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MACHINE COMPUTATION OF SUN AND STAR OBSERVATIONS

by

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SUMMARY

This Record contains instructions for preparing data for the computation of longitude and azimuth or declination using the Ferranti 'Sirius' computer, and a brief description of the programmes. An approximate interpolation method is outlined in the Appendix.

1. INTRODUCTION

The computation of azimuth and longitude from observations of the sun or a star is a task well-suited to electronic digital computation. Two programmes have been written for the Ferranti 'Sirius' computer to effect this computation. The first is called the 'azimuth programme'. It is designed to be used with observations of either the sun or a star. It uses the altitude of the observed body, the horizontal circle readings of the observed body and a reference mark, and Greenwich time as input data, and computes the longitude of the station and the azimuth of the reference mark. The latitude of the station must be known. The second programme is called the 'declination programme'. It is designed for observations of the sun which involve a reading of the magnetic meridian instead of a reference mark. The latitude and longitude of the station must be known.

Both programmes work to an accuracy of 0.1 minutes of arc.

2. PREPARATION OF INPUT DATA

Data are fed into the computer in the form of eight numbers, or 'words', each of 10 or less digits. All are in the form of integers, so no decimal point is used.

In the case of the azimuth programme the eight words, in the order in which they must be used, are as follows:

(1) YYYYMMDD, the Greenwich date. The first four digits indicate the year, the next two the month, and the last two the day. This is used for identification only,

(2) CCOOHHMMSS The first digit is a code indicating whether the observed body was east or west of the true meridian. The second digit indicates whether the observed body was the sun or a star. CC has the following significance:

CC = 00 sun or planet observed in the west

CC = 01 star observed in the west

CC = 10 sun or planet observed in the east

CC = 11 star observed in the east.

The third and fourth digits are always zero.

The last six digits indicate the Greenwich mean time in hours, minutes, and seconds.

The remaining six words in the group of eight specifying an observation are in degrees and minutes; the first three digits are the degrees and the last three the tenths of minutes. If the angle is less than 100° the first digit can be omitted. Thus the angle 85° 14.0' is written 85140. Final zeros must not be omitted.

(3) HHHHHH, the horizontal-circle reading of the observed body, when viewed directly, not through a mirror,

(4) AAAAAA, the altitude of the observed body above the horizontal, corrected for refraction and parallax,

(5) MMMMMM, the horizontal circle reading of the reference mark,

(6) LLLLLL, the latitude of the station. Southern latitude is considered positive,

(7) DDDDDD, the celestial declination of the observed body at the time of observation. Northern declination is positive, southern is negative. A plus sign can be omitted, but a minus sign must be included. This is the only word that can be negative,

(8) GGGGGG, the Greenwich hour angle of the observed body at the last integral hour before the observation. This is derived from the body of the almanac without using the interpolation tables at the back. Interpolation for minutes and seconds since the last hour is done by the computer.

The first five words are obtained from the observation sheets, the sixth (latitude) from a separate observation, or a map, and the last two from the Nautical Almanac.

In the case of the declination programme the eight words of input data differ only slightly from those for the azimuth programme. The words are:

(1) YYYYMMDD, the date,

(2) HHMMSS, the Greenwich time. No code digits are needed, but if they are included, they will be ignored, and no harm will be done,

(3) HHHHHH, horizontal circle reading of the sun, either directly or through a mirror,

(4) LLLLLL, south latitude,

(5) FFFFFF, longitude east of Greenwich,

(6) MMMMMM, the horizontal circle reading of the magnetic meridian. If HHHHHH is the reading of the sun viewed directly, the circle reading of magnetic south should be used; if HHHHHH is the reading of the sun viewed through a mirror (i.e. sun behind the observer), that of magnetic north should be used,

(7) DDDDDD, the solar declination, positive in the winter and negative in the summer,

(8) GGGGGG, Greenwich hour angle at the last integral hour.

As with the data for the azimuth programme, the last six words represent angles in degrees and tenths of minutes.

3. PUNCHING OF INPUT DATA

This section applies equally to the azimuth and declination programmes.

The name of each station must be punched onto the data tape in the following form:

(letters) NAME (figures)(figures)

The operation of the programme is to search for the letter-shift character, after finding it to copy each character up to two consecutive figure-shifts, then to read the next eight words as input data and use them in the computation. Therefore even if no name is used the characters

(letters)(figures)(figures)

must be punched before the data of each observation. The output format can be controlled by this means; e.g. if line-feed is punched four times between the letter-shift and the name, a four-line gap will be left between the output of one station and the next.

The following sequence of characters must be punched at the end of each data tape:

(letters)(figures)(figures)(space)(zero)(space).

This brings the machine to a 99 wait. On pressing 'continue' it will start again to search for a letter-shift. This facility is used when several data tapes are to be run consecutively.

It is usual to punch about eight blank characters (figure-shifts on a Sirius tape-punch, delay on a Silliac tape-punch) at the end of each observation. This is a help in correcting the tapes.

4. OUTPUT

The output of the azimuth programme consists of the date, Greenwich time, latitude, longitude, and azimuth of the reference mark, in that order. The azimuth is counted from south through west. It lies between 0° and 360°.

The output of the declination programme consists of the date, Greenwich time, latitude, longitude, and magnetic declination, in that order. The declination lies between -180° and +180°.

The results of each observation are printed on a separate line. All angles are expressed in degrees and minutes to the nearest tenth of a minute.

5. RESTRICTIONS

In the case of the azimuth programme, overflow in the machine imposes certain limitations on the range of observed data.

The bearing of the observed body must not be within 23° of true north. Also the local hour angle must be within the range ± 157°. If the observed body is the sun, the latter restriction means that observations must not be made within 1½ hours of local midnight. An observation made with the observed body near the true meridian would have low accuracy anyway, so the computing restrictions are not likely to be of practical importance.

There are no such restrictions for the declination programme, but if the altitude of the sun is too great, accuracy is lost.

6. OTHER USES OF THE PROGRAMMES

The azimuth programme can be used, when no reference mark has been observed, by putting the horizontal-circle reading of magnetic south in the group MMMMM. The easterly declination is then printed out under the heading 'azimuth'. In this case the declination will be in the range 0° to 360°.

If the latitude is not known accurately, position lines can be derived from the azimuth programme by carrying out the computation twice with different latitudes, and plotting the line joining the two pairs of latitude and longitude values. The assumed latitudes should be about 1° apart with the true latitude between them.

The declination programme can be used to derive the azimuth of a mark by entering the horizontal-circle reading of the mark as MMMMMM. If the sun has been observed through a mirror, 180° should be added. The azimuth will be printed out under the heading 'declination'. It will be in the range -180° to +180°.

The declination programme can be used for star observations by putting zeros for MM and SS in the second word of data and putting the Greenwich hour angle of the actual time of observation in the eighth word.

7. MACHINE OPERATION

This section applies to both azimuth and declination programmes. For a description of the terms used the reader is referred to the Programming Manual of the Ferranti Sirius Computer.

The standard programmes and library tapes required are:

(1) initial orders,

(2) fixed-point library.

After reading 'initial orders', the fixed-point library is fed into TR5 and the programme into TRO. When the programme and necessary sub-routines have been read, the machine stops on an E directive. The data tape is then fed into TRO. After starting the machine, the cycle of operation is:

(1) find letter-shift,

(2) copy onto output tape all characters up to a double figure-shift,

(3) read the next word; if it is zero, stop; if it is not zero, read the next seven words,

(4) punch out the three or four words which do not require computation,

(5) compute (which takes about 1 sec),

(6) punch the remainder of the output,

(7) search for the next letter-shift.

When the machine encounters a zero date it comes to a 99 wait in word 890. It can be restarted by pressing 'continue'. If it makes any other stop it can be restarted by jumping manually to word 891.

8. CHECK COMPUTATION WITH AZIMUTH AND ALTITUDE TABLES

If accurate computation of observations are not made in the field, it is desirable to have some immediate check that observations are roughly correct. The simplest way of doing this is by using tables of azimuth and altitude (Admiralty, 1952). The instructions for using these tables and a sample computation form, are shown in the Appendix.

9. REFERENCE

ADMIRALTY 1952 TABLES OF COMPUTED ALTITUDE AND AZIMUTH. London, Admiralty Hydrographic Dept. Hydrographic Publn. HD 486.

APPENDIX

INSTRUCTIONS FOR COMPUTING AZIMUTH USING AZIMUTH AND ALTITUDE TABLES.

Tables of computed altitude and azimuth (Admiralty, 1952) contain altitude values (to 0.1') and azimuth angles (to 0.1^{o}) for every degree of latitude, half degree of sun's declination, and degree of hour angle. The computation form is designed to make use of the tables in four different ways:

(a) accurate computation of azimuth and longitude, knowing latitude, declination, and altitude,

(b) accurate computation of azimuth, knowing latitude, time, longitude, and declination,

(c) approximate computation of azimuth, knowing latitude, declination, and altitude,

(d) approximate computation of azimuth, knowing latitude, time, longitude, and declination.

In every case the computation consists of a three-way linear interpolation. In cases (a) and (b) the quantity interpolated is the hour angle or altitude respectively. The azimuth is then found from the sine law

$$\sin A = \sin t . \cos d/\cos h$$

by logarithms. Space for this computation is provided in the lower right-hand corner of the computation sheet. In cases (c) and (d) the azimuth is determined directly by interpolation. Because the azimuth is tabulated only to 0.1^{o}, the result is accurate only to a few minutes.

The form allows two observations to be computed provided the sun's declination is the same for both. All entries are made to the nearest minute. It is found that keeping tenths of minutes does not improve the accuracy of the result.

The top part of the form is self-explanatory. Line 1 is called 'latitude', and is divided in the middle by brackets. Two latitudes, in integral degrees and one degree apart are entered on the two sides of the bracket, so that the actual latitude falls between them. The fractional difference between the actual latitude and the left-hand latitude is entered inside the brackets. Line 2, called 'declination', is divided into two halves, each half being divided by brackets (like the whole of Line 1). Two declinations, being integral multiples of 30', are entered, one on each side of the brackets, such that the actual declination is between them. The fractional difference between the left-hand declination and the actual declination is entered within the brackets. The right hand half of Line 2 is an exact copy of the left hand half.

From here on the procedure depends on the problem. For case (a) altitudes are entered on Line 3, so 'ha' is crossed out of the heading and written in the heading of Line 4. Using the table for the latitude in the left-hand half of Line 1 and the declination in the left-hand quarter of Line 2, search for two consecutive values of altitude which straddle the observed value of altitude (corrected for R and P) and enter them in the left-hand quarter of Line 3. Write the corresponding hour-angle values immediately below in Line 4. Write the proportional difference between the left-hand altitude and the observed altitude in the first bracket of Line 3, and the total difference between the two hour-angle entries (i.e. 60') in the first bracket of Line 4. The other three quarters of Lines 3 and 4 are filled in similarly, using the appropriate latitude and declination. Line 5 contains hour angles interpolated linearly from Line 4, and Line 6 contains those interpolated from Line 5 (see worked example below).

Lines 7, 8, 9, and 10 correspond to 3, 4, 5, and 6 but for the second observation. The hour angle obtained by interpolating Line 6 is entered as the first LHA (centre bottom of form), and that from Line 10 as the second. The corresponding log sines are entered in the bottom right hand part of the form. For an observation made in the morning use (360°-t) for the LHA entry. GHA is found from GMT and the almanac, and longitude is LHA - GHA. In the right-hand corner, d and h are known declination and altitude. Notice that log cos h must be subtracted. The value of A must take into account the local time of observation, i.e. it is greater than 180° in the morning and less than 180° in the afternoon (counting from S through W). The appropriate value of A is entered in the top line of the left-hand bottom part of the form, and the azimuth of the mark computed in the usual way.

For case (b), Lines 1 and 2 are the same. Compute GHA from GMT and enter it and the known longitude in the bottom centre part of the form; add them to obtain LHA. Cross out 'alt' on Line 3 and enter it on Line 4. Using the appropriate table, enter the hour-angle values which straddle LHA (or 360° - LHA in a.m.) on Line 3 and the corresponding altitude values in Line 4. Interpolate values of altitude for 1st and 2nd observations and enter their log cosines in the lower right-hand part of the form, thus computing A.

For case (c) Line 3 is filled as for case (a), but azimuths are entered on Line 4 instead of hour angles. The interpolated value of A is then entered directly in the left-hand bottom part of the form. Tabulated values of azimuth are negative in the morning, positive in the afternoon, for the southern hemisphere (counting from S through W).

For case (d), LHA is found as in case (b) and the straddling values of hour angle are entered on Line 3 with the corresponding azimuths on Line 4. Interpolated azimuths are treated as in case (c).

Worked Examples

The following worked example for case (a) will make the above clear. Actual latitude = 24° 34'

declination = 17° 14'

observed altitude = 30° 34'

On Line 1 enter 24° and 25°, because 24° 34' is between them.

The difference between 24° 34' and 24° is 34/60 of the difference between 24° and 25°, so 34/60 is entered in the brackets.
On Line 2 (each half) enter 17° and 17° 30' because 17° 14' is between them, and enter 14/30 in the brackets.
Now using the table for 24° latitude and 17° declination (i.e. page 227) look for values which straddle 30° 34'. They are 30° 38' and 29° 55'. The corresponding values of hour angle are 44° and 45°.
Now:

$$30^\circ\,38' - 29^\circ\,55' = 43'$$

and $$30^\circ\,38' - 30^\circ\,34' = 4'$$

and $$45^\circ - 44^\circ = 60'$$

Therefore 4/43 is entered in the first bracket of Line 3 and 60 in the first bracket of Line 4.

For the second quarter of Lines 3 and 4 we use the 17° 30' column of page 227 in just the same way, and for the 3rd and 4th quarters, page 251. The tables headed 'declination contrary name to latitude' are used because the observations were made in the winter.

The first entry of Line 5 is derived from the left-hand hour angle using the bracketed quantities on lines 4 and 3, thus:

$$44^\circ + (4/43) \times 60' = 44^\circ + 6' = 44^\circ\,06'$$

The 6' is added to the left-hand member (44°) because that member is less than the right-hand member (45°). Differences are always reckoned from the left-hand member regardless of sign. Other entries on Line 5 are

$$43^\circ + (25/41) \times 60' = 43^\circ\,37'$$

$$43^\circ + (7/41) \times 60' = 43^\circ\,10'$$

$$42^\circ + (27/41) \times 60' = 42^\circ\,40'$$

The differences are entered in the brackets of Line 5

$$44^\circ\,06' - 43^\circ\,37' = 29'$$

$$43^\circ\,10' - 42^\circ\,40' = 30'$$

The entries for Line 6 are derived from the bracketed quantities on Lines 5 and 2 thus:

$$44^\circ\,06' - (14/30) \times 29' = 43^\circ\,52'$$

$$43^\circ\,10' - (14/30) \times 30' = 42^\circ\,56'$$

and the difference entered in the brackets.

The fractional part is subtracted from the left-hand member (43° 37') because that member is less than the right-hand member (44° 06'). The final value of hour angle for the 1st observation is derived from Lines 6 and 1

$$43^\circ\ 52' - (43/60) \times 56' = 43^\circ\ 20'$$

The observation was made in the morning, so

$$LHA = 360^\circ - 43^\circ\ 20'$$

$$= 316^\circ\ 40'$$

By the conventional method, $316^\circ 39.1'$

Using the sine law, $A = 130^\circ\ 25'$

The conventional calculation gives 130° 23.7'

The same problem solved for case (c) gives

$$A = 130^\circ\ 25'$$

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COMPUTATION OF AZIMUTH AND LONGITUDE BY A and A TABLES

Station	Henbury NT	Date	9 May 1961
Observer	J. vd L.		
Latitude	24° 34'	Altitude (obs 1)	30° 34'
Sun's declination	17° 14'	Altitude (obs 2)	31° 12'

	h.	m.	s.	h.	m.	s.
Chron. time	9	39	54	9	43	30
Cor'n to G.M.T	-9	29	50	-9	29	50
G M T	0	10	04	0	13	40

No.						
1.		Latitude	24° (34 / 60) 25°			
2.		Declination	17° 00' (14 / 30) 17° 30'		17° 00' (14 / 30) 17° 30'	
3.	Obs 1	alt / ho	30°38'(4 / 43) 29°55'	30°59'(25 / 41) 30°18'	30°41'(7 / 41) 30°00'	31°01'(27 / 41) 30°20'
4.		hour angle	44° (60) 45°	43° (60) 44°	43° (60) 44°	42° (60) 43°
5.			44° 06' (29) 43° 37'		43° 10' (30) 42° 40'	
6.			43° 52' (56) 42° 56' = 43° 20'			
7.	Obs 2	alt / ho	31°20'(8 / 42) 30°38'	31°41' (29 / 42) 30°59'	31°22'(10 / 41) 30°41'	31°41'(29 / 40) 31°01'
8.		hour angle	43° (60) 44°	42° (60) 43°	42° (60) 43°	41° (60) 42°
9.			43° 11' (-30) 42° 41'		42° 15' (32) 41° 44'	
10.			42° 57' (57) 42° 00' = 42° 25'			

Az. of Sun	229° 34'	228° 53'	9 d 0 h =	180° 54'	9 d 0 h =	180° 54'	lg. sin. t	$\bar{1}$.83648	$\bar{1}$.82899
Circle reads	164° 47'	164° 06'	10 m 4 s =	2° 31'	13 m 40 s =	3° 25'	lg. cos. d	$\bar{1}$.98005	$\bar{1}$.98005
S. Mer. reads	295° 13'	295° 13'	G H A =	183° 25'	G H A =	184° 19'	lg. cos h	$\bar{1}$.93502	$\bar{1}$.93215
Mark reads	326° 38'	326° 38'	L H A =	316° 40'	L H A =	317° 35'	lg sin A	$\bar{1}$.88151	$\bar{1}$.87689
Az. of mark	31° 25'	31° 25'	Longitude =	133° 15'	Longitude =	133° 16'	A	49° 34'	48° 53'

TO ACCOMPANY RECORD No 1963/39

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PLATE I