL "YESNO" ( R ) @ ON R GOTO 230,150,440
225 ! zero test points of range
230 FOR J=R(A(2),1) TO R(A(2)+1,1)-1
235 B1(J), B2(J)=0
240 FOR K=2 TO 8 @ D(J,K),C(J,K)=0 @ NEXT K @ NEXT J
245 SUBEND
250 !
255 ! Prompt user for parameters.
260 !
265 CLEAR @ DISP "PARAMETERS FOR RANGE"; A(2)
270 DISP @ CALL "QUERY" ( "Enter reference channel.",R,R1,Z$ )
275 ON R GOTO 280,265,440
280 DISP @ CALL "QUERY" ( "Enter variable channel.",R,V1,Z$ )
285 ON R GOTO 290,280,440
290 DISP @ CALL "OUERY" ( "Enter frequency.", R, F1, Z$ )
295 ON R GOTO 300,290,440
300 R(A(2),2)=R1 @ R(A(2),3)=V1 @ R(A(2),4)=F1 @ R(A(2),1)=A(1)
305 CLEAR @ DISP "Do you want to test points at 310 CALL "YESNO" (Y) @ ON Y GOTO 315,390,440
                                                     regular intervals?"
315 CLEAR @ CALL "QUERY" ( "Enter starting phase angle.",R,S,Z$ )
320 ON R GOTO 325,315,440
325 DISP @ CALL "QUERY" ( "Enter ending phase angle.", R, E, Z$ )
330 ON R GOTO 335,325,440
335 DISP @ CALL "QUERY" ( "Enter angle increment.",R,I,Z$ )
340 ON R GOTO 345,335,440
345 NO=A(1)+INT((E-S)/I)+1 @ IF NO>91 THEN A(1)=92 @ GOSUB 435
```

```
350 !
355 ! Automatically set ideal readings.
360 !
365 FOR N=S TO E STEP I @ D(A(1),1)=S @ C(A(1),1)=S @ S=S+I
370 A(1)=A(1)+1 @ R(A(2)+1,1)=A(1) @ NEXT N @ GOTO 440
375 !
380 ! Manually set ideal readings.
385 !
390 CLEAR @ DISP "Enter phase angle, N (new range) or E (end)."
395 DISP A(1) @ CALL "QUERY" ( "",R,Z,S$ ) @ ON R GOTO 405,395,440
400 A(2)=A(2)+1 @ GOTO 175
405 IF S$[1,1]="E" THEN 440
410 GOSUB 435 @ D(A(1),1)=VAL(S$) @ C(A(1),1)=VAL(S$)
415 A(1)=A(1)+1 @ R(A(2)+1,1)=A(1) @ GOTO 395
420 !
425 ! Abort range entry if has too many test points.
430 !
435 CALL "CHKRNG" ( Z,A(),R(,) ) @ IF Z THEN RETURN
440 SCRATCHSUB "CHKRNG" @ SUBEXIT
```

| VAR A () | OCCURS IN L 100,150,1 160,160,1 165,175,1 205,205,2 265,300,3 300,300,3 365,365,3 370,370,3 | INE 50,155 60,165 90,205 30,230 00,300 45,345 70,370 95,400 | <pre>A(1)=next available test point; A(2)=present range no.</pre> |
|--------------------------|---|---|---|
| C (,) D (,) R (,) | 400,410,4 415,415,4 100,240,3 100,240,3 100,150,1 205,230,2 300,300,3 415,435 | 10,415 15,435 65,410 65,410 60,165 30,300 00,370 | check meter data. (see main program xref) test meter data. (see main program xref) array of range parameters (see main program xref) |
| B1() B2() Y R | 100 ,235 100 ,235 190 ,195 ,3 190 ,200 ,2 220 ,220 ,2 280 ,285 ,2 315 ,320 ,3 335 ,340 ,3 | 10 ,310 00 ,205 70 ,275 90 ,295 25 ,330 95 ,395 | no. of readings at each point of test meter no. of readings at each point of check meter information about user's request no. of range to set up |
| Z \$ | 190 ,270 ,2 315 ,325 ,3 | 80 ,290 35 | dummy string |
| J | 230 ,235 ,2 240 ,240 | 35,240 | data point no. loop control |
| K R1 V1 F1 | 240,240,2 270,300 280,300 290,300 | 40,240 | reading no. loop control reference channel voltage (see main program) variable channel voltage (see main program) frequency |
| S E | 315,345,3 365,365,3 325,345,3 | 65 65 | ending phase angle |
| I NO N | 335,345,3 345,345 365,370 395,435,4 | 65 ,365 35 | angle increment estimated last data point in range phase angle loop control |
| S \$ | 395,435,4 | 10,410 | user's reply to query |

```
100 SUB "HEADER" (C$,S1$,R1,R(,),N0,N1,M0,T0$,D0$)
105 !
110 ! This program handles all header interaction.
                                                     On entry,
115 ! NO=1 to edit the test meter header, 2 to edit the check
120 ! meter header, and 3 to print the existing headers.
                                                            AUG 87
125 !
130 OPTION BASE 1
135 DIM P$[75],Z$[30]
140 SARRAY P$
145 SLET P$(1) = "Manufacturer "
150 SLET P$(2) = "Model #"
155 SLET P$(3) = "Serial #"
160 \text{ SLET P}(4) = "Enter"
165 SLET P$(5) = "Test Date "
170 ON NO GOTO 175,180,400
175 I=0 @ GOTO 200
180 I=3
185 !
190 ! Edit the test or check meter header.
195 !
200 ON ERROR GOTO 210
205 IF DO$<>"" THEN 215
210 OFF ERROR @ DO$=S1$
215 CLEAR @ IF I=3 THEN DISP "Check Standard Data:" ELSE DISP "Test Instrument D
ata:"
220 ! Show the header.
225 DISP @ IF NOT I THEN DISP C$[1,30] @ DISP @ DISP "Folder #: ";C$[51,60]
230 DISP GET$(P$(5));DO$
235 FOR K=1 TO 3
240 DISP GET$(P$(K));GET$(TO$(K+I)) @ NEXT K
245 DISP @ DISP "Is the information correct?" @ CALL "YESNO" ( R ) @ ON R GOTO 3
80,255,375
250 ! Get the customer.
255 IF I THEN 300 ELSE Z$=C$[1,30] @ GOSUB 510
260 CALL "QUERY" ( "Enter customer.",R,Z,Z$ )
265 ON R GOTO 270,280,375
270 C$[1,30]=Z$
275 ! Get the folder #.
280 Z$=C$[51,60] @ GOSUB 510 @ CALL "QUERY" ( "Enter folder #.",R,Z,Z$ )
285 ON R GOTO 290,300,375
290 C$[51,60]=Z$
295 ! Get the test date.
300 Z$=D0$ @ GOSUB 510 @ CALL "QUERY" ( GET$(P$(4))&GET$(P$(5)),R,Z,Z$ )
305 ON R GOTO 310,320,375
310 D0$=Z$
315 ! Get the manufacturer.
320 Z$=GET$(TO$(I+1)) @ GOSUB 510 @ CALL "QUERY" ( GET$(P$(4))&GET$(P$(1)),R,Z,T
9$)
325 ON R GOTO 330,340,375
330 \text{ SLET TO}(I+1) = T9
335 ! Get the model #.
340 Z$=GET$(TO$(I+2)) @ GOSUB 510 @ CALL "QUERY" ( GET$(P$(4))&GET$(P$(2)),R,Z,T
9$)
345 ON R GOTO 350,360,375
350 \text{ SLET TO}(I+2) = T9
```
```
355 ! Get the serial #.
360 Z$=GET$(TO$(I+3)) @ GOSUB 510 @ CALL "QUERY" ( GET$(P$(4))&GET$(P$(3)),R,Z,T
9$)
365 ON R GOTO 370,215,375
370 SLET TO$(I+3) = T9$ @ GOTO 215
375 MO=1 @ SUBEXIT
380 MO=0 @ SUBEXIT
385 !
390 ! Print the header.
395 !
400 IF N1 THEN I1$=CHR$(0)&" " @ I2$=" " ELSE I1$=" " @ I2$=CHR$(0)&" "
405 PRINT @ PRINT @ PRINT
410 PRINT S1$;"
                ";TIME$
415 PRINT GET$(P$(5))&DO$
420 PRINT @ PRINT C$[1,30] @ PRINT
425 IF GET$(TO$(1))=" " THEN 445
430 PRINT @ PRINT I1$;GET$(TO$(1))
435 PRINT TAB(4);GET$(P$(2));GET$(TO$(2))
440 PRINT TAB(4); GET$(P$(3)); GET$(TO$(3))
445 IF GET$(TO$(4))=" " THEN 465
450 PRINT @ PRINT I2$;GET$(TO$(4))
455 PRINT TAB(4);GET$(P$(2));GET$(TO$(5))
460 PRINT TAB(4); GET$(P$(3)); GET$(TO$(6))
465 PRINT @ PRINT @ IF R1>0 THEN PRINT "RANGE";R1 ELSE SUBEND
470 V$="Voltage:"
475 I$="Current:"
480 IF R(R1,2)<0 THEN X$=I$ ELSE X$=V$
485 IF R(R1,3)<0 THEN Y$=I$ ELSE Y$=V$
490 PRINT USING 495 ; X$,ABS(R(R1,2)),Y$,ABS(R(R1,3)),R(R1,4)
495 IMAGE "Reference ",8A,3D.2D/"Variable ",8A,3D.2D/"Frequency:",7X,5D
500 PRINT @ PRINT
505 SUBEND
510 CLEAR @ ON ERROR GOTO 520
515 IF Z$[1,2]<>" " THEN DISP "No input implies ";Z$ @ DISP
520 OFF ERROR @ RETURN
```

| VAR | OCCURS IN LINE | |
|--------------|--|---|
| C \$ | 100 ,225 ,225 ,255 | test info from TOC (see main program xref) |
| | 270 ,280 ,290 ,420 | |
| S1\$ | 100 ,210 ,410 | present date |
| R1 | 100 ,465 ,465 ,480 485 ,490 ,490 ,490 | range no. (used when printing the header) |
| R (,) | 100 ,480 ,485 ,490 490 ,490 | array of range parameters (see main program xref) |
| NO | 100,170 | tells program what to do (see lines 110-120) |
| N1 | 100,400 | set if printout should point to check meter |
| MO | 100 .375 .380 | set if user requests an abort to main menu |
| T0\$ | 100,240,320,330 | test and check meter information (see main |
| | 340 ,350 ,360 ,370 | program xref) |
| | 425 ,430 ,435 ,440 | |
| | 445 ,450 ,455 ,460 | |
| D0\$ | 100 ,205 ,210 ,230 | date of test |
| | 300,310,415 | |
| Р\$ | 135 ,140 ,145 ,150 | array of strings of menu options |
| | 155 ,160 ,165 ,230 | |
| | 240 ,300 ,300 ,320 | |
| | 320 ,340 ,340 ,360 | |
| | 360 ,415 ,435 ,440 | |
| | 455 ,460 | |
| Ζ\$ | 135 ,255 ,260 ,270 | user's input |
| | 280 ,280 ,290 ,300 | |
| | 300 ,310 ,320 ,340 | |
| | 360 ,515 ,515 | |
| Ι | 175 ,180 ,215 ,225 | offset into TO\$() used to point to either |
| | 240 ,255 ,320 ,330 | the test or the check meter information |
| | 340,350,360,370 | |
| K | 235 ,240 ,240 ,240 | loop control |
| R | 245 ,245 ,260 ,265 | information about user's request (see QUERY |
| | 280,285,300,305 | xref) |
| | 320-,325 ,340 ,345 | |
| _ | 360,365 | |
| Z | 260,280,300,320 | dummy variable |
| T a b | 340,360 | |
| 19\$ | 320,330,340,350 | user's input |
| * * * | 360,370 | |
| 11\$ | 400,400,430 | space pads or points to test meter in printout |
| 12\$ | 400,400,450 | space pads or points to check meter in printout |
| V \$ | 4/0,480,485 | contains "Voltage:" |
| | 4/5,480,485 | contains "current:" |
| X \$ | 480,480,490 | reference channel units |
| ΥÞ | 485,485,490 | variable channel units |

```
100 SUB "INITAR" (A(),B1(),B2(),C(,),D(,),R(,),T0$)
105 !
110 ! This program initializes all data arrays to zero. JUL 87
115 !
120 OPTION BASE 1@ CLEAR @ DISP "Program is being initialized."
125 FOR I=1 TO 6 @ SLET TO$(I) = " " @ NEXT I
130 FOR I=1 TO 100 @ B1(I)=0 @ B2(I)=0 @ NEXT I @ FOR I=1 TO 5 @ A(I)=0 @ NEXT I
135 CALL "ZERO" ( "ranges",10,4,R(,) ) @ CALL "ZERO" ( "test data",100,8,D(,) )
140 CALL "ZERO" ( "check data",100,8,C(,) ) @ SCRATCHSUB "ZERO"
145 BEEP 70,100 @ BEEP 85,150
150 DISP "Initialization completed." @ WAIT 1500 @ SUBEND
```

| | ACOUDE THE | TAUC |
|-------|-------------|--------|
| VAR | OCCORS IN L | INE |
| A () | 100 ,130 | |
| B1() | 100 ,130 | |
| B2() | 100 ,130 | |
| C (,) | 100 ,140 | |
| D (,) | 100 ,135 | |
| R (,) | 100 ,135 | |
| TO\$ | 100 ,125 | |
| Ι | 125 ,125 ,1 | 25,130 |
| | 130 ,130 ,1 | 30,130 |
| | 130.130 | |

test info array (see main program xref) no. of readings at each point of test meter no. of readings at each point of check meter check meter data. (see main program xref) test meter data. (see main program xref) range parameters. (see main program xref) test and check meter info (see main program) loop control

```
360 SUB "INV F" (F,V1,V2,P)
361 !
362 ! This program calculates the upper % points for the F
363 ! statistic F with degrees of freedom V1 in the numerator
364 ! and V2 in the denominator.
365 X=1/(V1/V2*F+1) @ Y=1-X @ P1,P2=1 @ U1=V1 @ U2=V2
370 IF V1 MOD 2#0 THEN 372 ELSE 375
372 IF V2 MOD 2=0 THEN 390 ELSE 400
375 IF V2 MOD 2=0 THEN 377 ELSE 380
377 IF V2>=V1 THEN 390
380 FOR 7=1 TO V1/2-1 @ P1=P1*(.5/Z*Y*U2) @ P2=P2+P1 @ U2=U2+2 @ NEXT Z
385 P=X^ (V2*.5)*P2 @ GOTO 450
390 FOR Z=1 TO V2/2-1 @ P1=P1*(.5/Z*X*U1) @ P2=P2+P1 @ U1=U1+2 @ NEXT Z
395 P=1-Y<sup>(V1*.5)*P2</sup> @ GOTO 450
400 X2=ATN(SQR(F*V1/V2)) @ X=SIN(X2) @ Y=COS(X2) @ P2=Y @ P1=Y
405 IF V2=1 THEN 420
410 FOR Z=2 TO V2-3 STEP 2 @ P1=P1*Y*Y*Z/(Z+1) @ P2=P2+P1 @ NEXT Z
415 P2=P2*X @ X2=X2+P2
420 P2=1 @ P1=1 @ IF V1=1 THEN 445
425 FOR Z=2 TO V2-1 STEP 2 @ P1=P1*Z/(Z-1) @ NEXT Z
430 P1=P1*Y^V2*X @ P3,P2=1 @ U2=V2+1
435 FOR Z=3 TO V1-2 STEP 2 @ P3=P3*U2*X*X/Z @ P2=P2+P3 @ U2=U2+2 @ NEXT Z
440 X2=X2-P2*P1
445 P=1-X2*2/PI
450 REM
455 ! PRINT P
460 SUBEND
```

| VAR | 0000 | IRS IN | I LINE | |
|-----|------|--------|--------|------|
| F | 360 | ,365 | ,400 | |
| V1 | 360 | ,365 | ,365 | ,370 |
| | 377 | ,380 | ,395 | ,400 |
| | 420 | ,435 | | |
| ٧2 | 360 | ,365 | ,365 | ,372 |
| | 375 | ,377 | ,385 | ,390 |
| | 400 | ,405 | ,410 | 425 |
| | 430 | ,430 | | - |
| Р | 360 | ,385 | ,395 | ,445 |
| Х | 365 | ,365 | 385 | ,390 |
| | 400 | ,415 | ,430 | ,435 |
| | 435 | | - | |
| Y | 365 | ,380 | ,395 | ,400 |
| | 400 | ,400 | ,410 | ,410 |
| | 430 | - | | - |
| P1 | 365 | ,380 | ,380 | ,380 |
| | 390 | ,390 | ,390 | ,400 |
| | 410 | ,410 | ,410 | ,420 |
| | 425 | ,425 | ,430 | ,430 |
| | 440 | | | |
| P2 | 365 | ,380 | ,380 | ,385 |
| | 390 | •,390 | ,395 | ,400 |
| | 410 | ,410 | ,415 | ,415 |
| | 415 | ,420 | ,430 | ,435 |
| | 435 | ,440 | | |
| U1 | 365 | ,390 | ,390 | ,390 |
| U2 | 365 | ,380 | ,380 | ,380 |
| | 430 | ,435 | ,435 | ,435 |
| Z | 380 | ,380 | ,380 | ,390 |
| | 390 | ,390 | ,410 | ,410 |
| | 410 | ,410 | ,425 | ,425 |
| | 425 | ,425 | ,435 | ,435 |
| | 435 | | | |
| X2 | 400 | ;400 | ,400 | ,415 |
| | 415 | ,440 | ,440 | ,445 |
| P3 | 430 | ,435 | ,435 | ,435 |

F statistic degrees of freedom in numerator

degrees of freedom in denominator

upper percentage points

```
100 SUB "INV T" (F,T,P)
105 !
110 ! This program calculates the Student's T statistic for P
115 ! % points with F degrees of freedom.
120 !
125 ! from TECHNOMETRICS Vol.8, No.2, May 1964, "Approximation
130 ! to the Cumulative t-Distribution" by C.Y. Kramer.
135 !
140 ! DISP USING "2A,4X,A,5X,A" ; "df","t",""
145 C1=.503226 @ D1=-.06082
150 C2=-.044928 @ D2=.585243
155 C3=.112057 @ D3=-.208977
160 C4=1.94979 @ D4=.025489
165 C5=-5.917356 @ D5=.082228
170 C6=-7.549051 @ D6=-.276747
175 C7=11.311627 @ D7=.080726
180 C8=-.399205 @ D8=.011192
185 C9=5.48717
190 IF T<2 THEN 200
195 P=C1+C2/F+C3/F <sup>2</sup>2+C4/(F*T<sup>2</sup>)+C5/(F<sup>2</sup>*T<sup>2</sup>)+C6/(F*T<sup>3</sup>)+C7/(F<sup>2</sup>*T<sup>3</sup>)+C8/T<sup>4</sup>+C9/(
F*T©4)-.5 @ GOTO 205
200 P=D1+D2*T+D3*T <sup>2</sup>+D4*T <sup>3</sup>+D5/F+D6*T/F+D7*T<sup>2</sup>/F+D8*T/F<sup>2</sup>-.5
205 P=ABS(P)*1.005
210 SUBEND
```

| VAR | OCCURS IN LINE | |
|-----|--|-----------------------|
| F | 100 ,195 ,195 ,195 195 ,195 ,195 ,195 200 ,200 ,200 ,200 | degrees of freedom |
| Т | 100 ,190 ,195 ,195 195 ,195 ,195 ,195 200 ,200 ,200 ,200 200 ,200 | Student's t statistic |
| Ρ | 100 ,195 ,200 ,205 205 | percentage points |
| C1 | 145,195 | |
| D1 | 145,200 | |
| C2 | 150 ,195 | |
| D2 | 150 ,200 | |
| СЗ | 155 ,195 | |
| D 3 | 155 ,200 | |
| C4 | 160 ,195 | |
| D4 | 160 ,200 | |
| C5 | 165 ,195 | |
| D5 | 165,200 | |
| | 170,195 | |
| | 170,200 | |
| D7 | 175 200 | |
| 68 | 180 195 | |
| 08 | 180 200 | |
| 09 | 185,195 | |
| | 100 ,100 | |

```
100 SUB "LOAD" (C$,A(),R(,),D(,),C(,),B1(),B2(),DO$,TO$)
105 !
110 ! Have user select a test to load and then load it. AUG 87
115 !
120 OPTION BASE 10 Q$=".CALDAT" 0 DIM L(16),S$[30],T$[960]
125 I=0
130 !
135 ! Allow user to search tests for specific info.
140 !
145 CLEAR @ DISP "Enter a search specific or hit"
150 CALL "QUERY" ( " END LINE for the full table.", R, D, S$ )
155 !
160 ! Load the TOC.
165 !
170 ON ERROR GOTO 315 @ ASSIGN# 1 TO "CONTENTS"&O$ @ OFF ERROR
175 READ# 1 ; N,L(),T$@ IF N=0 THEN 320
180 !
185 ! Search for a specific, if requested.
190 !
195 ON R GOTO 200,260,335
200 IF I=N THEN P=0 @ GOTO 210
205 I = I * 60 + 1 @ P = POS(T [ ], S)
210 IF NOT P THEN DISP @ DISP "Specific not found." @ WAIT 2000 @ GOTO 125
215 P=P+I-1 @ I=INT((P+59)/60)
220 CLEAR @ DISP "You are about to LOAD:" @ DISP @ L=I*60-59
225 DISP USING 230 ; T$[L,L+29],T$[L+30,L+39],T$[L+50,L+59],I,T$[L+40,L+49]
230 IMAGE X,30A / X,11A, "Folder # ",10A / X,"@ TEST-",D,3X, "Serial # ",10A 235 DISP @ DISP "Is this correct?" @ CALL "YESNO" ( R )
240 ON R GOTO 280,200,145
245 !
250 ! Allow user to select a test from the full table.
255 !
260 CALL "SELECT" ( I,N,L(),T$ ) @ SCRATCHSUB "SELECT" @ IF NOT I THEN 335
265 !
270 ! Load the chosen test.
275 !
280 CRT OFF @ ASSIGN# 1 TO "TEST-"&VAL$(L(I))&Q$
285 READ# 1 ; A(),R(,),D(,),C(,),B1(),B2(),D0$
290 FOR P=1 TO 6 @ READ# 1 ; Z$@ SLET TO$(P) = Z$ @ NEXT P
295 C$=T$[I*60-59, I*60] @ CLEAR @ CRT ON @ SUBEXIT
300 !
305 ! Display problem messages.
310 !
315 DISP "Can't find data disk." @ GOTO 325
320 DISP "There are no tests on the data disk."
325 CRT ON @ WAIT 2000
330 !
335 SUBEND
```

| VAR | OCCURS IN LINE | |
|---|--|---|
| C \$ A () R (,) D (,) C (,) B1() B2() D0\$ | 100 ,295 100 ,285 100 ,285 100 ,285 100 ,285 100 ,285 100 ,285 100 ,285 | test info from TOC (see main program xref) test info array (see main program xref) range parameters (see main program xref) test meter data. (see main program xref) check meter data. (see main program xref) no. of readings at each point of test meter no. of readings at each point of check meter date of test |
| TO\$ Q \$ | 100 ,290 120 ,170 ,280 | test and check meter info (see main program) contains "CALDAT" saves some memory |
| L () S \$ | 120 ,175 ,260 ,280 120 ,150 ,205 | file name numbers. (see STORE xref) string for which to search in TOC |
| Τ\$ | 120 ,175 ,205 ,225 225 ,225 ,225 ,260 | table of contents (IOC) file. (see STORE) |
| I | 125 ,200 ,205 ,205 205 ,215 ,215 ,220 225 ,260 ,260 ,280 295 ,295 | no. of test in T\$ under consideration. also is a loop control |
| R D | 150 ,195 ,235 ,240 150 | information about user's reply dummy variable |
| N P | 175 ,175 ,200 ,260 200 ,205 ,210 ,215 215 ,215 ,290 ,290 | no. of elements (tests) in TOC position of search specific in T\$. also is a loop control |
| L | 290 220 ,225 ,225 ,225 225 ,225 ,225 ,225 225 | position of beginning of test information for the test under consideration |
| Ζ\$ | 290 ,290 | intermediate string used to transfer meter info |

```
100 SUB "MENU" (R,A$,P)
105 !
110 ! This program has the user select an option from among a
115 ! list of options. JUL 87
120 !
125 DIM L$[10]
130 !
135 ! Show the menu.
140 !
145 ALPHA 1 @ CLEAR @ P=0 @ KO=0
150 FOR I=1 TO R
155 DISP USING "10X,15A" ; GET$(A$(I))
160 NEXT I
165 !
170 ! Act on key.
175 !
180 ON KYBD KO, CHR$(32) & CHR$(143) & CHR$(154) & CHR$(161) & CHR$(162) GOTO 195
185 GOTO 210
190 GOTO 190
195 IF KO=143 OR KO=154 THEN 200 ELSE GOTO 210
200 CLEAR @ IF P=0 THEN 145
205 SUBEXIT
210 IF KO=161 THEN P=(P+R-2) MOD R+1 ELSE P=P MOD R+1
215 OFF CURSOR @ ALPHA P,8 @ AREAD L$ @ ON CURSOR
220 IF L$[4,5]=" " THEN 210
225 GOTO 190 @ SUBEND
```

| VAR | OCCURS IN LINE | |
|------|--|--|
| R | 100 ,150 ,210 ,210 ,210 ,210 | no. of options in menu |
| A \$ | 100 ,155 | array of strings of menu options |
| Р | 100 -,145 ,200 ,210 ,210 ,210 ,210 ,210 ,215 | cursor row and menu option no. |
| L \$ | 125 ,215 ,220 | used to see if cursor isn't on an option |
| КО | 145 ,180 ,195 ,195 210 | programmed key that the user presses |
| Ι | 150 ,155 ,160 | menu option no. loop control |

```
100 SUB "PDATA" (R(,),D(,),B1(),A,B,R1)
105 !
110 ! This program prints raw data to the internal printer.
115 !
120 OPTION BASE 1
125 PRINT @ PRINT " (I) Y(I)
                                   YHAT RESIDUALS"
130 PRINT "DEGREES DÈGREES DÈGREES MILLIDEG"
135 PRINT
140 FOR I2=R(R1,1) TO R(R1+1,1)-1
145 FOR J2=2 TO B1(I2)+1
150 \text{ Y}=B*D(I2,1)+A
155 PRINT USING 160 ; D(I2,1),D(I2,J2),Y,(D(I2,J2)-Y-360*(D(I2,J2)>359 AND D(I2,
J2)<361))*1000
160 IMAGE 3DZ.2D,4DZ.3D,4DZ.3D,M3DZ.D
165 NEXT J2 @ NEXT I2
170 PRINT @ PRINT
175 SUBEND
```

| VAR R (,) D (,) | OCCURS IN LINE 100 ,140 ,140 100 ,150 ,155 ,155 155 ,155 ,155 | range parameters (see main program xref) test or check meter data (see main program) |
|-----------------------|--|--|
| B1() A B R1 | 100 ,145 100 ,150 100 ,150 100 ,140 ,140 | <pre>no. of readings at each point of test meter a (fitted y-intercept) b (fitted slope) range no.</pre> |
| 12 | 140 ,145 ,150 ,155 155 ,155 ,155 ,155 165 ⁻ | data point no. loop control |
| J2 | 145 ,155 ,155 ,155 155 ,165 | reading no. loop control |
| Y | 150 ,155 ,155 | fitted angle |

100 SUB "PGHEAD" (TO\$) ! JUL 87 105 ! 110 ! This program prints the page heading to the Qume printer. 115 ! 120 OPTION BASE 1@ T=13 @ CONTROL 10,3 ; 15@ PRINTER IS 10,92 125 CLEAR @ CALL "QUERY" ("Enter page number.",R,P,Z\$) 130 ON R GOTO 135,125,155 135 FOR I=1 TO 4 @ PRINT @ NEXT I 140 PRINT TAB(T); "Phase Meter";TAB(35+T); "-";P;"-" 145 PRINT TAB(T); GET\$(TO\$(1)); " Model ";GET\$(TO\$(2)) 150 PRINT TAB(T); "Serial No. ";GET\$(TO\$(3)) @ PRINT 155 SUBEND

| VAR | OCCURS IN LINE | |
|------|--------------------|--|
| ТО\$ | 100 ,145 ,145 ,150 | test and check meter info (see main program) |
| Т | 120,140,140,145 | constant tab offset used to save memory |
| | 150 | |
| R | 125,130 | information about user's reply |
| Р | 125 ,140 | page no. |
| Ζ\$ | 125 | dummy string |
| I | 135 ,135 | loop control |
| | | |

```
100 SUB "PLOT" (C$,D(,),R(,),B(),R1,S1$,N1,T0$,D0$)
105 !
110 ! This program graphs data for visual analysis. JUL 87
115 !
120 OPTION BASE 1
125 DIM M2$[100]
130 SARRAY M2$
135 !
140 ! Have user select method of graphing.
145 !
150 ALPHA 1 @ CLEAR
155 C=0 @ M=5
160 SLET M2$(1) = "Plot Data"
165 SLET M2$(2) = "Print Plot"
170 SLET M2$(3) = "Overlay"
175 SLET M2$(5) = "Main Menu"
180 CALL "MENU" ( M,M2$,C )
185 ON C GOTO 205,195,220,100,610
190 ! Print plot.
195 SFLAG 3 @ GOTO 210
200 ! Plot data on a new screen.
205 CFLAG 3
210 PEN 1 @ GCLEAR @ CFLAG 2 @ GOTO 240
215 ! Overlay.
220 SFLAG 2
225 !
230 ! Prompt user for parameters for this graph.
235 !
240 CLEAR @ CALL "OUERY" ( "Enter range.", R.R1, Z$ )
245 IF R1<1 OR R1>8 THEN 240
250 ON R GOTO 260,240,155
255 !
260 C=0 @ M=2 @ CFLAG 44
265 \text{ SLET M2}(1) = "Avg. Data"
270 SLET M2$(2) = "All Data"
275 CALL "MENU" ( M,M2$,C )
280 ON C GOTO 295,285
285 SFLAG 44
290 !
295 CALL "QUERY" ( "Enter representation symbol.", R, Z, S$ )
300 R1=(R1-1) MOD 10+1
305 IF R(R1,2)=0 THEN 155
310 !
315 CALL "QUERY" ( "Enter scale of correction.", R, C1, Z$ )
320 ON R GOTO 340.315.155
325 !
330 ! Set up the graphics display if this isn't an overlay.
335 !
340 IF FLAG(2) THEN 415
345 SCALE -10,360,-C1,C1
350 XAXIS 0,10 @ YAXIS 0,.2*C1
355 FOR A=30 TO 360 STEP 30
360 MOVE A, .1*C1
365 LDIR 90 @ LABEL VAL$(A)
370 MOVE A,.05*C1 @ IDRAW 0,-(.1*C1)
```

```
375 NEXT A
380 FOR Y=-(.8*C1) TO .8*C1 STEP .2*C1
385 IF Y=0 OR Y=.2*C1 THEN 395
390 MOVE 20, Y-.05*C1 @ LDIR 0 @ LABEL VAL$(Y)
395 NEXT Y
400 !
405 ! Graph average readings.
410 !
415 IF FLAG(44) THEN 460
420 FOR I=R(R1,1) TO R(R1+1,1)-1
425 \times D(I,1) - 1.46 @ Y1 = -(D(I,8) - D(I,1) + .013 \times C1)
430 MOVE X, Y1 @ LABEL S$ @ ! PLOT CORRECTION
435 NEXT I
440 GOTO 485
445 !
450 ! Graph every reading.
455 !
460 FOR I=R(R1,1) TO R(R1+1,1)-1
465 FOR J=2 TO B(I)+1
470 X=D(I,1)-1.46 @ Y1=-(D(I,J)-D(I,1)+.013*C1)+360*(D(I,J)>359 AND D(I,J)<361)
475 MOVE X, Y1 @ LABEL S$ @ ! PLOT CORRECTION
480 NEXT J @ NEXT I
485 !
490 ! Wait for user to press <CONT>.
495 !
500 PAUSE
505 !
510 ! Allow user to see display as a line graph of averages.
515 !
520 DISP "Connect the averages?" @ CALL "YESNO" ( R ) @ ON R GOTO 525,575,155
525 Z=0
530 FOR I=R(R1,1) TO R(R1+1,1)-1
535 X=D(I,1) @ Y1=-(D(I,8)-X)
540 IF Z=0 THEN MOVE X, Y1 ELSE DRAW X, Y1
545 Z=Z+1 ·
550 NEXT I
555 PENUP
560 !
565 ! Copy the graph to the printer if appropriate.
570 !
575 IF FLAG(3) THEN 580 ELSE GOTO 595
580 CALL "HEADER" ( C$,S1$,R1,R(,),3,N1,M0,T0$,D0$ )
585 PRINT @ PRINT TAB(13);"CORRECTION" @ PRINT
590 GRAPH @ COPY
595 PAUSE
600 GOTO 155
605 !
610 SUBEND
```

| VAR | OCCURS IN LINE | |
|----------------------------|---|---|
| C \$ D (,) | 100 ,580 100 ,425 ,425 ,425 470 ,470 ,470 ,470 470 ,535 ,535 | test info from TOC (see main program xref) test or check meter data (see main program xref) |
| R (,) | 100 ,305 ,420 ,420 460 ,460 ,530 ,530 580 | array of range parameters (see main program xref) |
| B () R1 | 100 ,465 100 ,240 ,245 ,245 300 ,300 ,305 ,420 420 ,460 ,460 ,530 530 ,580 | readings/data point of test or check meter range no. |
| S1\$ N1 TO\$ DO\$ | 100 ,580 100 ,580 100 ,580 100 ,580 | present date N1 is set to point to test meter in printout test and check meter info (see main program) test date |
| M2\$ | 125 ,130 ,160 ,165 170 ,175 ,180 ,265 270 ,275 | array of strings of menu options |
| С | 155 ,180 ,185 ,260 275 ,280 | no. of selected menu option |
| M R | 155 ,180 ,260 ,275 240 ,250 ,295 ,315 320 ,520 ,520 | no. of options in menu info about user's input |
| Z \$ Z | 240 ,315 295 ,525 ,540 ,545 545 | dummy string used as dummy variable and as flag cleared to start and set to continue drawing a line |
| S'\$ C1 | 295,430,475 315,345,345,350 360,370,370,380 380,380,385,390 425,470 | contains symbol to represent data scale of correction |
| А | 355 ,360 ,365 ,370 375 . | phase angle loop control |
| Y | 380 ,385 ,385 ,390 390 ,395 | angle offset loop control |
| Ι | 420 ,425 ,425 ,425 435 ,460 ,465 ,470 470 ,470 ,470 ,470 480 ,530 ,535 ,535 550 | data point no. loop control |
| Х | 425 ,430 ,470 ,475 535 ,535 ,540 ,540 | phase angle x coordinate |
| Y1 | 425 ,430 ,470 ,475 535 ,540 ,540 | offset y coordinate |
| J | 465 ,470 ,470 ,470 480 | reading no. loop control |
| MO | 580 | dummy variable |

100 SUB "QUERY" (Q\$,R,N,I\$) ! JUL 87 105 OPTION BASE 1@ DIM T\$[30] 110 LINPUT Q\$,T\$ @ IF T\$="" THEN R=2 @ SUBEXIT 115 IF T\$[1,1]=CHR\$(128) THEN R=3 @ SUBEXIT 120 ON ERROR GOTO 125 @ N=VAL(T\$) 125 OFF ERROR @ R=1 @ I\$=T\$ @ SUBEND

| VAR | OCCURS IN LINE | |
|---------------|--|--|
| Q\$ R N | 100 ,110 100 ,110 ,115 ,125 100 ,120 | contains question to ask user l=expected response; 2=no input; 3=main menu value of user's input |
| I\$ T\$ | 100 ,125 105 ,110 ,110 ,115 120 ,125 | inputted string (changed only if input exists) actual input |

100 SUB "RANGE" (R(,))
105 !
110 ! This program display the list of ranges.
115 !
120 OPTION BASE 1
125 DISP "RANGE R(,)" @ DISP
130 FOR A=1 TO 8
135 DISP USING 140 ; A,R(A,1),R(A,2),R(A,3),R(A,4)
140 IMAGE 3D,2X,3D,D,2X,3D.D,2X,3D.D,2X,5D
145 NEXT A
150 DISP @ DISP "PRESS <CONT> TO CONTINUE"
155 PAUSE
160 SUBEND

VAR OCCURS IN LINE R (,) 100 ,135 ,135 ,135 array of range parameters (see main 135 program xref) A 130 ,135 ,135 ,135 range no. loop control 135 ,135 ,145

100 SUB "REG" (A,B) ! FEB 13-86 105 ! 110 ! Print estimated fit for angles at regular intervals. JUL 87 115 ! 120 OPTION BASE 1 125 ! 130 ! Prompt user for parameters. 135 ! 140 CLEAR @ CALL "QUERY" ("Enter starting phase angle.", R, S9, Z\$) 145 ON R GOTO 150,100,220 150 CALL "QUERY" ("Enter ending phase angle.", R, E9, Z\$) 155 ON R GOTO 160,150,220 160 CALL "QUERY" ("Enter size of increment.", R, I9, Z\$) 165 ON R GOTO 185,160,220 170 ! 175 ! Print the angles and their fits. 180 ! 185 PRINT @ PRINT " OBSERVED CORRECTED" 190 PRINT " DEGREES DEGREES" @ PRINT 195 FOR Y=S9 TO E9 STEP I9 200 X = (Y - A)/B205 PRINT USING "2(2X,M3DZ.3D)"; Y,X 210 NEXT Y 215 PRINT @ PRINT 220 SUBEND

| VAR | UCCURS IN LINE |
|------|--------------------|
| A | 100,200 |
| В | 100 ,200 |
| R | 140 ,145 ,150 ,155 |
| | 160 ,165 |
| S9 | 140,195 |
| Z \$ | 140,150,160 |
| E 9 | 150 ,195 |
| 19 | 160 ,195 |
| Y | 195,200,205,210 |
| Х | 200,205 |
| | |

OCCUDE IN LINE

VAD

a (fitted y-intercept) b (fitted slope) information about user's reply starting phase angle

dummy string ending phase angle angle increment fitted reading meter reading

```
100 ! Calibration Report Program
105 !
110 ! This program displays the main menu and dispatches control
115 ! to the various report printing routines. AUG 87
120 !
125 OPTION BASE 10 INTEGER B1(100), B2(100)
130 COM R(10,4),C(100,8),D(100,8),A(5),T0$[100]
135 DIM C$[60],M4$[140],M5$[26],Z(1),N$[20]
140 !
145 ! Display the main menu.
150 !
155 SARRAY M4$, M5$, TO$ @ L=0
160 SLET M4$(1) = "Read File"
165 \text{ SLET M4}(3) = "Page Header"
170 SLET M4$(4) = "Introduction"
175 SLET M4$(5) = "Fitted Data"
180 SLET M4$(6) = "Average Data"
185 \text{ SLET M4}(7) = "Raw Data"
190 SLET M4(8) = "Appendix"
195 \text{ SLET M4}(9) = "Test Folder"
200 SLET M4$(11) = "Range List"
205 C=0 @ M=11 @ CALL "MENU" ( M,M4$,C )
210 ON C GOTO 230,100,330,350,370,395,420,445,480,100,510
215 !
220 ! Load a test.
225 !
230 CALL "LOAD" ( C$,A(),R(,),D(,),C(,),B1(),B2(),D0$,T0$ ) @ SCRATCHSUB "LOAD"
235 ! N$=folder # without the trailing blanks.
240 FOR I=60 TO 51 STEP -1 @ IF C$[I,I]<>" " THEN 255
245 NEXT I @ I=51
250 ! Get the folder # if it isn't already known.
255 N$=C$[51,I] @ IF N$[1,1]<>" " THEN 290
260 CLEAR @ CALL "QUERY" ( "Enter test folder number.",R,Z,N$ )
265 ON R GOTO 290,260,160
270 ! Get date if it is in wrong format.
275 CLEAR @ DISP "Old date ";DO$;" is in" @ DISP " wrong format."
280 DISP @ CALL "QUERY" ( "Enter date (MM/DD/YYYY).",R,Z,DO$ )
285 OFF ERROR @ ON R GOTO 290,275,160
290 ON ERROR GOTO 275 @ Z=VAL(DO$) @ OFF ERROR
295 C$[31,40]=D0$ @ C$[51,60]=N$
300 ! Save changes.
305 CALL "STORE" ( C$,A(),R(,),D(,),C(,),B1(),B2(),D0$,T0$ )
310 SCRATCHSUB "STORE" @ GOTO 160
315 !
320 ! Print the page header.
325 !
330 GOSUB 530 @ GOTO 160
335 !
340 ! Print the report introduction.
345 !
350 CALL "RPTINTRO" ( DO$, TO$, N$ ) @ SCRATCHSUB "RPTINTRO" @ GOTO 160
355 !
360 ! Print a list of fitted data for angles of regular intervals.
365 !
370 GOSUB 530 @ GOSUB 550 @ GOSUB 560
375 CALL "RPTFIT" ( R(,),S(),R1,A,B,L ) @ SCRATCHSUB "RPTFIT" @ GOTO 480
```

```
380 !
385 ! Print the list of average readings for each test point.
390 !
395 GOSUB 530 @ CALL "RPTAVG" ( R(,),D(,),M(),R5,R1,L )
400 SCRATCHSUB "RPTAVG" @ GOTO 480
405 !
410 ! Print the list of all test meter readings that were taken.
415 !
420 GOSUB 530 @ CALL "RPTRAW" ( R(,),D(,),B1(),R1,L )
425 SCRATCHSUB "RPTRAW" @ GOTO 480
430 !
435 ! Print the statistical info of this calibration (appendix).
440 !
445 GOSUB 530 @ GOSUB 550 @ GOSUB 560
450 CALL "RPTAPP" ( R(,),S(),N,K,A,B,X,Y,S,S1,S2,T1,T2,F1,R1,L )
455 SCRATCHSUB "RPTAPP"
460 !
465 ! Print the folder # at the bottom of the page.
470 !
475 ! L=# of lines printed by last program CALL.
480 IF L>54 THEN 490
485 FOR I=L TO 54 @ PRINT @ NEXT I
490 PRINT @ PRINT TAB(13);"722/";N$;"-";D0$[LEN(D0$)-1] @ GOTO 160
495 !
500 ! Display the list of ranges.
505 !
510 CALL "RANGE" ( R(,) ) @ SCRATCHSUB "RANGE" @ GOTO 160
515 !
520 ! Routine to print the page header.
525 !
530 L=6 @ CALL "PGHEAD" ( TO$ ) @ SCRATCHSUB "PGHEAD" @ RETURN
535 !
540 ! Routine to fit the data and estimate the goodnes of the fit.
545 !
550 CALL "ENTER" ( R(,),D(,),B1(),S(),N,K,A,B,X,Y,S,S1,S2,T1,T2,F1,R1 )
555 SCRATCHSUB "ENTER" @ RETURN
560 CALL "STAT" ( S(), N, K, A, B, X, Y, S, S1, S2, T, T1, T2, F, F1, 0 )
565 SCRATCHSUB "STAT" @ RETURN
```

VAR OCCURS IN LINE B1() 125,230,305,420 no. of readings at each point of test meter 550 B2() 125,230,305 no. of readings at each point of check meter R (,) 130,230,305,375 array of range parameters (see main program 395,420,450,510 xref) 550 130 ,230 ,305 check meter data. (see main program xref) C (,) 130 ,230 ,305 ,395 test meter data. (see main program xref) D (,) 420,550 130 ,230 ,305 test info array (see main program xref) A () T0\$ 130 ,155 ,230 ,305 test and check meter info array (see main 350,530 program xref) 135 ,230 ,240 ,255 C \$ test info from TOC (see main program xref) 295,295,305 M4\$ 135 ,155 ,160 ,165 array of strings of menu options 170 ,175 ,180 ,185 190 ,195 ,200 ,205 M5\$ 135,155 unused Ζ() 135 unused N \$ 135 ,255 ,255 ,260 contains folder no. 295,350,490 155,375,395,420 no. of lines printed on page so far L 450 ,480 ,485 ,530 205,205,210 С selected menu option М 205,205 no. of menu options in menu 230 ,275 ,280 ,290 test date D0\$ 295,305,350,490 490 240 ,240 ,240 ,245 Ι loop control 245,255,485,485 R 260,265,280,285 information about user's reply 260 ,280 ,290 Ζ dummy variable S () 375,450,550,560 intermediate sums (see ENTER xref) R1 375,395,420,450 range no. 550 a (fitted y-intercept) Α 375,450,550,560 В 375,450,550,560 **仓** (fitted slope) M () 395 dummy array R5 395 dummy variable N 450,550,560 nk (see ENTER xref) 450 ,550 ,560 Κ k (no. of data points in range) χ 450,550,560 average ideal reading Y 450,550,560 average actual reading S 450,550,560 standard deviation S1 S(a) 450 ,550 ,560 S2 450 ,550 ,560 S(16) 450,550,560 T1 t1 T2 450,550,560 t2 F1 F1 450,550,560 T 560 Student's t F 560 upper 1% point of F distribution

100 SUB "RPTAPP" (R(,),S(),N,K,A,B,X,Y,S,S1,S2,T1,T2,F1,R1,L) 105 ! 110 ! This program prints the statistical info of the calibration, 115 ! which forms the appendix in the test report. JUL 87 120 ! 125 OPTION BASE 1@ CONTROL 10,3 ; 15@ PRINTER IS 10,92 @ T=13 @ DIM T\$[79] 130 ! 135 ! Print the title and the first two paragraphs. 140 ! 145 PRINT TAB(47); CHR\$(27); "IAppendix"; CHR\$(27); "J" @ PRINT 150 FOR I=1 TO 12 @ READ T\$@ PRINT TAB(T);T\$ @ NEXT I 155 DATA " The calibration of this phase meter provides an equation to corre ct the" 160 DATA "reading obtained from the phase meter so that the result of the measur ement" 165 DATA "will be close in agreement with the corresponding value supplied by th e NBS" 170 DATA "standard. These corrections are calculated from the unprocessed calib ration" 175 DATA "data obtained during the test, which are shown on separate pages."," " Because random fluctuations tend to mask the limiting mean of the 180 DATA " phase" 185 DATA "meter response at any particular test point, the corrections calculate d are" 190 DATA "based on predicted values. These values are obtained by fitting the" 195 DATA "unprocessed data (y) for each set of current, voltage, and frequency" 200 DATA "conditions to an equation which models the average response of the pha se meter" 205 DATA "to phase angles (x) supplied by the NBS standard." 210 ! 215 ! Print the parameters of this range and the statistics. 220 ! 225 CALL "RPTRNG" (R(,),R1) @ SCRATCHSUB "RPTRNG" 230 S1\$=" "- @ S2\$=" +" @ IF A<O THEN S1\$="-" 235 IF B<O THEN S2\$=" -" 240 D\$="(degrees)" @ PRINT USING 285 ; S1\$, ABS(A), S2\$, ABS(B), D\$ @ PRINT USING 29 0 ; S1,S2,D\$ 245 CALL "INV T" (N-2,T1,A1) @ CALL "INV T" (N-2,T2,A2) @ SCRATCHSUB "INV T" 250 PRINT USING 295 ; CHR\$(27)&"D3"&CHR\$(27)&"U",ABS(A1*2),ABS(A2*2) @ PRINT 255 PRINT USING 300 ; S,S*2,D\$ @ PRINT USING 305 ; F1 @ CALL "INV F" (F1,K-2,N-K.A2) 260 SCRATCHSUB "INV F" @ PRINT USING 310 ; CHR\$(27)&"D4"&CHR\$(27)&"U", A2 @ PRINT 265 PRINT TAB(T); "Estimated limits of phase offset from NBS standard:" @ PRINT 270 S1\$="+" @ IF X<Y THEN S1\$="-" 275 PRINT USING 315 ; S(8), D\$ @ PRINT USING 320 ; S1\$, ABS(X-Y), S(9), D\$ 280 PRINT USING 325 ; S(10), D\$ @ PRINT 285 IMAGE 12X, "Predicted value", 9X, "y' = ", A, DZ.6D, 3A, 2DZ.6D, " x", 12X, 9A 290 IMAGE 12X, "Standard errors", 15X, "(",Z.6D,") (",Z.6D,")", 13X, 9A 295 IMAGE 12X, "Significance levels", 5A, 10X, "(",Z.3D,")", 6X, "(",Z.3D,")" 300 IMAGE 12X, "Residual standard deviation", 8X, "s =", DZ.6D," 2s =", DZ.5D, 4X, 9A

305 IMAGE 12X, "Lack-of-fit", 24X, "F'=", DZ.3D 310 IMAGE 12X, "Significance level", 5A, 19X, "(", Z. 3D, ")" 315 IMAGE 17X, "without corrections", 8X, "(x' = y)", 12X, 3DZ. 3D, 6X, 9A 320 IMAGE 17X, "with a constant correction (x' = y ",A,DZ.3D,")",4X,3DZ.3D,6X,9A 325 IMAGE 17X, "using the fitted linear equation (see above) ", 3DZ.3D, 6X, 9A 330 ! 335 ! Print the footnotes. 340 ! 345 PRINT TAB(T); CHR\$(27); "I"; TAB(36); CHR\$(27); "J" @ PRINT 350 PRINT CHR\$(27);"C12";CHR\$(27);"D3";CHR\$(27);"U"; 355 FOR I=1 TO 6 @ READ T\$@ PRINT CHR\$(27);"C17";T\$ @ NEXT I 360 DATA "Significance levels are derived using the statistical t-tests to decid e" 365 DATA "if the intercept and slope of the fitted straight line are different f rom" 370 DATA "their ideal values, zero and one respectively. A level near zero (les s " 375 DATA "than or equal to 0.05) shows that the associated parameter is probably 380 DATA "different from the ideal value."." " 385 PRINT CHR\$(27);"C12";CHR\$(27);"D4";CHR\$(27);"U"; 390 FOR I=1 TO 8 @ READ T\$@ PRINT CHR\$(27);"C17";T\$ @ NEXT I 395 DATA "The significance level of F' is associated with an objective statistic a1" 400 DATA "test for the adequacy of a linear model relating the user's phase mete r" 405 DATA "response and the NBS assigned values. Significance levels near zero (less" 410 DATA "than or equal to 0.01) indicate that the assumption of a straight line as a" 415 DATA "model for the phase meter response may be incorrect. However, if the" 420 DATA "variability of the repeat readings is of the same order as the resolut ion" 425 DATA "of the meter, and the data points are therefore not normally distribut ed," 430 DATA "the table of values on which this test is based are not applicable." 435 ! 440 L=55 @ SUBEND

| VAR | OCCURS IN LINE | |
|-----------------------------------|---|--|
| R (,) S () N K A B | 100 ,225 100 ,275 ,275 ,280 100 ,245 ,245 ,255 100 ,255 ,255 100 ,230 ,240 100 ,235 ,240 | <pre>range parameters (see main program xref) intermediate sums (see ENTER xref) nk (see ENTER xref) k (no. of data points in range) â (fitted y-intercept) b (fitted slope)</pre> |
| X | 100 ,270 ,275 | average ideal reading |
| Y | 100 ,270 ,275 | average actual reading |
| S | 100 ,255 ,255 | standard deviation |
| SI S2 | 100,240 | S(à) |
| 52 T1 | 100,240 | S(b) |
| 11 | 100 ,245 | |
| F1 | 100 ,245 | |
| R1 | 100,225 | |
| L | 100,440 | no. of lines printed by this program |
| Ť | 125,150,265,345 | constant tab offset used to save memory |
| Т\$ | 125 ,150 ,150 ,355 355 ,390 ,390 | text read from data statements |
| I | 150 ,150 ,355 ,355 390 ,390 | loop control |
| S1\$ | 230 ,230 ,240 ,270 270 ,275 | contains sign of a on lines 230-240 and sign of uncorrected offset |
| S2\$ | 230 ,235 ,240 | contains sign of b |
| D \$ | 240 ,240 ,240 ,255 275 ,275 ,280 | contains "(degrees)" saves memory |
| A1 | 245 ,250 | % points for statistic tl |
| A2 | 245 ,250 ,255 ,260 | % points for statistic t2 |

```
100 SUB "RPTAVG" (R(,),D(,),M(),R5,R1,L) ! July 1987
105 !
110 ! This program prints the average readings for each test
115 ! point. JUL 87
120 !
125 OPTION BASE 1
130 !
135 ! This function rounds X to the thousandths place.
140 !
145 DEF FNP(X) = SGN(X)*ABS(INT(X*1000+.5)/1000)
150 !
155 ! Prompt user for range.
160 !
165 CLEAR @ CALL "QUERY" ( "Enter range.", R, R1, Z$ )
170 ON R GOTO 175,165,280
175 IF R(R1,2)=0 THEN DISP "Data not present for range ";R1 ELSE GOTO 200
180 DISP @ DISP "Press <CONT> to continue." @ PAUSE @ GOTO 280
185 !
190 ! Print the range parameters and the table column labels.
195 !
200 PRINT @ PRINT @ CALL "RPTRNG" ( R(,),R1 ) @ SCRATCHSUB "RPTRNG" @ PRINT
205 PRINT TAB(13); "Phase Angle of NBS"; TAB(42); "Average Reading"; TAB(69); "Correc
tion"
210 PRINT TAB(18);"Standard";TAB(42);"of Phase Meter* [Add to Phase Meter Rea
dings]"
215 PRINT TAB(18);"(Degrees)";TAB(45);"(Degrees)";TAB(70);"(Degrees)"
220 !
225 ! Print the list of average readings.
230 !
235 PRINT @ N=21 @ FOR X=R(R1,1) TO R(R1+1,1)-1
240 PRINT USING 245 ; D(X,1),D(X,8),FNP(D(X,1))-FNP(D(X,8))
245 IMAGE 12X,6X,2DZ.3D,20X,2DZ.3D,17X,2DZ.3D
250 N=N+1 @ NEXT X
255 !
260 ! Print the footnote.
265 !
270 FOR I=N TO 54 @ PRINT @ NEXT I
275 PRINT TAB(13); ** Average of four readings. @ L=52
280 SUBEND
       OCCURS IN LINE
VAR
       100 ,175 ,200 ,235
                                 array of range parameters (see main program
R (,)
       235
                                   xref)
D (,)
       100,240,240,240
                                 any meter data. (see main program xref)
       240
M ( )
       100
                                 unused
R5
       100
                                 unused
R1
       100 ,165 ,175 ,175
                                 range no.
       200 ,235 ,235
L
       100,275
                                  no. of lines printed by this program
R
       165,170
                                  information about user's reply
Ζ$
       165
                                  dummy string
Ν
        235,250,250,270
                                  no. of lines printed by end of table
Х
       235,240,240,240
                                 data point no. loop control
       240,250
I
       270,270
                                  loop control
```

```
100 SUB "RPTFIT" (R(,),S(),R1,A,B,L)
105 !
110 ! This program prints a list of fitted angles for angles
115 ! read on the meter. JUL 87
120 !
125 OPTION BASE 1
130 !
135 ! Query user for necessity of fit.
140 !
145 CLEAR @ DISP "Limits to Offset:" @ DISP @ DISP USING 150 ; S(8),S(9),S(10) @
 DISP
150 IMAGE " no correction", 8DZ.3D/ " constant correction", 2DZ.3D/ " full corr
ection",6DZ.3D
155 DISP "Is correction needed?" @ CALL "YESNO" ( R ) @ ON R GOTO 175,445,455
160 !
165 ! Prompt user for info about this list.
170 !
175 CALL "QUERY" ( "Enter starting phase angle.", R, A1, Z$ )
180 ON R GOTO 190,175,455
185 !
190 CALL "OUERY" ( "Enter ending phase angle.", R, A2, Z$ )
195 ON R GOTO 205,190,455
200 !
205 CALL "QUERY" ( "Enter angle increment.", R, I1, Z$ )
210 ON R GOTO 220,205,455
215 !
220 CALL "QUERY" ( "Enter decimals of accuracy.", R, D, Z$ )
225 ON R GOTO 230,220,455
230 IF D<1 OR D>3 THEN 220
235 !
240 ! Print the fit equation, the range, and the table header.
245 !
250 S1$=" " @ S2$=" +" @ IF -(A/B)<0 THEN S1$="-"
255 IF B<0 THEN S2$=" -"
260 GOSUB 475 @ PRINT USING 265 ; S1$, ABS(A/B), S2$, ABS(1/B) @ PRINT @ PRINT @ PR
INT
265 IMAGE 12X, "Corrected Phase Angle:* x'= ",A,DZ.6D,2A,DZ.6D," y"
270 PRINT TAB(28);"Table of Corrected Phase Angles (x') in Degrees";CHR$(27);"D*
":CHR$(27):"U"
275 FOR I=1 TO 4 @ PRINT @ NEXT I @ PRINT USING 280
280 IMAGE 21X, "OBSERVED", 7X, "CORRECTED", 12X, "OBSERVED", 7X, "CORRECTED"
285 T$="PHASE ANGLE" @ PRINT TAB(21);T$;TAB(36);T$;TAB(57);T$;TAB(72);T$
290 T$="(Degrees)" @ PRINT TAB(22);T$;TAB(37);T$;TAB(58);T$;TAB(73);T$ @ PRINT @
 PRINT
295 !
300 ! Print the table. D1=span of degrees for half of table,
305 ! used to print table in two columns.
310 !
315 L=31 @ D1=INT((A2-A1)/I1/2+1)*I1 @ FOR I=A1 TO A1+D1-I1 STEP I1
320 L=L+1 @ Y1=1/B*I-A/B @ IF I+D1>A2 THEN 365
325 Y2=1/B*(I+D1)-A/B
330 ON D GOTO 335,345,355
335 PRINT USING 340 ; I, Y1, I+D1, Y2 @ GOTO 400
340 IMAGE 25DZ.D,11DZ.2D,18DZ.D,11DZ.2D
345 PRINT USING 350 ; I, Y1, I+D1, Y2 @ GOTO 400
350 IMAGE 24DZ.2D,11DZ.3D,16DZ.2D,11DZ.3D
```

355 PRINT USING 360 ; I, Y1, I+D1, Y2 @ GOTO 400 360 IMAGE 24DZ.3D,10DZ.3D,16DZ.3D,10DZ.3D 365 ON D GOTO 370,380,390 370 PRINT USING 375 ; I, Y1 @ GOTO 400 375 IMAGE 25DZ.D, 11DZ.2D 380 PRINT USING 385 ; I, Y1 @ GOTO 400 385 IMAGE 24DZ.2D,11DZ.3D 390 PRINT USING 395 ; I, Y1 @ GOTO 400 395 IMAGE 24DZ.3D,10DZ.3D 400 NEXT I 405 ! 410 ! Print the footnote. 415 ! 420 PRINT @ PRINT @ PRINT TAB(24);"* Calculated values based on linear model (se e appendix)" 425 GOTO 455 430 ! 435 ! Print notice that fit is unnecessary. 440 ! 445 GOSUB 475 @ PRINT TAB(13); "No correction is needed to bring the observed pha se angle"; 450 PRINT " reading into" @ PRINT TAB(13); "agreement with the NBS standard." @ L =16 455 SUBEND 460 ! 465 ! Routine to print range parameters. 470 ! 475 PRINT @ PRINT @ CALL "RPTRNG" (R(,),R1) @ SCRATCHSUB "RPTRNG"

480 PRINT @ RETURN

| VAR R() | OCCURS IN LINE | | range parameters (see main program vrof) |
|-------------------|--|------------------------------|--|
| S () R1 | 100,145,145 | ,145 | intermediate sums (see ENTER xref) |
| A | 100,250,260 | ,320 | a (fitted y-intercept) |
| В | 100 ,250 ,255 260 ,320 ,320 325 | ,260 ,325 | ∧ (fitted slope) |
| L | 100 ,315 ,320 450 | ,320 | no. of lines printed by this program |
| R | 155 ,155 ,175 190 ,195 ,205 220 ,225 | ,180 ,210 | information about user's reply |
| A1 Z \$ A2 | 175 ,315 ,315 175 ,190 ,205 190 ,315 ,320 | ,315 ,220 | starting phase angle dummy string ending phase angle |
| I 1 | 205 ,315 ,315 315 | ,315 | angle increment |
| D | 220 ,230 ,230 365 | ,330 | decimals of accuracy |
| S1\$ S2\$ I | 250,250,260 250,255,260 275,275,315 320,325,335 345,345,355 370,380,390 | ,320 ,335 ,355 ,400 | contains sign of y-intercept contains sign of slope multi-purpose loop control |
| Т\$ | 285,285,285 285,290,290 290,290 | ,285 ,290 | constant text used to save memory |
| D1 | 315 ,315 ,320 335 ,345 ,355 | ,325 | span of degrees for half of the table |
| Y1 | 320 ,335 ,345 370 ,380 ,390 | ,355 | left column corrected angle |
| Y2 | 325 -, 335 , 345 | ,355 | right column corrected angle |

```
100 SUB "RPTRAW" (R(,),D(,),B1(),R1,L)
105 !
110 ! This program prints a table of all the readings in a
115 ! given range. JUL 87
120 !
125 OPTION BASE 1
130 !
135 ! Prompt user for info about this table.
140 !
145 CLEAR @ CALL "QUERY" ( "Enter range.",R,R1,Z$ )
150 ON R GOTO 160,145,390
155 !
160 CALL "QUERY" ( "Enter decimals of accuracy.", R, D, Z$ )
165 ON R GOTO 170,160,390
170 IF D<1 OR D>3 THEN 160
175 !
180 ! Print title, range parameters, and table header.
185 !
190 PRINT @ PRINT @ PRINT TAB(13); "Unprocessed Calibration Data for Range:"
195 CALL "RPTRNG" ( R(,),R1 ) @ PRINT @ PRINT @ PRINT
200 PRINT TAB(19); "NBS STANDARD METER UNDER TEST
                                                         NBS STANDARD
                                                                        METER UND
ER TEST"
205 T$="(degrees)" @ PRINT TAB(20);T$;TAB(37);T$;TAB(57);T$;TAB(74);T$ @ PRINT
210 !
215 ! Initialize the pointers needed to print the table.
220 !
225 ! N=total # of readings.
230 N=0 @ FOR I=1 TO R(R1+1,1)-1 @ N=N+B1(I) @ NEXT I
235 ! K1,K2=present left, right column test point #; J1,J2=
240 ! present reading in test point of left, right column;
245 ! L=# of rows in table.
250 ! Point K1,K2,J1,J2 to beginning of the requested range.
255 K1=1 @ K2=1 @ J1=0 @ J2=0 @ L=INT(N/2+.5) @ FOR I=1 TO L
260 J2=J2+1 @ IF J2>B1(K2) THEN K2=K2+1 @ J2=1
265 NEXT I
270 !
275 ! Print the table.
280 !
285 FOR I=1 TO L
290 J1=J1+1 @ IF J1>B1(K1) THEN K1=K1+1 @ J1=1
295 J2=J2+1 @ IF J2>B1(K2) THEN K2=K2+1 @ J2=1
300 IF I=L AND N/2<>INT(N/2) THEN 340
305 ON D GOTO 310,320,330
310 PRINT USING 315 ; D(K1,1),D(K1,J1),D(K2,1),D(K2,J2) @ GOTO 375
315 IMAGE 22DZ.3D,13DZ.D,16DZ.3D,13DZ.D
320 PRINT USING 325 ; D(K1,1),D(K1,J1),D(K2,1),D(K2,J2) @ GOTO 375
325 IMAGE 22DZ.3D,12DZ.2D,16DZ.3D,12DZ.2D
330 PRINT USING 335 ; D(K1,1),D(K1,J1),D(K2,1),D(K2,J2) @ GOTO 375
335 IMAGE 22DZ.3D,12DZ.3D,15DZ.3D,12DZ.3D
340 ON D GOTO 345,355,365
345 PRINT USING 350 ; D(K1,1),D(K1,J1) @ GOTO 375
350 IMAGE 22DZ.3D,13DZ.D
```

```
355 PRINT USING 360 ; D(K1,1),D(K1,J1) @ GOTO 375
360 IMAGE 22DZ.3D,12DZ.2D
365 PRINT USING 370 ; D(K1,1),D(K1,J1) @ GOTO 375
370 IMAGE 22DZ.3D,12DZ.3D
375 NEXT I
380 !
385 L=L+19
390 SUBEND
```

| VAR | OCCURS IN LINE | |
|----------------|-------------------------------------|---|
| R (,) D (,) | 100 ,195 ,230 100 ,310 ,310 ,310 | range parameters (see main program xref) test or check meter data. (see main |
| - ()/ | 310 ,320 ,320 ,320 | program xref) |
| | 320,330,330,330 | |
| | 330,345,345,355 | |
| | 355 ,365 ,365 | |
| B1() | 100 ,230 ,260 ,290 295 | no. of readings at each point of test or check meter |
| R1 | 100 ,145 ,195 ,230 | range no. |
| L | 100 ,255 ,255 ,285 300 ,385 ,385 | no. of lines printed by this program |
| R | 145 ,150 ,160 ,165 | information about user's reply |
| Ζ\$ | 145 ,160 | dummy string |
| D | 160 ,170 ,170 ,305 340 | decimals of accuracy |
| Τ\$ | 205 ,205 ,205 ,205 205 | constant text used to save memory |
| Ν | 230,230,230,255 | total no. of readings |
| I | 230,230,230,255 | loop control |
| • | 265 .285 .300 .375 | |
| K1 | 255,290,290,290 | left column test point no. |
| | 310 ,310 ,320 ,320 | |
| | 330,330,345,345 | |
| | 355,355,365,365 | |
| К2 | 255 ,260 ,260 ,260 | right column test point no. |
| | 295 ,295 ,295 ,310 | |
| | 310 ,320 ,320 ,330 | |
| | 330 | |
| J1 | 255 ,290 ,290 ,290 | left column reading no. |
| | 290,310,320,330 | |
| 10 | 345,355,365 | |
| J2 | 255 ,260 ,260 ,260 | right column reading no. |
| | 260,295,295,295 | |
| | 295,310,320,330 | |

100 SUB "RPTRNG" (R(,),R1) 105 OPTION BASE 1 110 T1\$=" Voltage: " @ T2\$=" Current: " @ T3\$=T1\$ 115 U1\$=" V" @ U2\$=" A" @ U3\$=U1\$ 120 IF R(R1,2)<0 THEN T1\$=T2\$ @ U1\$=U2\$ 125 IF R(R1,3)>0 THEN T2\$=T3\$ @ U2\$=U3\$ 130 T3\$="Frequency:" @ U3\$=" Hz" @ F=R(R1,4) @ IF F>=1000 THEN F=F/1000 @ U3\$=" kHz" 135 F1=F @ I=1 140 IF F1<>INT(F1) THEN I=I+1 @ F1=F1*10 @ GOTO 140 145 PRINT @ PRINT USING 150 ; T1\$, ABS(R(R1,2)), U1\$ @ PRINT USING 155 ; T2\$, ABS(R (R1,3)),U2\$150 IMAGE 12X,"Reference Signal",10A,12DZ.2D,2A 155 IMAGE 12X,"Variable Phase Signal",10A,7DZ.2D,2A 160 ON I GOTO 165,175,185,195 165 PRINT USING 170 ; T3\$,F,U3\$ @ GOTO 205 170 IMAGE 12X,10A,29X,3D,4A 175 PRINT USING 180 ; T3\$,F,U3\$ @ GOTO 205 180 IMAGE 12X, 10A, 26X, 3DZ. D, 4A 185 PRINT USING 190 ; T3\$,F,U3\$ @ GOTO 205 190 IMAGE 12X, 10A, 25X, 3DZ. 2D, 4A 195 PRINT USING 200 ; T3\$,F,U3\$ 200 IMAGE 12X,10A,24X,3DZ.3D,4A 205 PRINT @ SUBEND

| VAR | OCCURS IN LINE | |
|-------|--------------------------------|---|
| R (,) | 100 ,120 ,125 ,130 145 ,145 | array of range parameters (see main program xref) |
| R1 | 100 ,120 ,125 ,130 145 ,145 | range no. |
| T1\$ | 110 ,120 ,145 | reference signal units |
| T2\$ | 110 ,120 ,125 ,145 | variable signal units |
| T3\$ | 110 ,125 ,130 ,145 | multi-purpose string. on lines 110-125 it |
| | 145,165,165,175 | contains " Voltage: ". from line 130 it |
| | 175 ,185 ,185 ,195 | contains "Frequency:" |
| | 195 | |
| U1\$ | 115 ,115 ,120 ,145 | abbreviated reference signal units |
| U2\$ | 115 ,120 ,125 ,145 | abbreviated variable signal units |
| U3\$ | 115 ,125 ,130 ,130 | abbreviated units for units of T3\$ |
| | 165 ,175 ,185 ,195 | |
| F | 130 ,130 ,130 ,130 | frequency |
| | 135 .165 .175 .185 | requency |
| | 195 | |
| F1 | 135 ,140 ,140 ,140 | used to determine digits in frequency after |
| | 140 | the decimal |
| Ι | 135 ,140 ,140 ,160 | no, of digits after decimal +1 |
| | , , , | no. of diffico after decimar (1 |

100 SUB "SEL" (A,B) 105 ! 110 ! This program prints the fitted angles for selected test 115 ! meter angles. JUL 87 120 ! 125 OPTION BASE 1 130 ! 135 ! Print the table header. 140 ! 145 PRINT @ PRINT " OBSERVED CORRECTED" 150 PRINT " DEGREES DEGREES" @ PRINT 155 ! 160 ! Loop to get angle from user and find its fitted value. 165 ! 170 CLEAR @ DISP "ENTER PHASE ANGLE" 175 DISP @ DISP @ DISP "Press <kl> to quit." 180 CALL "QUERY" ("",R,Y,Z\$) 185 ON R GOTO 190,170,205 190 X = (Y - A) / B195 PRINT USING "2(2X,M3DZ.3D)" ; Y,X 200 GOTO 170 205 PRINT @ PRINT 210 SUBEND

VAR OCCURS IN LINE â (fitted y-intercept) b (fitted slope) 100,190 Α В 100,190 R 180 ,185 information about user's reply 180 ,190 ,195 Y observed degrees Ζ\$ dummy string 180 190 ,195 Х corrected degrees

```
100 SUB "SELECT" (I,N,L(),T$)
105 !
110 ! This program has the user select a test from the TOC.
115 ! AUG 87
120 !
125 OPTION BASE 1
130 !
135 ! Clear all 4 screens.
140 !
145 FOR I=1 TO 49 STEP 16 @ OFF CURSOR @ ALPHA I @ CLEAR @ NEXT I @ ALPHA 1 @ CR
T OFF
150 !
155 ! Show table of contents (TOC).
160 !
165 FOR P=1 TO N*60-59 STEP 60
170 DISP USING 175 ; T$[P,P+29],T$[P+30,P+39],T$[P+50,P+59],VAL$(L(INT(P/60)+1))
.T$FP+40.P+491
175 IMAGE X,30A / X,11A,"Folder # ",10A / " @ TEST-",4A,"Serial # ",10A //
180 NEXT P
185 !
190 ! Wait for user to press a key.
195 !
200 I=1 @ K$=CHR$(128)&CHR$(154)&CHR$(161)&CHR$(162)&CHR$(32)
205 OFF CURSOR @ ALPHA I*4-3
210 ON CURSOR @ CRT ON @ ON KYBD K,K$ GOTO 220
215 GOTO 215
220 ON POS(K$,CHR$(K)) GOTO 310,330,240,270,270
225 !
230 ! <Cursor up> moves cursor to previous test.
235 !
240 I=I-1
245 IF I<1 THEN I=N @ GOTO 285
250 IF FP(I/4) THEN 205 ELSE 285
255 !
260 ! <Cursor down> and <Space bar> move cursor to next test.
265 !
270 I=I+1
275 IF I>N THEN I=1
280 IF FP((I-1)/4) THEN 205
285 Q=INT((I-1)/4)*16 @ OFF CURSOR @ CRT OFF @ ALPHA ABS(49-Q) @ ALPHA Q+1 @ GOT
0 205
290 GOTO 205
295 !
300 ! <k1> aborts selection.
305 !
310 I=0
315 !
320 ! END LINE selects a test.
325 !
330 SUBEND
```

| V | AR | | 0000 | JRS II | N LINE | - | |
|---|----|---|------|--------|--------|------|--|
| Ι | | | 100 | ,145 | ,145 | ,145 | |
| | | | 200 | ,205 | ,240 | ,240 | |
| | | | 245 | ,245 | ,250 | ,270 | |
| | | | 270 | ,275 | ,275 | ,280 | |
| | | | 285 | ,310 | | | |
| Ν | | | 100 | ,165 | ,245 | ,275 | |
| L | (|) | 100 | ,170 | | | |
| T | \$ | | 100 | ,170 | ,170 | ,170 | |
| | | | 170 | | | | |
| Ρ | | | 165 | ,170 | ,170 | ,170 | |
| | | | 170 | ,170 | ,170 | ,170 | |
| | | | 170 | ,170 | ,180 | | |
| Κ | \$ | | 200 | ,210 | ,220 | | |
| Κ | | | 210 | ,220 | | | |
| Q | | | 285 | ,285 | ,285 | | |

multi-purpose variable. used as a loop control and as the no. of the element of T\$ to which the cursor points

no. of elements (tests) in TOC file name numbers. (see STORE xref) table of contents (TOC) file. contains an array of elements in format of C\$ points to beginning of a test in TOC T\$

string of programmed keys programmed key that the user presses no. of logical lines before top of screen

```
100 SUB "STAT" (S(), N, K, A, B, X, Y, S, S1, S2, T, T1, T2, F, F1, O)
105 !
110 ! "STAT" determines the applicability of the linear model,
115 ! determines the significance of differences between fitted
120 ! and standard intercepts and slopes, determines the limit
125 ! to the offset for each level of correction, and prints the
130 ! values of various variables used in the calculations if
135 ! requested. last modified 7-07-87, 11:28.
140 !
145 ! INPUT: S()=intermediate sums, N=nk, K=k, A=a-hat, B=b-hat,
150 ! X=av. ideal reading, Y=av. actual reading, S=s, S1=S(a-hat),
155 ! S2=S(b-hat), T1=t1, T2=t2, F1=F', O=printout flag (1 is print);
160 ! OUTPUT: T=Student's t, F=upper 1% point of F distribution
165 !
170 OPTION BASE 1
175 SCRATCHSUB "ENTER"
180 DIM X(4),A$[2]
185 \times (1), \times (2) = 0 \otimes \times (3), \times (4) = 360
190 Q,I=1
195 !
200 ! determine applicability of linear model
205 !
210 CALL "F TABL" ( .01,K-2,N-K,F ) @ IF NOT O THEN 240
215 PRINT "Linear model is ";@ IF F1>=F THEN PRINT "not ";
220 PRINT "applicable." @ PRINT
225 !
230 ! calculate Student's T
235 !
240 DEF FNZ(A1) = 4.932*((1-A1)@.14-A1@.14)
245 A1=.025 @ N1=N-2 ! .nk-2
250 T=SQR(N1*EXP(FNZ(A1) 2*(N1-1.5)/(N1-1) 2)-N1)*.991+.00006*N1 @ IF NOT O THEN
 310
255 !
260 ! determine significance of differences between fitted and
265 ! standard intercepts and slopes
270 !
275 PRINT "Intercept is";@ IF T1<=T THEN PRINT " not";
280 GOSUB 590 @ PRINT "zero." @ PRINT
285 PRINT "Slope is"; O IF T2<=T THEN PRINT " not";
290 GOSUB 590 @ PRINT "one." @ PRINT
295 !
300 ! function to calculate R(xt)
305 !
310 DEF FNR
315 IF O=1 THEN X1=X ELSE X1=Y
320 FNR=S*SQR(2*F2*(1/N+(X(I)-X1)<sup>2</sup>/S(5)))
325 FN END
330 !
335 ! function to calculate maximum L(xt) and U(xt)
340 !
345 DEF FNL(A2)
350 L9=0
355 FOR I=1 TO 4
360 L=A+A2+(B-1)*X(I)+(-1) <sup>1</sup>*FNR
365 L9=MAX(L9,ABS(L)) @ NEXT I
370 FNL=L9
375 FN END
```

```
380 !
385 ! calculate limit to offset at each level
390 !
395 CALL "F TABL" ( .05,2,N-2,F2 ) @ SCRATCHSUB "F TABL"
400 ! no correction
405 L1 = FNL(0)
410 ! constant correction
415 L2=FNL(X-Y)
420 ! full correction
425 Q,L3=0
430 FOR I=1 TO 4
435 L=FNR/B @ L3=MAX(L3,ABS(L))
440 NEXT I
445 !
450 S(8)=L1 @ S(9)=L2 @ S(10)=L3 @ IF NOT O THEN SUBEND
455 !
460 ! function to round to 1000ths place accuracy
465 !
470 DEF FND(X) = SGN(X)*INT(ABS(X*1000)+.5)/1000
475 !
480 ! print values of various variables
485 !
490 IF B<O THEN A$="-" ELSE A$="+" @ ! A$=sign of slope
495 PRINT USING 500 ; A,A$,ABS(B)
500 IMAGE "Predicted"/"y=",MZ.6D,2X,A,2X,Z.6D," x"/
505 PRINT USING 510 ; N,N/K,K,X,Y,T
510 IMAGE "N=", 3D/"n=", 3D. 3D/"k=", 3D/"X=", 4D. 3D/"Y=", 4D. 3D/"t[.025, nk-2]=", 2D. 4D
\prod
515 CALL "INV T" ( N-2,T1,A1 ) @ A$="a="
520 PRINT USING 525 ; A$,A,A$,S1,A$,T1,A$,ABS(2*A1)
525 IMAGE 2A, MDZ.6D/"s", 2A, DZ.6D/"t", 2A, DZ.3D/"", 2A, DZ.3D//
530 CALL "INV T" ( N-2,T2,A2 ) @ A$="b="
535 PRINT USING 525 ; A$, B, A$, S2, A$, T2, A$, ABS(2*A2)
540 PRINT USING 545 ; S,F1,SQR(S(7)-S(6)),SQR(S(6)),F
545 IMAGE "s=",MDZ.6D/"F1=",MDZ.3D/"[SL]=",MDZ.3D/ "[SE]=",MDZ.3D/ "F[.01(k-2,k(
n-1))]=",MDZ.3D
550 CALL "INV F" ( F1,K-2,N-K,A2 ) @ PRINT USING 555 ; A2 @ SCRATCHSUB "INV F"
555 IMAGE "Level of significance", MZ.3D
560 PRINT USING 565 ; "L1=",L1,"L2=",L2,"L3=",L3
565 IMAGE 3(3A, MZ.3D/)
570 SUBEND
575 !
580 ! this subroutine saves memory, and this line makes up for it
585 !
590 PRINT " significantly" @ PRINT " different from ";@ RETURN
```

| VAR | OCCURS IN LINE | |
|----------------------------------|--|--|
| S () | 100 ,320 ,450 ,450 450 ,540 ,540 ,540 | intermediate sums (see ENTER xref) |
| N | 100 ,210 ,245 ,320 395 ,505 ,505 ,515 530 ,550 | nk (see ENTER xref) |
| К | 100 ,210 ,210 ,505 505 ,550 ,550 | k (no. of test points in range) |
| A B | 100 ,360 ,495 ,520 100 ,360 ,435 ,490 495 ,535 | â (fitted y-intercept) 6 (fitted slope) |
| X Y S S1 | 100 ,315 ,415 ,505 100 ,315 ,415 ,505 100 ,320 ,540 100 ,520 | ideal readings, average of average of actual readings standard deviation S(දු) |
| S2 T | 100 ,535 100 ,250 ,275 ,285 505 | S(b) Students t statistic |
| T1 T2 F F1 O X () | 100 ,275 ,515 ,520 100 ,285 ,530 ,535 100 ,210 ,215 ,540 100 ,215 ,540 ,550 100 ,210 ,250 ,450 180 ,185 ,185 ,185 | tl t2 F statistic that determines model applicability F' set to print results to internal printer array of lower and upper limit degrees |
| A \$ | 185,320,360 180,490,490,495 515,520,520,520 520,530,535,535 535,535 | multi-purpose string. |
| Q I | 190 ,315 ,425 190 ,320 ,355 ,360 360 ,365 ,430 ,440 | set when finding R(xt) for avg. ideal reading index into X() and loop control |
| A1 N1 | 245 ,250 ,515 ,529 245 ,250 ,250 ,250 250 ,250 | percentage points for tl degrees of freedom nk-2 |
| X1 F2 L9 L1 L2 L3 | 315 ,315 ,320 320 ,395 350 ,365 ,365 ,370 360 ,365 ,435 ,435 405 ,450 ,560 415 ,450 ,560 425 ,435 ,435 ,450 | average of ideal or actual reading F statistic for limit to offsets greatest offset offset for limit X(I) offset for no correction offset for constant correction offset for full correction |
| A2 | 530,535,550,550 | percentage points for t2 |
100 SUB "STORE" (C\$,A(),R(,),D(,),C(,),B1(),B2(),D0\$,T0\$) 105 ! 110 ! This program saves data and updates the table of contents (TOC). AUG 87 115 ! 120 OPTION BASE 10 DIM L(16), T\$[960] 125 C\$[31,40]=D0\$ @ C\$[41,50]=GET\$(T0\$(3)) @ 01\$=".CALDAT" @ 02\$="CONTENTS"&01\$ 130 ! 135 ! Verify that info should be saved. 140 ! 145 CLEAR @ DISP "You are about to SAVE data for" @ DISP 150 DISP USING 155 ; C\$[1,30],D0\$,C\$[51],C\$[41,50] @ DISP 155 IMAGE X,30A / X,11A,"Folder # ",10A / X,"@ ?",8X,"Serial # ",10A 160 DISP "Is this correct?" @ CALL "YESNO" (R) @ ON R GOTO 180,460,460 165 ! 170 ! Retrieve TOC. If there is no TOC then make one. 175 ! 180 ON ERROR GOTO 315 @ ASSIGN# 1 TO Q2\$ @ OFF ERROR @ READ# 1 ; N,L(),T\$ 185 ! 190 ! Overwrite test if it already exists. 195 ! 200 P=POS(T\$,C\$[1,50]) @ I=INT(P/60)+1 @ IF NOT P THEN 230 205 CLEAR @ DISP "This test is already on disk. Do you want to overwrite it?" 210 CALL "YESNO" (R) @ ON R GOTO 430,460,460 215 ! 220 ! Allow user to overwrite an existing test. 225 ! 230 CLEAR @ DISP "Do you want to overwrite an existing test?" 235 CALL "YESNO" (R) @ ON R GOTO 240,295,460 240 CLEAR @ DISP "You are about to select the test you want to overwrite..." 245 DISP @ OFF CURSOR 250 WAIT 2000 @ CALL "SELECT" (I,N,L(),T\$) @ IF NOT I THEN 230 255 P=I*60-59 @ CLEAR @ DISP "You are about to OVERWRITE" @ DISP 260 DISP USING 265 ; T\$[P,P+29],T\$[P+30,P+39],T\$[P+50,P+59],I,T\$[P+40,P+49] 265 IMAGE X,30A / X,11A, "Folder # ",10A / X,"@ TEST-",D,3X, "Serial # ",10A 270 DISP @ DISP "Is this correct?" @ CALL "YESNO" (R) 275 ON R GOTO 430,230,460 280 ! 285 ! See if there is room in TOC for new test. 290 ! 295 IF N<16 THEN 375 ELSE CLEAR @ DISP "The data disk is full." @ GOTO 320 300 ! 305 ! Initialize disk and TOC with user's permission. 310 ! 315 OFF ERROR @ CLEAR @ DISP "You don't have an initialized data disk in eithe r drive." 320 DISP @ DISP "Do you want to initialize the disk in drive 1 (right drive)?" 325 CALL "YESNO" (R) @ ON R GOTO 330,460,460 330 DISP @ DISP "All information now on the disk in drive 1 will be lost. Are you sure?" 335 CALL "YESNO" (R) @ ON R GOTO 340,460,460 340 CLEAR @ DISP "Initializing. Please wait." 345 INITIALIZE 01\$[2],":D701" 350 FOR I=1 TO 16 @ L(I)=0 @ NEXT I @ T\$[960]=" " 355 CREATE Q2\$,5,256 @ ASSIGN# 1 TO Q2\$ @ N=0

```
360 !
365 ! Make room for test in alphabetical index.
370 !
375 FOR P=1 TO 841 STEP 60 @ IF C$[1,50]<T$[P,P+49] OR T$[P,P+3]=" " THEN 385
380 NEXT P
385 FOR J=841 TO P STEP -60 @ I=INT(J/60)+1 @ L(I+1)=L(I)
390 T$[J+60,J+119]=T$[J] @ NEXT J
395 !
400 ! Create a file for the test data.
405 !
410 N=N+1 @ L(I)=N @ CREATE "TEST-"&VAL$(N)&Q1$,65,256
415 !
420 ! Update TOC and test file.
425 !
430 CRT OFF @ T$[P,P+59]=C$ @ ASSIGN# 1 TO Q2$ @ PRINT# 1 ; N,L(),T$
435 ASSIGN# 1 TO "TEST-"&VAL$(L(I))&Q1$
440 PRINT# 1 ; A(),R(,),D(,),C(,),B1(),B2(),DO$
445 FOR I=1 TO 6 @ Q$=GET$(TO$(I)) @ PRINT# 1 ; Q$ @ NEXT I
450 ASSIGN# 1 TO * @ CLEAR @ CRT ON
455 !
460 SUBEND
```

| VAR C \$ | OCCURS IN LINE 100 ,125 ,125 ,150 150 ,150 ,200 ,375 430 | test info from TOC (see main program xref) |
|--|--|---|
| A () R (,) D (,) C (,) B1() B2() D0\$ T0\$ L () | 100 ,440 100 ,440 100 ,440 100 ,440 100 ,440 100 ,440 100 ,125 ,150 ,440 100 ,125 ,445 120 ,180 ,250 ,350 385 ,385 ,410 ,430 435 | test information (see main program xref) range parameters (see main program xref) test meter data. (see main program xref) check meter data (see main program xref) no. of readings at each point of test meter no. of readings at each point of check meter date of test test and check meter info (see main program) array of file name numbers. subscript corresponds to the alphabetical element no. |
| Т\$ | 120 ,180 ,200 ,250 260 ,260 ,260 ,260 350 ,375 ,375 ,390 390 ,430 ,430 | <pre>table of contents (TOC) file. contains an array of elements in format of C\$</pre> |
| Q1\$ | 125 ,125 ,345 ,410 435 | contains ".CALDAT" and is used to save memory |
| Q2\$ | 125,180,355,355 430 | contains "CONTENTS.CALDAT" and is used to save memory |
| R | 160 ,160 ,210 ,210 235 ,235 ,270 ,275 325 ,325 ,335 ,335 | information about user's reply |
| N | 180 ,250 ,295 ,355 410 ,410 ,410 ,410 430 | no. of tests in the TOC |
| Ρ | 200 ,200 ,200 ,255 260 ,260 ,260 ,260 260 ,260 ,260 ,260 375 ,375 ,375 ,375 375 ,380 ,385 ,430 430 | position of test in TOC T\$ |
| I | 200 ,250 ,250 ,255 260 ,350 ,350 ,350 385 ,385 ,385 ,410 435 ,445 ,445 ,445 | index no. of test |
| J | 385,385,390,390 390,390 | loop control |
| Q \$ | 445 ,445 | intermediate string for copying TO\$() to disk |

100 SUB "TALK" (A,D\$,Q) 105 ! 110 ! This program is the software interface between the HP and 115 ! the standard. JUL 87 120 ! 125 ! INPUT: A=bus address, D\$=key sequence, Q=no. of queries; 130 ! OUTPUT: D\$=last ENTERed info, Q=-1 if successful. 135 ! 140 ! ON INTR tells HP where to go when standard has data to send 145 ! and program isn't in the process of ENTERing it. 150 ! 155 ON INTR 7 GOTO 280 @ DIM I\$[20] 160 ! 165 ! Have HP SUBEXIT if 5 seconds elapse before the standard 170 ! completes a handshake (i.e. acknowledges data it said it 175 ! could acknowledge). 180 ! 185 SET TIMEOUT 7;5000 @ ON TIMEOUT 7 GOTO 335 @ I\$="ERROR" 190 ! 195 ! Send request. WAIT 1500 is needed because interrupt must 200 ! be requested before it's enabled. (HP guirk?) 205 ! 210 OUTPUT A USING "K" ; D\$ @ RESET 7 @ WAIT 1500 215 ! 220 ! Head of loop that shows all queried info. 225 ! 230 Q=Q-1 @ IF Q=-1 THEN ON ERROR GOTO 335 @ D\$=I\$ @ GOTO 335 235 ! 240 ! Wait for standard to interrupt. If a minute passes without 245 ! interrupt then abort wait and warn user. 250 ! 255 ON TIMER# 1,60000 GOTO 310 @ ENABLE INTR 7:8 260 GOTO 260 265 ! 270 ! Get data if no problems. 275 ! 280 OFF-TIMER# 1 @ IF SPOLL(A)=117 THEN ABORTIO 7 @ RESET 7 @ GOTO 280 285 IF SPOLL(A)>90 THEN DISP "Bus Error. ";@ GOTO 320 290 ENTER A USING "#%K" ; I\$@ DISP I\$ @ GOTO 230 295 ! 300 ! Warn user about DC offset or lengthy auto-zero. 305 ! 310 OFF TIMER# 1 @ DISP @ DISP "Phase standard malfunction." @ DISP 315 BEEP 70,100 @ BEEP 100,150 @ BEEP 70,150 320 DISP "Press <CONT> when ready." @ PAUSE 325 CLEAR 7 @ RESET 7 330 ! 335 OFF ERROR @ ABORTIO 7 @ SUBEXIT

| VAR | OCCURS IN LINE | |
|------|--------------------|---------------------------------|
| А | 100 ,210 ,280 ,285 | address of phase standard |
| | 290 | |
| D \$ | 100 ,210 ,230 | instruction string for standard |
| Q | 100 ,230 ,230 ,230 | no. of queries to ENTER |
| I\$ | 155 ,185 ,230 ,290 | string ENTERed from standard |
| | 290 | |

100 SUB "YESNO" (R)
105 !
110 ! This program has the user select 'yes' or 'no' by acting
115 ! on keys Y and N. JUL 87
120 !
125 OPTION BASE 1@ OFF CURSOR @ ON KYBD K, "YyNn"&CHR\$(128) GOTO 135
130 GOTO 130
135 OFF KYBD
140 R=POS("YN"&CHR\$(128)&"yn",CHR\$(K)) @ IF R>3 THEN R=R-3
145 ON R GOTO 150,155,165
150 DISP "Yes." @ GOTO 160
155 DISP "No."
160 OFF CURSOR @ WAIT 1500
165 ON CURSOR
170 SUBEND

| VAR | OCCURS IN LINE | |
|-----|--------------------|---|
| R | 100 ,140 ,140 ,140 | user's reply. 1=yes; 2=no; 3=abort and go |
| | 140 ,145 | to the main menu |
| К | 125 ,140 | programmed key that the user enters |
| | | |

```
100 SUB "ZERO" (Z$,I1,J1,A(,))
105 !
110 ! This program zeros A(1 to I1, 1 to J1). JUL 87
115 !
120 OPTION BASE 1@ DISP " zeroing ";Z$
125 FOR I=1 TO I1 @ IF NOT (I MOD 10) THEN BEEP 20,2
130 FOR J=1 TO J1-3 STEP 4 @ A(I,J),A(I,J+1),A(I,J+2),A(I,J+3)=0 @ NEXT J
135 NEXT I @ SUBEND
```

| VAR | OCCURS IN LINE | |
|-------|--------------------|-------------------------------------|
| Ζ\$ | 100 ,120 | text name of array being zeroed |
| I1 | 100 ,125 | size of 1st dimension of array A(,) |
| J1 | 100 ,130 | size of 2nd dimension of array A(,) |
| A (,) | 100 ,130 ,130 ,130 | array to clear to zeros |
| | 130 | |
| Ι | 125 ,125 ,130 ,130 | lst dimension loop control |
| | 130 ,130 ,135 | |
| J | 130 ,130 ,130 ,130 | 2nd dimension loop control |
| | 130 ,130 | |

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| calibration service | for audio-frequency p | hase meters. The calib | rations are based on a |
| phase angle standard | developed at NBS tha | t generates two sinusol | dal signals, over a fre- |
| quency range of 2 he | rtz to 50 kilohertz, | displaced relative to o | divide the op oach chan- |
| ly known phase angle | . The signal amplitu | des are independently a | $a_{justable} = 0000$ at the |
| nel from 0.5 volts t | o 100 volts. The ang | α | gh end. The uncertain- |
| tw of the phase angl | a between the two sig | nals generated by the s | tandard varies from |
| 0.005° to 0.04° depe | anding on frequency ar | d amplitude. | |
| Using the phase | angle standard, phas | e meter readings are ob | tained at selected test |
| points. From the ca | libration data, the r | hase meter response cha | racteristic is determine |
| and is compared to t | hat of an ideal meter | having a linear charac | teristic. If the phase |
| meter response confo | orms to the linear mod | el, a straight-line cal | ibration curve is de- |
| rived from the data | and serves to calcula | te corrected readings. | From the statistical |
| parameters associate | d with the calibratio | on curve, it is possible | to estimate the limits |
| of offset between th | ne calibrated meter ar | nd the calibration stand | ard. By extension, the |
| uncertainty of readi | ngs of the phase mete | er in the user's laborat | ory can be estimated. |
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