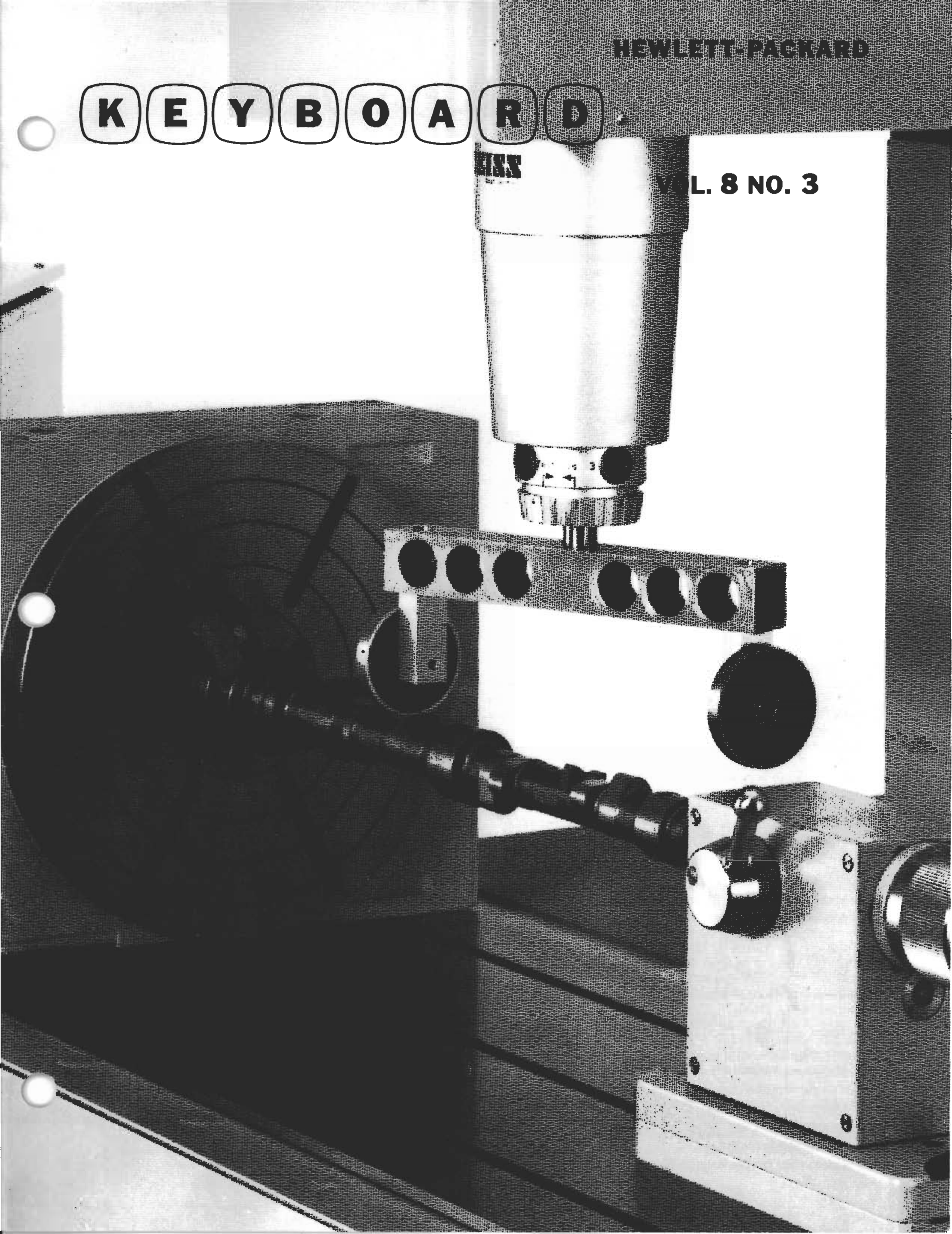
HEWLETT-PACKARD

# KEYBOARD

VOL. 8 NO. 3



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**APPLICATIONS INFORMATION FOR HEWLETT-PACKARD CALCULATORS PUBLISHED AT P.O. BOX 301, LOVELAND, COLORADO 80537**

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# Precision Measurement

## with the ZEISS UMM 500 and the HP 9810A

Figure 1

by Hans Joachim Neumann

Numerically controlled machines are a major breakthrough in producing parts faster, more accurately, and more economically. Even complex contours present few problems. However, careful pre-machining preparation is very important to ensure correct design interpretation. In addition, rapid checks for workpiece tolerances of first units and after the exchange of tools are necessary to avoid high reject rates. Speed and accuracy are essential, since the expensive production machinery during this checking period is either idle or producing possible rejects. Advanced measurement devices such as coordinate measuring machines meet these criteria and have become the next major breakthrough in the production of machined parts.

The benefits of using coordinate measuring machines are greatly enhanced by on-line computers or calculators. Data obtained by probing are processed by the calculator, yielding comprehensive information on workpiece geometry and an immediate measurement result. Time-consuming manual workpiece alignment and measurement evaluation is the alternative.

The advantages of using a calculator with coordinate measuring machines are not limited to data reduction and evaluation, however, since the calculator can also automatically execute the whole measuring sequence. The Zeiss UMM 500 Universal Measuring Machine interfaced with the HP 9810A clearly demonstrates these capabilities.

### Design and Operation of the UMM 500

The UMM 500 differs in many respects from other measuring devices. The machine shown in Figure 1 has 3 motor-driven measuring axes (X, Y, and Z) forming the machine's coordinate system. For quick table traverse and high-sensitivity probing, the drives operate without gear change over a wide range of speeds. They are operated by control sticks, which regulate travel speed from 1$\mu$m/s to 40 mm/s.

A photoelectrical incremental-length measuring system using a grid scale with 16-$\mu$m spacing records the distances traveled in the 3 axes. After linear interpolation, the coordinates are simultaneously displayed at the control cabinet and transferred to the 9810 for further data processing. Resolution is 0.5 $\mu$m or 0.2 $\mu$m. To ensure that this high-resolution measurement is free of vibration error, the machine can, on request, be equipped with a pneumatically operated, self-leveling mechanism.

### Probing With the 3D Point

Probing the workpiece is the most important operation in the measuring sequence. With the patented 3D probing head designed by Zeiss, new techniques have been applied in this field. The probe head is mounted in spring parallelograms and moves freely along the 3 axes. An inductive linear transducer is used in each axis to measure the probe head position. The 3D probe head is interrelated with the machine control.

The probe head has receptacles arranged radially for up to 5 probing styli. An object can be probed from all directions without having to be reclamped. When the styli are inserted, an automatic balancing device built into the probe head compensates for differences in weight. This feature also ensures that equal measuring force is applied in both directions of the Z axis.

As soon as the probe is in contact with the workpiece, the measuring force is applied and operation is transferred from the control sticks to a positioning system that adjusts the respective slide to the zero point of the probe head. The positioning procedure takes 1 to 2 seconds and is accurate to within 0.3 $\mu$m. This "active" probing enables measurement while the system is in a state of rest, eliminating kinematic errors.

In the probing axis the machine can also keep track of the workpiece during probing, similar to a copying control, a feature used especially in cam measurements where the machine is combined with a calculator-controlled rotary table. Probe head zero gained in the probing axis by the position control is also obtained in the other two axes. This is accomplished by motor-driven clamping devices, which keep the probe head slides precisely in the zero position of the inductive measuring system at all times. It, therefore, represents a stable 3-dimensional datum point with unlimited probing ability from any direction and even includes the probing of arbitrarily sloped surfaces.

Measuring force is generated in 3 preselected steps from 0.1 N to 0.4 N by fixed currents induced in solenoids, thus securing continuous static probing pressure.

The function of the probe head as a whole is controlled by a logic circuit. As a result, the 3D probe head acquires a "sense of touch", relieving the operator of many control functions except for handling the control sticks.

The machine uses its "sense of touch" to inform the 9810 of the probing axis and direction.

Before the actual measurement starts, the calculator determines the ball centre and diameter of each probing stylus for the selected styli combination by conducting several probings of a sphere or cube standard. The probing stylus parameters determined by this method are compensated for by the 9810, providing a nondimensional probing point.

### Basic Operations of the 9810

The 9810 goes into a standby status after terminating the computing and output operations. When probing in any axis, the calculator is given a continue instruction. Then the following operations are executed:

- transfer of probing stylus number and probing direction to the calculator,
- entry of machine coordinates X, Y, and Z into the 3 display registers of the calculator,
- addition of centre coordinates of the probe head selected,
- translation of machine coordinate system into workpiece coordinate system in all 3 axes,
- subtraction of workpiece zero position,
- addition of probe head radius in probing axis (with correct sign),
- output of probing point on the workpiece in direction of probing.

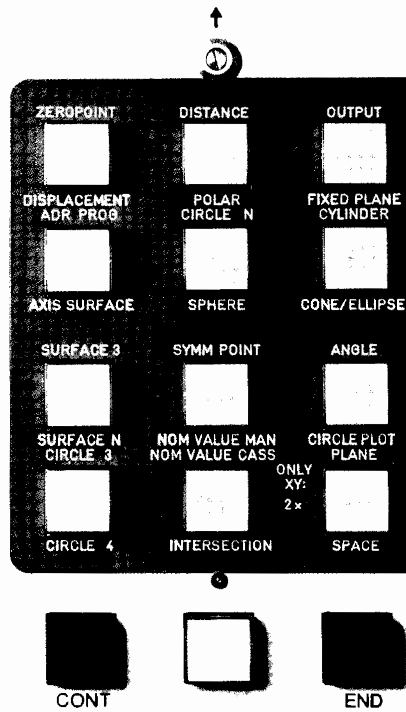


**Figure 2**

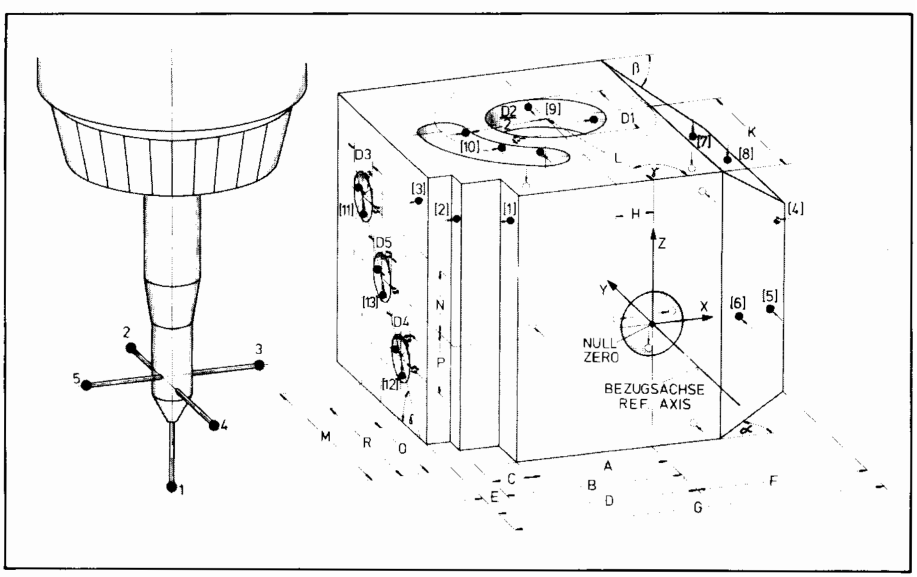


**Figure3**

BEDIENUNGS-OPERATIONEN

| TASTENFELD | ANTASTUNGEN |
|---|---|
| ZYLINDER | 12 x,z |
| SHIFT DREHUNG RAUM | |
| FLAECHE 3 | 3 y |
| SHIFT ACHSE FLAECHE | |
| NULLPUNKT | |
| | 1 z |
| | 1 z |
| DREHUNG EBENE | |
| SHIFT SHIFT | |
| | 1 x |
| | 1 x |
| DISTANZ | 1 x |
| DISTANZ | 1 x |
| DISTANZ | |
| | 1 y |
| | 1 y |
| WINKEL | |
| | 1 z |
| | 1 z |
| WINKEL | |
| KREIS 3 SHIFT POLAR | 3 x,y |
| KREIS 3 DISTANZ | 3 x,y |
| SHIFT KREIS 4 | 4 y,z |
| SHIFT KREIS 4 WINKEL | 4 y,z |
| SYMM PUNKT | |
| SHIFT KREIS 4 DISTANZ | 4 y,z |

```
[  1] TAS 2  ZYLINDER
             12P  INNEN        86.6345              -14.8547
      X/Z    [GR,MIN,SEC]      -5.7767    -46.0     -36.0      15.5954    0.0094
      XZ/Y   [GR,MIN,SEC]       1.8754     52.0      31.4       0.0024   -0.0106
             AR

[  1]        FLAECHE 3P                   10.6076
      X/Z    [GR,MIN,SEC]      17.8714     52.0      17.0
      XZ/Y   [GR,MIN,SEC]       0.1280      7.0      40.8
[  2]        ACHSE/FLAECHE     88.5062     10.5724  -12.0039
             0-PUNKT           88.5062     10.5724  -12.0039
[  3]                                                31.4182
[  4]                                                31.2529
             AR


MESSPROTOKOLL                ZEISS  UMM 500

WERKSTUECK: UEBUNGSSTUECK  PRUEFER: GEORGI    DATUM: 1975-04-24

NR           MESSUNG           X           Y         Z          D          A
==============================================================================
[  1] TAS 2                   -34.0886
[  2]                         -44.0947
             DISTANZ           10.0062
[  3]                         -50.0346
             DISTANZ            5.9398
[  4]                          41.6355
             DISTANZ           91.6701
[  5]                                     12.7060
[  6]                                      2.9203
             WINKEL
      Y/X    [GR,MIN,SEC]      29.9061     54.0      21.8
[  7]                                                26.8853
[  8]                                                12.4909
             WINKEL
      Z/X    [GR,MIN,SEC]     -40.0886     -5.0     -19.1
[  9] TAS 1  3P BOHRUNG       -10.1364     45.9467              30.5214
             POLAR             47.0515
             [GR,MIN,SEC]     102.4409     26.0      27.1
[ 10]        3P BOLZEN        -10.0312     45.9595              42.9601
             DISTANZ            0.1052      0.0128
[ 11] TAS 3  4P BOHRUNG                    62.8298   12.2940    12.4863    0.0126
[ 12]        4P BOHRUNG                    33.1419  -17.4352    12.4799    0.0091
             WINKEL
      Y/Z    [GR,MIN,SEC]      44.9602     57.0      36.6
             SYMM PUNKT                    47.9859   -2.5706
[ 13]        4P BOHRUNG                    47.9586   -2.5505    12.4778    0.0080
             DISTANZ                        0.0272    0.0200
```

**Figure 4**

These basic operations are executed simultaneously for all 3 axes, so that a 3D probing point on the workpiece is continuously available. All subsequent minimum or multipoint measuring programs use probing points computed in this manner. When there are undefined probing surfaces, such as drill holes, cylinders, and tapered parts, the correction of the ball radius is not made until the end of the calculation. In most cases this operation is combined with a test, which enables the 9810 to distinquish between external and internal probing.

### Calling Measuring Programs

Zeiss has developed a special interface that, apart from data communication, controls branching to symbolically addressed subroutines while the calculator is in the keyboard mode. When a key is pressed on the right side of the machine panel (Figure 2), the program branches to the subroutine selected by the operator. The function of each key is therefore user-programmable and can be matched to meet existing measuring problems. An interchangeable template allows for keyboard adaptation to the software by use of a direct subroutine call, without entering code digits or characters.

Some 30 different program sections can be called up via the interface keyboard. All keys have 2 or 3 functions, activated by pressing a prefix shift key. A major simplification is that it is no longer necessary to enter the probing axis or measuring plane separately. Each probing operation is interpreted by the 9810.

The template shown in Figure 2 is assigned to U1 Universal Software, which uses mathematics adapted to the 9810, subdivides programs into hierarchical sections, and includes cartridge storage.

The use of desktop computing devices is most advantageous in coordinate measurement. The calculator's accuracy is absolutely necessary because of the great number of transformations. Programming requires no expensive special features and is done by quick-access keying operations. In addition, the machine-oriented program language of the 9810 is easy to learn and allows for essentially shorter calculating times than do BASIC language calculators.*

### Example of a Measuring Operation

A simple example of a measurement taken on the workpiece in Figure 3 shows the interaction between probing operations and program calls via the keyboard. The corresponding measurement printout containing the operating sequence in the 2 lefthand columns is given in Figure 4.

Before the measurement data is printed out, the position of the workpiece coordinate system is determined. Any of the measuring programs can be used to determine workpiece position. The angular position of the test workpiece is calculated by pressing the DREHEN (rotate) program key and is used for coordinate transformation in subsequent measurements. This method allows practically unlimited position determination of arbitrarily shaped workpieces and eliminates the usual physical alignment.

As shown in Figure 3, the coordinate system of the test workpiece has its Y axis in the cylinder's centre axis, which is determined by probing 5 to 15 points.

The measurement printout shows the diameter of the reference cylinder, maximum deviation from the optimum cylinder shape, and the angular position of the cylinder axis relative to a coordinate system, which is not yet referenced to the workpiece. The letters "AR" for alignment refer to the transformation of the coordinates into the cylinder axis, which has now been defined. The coordinate system's zero position is defined by the intersection of the cylinder axis with the front surface, which is probed in 3 to n points. In the printout, this surface is given by its position in the Y axis and by the angles of the surface normal.

The angle of rotation around the Y axis is determined by two probings in the Z direction (n probings, if required). Coordinate transformation made around this rotary angle is again marked "AR" in the printout.

After the workpiece position is determined, the printout head for the measurement printout is called up, after which the actual measurement starts. The numbers given in square brackets in the printout indicate the measuring points, also shown on the workpiece in Figure 3. The total operating sequence needed for the program can be seen from the 2 columns on the left side of the measurement printout. Measuring time for this example is 10 minutes.

The measurement printout can be made on a number of output devices, such as the 9871A Character Impact Printer, 9866A/B Page Printer, or RENA high-speed printer.

The whole job sequence could be "summarized" in a special program called up by entering a program address from the keyboard. Even the operating sequence for calling the measurement program can be included, since measuring programs can operate as subroutines. Such a programmed measuring sequence eliminates all keyboard operation during the entire job time, permitting the staff on the job to obtain error-free measuring results. About 100 such special programs can be sorted in addition to the U1 software on the tape cassette. The nominal workpiece data are stored on a second tape cassette.

*The 9825A desktop computer, which will be offered in the future, offers additional advantages such as fast data handling and interrupt capabilities. This computer reduces, once more, the measuring time and improves the measurement capabilities.

## Programs for Special Measurements

The UMM 500 can replace numerous high-cost, single-purpose instruments, especially when combined with a calculator-controlled indexing table (Zeiss RT 05). In measuring cam shafts (Figure 5), for instance, the UMM 500 determines deflection, curvature, and slant of the cam shaft. Cam angles can also be measured relative to reference points of any kind, such as drill hole and bolt centres or symmetrical lines through keyways. When combined with 3-axis numerical control, cam shaft measurement is fully automatic. The HP 9862A Plotter shows shape deviation with selectable error amplification. All such factors as deflection, inclination, and curvature are compensated for by the 9810.

Measurement of such complex 3D shapes as spiral-toothed gears can be done automatically by multipoint measurements in preselected coordinate networks. The results can be easily shown by 3D graphs on the 9862.

Another field of application is the measurement of the combustion chambers of rotary engines.

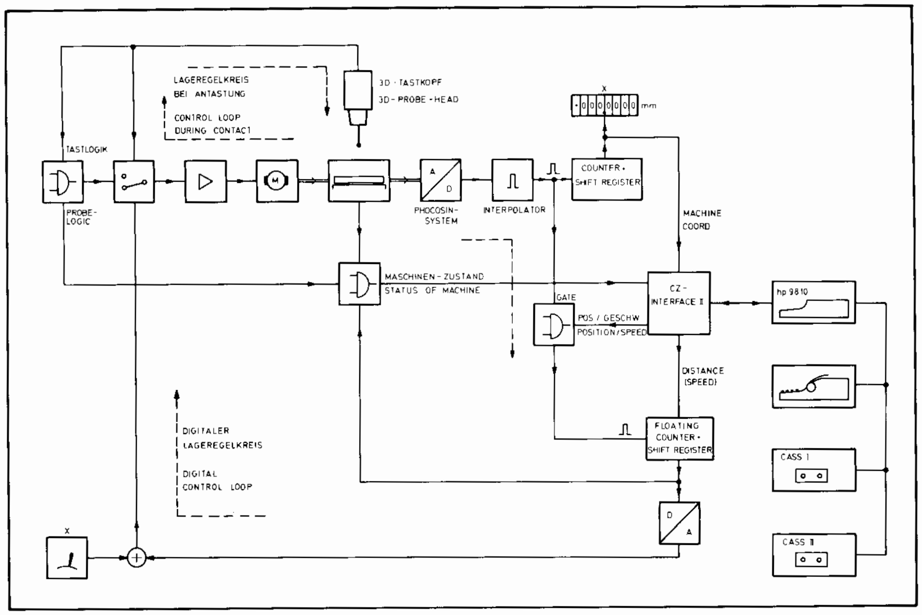


**Figure 6**

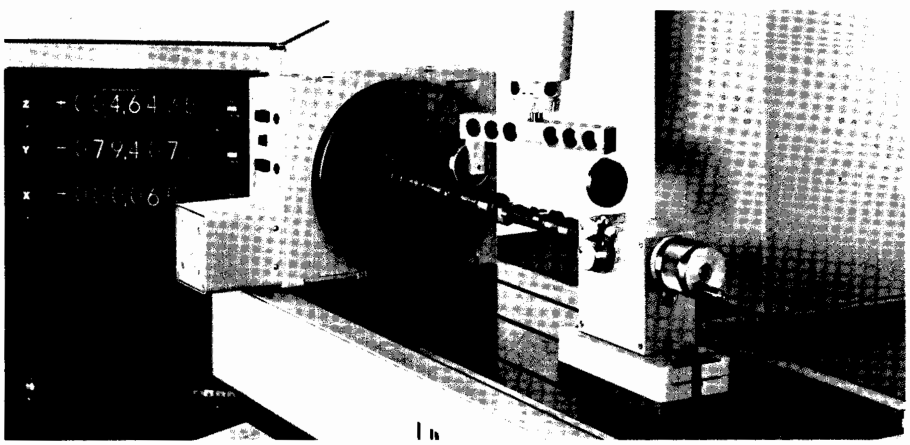

**Figure 5**

The integration of the UMM 500 and the HP 9810 achieves a balanced combination of data acquisition and data processing. The calculator-controlled rotary table, highly advanced software, and operating ease further ad to the system's versatility, providing parts manufacturers valuable assistance in producing a better product more quickly and economically.

## 3-Axis Numerical Control

In series measurements in particular, automation of the entire measuring procedure entails optimal rationalization. Nevertheless, an automatic measuring machine should also provide easy manual operation for intricate individual workpeices. The retrofittable 3-axis control therefore retains a high level of operator comfort in the manual mode.

The 3-axis numerical control takes over the positioning function from the calculator. For this function, floating counters are used, which, after the travel distance is entered, always contain the amount of deviation. They control the drives via digital analog converters with a special interpretation function. During positioning operations the calculator is not involved in the process and can be used for other purposes. As you can see from Figure 6, the point of engagement of the digital control is identical with that of the control sticks. However, all of the "touching" functions are maintained when the machine is controlled by the 9810. This results in substantially simpler software. If the floating counters are disconnected from distance pulses by a calculator-controlled gate circuit, machine slides move at constant traverse speeds controlled by the 9810.

Active control of the measuring process is accomplished by continuous interrogation of a machine status code divided into different priority codes.

An automatic measuring operation is programmed by trial on a sample workpiece. The program stores the probing strategy, the entered nominal values and tolerances, and commands calling up the subroutines for data evaluation on a second workpiece-dedicated tape cartridge. Another program takes over automatic measurement operation and executes the stored data step by step.

The data set stored on the workpiece-dedicated tape cartridge can be loaded independently of the measuring machine under certain conditions. Because of the more abstract manner of presentation, in most cases more time and a higher degree of staff qualification are needed.

## CURRICULUM VITAE

Hans Joachim Neumann, born in 1932, studied communications in Mittweida in the German Democratic Republic, where he received an engineering degree. After working two years in a large industrial plant, he came to the Federal Republic of Germany, where he joined Carl Zeiss Company in 1957. He first handled electronic research for use in machines for the production of precision parts. Before he became head of the Electronic Research Laboratory for Measuring Instruments, his main activity was in development work for astronomical telescopes.

**IMPROVED FORM-FEED MECHANISM FOR THE 9871A PRINTER**

The 98021A Form-Feed Mechanism is used with the 9871A for paper and forms handling. On May 1, 1976, a paper-handling basket was included as a standard item when the 98021 was ordered. The price was increased by $75 U.S. The basket improves the forms-handling capability of the 98021. Therefore, we are offering the basket as a separate item, Part Number 98021-66012, price $75 U.S., for those customers who were not able to order the basket with their initial purchase.

# Calculator Users Club

## 9820A/21A CALCULATOR USERS CLUB NOW INCLUDES 9825A

**by Ine van Sabben**

The Calculator Users Club, long known as an active organization with equally active membership, is expanding to include 9825 users. The enthusiasm of the membership is indicated in the extensive program library. It now contains more than 1000 programs submitted by 9820/21 users from all over the world. These programs cover a wide variety of applications:

- Structures/foundations
- Surveying
- Heating
- Geophysics
- Hydraulics
- Soil mechanics
- Circuit design
- Circuit analysis
- Magnetics
- Power distribution
- Mechanical design
- Numerical control
- Gear transmissions
- Pneumatics
- Thermodynamics
- Medical
- Business/finance
- Education
- Statistics
- Mathematics
- Chemistry
- Navigation
- Plot programs
- Games, miscellaneous

### 9820/21 Users

C.U.C. operates on an exchange basis. One 9820/21 program submitted to the Club and accepted earns the author 5 programs from the program library in return and membership in the Calculator Users Club. Membership entitles you to a C.U.C. program library index and catalog and regular updates of the index plus programming tips, notices of user club meetings, etc.

### 9825 Users

9825 Calculator users may now also join C.U.C., and to encourage membership and participation, the club is enclosing a brochure containing a coupon in all 9825 shipments. The brochure explains the Calculator Users Club and its advantages. The coupon entitles the 9825 user to a standard package of 10 programs taken from the C.U.C. library and converted to the 9825, a copy of the program library index, a letter covering the Club's policies and procedures for submitting programs, and program submittal forms. You are now a conditional member of the Calculator Users Club.

The package of 10 programs offered by C.U.C. contains:

- 3-D Hidden Line Plot
- Design of Small Transformers
- 15 Regression Curves
- Histogram
- Loan Amortisation Schedule
- Numerical Inversion of LaPlace Transform
- Pipe Network Analysis
- Horizontally Movable Plane Frame
- Skew Ray Trace
- Gearing Specifications

To become a full-fledged member, you must follow the normal procedure of having one of your programs accepted by the Club. You will then receive a complete program library catalog, the regular updates, and, of course, 5 programs of your choice.

9820/21 programs are easily converted for use on the 9825 — the languages are very similar — so not only are you kept informed of all the 9825 programs collected into the program library, you can also take advantage of the 9820/21 programs now in the library and those accepted in the future.

If you would like more information on the Calculator Users Club, please write:

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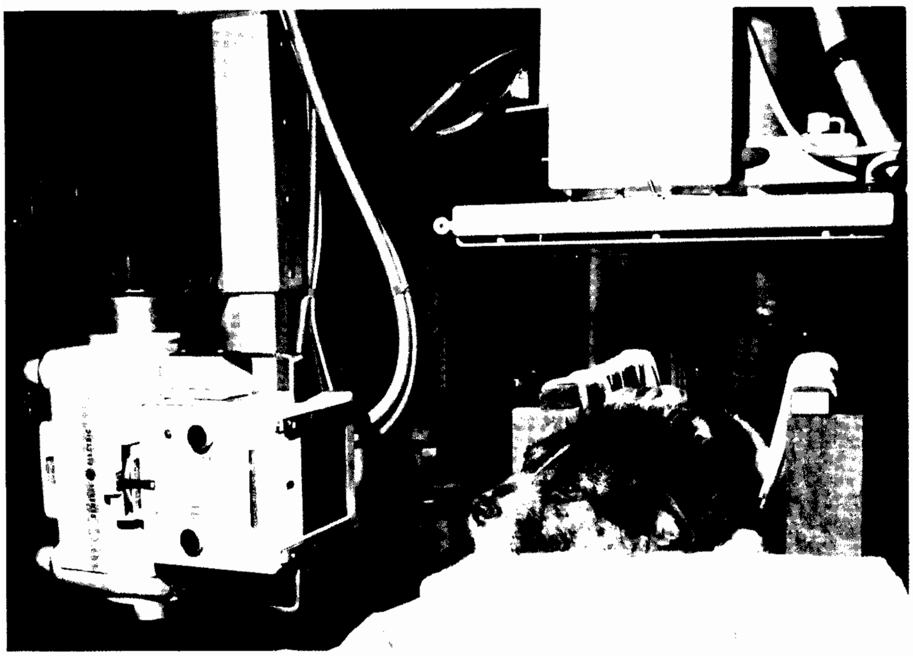
D-703 Böblingen
Federal Republic Germany

# The HP 9820A System for Experimental and Clinical Cardiac Radiology

**by Dr. Hans G. Ringertz**



**Position of dog in relationship to the X-ray beams in the laboratory.**

HP computing systems have for a long time been used for various physiological calculations in cardiology. A closely related field in which the need for advanced calculator systems is rather marked is cardiac radiology, where such a system has a wide use both clinically and experimentally.

Biplane cineradiography examinations are routinely employed in the study of ventricular cavities and valvar prostheses, and the majority of institutions in which detailed cardiac radiology is performed use this method. At the University of California School of Medicine in San Francisco, the Cardiac Section of the Department of Radiology uses the HP 9820A computing device for part of the analysis of cine films. Some of its applications are for (1) calculations of left and right ventricular volumes with plotted output, (2) analysis of normal and abnormal motion of valvar prosthesis, (3) calculations of multiple spatial distances between myocardial markers in experimental animals, and (4) construction of length-pressure approximations of regional myocardial stress-strain integrals with plotted output.

### Equipment Required

The HP 9820 with extended memory (1453 internal registers), is the basic equipment used for the analyses. Cineangiographic data are entered through the HP 9864A Digitizer and numeric data through the 9820 keyboard. For intermediate data handling, the HP 9865A External Tape Cassette and the cassette memory ROM are included. Output is recorded on the HP 9862A Plotter as well as on the printer tape (Figure 1). The program system as currently available includes the previously mentioned options but can, of course, be extended or modified in accordance with the needs and desires of the individual user. The 9820 is used essentially in a conversational mode. Contrast shadows of the ventricles in 2 projections, elliptical shape and orientation or projected valvar prosthesis, biplane position of myocardial markers, etc., are entered using the digitizer.

### Calculations of Ventricular Volumes

The end-diastolic (maximal) and end-systolic (minimal) volumes of the left or right ventricle are calculated from biplane cineangiographic recordings. The general principles of the computations have been described by Goerke and Carlsson (1967). The magnification is calculated in the same way as in that article, but the ventricular outlines are traced with a digitizer. Each projection is divided into 20 sections along the head – foot axis and the volume V is calculated according to the formula

$$V=\frac{\pi f}{4}\sum_{i=1}^{20} a_i b_i$$

where f is the total magnification factor calculated according to

$$f=f_1 f_2 (f_1+f_2)/2$$

– $f_1$ and $f_2$ are the enlargement factors calculated for the antero-posterior and lateral projections and $a_i$ and $b_i$ are right – left and front – back axes of the i'th elliptical cut. The left and right ventricular volumes are corrected according to Carlsson et al. (1971), including the filling time correction for the right ventricle.

### Motion of the Valvar Prosthesis

The valvar prosthesis moves with the heart during the heart cycle. It has a combined rocking and translational movement, which can be studied from the radiographic image of the radiopaque metal ring that forms the periphery of the prosthesis. A frame-by-frame analysis of the size and form of the projected ellipse gives 2 repeating functions, the type of which indicates whether the prosthesis is sufficiently fixed or not. One function is the angle that the valvar plane forms with the direction of the X-ray beam, and the other is the linear motion of the center of the valve. The great advantage of this method of analysis is that no catheterization or injection of contrast medium is needed – just a short cinerecording of the motion of the fixed parts of the prosthesis.

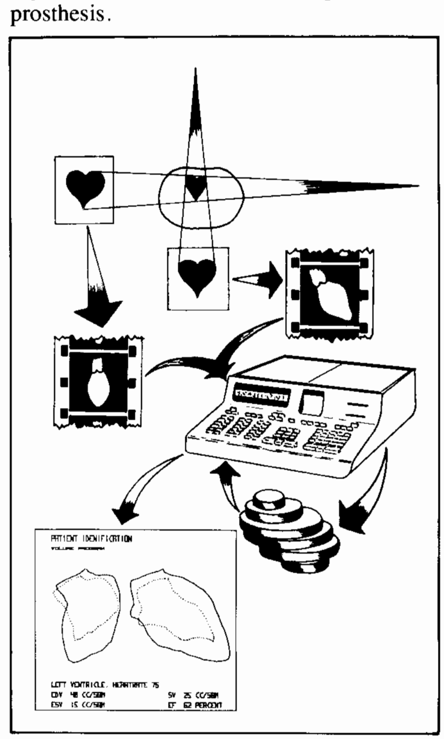


**Figure 1**

**Calculations of Multiple Distances Between Myocardial Markers**

To determine segmental myocardial length in normal and pathologic conditions without thoracic surgery, myocardial markers have to be used. They can be introduced according to the method originally described by Carlsson and Milne (1967), using a catheter to guide a flexible screwdriver to introduce small spirals of tantalum into the myocardium. These markers are then identified cineradiographically (60 or more frames per second) in 2 planes.

The program calculates the spatial distances between all possible combinations of 2 screws and gives an estimate of the linear accuracy from the over-estimated positional information along the common axis in the biplane cineradiographic recording system. The data-handling includes reading the plane positions with the digitizer and correcting for the different magnifications in the 2 planes, as well as for the difference in magnification between the individual markers. The positional information and the simultaneously measured intraventricular pressures are stored on cassette tape. The output includes a listing of the individual vector length, its changes over the heart cycle, and the plot of each regional length-pressure loop (Figure 2) (see Tyberg et al., 1973). The length-pressure loop is an approximation of the myocardial stress-strain relation — the loop area representing the work done and the length coordinate of the centroid of the loop representing the compliance of the myocardial segment (Figure 3).

**CURRICULUM VITAE**

Hans G. Ringertz received his MD in 1964 and PhD in Biophysics in 1969 from the Karolinska Institute in Stockholm, Sweden. His present position is Associate Professor in Radiology and Assistant Head of the Department of Pediatric Radiology at the Karolinska Hospital in Stockholm. The program system was designed and written when he was Affiliated Clinical Visitor at the Department of Radiology and the Cardiovascular Research Institute, University of California School of Medicine in San Francisco. Dr. Ringertz has had a large number of articles published in both biophysical and radiological journals.

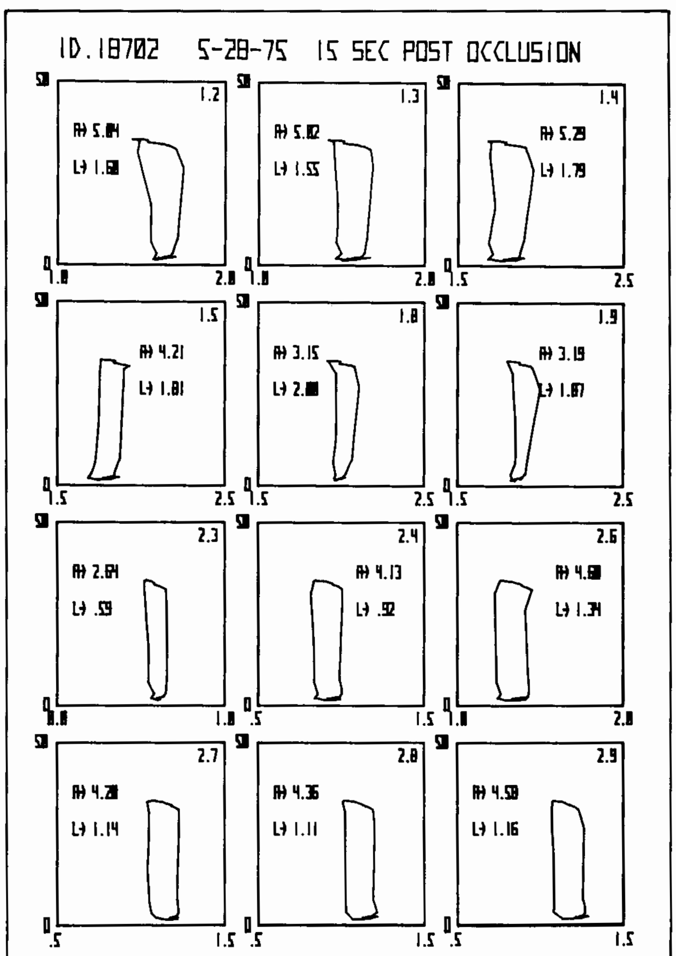



Figure 2

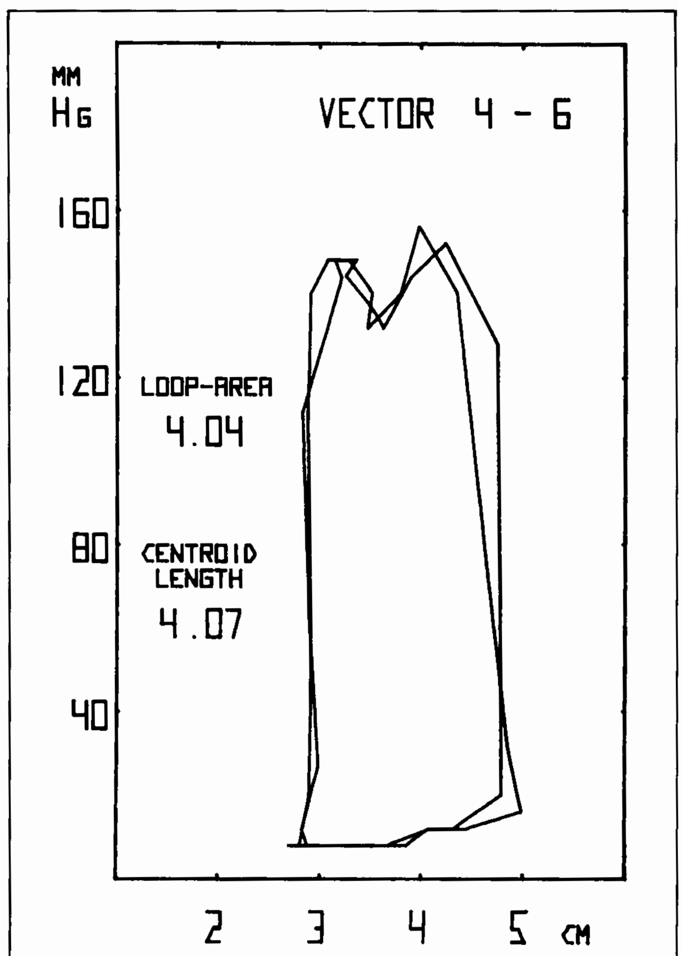



Figure 3

# Marine Archeological Surveying

by J. Barto Arnold III

The coastline of the Gulf of Mexico has been an established seaway since the Spaniards' conquest of Mexico in the 1500's. Early mariners followed the coastline all the way to the southern tip of Florida on the way to Havana, keeping sight of land, before sailing for Spain because the navigational equipment of the time was rudimentary and unreliable. The frequently stormy Gulf claimed many victims among these early sailing vessels.

During the summers of 1974 and 1975, the Underwater Archeological Research Section of the Texas Antiquities Committee conducted an extensive program to locate, record, and test excavate shipwreck sites, some dating as far back as 1554, off the coast of Padre Island, which skirts the Gulf side of southern Texas (Figure 1). The value of establishing such an inventory lies in methodically and comprehensively researching and excavating these sites and in knowing their locations. If an historically important site is threatened, steps may be taken to either remove the threat or excavate the site before its destruction.

The research design for the field phase of the project was broken into 4 phases – search mode magnetometer survey, in-site magnetometer survey, site test excavations, and intensive selected-site excavation. The search mode magnetometer survey and three in-site surveys took place during July, 1974, and June, 1975. The third phase occurred the summer of 1975 between the last week of July and the end of October. Intensive selected-site excavations for the more promising sites will be scheduled in the future.

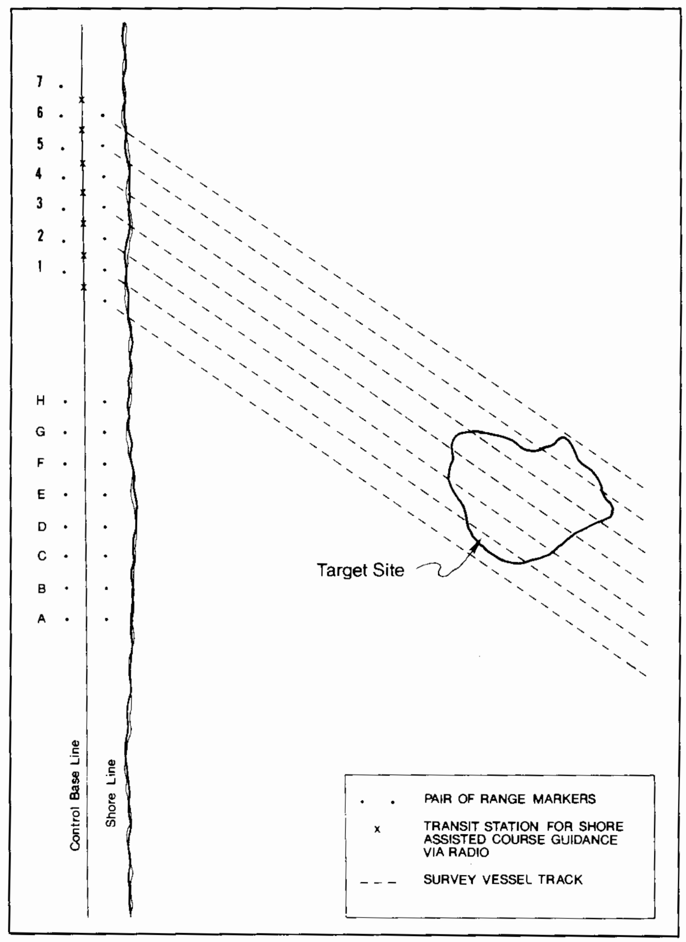



**Figure 3. Optical control system for the magnetometer survey.**

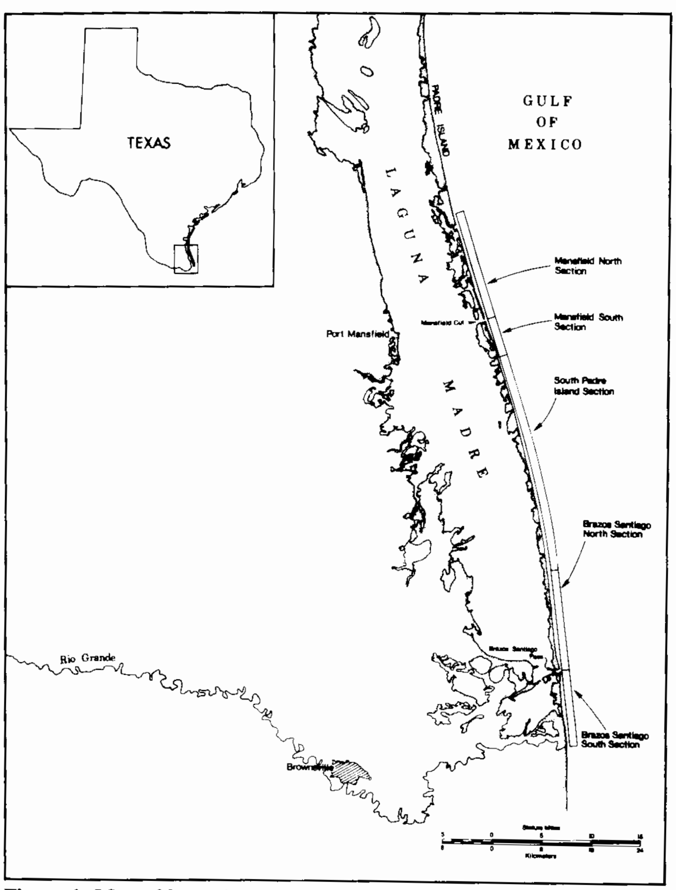



**Figure 1. Map of lower Texas coast showing search mode magnetometer survey areas.**

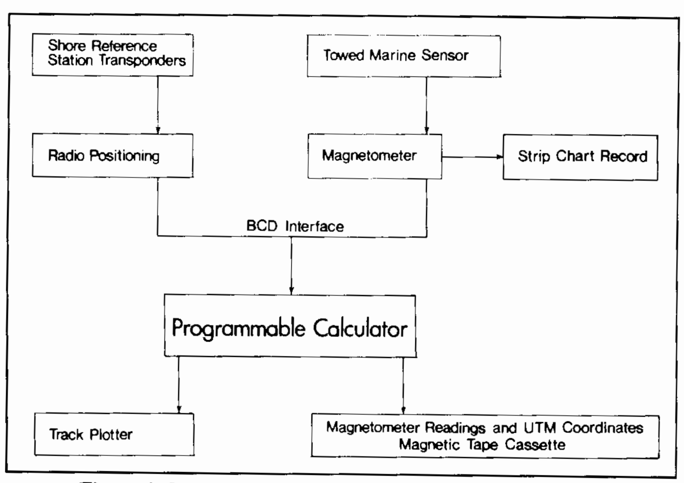



**Figure 2. Marine magnetometer survey system diagram.**

## PHASE 1, SEARCH MODE MAGNETOMETER SURVEY

A major problem in conducting the entire program was locating and recording the shipwreck sites with such a degree of accuracy that these sites could be readily and quickly relocated. New technology was developed to meet that need.

### Instrumentation

Figure 2 shows the diagram of the survey instrumentation system.

In underwater archeology the magnetometer is of particular importance. Visual searches by divers are often impractical because of poor visibility, the large search areas involved, and the possibility of the site being covered by sediment.

The magnetometer measures the strength of the earth's magnetic field. Distinctive disturbances or variations in the strength of that field, known as anomalies, are caused by ferrous elements present on and around the wreck such as anchors, cannons, and fastenings and are recorded by the magnetometer.

The Varian V-85 proton magnetometer with a marine sensor was used on this survey. A Hewlett-Packard 680 Strip Chart Recorder created a permanent record of the magnetometer readings, which were taken at a sample rate of 1/s. The magnetometer sensor was streamed 30 meters behind the survey vessel, a 10,3 meter (34 ft) all-aluminum crew boat, and about 2 feet below the surface of the water. An oscilloscope was used to check tuning and the strength of the precession signal from the sensor.

Controlling the position of a survey vessel is a universal problem for marine archeologists. Precise positioning control is necessary for accurate mapping of the data gained from the magnetometer survey and for plotting the survey vessel's course for complete and even coverage of the survey area. An advance in accuracy was gained by using a system of 2 optical ranges set at appropriate angles to cover the target area with an evenly spaced grid, 1 set of axes representing the vessel track and the event marks being applied to the magnetometer strip chart as the axes of the second set of ranges were crossed one by one. This system is still dependent to some extent upon the assumption of a straight vessel track, although control can be improved through shore-assisted guidance with a transit and 2 way radio communications (Figure 3).

The Motorola Mini-Ranger III was selected as the vessel position controller. It was the source for each position reading recorded on magnetic tape and continuously updated the vessel position for the course or track plotter. The Mini-Ranger read the distance from the vessel to 2 reference stations on shore simultaneously. Aboard the vessel a radar pulse was emitted, activating a return pulse from the radar transponder at each reference station. Distance was measured by timing the interval between the 2 pulses. Accuracy was $\pm 1$ meter, or 3 times better than a similar method of position control using sonar.

The distance readings were translated into coordinates for the track plotter and were also used to calculate the position of the magnetometer sensor, thereby providing provenience* control for those readings. To produce these coordinates, the coordinates of the reference stations must also be known, which entailed the prior, accurate surveying of each reference station location. The Universal Transverse Mercator Grid System was selected for this project because it is a metric, international system that can be used and understood by all.

The Hewlett-Packard 9821A (in 1974, and the 9830A in 1975) was selected to translate the distances provided by the Mini-Ranger into coordinates for the track plotter and to act as coordinator to take instrument readings, calculate coordinates of the vessel and magnetometer sensor, send instructions to the track plotter, and send accumulated data from its memory to be recorded on magnetic tape cassettes, each function at its allotted time and in its allotted order (Figure 5). To enable the calculator to act as coordinator, both hardware and software interfaces were developed, as well as programs for calculating coordinates and controlling the track plotter. Cycle time for the complete sequence was about 2 seconds.

The 9821's built-in magnetic cassette drive was used for storing magnetometer readings and their location coordinates. A Hewlett-Packard 9862A X-Y Plotter was the track plotter .

The survey vessel was also equipped with a Simrad 160 Fathometer. It was used to obtain a chart record of the depth data along the survey lines. Accurate maps of the bottom contours were made from the depth data and the 9862 plots of the survey vessel's actual path, since a BCD interface with the calculator was not possible with this particular fathometer.

If the proton magnetometer, radio-positioning system and calculator – plotter system were to be purchased, the cost would have run between $40,000 and $50,000, a figure beyond the budget of most archeological projects. The answer for us was to lease them, which for 1 month in 1974, came to something less than $8500. The instrumentation package allowed the accurate and rapid coverage of large areas, and the cost, when compared with the amount of area covered and data acquired, is quite reasonable. The only real concern at the outset of the project was that, even though the instrument interfacing was perfectly possible in theory, there is always the specter of some unforseen problem when putting together a system that has never before been interfaced. After only minor adjustments, however, the system proved successful.

## Strategy

Two sections of coastline were of particular interest the first year – a 10-mile portion of the Mansfield Section centering around the Mansfield Cut and a 15-mile stretch of the Brazos Santiago Section north and south of Brazos Santiago Pass. In 1975 the 20-mile gap between the two was covered, as well as a contiguous 5-mile stretch to the north. Three Spanish ships were known to have wrecked near what is now the Mansfield Cut in 1554. One was excavated in 1972 and 1973 by the Texas Antiquities Committee and another had been exploited by treasure hunters. The survey was designed to locate the third vessel and any other wrecks, the probable existences of which were indicated by artifacts found on the beaches of Padre Island. The Brazos Santiago section was selected because it has long been a center of heavy maritime activity. At least 200 ships have been lost since the early 19th century in that vicinity. Also, parts of these areas had been surveyed earlier and further data was needed.

Wrecks on this high-wave-and-surf-action coast seem to have a pattern of a large central anomaly covering an area representing the main body of the wreck and smaller anomalies scattered over an area several times the size of the main body. Previous in-site delineations of the two rather small Spanish ships provided the minimum dimensions necessary for determining track spacing. Given the worst case with the long axis of the wreck site's main body running parallel to the survey tracks, the spacing was arranged so that the site would be crossed at least twice. Taking this into account, as well as the fact that most of the sites would represent the remains of larger ships, we felt that the selected 45-meter spacing would provide close to 100% confidence that all shipwreck sites in the survey area would be located.

The data acquired on this survey went through 3 stages of automated processing and analysis; a rough field plot of anomalies carried out with the 9821 or 9830 and 9862, transfer from cassette to 1-inch tape and editing, and contour plotting by computer.

The field analysis was an important check on the proper functioning of the instrument system as well as a rough indication of anomaly distribution. The memory capacity of the 9821 was not large enough to produce contour plots, but a program was written that searched for a significant change in successive magnetometer readings. When a change above a defined value was found, the calculator was directed to draw an X on the plot at the proper location as indicated by the coordinates recorded with each magnetometer reading and to print the value of the change. These field plots provided a rough idea of the distribution patterns of anomalies present in the data, and comparison with the contour plots produced by computer proved them reasonably reliable.

Transferring the data from cassettes to a 1-inch magnetic tape for the computer was carried out with a Hewlett-Packard 9830A. With the proper configuration of options, the 9830 can function as an interactive terminal, and through a telephone link with the University of Texas at Austin Computation Center's CDC 6600-6400 computer the data transfer was achieved. A program was then written to edit the data to eliminate the faulty readings (less than 1%), arrange the data in the format required by the contour-plotting routine, and calculate certain parameters required for that routine.

Analysis of the anomaly distribution plots prepared in the field indicated 121 significant clusters of anomalies. Each anomaly was identified, cataloged, and its location indicated by Universal Transverse Mercator (UTM) grid coordinates. Returning to the anomalies for site testing was a simple matter of calculating either an angle from each of two shore reference stations or an angle and a distance from one shore station.

Roughly 25 miles (40 km) of coast were covered by each survey, and the total of about 50 miles (80 km) forms an unbroken stretch beginning at and continuing north from the Rio Grande River, which is the U.S. — Mexico border.

## PHASE 2, IN-SITE MAGNETOMETER SURVEY

The in-site survey of a particular wreck is designed to cover the site with closely spaced tracks in order to produce a highly detailed magnetic contour map. It provides, in effect, a preview of the distribution of the ferrous artifacts. Two in-site surveys were carried out in 1974 – one on a wreck thought to be the sister ship of the Spanish ships that went down near the Mansfield Cut and another near the north end of the second survey area near Brazos Santiago. A second 1554 wreck was covered in 1975.

It is very unusual for the magnetometer survey vessel to cross the exact center of an anomaly or to cross directly over the object causing the anomaly. Test excavations based solely on the anomaly location noted during the search mode survey would be long and difficult if a magnetometer or some other metal detector were not used to pinpoint the anomaly's center of highest intensity before test excavations begin.

The sensor of a portable proton magnetometer was towed behind the crew boat during the initial relocation of the anomaly. A buoy was dropped as the anomaly was recorded on one pass headed toward shore, and one was dropped on another pass headed away from shore to bracket the anomaly. Further passes at right angles to the first two further defined the position of the anomaly's center. The boat was then anchored using a 3-point anchoring system and maneuvered by means of the anchor lines into the area near the anomaly's center. The magnetometer's sensor was used again, this time towed by a surface swimmer, to precisely locate and buoy the center of the anomaly. The boat was then moved over this location and excavations commenced.

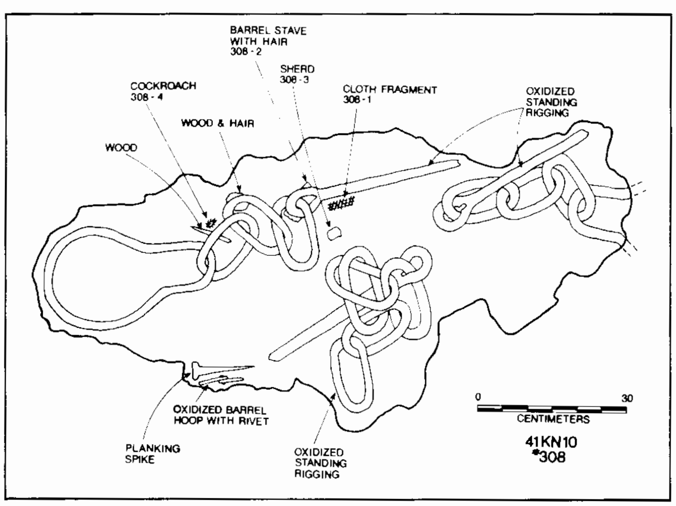



**Figure 4. Medium-sized conglomerate recovered at a previously unexcavated area of site 41 KN 10 (anomaly MN 10-13 b). Along with the smaller items indicated, the conglomerate contained 3 examples of standing rigging, which can probably be identified as chain plates. (From a drawing by the Antiquities Conservation Facility of the Texas Archeological Research Laboratory, University of Texas at Austin, which carries out conservation under contract to the Texas Antiquities Committee.)**

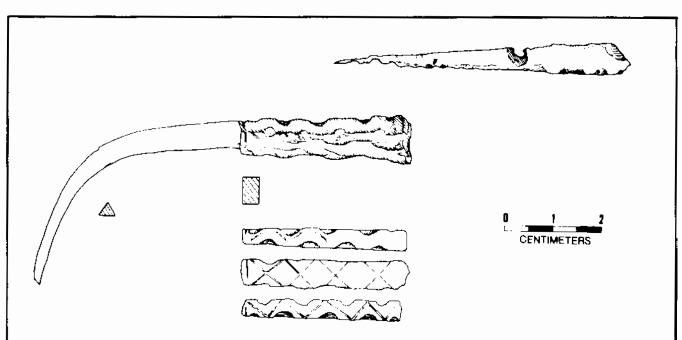



**Figure 5. Bronze items from 41 KN 10 (anomaly MN 10-13 b), a 1554 Spanish wreck site.**

## PHASE 3, SITE TEST EXCAVATION

From about 2 to 5 feet (0,6 to 1,5 m) of sand and shell cover most artifacts, which had shifted down to the top of a dense layer of Pleistocene clay into which there is little or no penetration. An ocean bottom sediment displacement unit, also called a prop wash deflector or blower, was used to erode the overlying sediments down to the layer of Pleistocene clay, thus exposing any artifacts. Divers worked around the edges of the expanding, crater-like hole to assist in excavation by stirring sediment into suspension to be blown away by the artificially created current and to remove larger shells that tended to pile up around the edge of the hole and block the erosion process. Small conglomerates of artifacts cemented together by corrosion products, metallic, or other relatively dense items that remained on the sites were not disturbed by the blower.

The blower could excavate a hole 3 to 5 meters in diameter in about 15 minutes, depending on water depth, depth of overburden, and other less important factors such as speed of the alongshore current, sea state, and size and ratio of shell to sand.

Test excavation strategy was to recover a few small artifacts or conglomerates from sites of possible historical interest. After they were cleaned in the conservation laboratory, specific identification*of nationality and time period of the wrecks would hopefully be possible.

The provenience control system used the UTM grid also, but no physical grid of plastic pipes or other material was constructed, as it sometimes is in underwater archeological excavation. Instead, base points or trilateration stations were established by driving sequentially numbered section of aluminum pipe vertically into the bottom at convenient locations. Measurements to artifacts and other objects and base points were made from at least 2 such base points. Angles to at least 2 base points at each site were surveyed from the reference stations on shore in order to calculate their UTM coordinates. A site plan was constructed using this information. Because of re-sorting, the only vertical

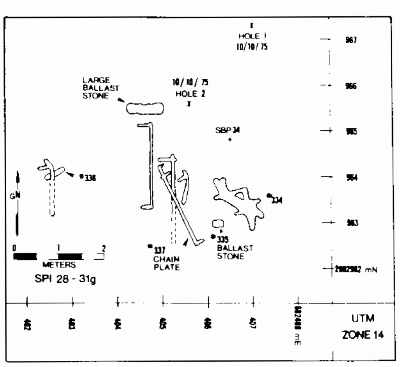



**Figure 6. Site plan of one of 2 groups of artifacts found by test excavations at anomaly SPI 28-31 g. Several of the artifacts are chain plates from a sailing ship of the mid-19th century. SBP=sub-base point. The centers of the test excavation "pits" are also indicated.**

provenience with any meaning is that which was permanently preserved by the concrete-like corrosion products of the artifact conglomerates.

The angles to each hole excavated during the site-testing were also surveyed from the shore reference stations. This information was used to make tactical decisions and avoid wasted effort. A simple method of making a planned and efficient excavation pattern was developed by plotting the relative location of the center of each hole as excavation was begun. The angles surveyed for each hole were also used to calculate UTM coordinates for the center and enable a more accurate plotting on the site plan along with artifact distribution.

Underwater photography was difficult in the murky waters off Padre Island. However, it was often desirable to take pictures and construct photo mosaics of complex groups of artifacts that were not recovered and for which underwater mapping by hand would have been too time-consuming. It proved a satisfactory method for constructing the needed drawings later, although publishable photos were rare.

The test excavations were carried out with almost pinpoint accuracy. Of the 26 anomalies tested by excavation at 24 sites, the cause of the anomaly was located in 2 holes or less 58% of the time.

Thirty-five small anomalies or clusters of anomalies appeared promising in pattern if not in magnitude and were examined during the site-test phase. Test excavations were carried out on 3 of these anomalies to determine their nature, but no objects were located; it is suspected the anomalies are geological in nature. Twenty-nine others were examined with the magnetometer only and are also possible geological anomalies. Three small anomalies proved to be distant readings of larger anomalies, of which only the edge was crossed during the search mode survey. This information, together with the readings from the already intensively excavated 1544 wreck, indicate the satisfactory nature of the 45-meter search mode survey track spacing.

The area examined most intensively was that of the north section of the Mansfield Cut Underwater Archeological National Register District and the neighboring stretches of coastline. Within this area the third Spanish shipwreck had been located and identified during the survey and test excavation phases. It lay at the Cut and had been obliterated by the dredging of that artificial opening through Padre Island and construction of jetties, and/or by treasure hunters.

The cause of an anomaly located at the northernmost 1554 shipwreck site proved to be an unexcavated extension of the site. A medium-sized conglomerate containing a "chain plate" and several smaller items including a large silver disc, a bottle base, and two small bronze items were recovered (Figures 4 and 5).

Another anomaly associated with the 1554 wrecks was located about 250 meters inshore and 200 meters south. The cause was a ship's anchor of the type recovered earlier from the nearby wreck site. It seems unlikely that if it belonged to that wreck, it reached its resting place through natural forces, since it was so far inshore from the main body of the wreck. Spanish salvagers might possibly have moved it from the wreck for use in anchoring small boats just outside the surf line. Another and perhaps more likely possibility is that this anchor and the small anomaly remaining after its removal might represent the wreck of a small vessel belonging to a Spanish salvage party.

Of the other test excavations, the most historically significant were at the sites of 2 wrecks, one dating to the middle of the 19th century and the other dating to the last half of the 19th century. Figure 6 shows the site plan for a test excavation of the mid-19th century wreck.

The 3 months of the 1975 season's work covered 59 anomalies located during the two 1-month magnetometer surveys in 1974 and 1975. A further 6 to 8 months of field work is necessary to complete the historical and cultural resource inventory of the southernmost 50 miles (80 km) of the Texas coast.

### Curriculum Vitae

J. Barto Arnold III received his BA in 1971 and MA in 1972 from the University of Texas at Austin. The degrees are in anthropology with specialization in archeology. He has been associated with the Texas Archeological Research Laboratory (1971-1972) and the Underwater Archeological Research Section of the Texas Antiquities Committee (1972 to present), and he is now Director of the Padre Island Underwater Archeological Research Project. A number of Barto Arnold's published articles and papers presented before professional organizations have detailed the automated systems and the project results described in this article.

*"Provenience" is a term used by archeologists when referring to the location of an object relative to the locations of other objects and the environment.

# A Computerized Election Campaign Game

by Dr. Richard A. Blade

I have written a 9820A election campaign simulation program for teaching political science classes the mechanisms and strategies involved in election campaigns. Since U.S. citizens will be electing a President and Vice President this November, I thought the program would be interesting to other *KEYBOARD* readers for possibly a number of reasons. Educators constantly look for new and interesting teaching methods, and while this program is written for the U.S. electoral system, it could be amended for use with the systems of other countries. The "recreational" aspect should appeal to many other 9820 users.

The election campaign simulation is played somewhat like a parlor game. The class is divided into two teams, Republicans and Democrats, and each party "plays" a certain strategy for a number of turns, each turn representing 1 week of a 10-week U.S. presidential campaign. Equipment required is the 9820A Opt. 001, 9862A Plotter, 9865A Cassette Memory, and 9866A Printer (optional).

The original game concept was worked out with a colleague, Burnell G. West. Our primary problem in creating the simulation was to devise a process whereby the information entered by the teams contains all the essential factors realistically determining the attitudes of the electorate, yet is simple enough to have one entire campaign simulated in a single class period. We decided the many factors involved could be grouped into 4 broad categories of

- economics,
- civil rights,
- foreign policy, and
- influenceability.

Influenceability describes the general reaction of a segment of the population to publicity alone, regardless of the politician's stand on issues. We originally thought a class of personal characteristics, labeled charisma, should be included, but since it is an unchanging set of factors and would have to be assigned arbitrarily at the beginning of the game, we decided its inclusion would only detract from the game.

Rather than consider each of the 50 states separately, we decided to use 24 geographical regions, chosen somewhat on the basis of uniformity in political attitudes, but mostly to make the game interesting and workable. Each region is assigned 3 numbers between $-3$ and $+3$ to indicate the attitudes of the general population on economics, civil rights, and foreign policy (Table 1). In general, a more negative number indicates a more "liberal" attitude, and a more positive number indicates a more "conservative" attitude, zero being neutral. For instance, $-3$ on economics indicates the electorate heavily favors welfare and public spending; $+3$ indicates heavy opposition to public spending and (perhaps) a favoritism toward business. A $-3$ on foreign policy indicates a strong desire for isolationism, while $+3$ indicates an equally strong intervention tendency. A $-3$ on civil rights indicates a strong support of government enforcement of civil rights and sympathy for minority group movements, and $+3$ indicates strong opposition. Influenceability ranges from 0 (electorate decides totally on the issues) to $+3$ (electorate is heavily influenced by publicity completely apart from the issues). The numbers assigned to each region in Table 1 are based mostly on 1968 election information. I stands for influenceability, E for economics, C for civil rights, and F for foreign policy.

Publicity (or public relations) is accounted for in 2 ways. First, it reflects the effect of each candidate's stand on the issues in each region visited and, to a lesser degree, in the remaining regions. Second, it affects popularity through the influenceability factor characteristic of each region. It was thought that expenditures on publicity should be broken down into television, radio, billboards, etc., but after much study we decided for reasons of simplicity to assume that the "best" mode of publicity will always be chosen, and for this mode (or combination of modes) the cost per unit of influence per voter is constant. Of course, there is always a certain amount of publicity credited a candidate both regionally and nationally regardless of publicity expenditures by a party.

National publicity is both automatic and purchased through network television time. Here, as in the individual regions, the publicity always helps the candidate through the influenceability factor, but it may hurt the candidate in regions where the electorate's ideas on economics, civil rights, and foreign policy are contrary to the candidate's stands.

The popularity of each candidate in a given region is determined by his or her cumulative score in that region compared with that of the other candidate. The percent of popularity for the Democrats, for instance, is given by

$$\%D = 100\% \, D/(R+D)$$

where D is the score for the Democrats in that region and R is the score for the Republicans.

If either candidate has a negative score, the percent of popularity is recorded as 0.

The score for each candidate in each region is the sum of 2 parts. The first part, $D_1$ (or $R_1$), is independent of which region is visited and is affected by national television. This takes the form

$$D_1 \text{ (or } R_1) = W(1 + T/2x10^6)(21 + S_E E + S_C C + S_F F)$$

where W = 1 for weeks 1 through 9, 3 for week 10,

T = amount spent on national television,

I = influenceability,

SE = stand on economics,

E = attitude of the region on economics,

SC = stand on civil rights,

C = attitude of the region on civil rights,

SF = stand on foreign policy,

F= attitude of the region on foreign policy.

The W factor makes the tenth week, the week of the election, 3 times as important as the other weeks. For \$5 million spent on national television, the candidate can double this part of the score in every one of the 24 regions; for \$10 million he or she can triple it, etc.

The second part of the score is determined by the candidate's itinerary. Each turn represents 1 week of campaigning and is broken down into three 2-day periods of speech-making. During each 2-day period the candidate can visit one region only to either campaign or raise funds. Since it is assumed that in fund-raising the candidate influences only a small segment of the population that would vote for him or her anyway, no regional or political attitudes or stands on the issues enter into consideration. For each 2-day fund raising period, the candidate receives \$2 million. Each candidate is given \$25 million to start the campaign.

For each 2-day period the candidate visits a region to campaign, the second part of the score in that region is obtained as follows:

$$D_2 \text{ (or } R_2) = W(2+P) \quad (PI + S_E E + S_C C + S_F F)$$

where W, I, $S_E$, E, $S_C$, C, $S_F$, and F are as defined earlier, and P, the effect of publicity in that region, is found by

$$P = \frac{\Lambda}{10^5 V}$$

where $\Lambda$ = dollars spent on publicity in that region during that 2-day period, and

V = number of electoral votes in that region.

The conclusion drawn from this formula is that spending \$200,000 per electoral vote in the region more than doubles that portion of the score. (It would double exactly if the PI term were not to be changed.) These figures on regional and national publicity may prove somewhat unrealistic. Almost certainly they represent the weakest part of the game; but having been ascertained primarily as a result of trial and error, they do seem consistent with the relative impact on public opinion. Moreover, the results would be unchanged if all the monetary factors (cost of publicity units, amount of money initially provided, and money raised in each fund-raising effort) were increased or decreased by the same proportional amount.

The best way to show how the game works is to go through one turn as an example. The origin of inquiry and response is indicated by D (9820 display), P (9820 Printer), and K (9820 keyboard). The game is started by pressing the RUN PROGRAM key; the same key is pressed after each keyboard entry also. The program proceeds as follows:

```
P:  ELECTION GAME
    DEMOCRATS TURN
D:  ECONOMIC POLICY?
K:  -1
D:  CIVIL RIGHTS?
K:  -2
D:  FOREIGN POLICY?
K:  -1
D:  WHERE MONDAY-TUESDAY?
K:  20
D:  SPENT ON PR?
K:  2 000 000
D:  WHERE
    WEDNESDAY-THURSDAY?
K:  RUN PROGRAM (for fund raising)
D:  WHERE FRIDAY-SATURDAY?
K:  21
D:  SPENT ON PR?
K:  0
D:  HOW MUCH
    NATIONAL TELEVISION?
K:  5 000 000
P:  REPUBLICANS TURN
```

The Republicans then enter their information. Both teams have already met in separate rooms and decided their entries before meeting at the 9820. The Republicans are not allowed to change their entries after seeing those of the Democrats. There are a number of aspects of the game where the teams are put on their honor to conform to the rules. For example, while there is no obligation on the part of either team to take any particular stand (e.g., the Democrats do not have to be at all liberal), a candidate should not change his or her stand on any issue by more than one unit per week. We could have included tests in the program to detect such infractions of the rules, but the memory capacity of our 9820 would not permit it.

Continuing with the readout after the first turn for both the Republicans and Democrats, we have:

```
P:  WEEK NO. 1
    DEMOCRATIC SPEECHES ON
    ECONOMICS -1
    CIVIL RIGHTS -2
    FOREIGN POLICY -1
    REPUBLICAN SPEECHES ON
    ECONOMICS 3
    CIVIL RIGHTS 1
    FOREIGN POLICY 0
    RESULTS OF POLLS
    REGION 1
    DEMOCRATS 52
    REPUBLICANS 48
    REGION 2
    . . .
    . . .
    . . .
    ELECTORAL VOTES
    DEMOCRATS 140
    REPUBLICANS 173
    CAMPAIGN FUNDS REMAINING
    DEMOCRATS 20 000 000
    REPUBLICANS 23 000 000
```

A second copy of this readout is made so that both teams may retire to their separate rooms to study the results and prepare their entry for the next turn.

The final turn simulates the election itself, and in addition to the printer readouts (or instead of, if preferred), we use the plotter to draw a map and give the results of the election. This dramatic way of presenting the results makes the conclusion very exciting. If desired, the map may be drawn after each turn instead of only at the last. It provides no additional information that would influence the players' strategies except for the popular vote, which is of no great value other than general interest. Plotting the map early also permits the game to be completed in less than 10 turns, which is useful for demonstration purposes and shorter class periods.

The game was introduced to an upper-division class in political parties and played in several 2-1/2-hour class periods. The students' reactions were highly favorable, as evidenced by written evaluations. The teams tended to follow a strategy of starting with rather extreme stands and "sewing up" easy regions, progressing to a moderate stand and emphasizing important contested regions at the end. In some cases they emphasized winning in a large number of unimportant regions, and in other cases they concentrated on a smaller number of very important regions.

The game has 2 disadvantages. It does not deal with specific current issues and personalities, which tends to make it somewhat abstract. It is also difficult to determine how real the simulation is, which affects the educational usefulness. To increase reality and accuracy, a colleague in political science and I plan to have the students research and update the grading of the regional political attitudes as an advance phase of playing the game.

A paper on this election campaign simulation program was presented at the 7th annual Conference on Computers in Undergraduate Curricula at the State University of New York at Binghampton held June 14, 15, and 16, 1976. C.C.U.C. has given permission for an extract of this paper to be published in *KEYBOARD*.

*EDITOR'S NOTE: Dr. Blade reports the program was very popular with the educators at the Conference. If you are interested, a listing of "A Computerized Election Campaign Game for Political Science Classes" is available on request by writing to KEYBOARD, Hewlett-Packard, P.O. Box 301, Loveland, Colorado 80537, U.S.A.*

**Table 1: POLITICAL CHARACTERISTICS OF THE ELECTORATE BY GEOGRAPHICAL REGION**

| Electoral Region | States | Electoral Votes | I | E | C | F |
|---|---|---|---|---|---|---|
| 1 | California-Nevada-Hawaii | 47 | 1 | 2 | 0 | −1 |
| 2 | Colorado-Utah-Arizona-New Mexico | 19 | 1 | 2 | 1 | 1 |
| 3 | Florida | 14 | 1 | −1 | −2 | −2 |
| 4 | Georgia-Alabama-Mississippi | 29 | 0 | 3 | 3 | 2 |
| 5 | Idaho-Montana-Wyoming | 11 | 1 | 2 | 2 | 1 |
| 6 | Illinois-Indiana | 39 | 2 | −1 | 0 | 1 |
| 7 | Kansas-Missouri | 19 | 2 | 1 | 1 | 1 |
| 8 | Kentucky-Tennessee | 20 | 1 | 2 | 1 | 2 |
| 9 | Louisiana-Arkansas | 16 | 1 | 1 | 2 | 2 |
| 10 | Maine-New Hampshire-Vermont | 11 | 1 | −1 | −2 | 2 |
| 11 | Maryland-District of Columbia | 13 | 1 | −2 | −1 | −2 |
| 12 | Massachusetts-Rhode Island-Conn. | 26 | 0 | −2 | −3 | 1 |
| 13 | Michigan | 21 | 1 | −1 | 1 | −2 |
| 14 | Minnesota-Iowa | 19 | 0 | −3 | −2 | −2 |
| 15 | North Carolina-South Carolina | 20 | 2 | 1 | 1 | 1 |
| 16 | North Dakota-South Dakota-Nebraska | 13 | 0 | 3 | 3 | 1 |
| 17 | New Jersey-Delaware | 20 | 2 | −1 | −1 | −1 |
| 18 | New York | 43 | 0 | −3 | −3 | −2 |
| 19 | Ohio | 26 | 1 | 1 | 1 | 2 |
| 20 | Pennsylvania | 29 | 2 | 1 | 0 | −0 |
| 21 | Texas-Oklahoma | 33 | 3 | 0 | 0 | 0 |
| 22 | Virginia-West Virginia | 19 | 2 | 1 | 0 | −1 |
| 23 | Washington-Oregon-Alaska | 19 | 0 | −2 | −2 | −3 |
| 24 | Wisconsin | 12 | 1 | −2 | −2 | −1 |

**Curriculum Vitae**

Richard A. Blade was born and raised in Bartlesville, Oklahoma. He holds a BS degree in engineering physics and a PhD in theoretical physics, both from the University of Colorado at Boulder. Since receiving his doctorate in 1964, Dr. Blade has taught at Wisconsin State University at LaCrosse, California Insititute of Technology, and the University of Colorado at Colorado Springs, where he is currently chairman of the department of Physics. He acquired the 9820 and peripheral equipment referred to in this article through a grant to establish a self-paced studies program in mathematics at the University of Colorado, Colorado Springs, and designed a system for computer grading placement exams administered one day before registration.

Burnell G. West, currently Vice President for Engineering at EH Research Labs, Oakland, California, worked with Dr. Blade in the initial stages of developing the simulation. Burnell holds a BS degree from the Massachusetts Institute of Technology and a PhD in physics from the University of Colorado at Boulder.

# THE Crossroads

## Fractional Arithmetic

**by John Nairn, PhD**
**Hewlett-Packard Calculator Products Division**

"God made integers, all else is the work of man."
Leopold Kronecker

Modern calculators and digital computers typically provide 12 decimal digits of accuracy, which is usually sufficient for most numerical calculations. Even so, certain numbers like 1/3 cannot be represented exactly and must be approximated by a finite decimal (or binary) representation. This can be the source of difficulties in calculations where fine differences between numbers are significant.

For example, consider the problem of the dice game presented in an earlier Crossroads article (see Reference 1). The game consisted of throwing dice on a table one at a time until 1 of the 6 numbers repeated (i.e., appeared on two of the dice). The problem was to find the probability of the game ending on the first, second, third, etc., throws and to determine on which throw the game was most likely to end. The probability was found to be

$$P(n) = (n-1)/6 * S(n-1)$$

where $S(n-1) = 1-$(sum of the first $n-1$ P's). If the values for P(n) are then calculated using a machine with 12-digit arithmetic, the results given in Column 2 of the following table are obtained.

| Throw | Decimal Calculation | Actual Value |
|---|---|---|
| 1 | 0.000 000 000 000 | 0 |
| 2 | 0.166 666 666 667 | 1/6 |
| 3 | 0.277 777 777 777 | 5/18 |
| 4 | 0.277 777 777 780 | 5/18 |
| 5 | 0.185 185 185 187 | 5/27 |
| 6 | 0.077 160 493 825 | 25/324 |
| 7 | 0.015 432 098 760 | 5/324 |
| | 0.999 999 999 996 | 1 |

Since the game must end by the seventh throw, all higher probabilities are zero. With only the results of the decimal calculations, several questions arise. Does the fact that the probabilities do not total 1 indicate simple round-off error or a flaw in our derivation of the formula for P(n)? Is P(4) really greater than P(3) or is this again due to round-off error? Since the entire problem is to determine on which throw the game is most likely to end, this last question is hardly a trivial one.

The problem is further complicated by the fact that the decimal values obtained for P(n) will depend on the exact manner in which arithmetic and round-off are implemented on the given machine. Another calculator or computer might give better results for this particular problem and worse results for another problem.

Many calculations of this sort can be carried out exactly without any accumulated round-off errors if the arithmetic is done with fractions rather than with decimal (or octal or binary) approximations to these fractions. If the same calculations of the values of P(n) are carried out using fractions, the results in the last column of the table are obtained, and the questions posed are immediately resolved.

As Knuth observes,

> "This (fractional arithmetic) results in a comfortable feeling of security which is often lacking when floating-point calculations have been made, and it means that the accuracy of the calculation cannot be improved upon."

The actual implementation of fractional arithmetic is a reasonably straightforward procedure. For example, adding two fractions A/B and C/D results in a new fraction X/Y where X=AD+BC and Y=BD. The formulas for subtraction, multiplication, and division are just as simple. The only real difficulty encountered is in the process of reducing X/Y to its lowest terms (i.e., removing any common factors in X and Y). You might wonder why we would even bother, since the number is exactly represented whether or not it is reduced. For one thing, although the 2 fractions 466560/1679616 and 5/8 both represent the same number, that fact is neither readily apparent nor easily testable without the reduction step. For another, the whole point of fractional arithmetic is to avoid inexact representation and round-off errors. If you let your fractional representations needlessly grow in size, you will soon be up against the limited accuracy provided by your n-digit machine. As an example, a 6-digit machine could have easily calculated the fractional results of the dice problem. Without reduction, however, about 100-digit precision would have been required to obtain the exact results.

Thus, any fractional arithmetic routines should return to their results in the so-called reduced form. If the original results of the operation yield a numerator and denominator X and Y, the results returned should be X/gcd(X,Y) and Y/gcd(X,Y), where gcd (X,Y) is the greatest common divisor of X and Y, that is, the largest integer that is an exact divisor of both X and Y.

Our problem, then, is to find a good algorithm for calculating the gcd of 2 integers. One obvious method is to factor both numbers and collect any common factors. For example, by observing that

$$13272 = 2 \bullet 2 \bullet 2 \bullet 3 \bullet 7 \bullet 79$$
$$17115 = 3 \bullet 5 \bullet 7 \bullet 163$$

have common factors of 3 and 7 only, then gcd (13272,17115) = 21. This method could be somewhat improved factoring only 1 of the numbers and testing just those factors as divisors of the second number. But even this can require enormous amounts of work. If you're not convinced, look at the work involved in finding gcd (881717,891127) by this method.

Surprisingly enough, one of the best methods for finding the gcd of 2 integers was described by Euclid about 300 BC and (are you ready?) is known as Euclid's algorithm. It is perhaps the oldest nontrivial algorithm that has survived to the present day. I will present here only the method of the algorithm, and not any proof of its validity. The proof is based in the theory of continued fractions and the interested reader should check the reference by Olds for an excellent introduction to the subject, and the one by Knuth for many good details on computer implementation of the algorithm.

The algorithm involves a simple repetitive division process and requires no trial-and-error methods. Let the 2 numbers be N1 and N2 such that N1≥N2. Divide N1 by N2 to obtain a quotient (Q1) and a remainder (N3). Now divide N2 by N3 to obtain a new quotient and remainder, Q2 and N4. Continue this process as in the following example.

| | |
|---|---|
| 17115 | |
| 13272 | 1 |
| 3843 | 3 |
| 1743 | 2 |
| 357 | 4 |
| 315 | 1 |
| 42 | 7 |
| 21 | 2 |
| 0 | |

Because each remainder must be smaller than the previous divisor, the series of remainders will eventually terminate with a zero. The last nonzero remainder is the gcd of the 2 original numbers. Thus, gcd (17115,13272)=21, which agrees with our previous results obtained by factoring.

And thus, Euclid's algorithm provides a quick and easily implemented means of reducing the results of fractional arithmetic routines. Even fractional representations, however, can grow out of bounds for a given n-digit machine. Although more numbers may be accurately represented by this method, care should still be taken to detect overflow and consequent rounding errors. For example, in evaluating (A/B)*(C/D)=AC/BD, which reduces to X/Y, X and Y may be well within the range of the machine, whereas AC or BD may not and will suffer from rounding, yielding an incorrect X or Y. This can be avoided by first calculating gcd (A,D) and gcd (B,C) and dividing these out before carrying out the multiplications. This requires 2 gcd calculations instead of 1, but each calculation requires fewer iterations than in finding gcd (AC,BD), with the result that the total number of iterations is about equal.

Similarly for addition, in evaluating (A/B)+(C/D)=X/Y where X=AD+BC and Y=BD, finding the gcd (B,D) and "factoring it out" will minimize the size of the intermediate results. In fact, Knuth discusses a method of minimizing intermediate results that guarantees answers in reduced form (See Volume II, p. 291 of the reference).

At any stage of the calculations, the exact results in fractional form may be converted to a decimal representation for output purposes by the simple expedient of division. But what if I have a decimal number and want to find a fractional representation for it? Is that possible? (Would I ask if it weren't?) As an example, let's use a representation of 5/18 to 5 digits, namely 0.27777. Obviously, the only fractions that represent 0.27777 exactly are all equal to 27777/100 000 (i.e., reductions of multiples of this value). But are there fractions with smaller denominators that are good approximations for this decimal value? An extension of Euclid's algorithm provides the answer to this question.

We first form a remainder table as was used to find the gcd of 2 numbers on the fraction 27777/100 000.

| | | | |
|---|---|---|---|
| | | 0 | 1 |
| 27777 | | 1 | 0 |
| 100000 | 0 | 0 | 1 |
| 27777 | 3 | 1 | 3 |
| 16669 | 1 | 1 | 4 |
| 11108 | 1 | 2 | 7 |
| 5561 | 1 | 3 | 11 |
| 5547 | 1 | 5 | 18 |
| 14 | 396 | 1983 | 7139 |
| 3 | 4 | 7937 | 28574 |
| 2 | 1 | 9920 | 35713 |
| 1 | 2 | 27777 | 100000 |
| 0 | | | |

Notice that this time instead of first dividing the larger number by the smaller one as with the gcd calculation, we start by dividing the numerator by the denominator, regardless of which is larger. Thus, fractions <1 will generate a sequence of partial quotients that begin with a 0. The preceding sequence of partial quotients (0,3,1,1,1,1,396,4,1,2) is unique to the given fraction and, indeed, has just as legitimate a claim to being a representation of that number as do 0.27777 and 27777/100 000. But the sequence has the advantage of being able to yield approximate fractional representations of the number as well (which somewhat makes up for its ugly-duckling appearance). Let's call the terms in the sequence of partial quotients $a_1$, $a_2$, $a_3$, etc. We now want to generate 2 more series called $p_j$ and $q_j$ defined by the relations

$$p_j = a_j \bullet p_{j-1} + p_{j-2}$$
$$q_j = a_j \bullet q_{j-1} + q_{j-2}$$

with the initial conditions of $p_{-1}=0$, $p_0=1$, $q_{-1}=1$, and $q_0=0$. The p-series and the q-series for 0.27777 is shown as Columns 3 and 4 of the preceding table. The fraction $p_j/q_j$ is called the j'th convergent to the given decimal value. Each convergent forms a better approximation to the decimal value until the last convergent is the exact value of the decimal number. What exactly is meant by "better" is difficult to explain without explaining the background theory of continued fractions. But it can be described qualitatively by saying that for a given convergent, $p_j/q_j$, there is no fraction with a denominator $<q_j$ that is a closer approximation to the given decimal value.

Notice the very large entry (396) in the series of partial quotients for 0.27777. This is typical when a given fraction (in this case 5/18) is a very close approximation to the starting decimal value. A much larger denominator is required to increase the accuracy of the approximation.

As a final example, it is interesting to perform the same expansion on the value of pi (= 3.141 592 653 6). The sequence of partial quotients that represents it is infinite. After calculating the p's and q's we find the sequence of convergents to be 3, 22/7, 333/106, 355/113, etc. From the time that pi was first given as the ratio of the circumference to the diameter of a circle, 3 has been a popular candidate for its value. About 225 BC Archimedes gave 22/7 as a lower bound and better approximation to pi, and this value is still used today when an approximate value of pi is required and a calculator is not handy. And finally, a Chinese mathematician, Tsu Ch'ung-chih used the value of 355/113 for pi during the 5th century.

Euclid's algorithm was only known for finding common divisors, and the extension of his table to find the partial-quotient series and the fractional convergents of a decimal value is a relatively modern adaptation. Since these early fractional approximations to pi were mostly obtained by geometric means, their coincidence with the sequence of convergents for pi is even more striking.

### References

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# programming tips

## CONVERTING FORTRAN PROGRAMS TO THE 9830A

William Thompson III of Miner and Miner, Consulting Engineers, Inc., Greeley, Colorado, submits a series of valuable tips and "how-to's" on converting FORTRAN programs.

The HP 9830, despite its small size and cost, is capable of much more than most users realize at purchase time. Through experience it is soon found that with careful programming, major programs developed for larger machines may be adapted to the 9830. The program run time is normally slower on the 9830, but because of the ready access of the 9830, the user will frequently get results hours or days ahead of batch or time-share solutions. If the large programs are run infrequently, converting the program for use on the 9830 may eliminate entirely the necessity for batch or time-shared connections with costly minimum charges. With this in mind, I wish to offer the following tips and outline for such conversions, gained from the conversion of a Load Flow Circuit Analysis program from FORTRAN (run on an IBM 360 and a Xerox Sigma 3) to HP 9830 BASIC.

1. First, the dimension statements were closely examined to determine the number of words of 9830 memory necessary to fully dimension the arrays. In this conversion a 9830 with 5856 words of available memory was to be used, so the dimension statements were set up as in Figure 1, decreasing the size of circuit that could be analyzed, but not critically since past experience indicated that 95% of all cases run in our office used less than 20 busses and spare lines. Note that split precision in the 9830 is the same degree as full precision frequently found in other machines, and in a like manner double precision on other machines may represent the same degree of precision as 9830 full precision.

2. Next, the program flow was examined, and it was found that the program naturally broke into 5 segments. Iterative processes and loops that must cycle repeatedly were retained completely within a segment so that repeated loading of tape files, one of the slowest 9830 functions, was avoided. If disc files are available, such repeated program loads may be tolerable but still are avoided ideally.

3. Conversion on a line-to-line basis was begun. After some thought, the decision was made to replace FORTRAN variables by BASIC variables in sequence as they appear in the program. The alternative, attempting to imitate the FORTRAN variables by the retention of the same first letter or other means, results in a great confusing tangle. The only exception was to retain all index variables such as I,J,K, and M, used in "DO" loops, since they will be used repeatedly. A table starting with A0, A1, A2, etc., was set up and FORTRAN variables assigned as each line was translated.

4. In a like manner, a table listing equivalent line numbers eases the conversion of transfer of control statements (IF. . . THEN, GO TO, etc.).

5. FORTRAN "IF" statements are replaced by 1 or 2 BASIC "IF" statements. When replacing line numbers in "IF" and "GO TO" statements, use a standard number such as 1 or 9999 if the number refers to a statement that has yet to be translated, rather than attempt to calculate its future line number. After conversion, these are easily picked out and the line numbers changed to effect the proper transfer.

6. "FORMAT" statements that cannot be translated directly because of a required change in format, such as moving from a 132-character line to an 80-character line, are best changed by entering a statement like:

950 FORMAT "FORTRAN STATEMENT #125", 8F8.0

Then when you have the program running, it will print out the values and a reference to an appropriate format statement in your FORTRAN programs. With values for the Variables, you can experiment and change the format statement appropriately to achieve a readable output.

HP 9830 BASIC

```
2000 DIM AS[25],BS[25],CS[25,4],DS[25,4],ES[25],
         FS[25],GS[25],HS[25,7],II[25,2]
2010 DIM LS[25],MS[25],NS[25],OS[25],PS[25],RS[25],
         SS[25],TS[25]
2020 DIM US[25,9],VI[25,2],WS[100],XS[25],YS[25],
         ZS[25],JS[25],KS[25]
2030 DIM A$[25],B$[40],C$[240]
```

FORTRAN (IBM 360)

```
C         360 ELECTRIC POWER LOAD FLOW PROGRAM
C         CAPACITY 100 LINES AND 100 BUSES
          DIMENSION P(100), Q(100), GS(100), BS(100), EMR(100), JSTR(100), EMB(100),
            ER(100), EI(100), PLOD(100), QLOD(100), QMAX(100), QMIN(100), PDEL(100),
            QDEL(100), ZLR(100), ZLI(100), ZKLR(100), ZKLI(100), OGEN(100)
          DIMENSION G(100), B(100), NFTO(100), RATO(100), RATG(100), B2(100),
            QQQ(100)
          DIMENSION NAM(5), ITIL(40), LNAM(100,5), NNAM(100,5), CLIN(10,7), LLIN(10,7),
            CBUS(10,9), LBUS(10,5), KBUS(200)
```

**Figure 1**

The Load Flow program was converted to BASIC in about two weeks in spite of a complete lack of knowledge of the actual power system formulas and units that the program used. A sample case was run on the 9830 to compare with results from a FORTRAN solution of the case. The 9830 results were in close agreement.

Do not expect exact agreement. The way the numbers and calculations are handled in different machines varies and may result in a buildup of accumulated "errors" – residuals may be a better word. The results should not be significantly different, however, so if they vary greatly, closer study is certainly necessary.

Converting the Load Flow program for use on the 9830 had an unforeseen outcome. Access to the program and turnaround time was so greatly improved that use of the program on the 9830 increased to a point where former users were finding it difficult to gain access to the 9830. Since our budget didn't allow purchase of another machine, another solution had to be found. The users of the Load Flow program indicated it would be acceptable to run the long cases, which were running up to 2 hours at a time, on an overnight basis. This would normally give results in less than a day or quicker, if priority seemed to demand it. These runs were not necessary every night and hiring another operator did not seem reasonable, so a sort of job-control program and operating system was created.

For this purpose the program listed in Figure 2 was written. Using 3 files (335 words) on a tape, it is able to run the program stored in files 1 through 5 with the data in up to 44 of the following files. The data for the original load flow was input as a card deck, and the converted version retained a semblance of this using "DATA" lines to imitate the cards. This seemed more desirable than keyboard entry during the program because of the great amount of data input necessary and the wish to keep it in a form where minor alterations could be made and the program rerun without duplicating the original key input. The only necessary addition to the data files was the last line (Figure 3) "MERGE 1,2000,2000". Changes to the load flow program itself were minimal. All exits such as "END" statements were changed to "LOAD 6, 10, 10", which returns control to the job-control program. If you have the "SERROR" statement available on your 9830, even data and program errors won't stop the sequence of the jobs to be processed.

```
10 DIM A$[45]
20 FOR I=1 TO 44
30 A[I]=999
40 NEXT I
50 A[45]=0
60 DISP "NUMBER OF DATA FILES";
70 INPUT N
80 IF N>44 THEN 60
90 FOR I=1 TO N
100 DISP "DATA SET";I;"TAPE FILE NO.";
110 INPUT A[I]
120 NEXT I
130 IF A[45]=0 THEN 150
140 LOAD  DATA 7,A
150 A[45]=A[45]+1
160 IF A[A[45]]=999 THEN 190
170 STORE  DATA 7,A
180 LOAD A[A[45]],10,10
190 DISP "ALL DATA COMPLETE";
200 END
```

FILE 0

```
10 DIM A$[45]
20 LOAD  DATA 7,A
30 A[45]=A[45]+1
40 IF A[A[45]]=999 THEN 70
50 STORE  DATA 7,A
60 LOAD A[A[45]],10,10
70 DISP "ALL DATA COMPLETE";
80 REWIND
90 END
```

FILE 6

FILE 7 - Data file in which array "A" is stored.

**Figure 2**

```
10 DATA "NRPFD RUSHVILLE"
20 DATA 1,0,1,1,400,100,115,0.01,1.5,1.5,5,75,"  "
30 DATA 2,1,0,1,2,1.193,2.72,0.1571,460,0,0,0,
   "RUSHVILLE SS-CLAY"
40 DATA 2,2,0,2,3,15,73.5,0,74,1,0,0,
   "WHITE CLAY CREEK SUB"
50 DATA 2,3,0,2,4,2.332,5.32,0.3071,460,0,0,0,
   "CLAY CREEK-LARRABEE"
60 DATA 2,4,0,4,5,15,73.5,0,74,1,0,0,
   "LARRABEE CREEK SUB"
70 DATA 3,1,0,0,0,100,50,0,0,1,0,0,"RUSH SS"
80 DATA 3,2,0,0,0,0,0,0,0,0,0,0,"CLAY 110"
90 DATA 3,3,0,0,0,0,0,0,0,0,10.831,5.253,"CLAY 25"
100 DATA 3,4,0,0,0,0,0,0,0,0,0,0,"LAR.110"
110 DATA 3,5,0,0,0,0,0,0,0,0,10.764,5.221,"LAR.25"
120 DATA 6,0,0,0,0,0,0,0,0,0,0,0,"  END  "
130 MERGE 1,2000,2000
```

**Figure 3**

This program has been used very successfully, expanding the use of the 9830 to around-the-clock on many days. In addition, this job control has been extended to other programs. Indeed, more than one type of program may be run at night by changing only the "MERGE" statement at the end of the data file to link with the appropriate program file. The number of programs or program runs is limited only by your tape or disc capacity or the means of entering external data into the machine. Even without the addition of that lovely HP Mass Memory, we still are planning on greater use of "batch" processing aided by a paper tape reader for data and the later addition of an external cassette for more program storage.

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## CONSERVING CORE MEMORY (9830A)

1st Lt. Richard Virost of the U.S. Air Force Environmental Health Laboratory at Kelly Air Force Base, Texas, submits this tip, which may be useful to many of you.

I have found the following algorithm useful in conserving core memory when using large arrays in which each element is positive and has only 4 significant digits at most. The algorithm permits storage of such numbers in an integer array rather than a split or full precision array. The range of numbers that can be stored using this algorithm is $1x10^{N}<X<1x10^{N+9}$ where N is any integer — positive, negative, or zero — so that decimal numbers can also be stored in the integer array. To store X, use these steps:

```
10 DIM G[10]
20 INPUT N
30 INPUT X
40 R=INT(LGTX)
50 IF R>N+2.5 THEN 70
60 R=N+3
70 G[1]=(-1)*X*10↑(3-R)+(R-(N+5))*10000
```

X is now stored in a coded form in G(1).
To recover X, use these steps:

```
80 Y=INT(G[1]/10000)+N+6
90 X=(-1)*(10)↑(Y-3)*(G[1]-(Y-N-5)*1000)
```

## IDENTIFYING THE LAST MARKED FILE (9820A)

Dr. R. K. Littlewood of the University of Wisconsin, Madison, Wisconsin, submits the following helpful programming tip.

I sometimes find it useful to know exactly how many files have been marked on a cassette tape. The following 9820 coding sequence automatically does an Identify File operation on the last marked file on a tape, provided that the tape is not currently positioned beyond that mark:

FDF 999; BKS; IDF A, B, C, A; BDS; . . . .

Under normal circumstances B and C will both have the value zero, as A will be a "dummy" file; i.e., the extra file marked in the last Mark Tape operation.

## CALCULATIONS DURING INPUT (9830A)

Mechanical Engineer Director A. de Faro Barros of GESPO, Porto, Portugal, submits a programming tip that should be useful to a number of readers.

For making some calculations during any input step without losing the trail of the program, I suggest the following routine:

```
. . . .
110 DISP "NUMBER OF ITEMS (B)";
120 INPUT A
130 GO SUB 2010
140 GO TO Z OF 110
150 B=A
. . . .
2010 Z=0
2020 IF A= 9999 THEN 2050
2030 STOP
2040 Z=1
2050 RETURN
. . . .
```

The input of a special number (ex. 9999) throws the machine into calculation mode, returning to the same display line when required.

For not losing the results of your calculations and to keep a record of it, as soon as you enter into STOP (line 2020), press PRINT ALL (on), make your calculations, again press PRINT ALL (off), CONT, and EXECUTE. You now can continue programming.