IMPLEMENTATION OF INVERSE MULTIPROFILE STREAK TECHNIQUE

(U) ARMY ARMAMENT RESEARCH DEVELOPMENT AND ENGINEERING CENTER

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IMPLEMENTATION OF INVERSE MULTIPROFILE
STREAK TECHNIQUE

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The inverse multiprofile streak technique is a new measurement technique available to researchers and was implemented to better achieve measurements on detonation phenomena. This technique provides the wave front geometry around the perimeter of an explosive charge through the use of multiple slits placed on the charge and a high speed streak camera. Testing and analysis and methodology for this technique are presented in order to provide information to interested researchers. A personal computer program and sample tests are included to illustrate the methods used.
ACKNOWLEDGMENT

The authors wish to thank Everett Dalrymple, John Fancher, Thomas Graziano, Sidney Kravitz, and Donald Rowland for their assistance.
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INTRODUCTION

The inverse multiprofile streak technique is a method that provides information on the detonation wave front's geometry around the perimeter of an explosive charge. This is achieved by placing multiple slits, in the form of dark and clear horizontal bands, around the perimeter of the charge. The detonation is then observed with a high speed streak camera. The film results yield the time the detonation wave front passes each intersection between the dark and clear bands. The orientation of the detonation wave can be determined from the time of arrival data.

This technique was previously published by its developers (ref 1). Their paper did not discuss the details of the testing or the analysis used. This report details our implementation of the technique and our analysis of multiple tests was made easier by interfacing a motion analyzer with a personal computer. A program listing is included in the appendix. The objective of this report is to make the inverse multiprofile streak technique readily available for use in the development programs.

TEST METHODS IN STUDYING DETONATIONS

Over the years, many testing techniques were developed to enable the scientist to characterize detonation phenomena. Two properties in which researchers are interested are: the detonation propagation velocity and the detonation front geometry. These properties are the easiest to measure. Several techniques that enable the researcher to simultaneously measure the detonation velocity and geometry are flash x-ray, ionization pins, and ultra-high-speed photography.

Flash x-ray tubes emit a cone of higher power x-ray radiation of very short duration that can obtain a still picture of a fast moving detonation event. By using a soft x-ray tube that emits a large proportion of low energy x-ray radiation, the slightly denser shock front of the detonation wave can be captured on film (ref 2) (fig. 1). Quality results are very difficult to obtain, because the absorption of x-ray radiation at the detonation front is only slightly greater than that of the detonated or undetonated charge. The photographs obtained are a projection of the full view onto a plane that sometimes obscures much of the shock and reaction front's fine structure.

Multiple views at different times are required for detonation velocity measurements. The number of views with a flash x-ray system are limited by the capacitor banks, which supply the power for the tubes, and by the flash x-ray tubes. The capacitor banks require time to recharge after each test, necessitating one capacitor bank for each view obtained. The flash x-ray tubes are not durable when used repetitively within short intervals. For multiple testing times, separate pairs of x-ray tubes and capacitors are required. This severely limits the number of views obtained as well as complicates the analysis since each view is taken from a separate angle.

The electrical conductivity of the ionized products behind the detonation front was used in characterizing detonation waves. Ionization pins inserted into
the surface of a test sample are charged with an electrical potential that is
shorted by the passing conductive ionized products. With a simple electrical
circuit and a fast time recorder or oscilloscope, the arrival times of the
detonation wave front can be measured. If the ionization pins are placed circum-
ferentially and longitudinally within a test sample, the arrival time of the
detonation wave at each pin location can be recorded (fig. 2). With the location
of each pin, the orientation and velocity of the detonation front can be calcu-
lated. The technique is accurate, but suffers two major drawbacks. A complete
measurement on a complicated test piece requires many ionization pins and many
time interval meters or very fast oscilloscopes, both are very expensive. The
pins also require an electrical circuit attached to them, which poses an addi-
tional safety hazard around explosive charges.

Ultra-high-speed photography does not pose this risk of accidental initia-
tion, and can inexpensively obtain more complete data by viewing and testing a
larger area of the charge. Two basic types of ultra-high-speed cameras are
available: the framing and streak cameras. Framing cameras that can record
individual frames or pictures at rates of millions of frames a second are avail-
able. The cameras are very limited in the number of frames obtained (about 25
frames). Generally, the results are easily analyzed because the researcher can
clearly observe the event on the film. The detonation front geometry of the
charges perimeter is viewed directly, while multiple frames can be used to com-
pute the detonation velocity.

Framing cameras are limited to providing data at discrete points in time,
which can be a disadvantage when studying events that vary continuously, as in
varying detonation front geometries or detonation velocities in nonuniform
charges. For this reason, streak cameras were used effectively in studying
detonation phenomenon separately and in conjunction with framing cameras.

A streak camera quickly sweeps the image of the event over the film by
either rotating the film in a drum or reflecting the image off a rotating mirror
onto the film (fig. 3). High image sweep speeds of 20 mm/μ are possible in many
cameras. Because the film is constantly being exposed by the image, some means
must be used to prevent an event at one time and position from obscuring an event
at another. The most common means is limiting the size of the image that is
exposing the film by either inserting a slit perpendicular to the film sweep at
the image plane in the optical system, or by placing a slitted mask directly upon
the charge. The film results yield the time that a luminous event occurs at each
position along the slit. With the proper placement of the slit, a large variety
of information can be obtained with a streak camera. These can be separated into
three categories: detonation velocity, time of arrival at a specific location, and
detonation wave profile measurement.

The streak camera is ideally suited for determining the instantaneous
detonation velocity of a charge. By placing the slit along the axis of a
charge, which is then detonated, the resulting image obtained is a line with
slope equal to a scaled detonation velocity (fig. 4). This is a common use of
the streak camera. This method does not yield any information on the detonation
wave form within the explosive; it requires other techniques.
Two types of ultra-high-speed streak photographic test methods available that yield information on the detonation wave geometry are: the arrival time measurement and the detonation wave profile measurement (ref 3) (fig. 4). In the arrival time measurement, the slit is placed along the surface farthest from the initiation of the explosive charge. This allows the arrival or breakout time of the detonation wave at this surface to be determined. This method yields the breakout history of the detonation wave along only one line on the horizontal plane of the base. Multiple horizontal slits have also been placed on the base of the charge to increase the information obtained. The geometry of the detonation wave cannot be determined without knowing the detonation velocity. To obtain detonation velocities simultaneously on the charge, mirrors can be used to obtain a side view of the charge during testing.

In the profile test, the slit is placed perpendicular to the axis of the charge, yielding the profile of the detonation wave as it passes the slit. If the detonation velocity is known and the intersection of the detonation wave and the perimeter of the charge lie in a plane, the tilt of the wave from the central axis can be determined.

The inverse multiprofile streak technique, developed by Held and Nikowitsch (ref 1) and studied in this paper, is a variation on the profile technique (fig. 5). In this test, the slit is removed from the streak camera and placed around the charge. The slit takes the form of horizontal clear and dark bands placed on flexible film or acrylic tubing. This allows the use of multiple slits which are the intersections between the dark and clear bands. The detonation velocity can also be determined by measuring the time required to pass each band.

By reflecting the image off a pair of mirrors, the camera can view a full 360 degrees around the perimeter of the detonating charge. This assures that the measurements on the wave tilt are not unduly influenced by any irregularities in the detonation wave structure.

EXPERIMENT

Two test devices were used to verify the analysis. Each had a 1-inch diameter by 1-inch tall TNT charge with a 1/2-inch diameter by 1-inch tall TNT booster pellet initiated with an RP-2 Reynolds Corporation exploding bridgewire detonator. The first test was initiated with the booster centered on the charge. The second test placed the booster 1/4-inch off center at 90 degrees from the front of the image. The pellets had a low density averaging 1.548 gm/cm$^3$ for the charge and 1.487 gm/cm$^3$ for the booster pellets. TNT crystal has a theoretical maximum density of 1.654 gm/cm$^3$ (ref 4). Previous work indicated very large wave tilts when a booster was not used. The booster pellet provides a section of explosive which allows the detonation wave front to expand and become more planar. The charge is wrapped in a mask made of Kodak brand Ektachrome film with alternate transparent and opaque horizontal bands. The original for the film wrap was drawn in ink on paper that was copied with a photographic reproduction process. These methods obtained quality reproduction on the film with high contrast. Vertical marks were placed on the film as reference marks.
Since the bands were originally hand drawn, variations were expected from the nominal 0.1 inch (2.54 mm) between bands. For this reason, the heights of each band were measured by means of microscope. The measured heights were 5.799, 8.420, 11.280, and 14.691 mm as measured from the upper edge of the charge and were used in the analysis.

While detonations are luminous events, they are not bright enough to expose film at very high writing speeds. To produce a brighter light, a small controlled air gap is left between the film and the charge. When the detonation passes the small air gap, it shock heats the air which becomes luminous. Drafting tape was placed on the inside of the film, along the dark bands, in order to obtain a controlled air gap 0.13 mm thick.

When the film is wrapped around the sample, the upper portion is placed tightly against the plate that aligns the booster to the charge. Scotch tape is used to hold the film tightly around the charge. Earlier tests indicated that the film by itself is not strong enough to stay tightly wrapped during detonation. For this reason, a section of clear film is wrapped around the charge to hold the assembly together during testing.

Flat front surface mirrors (4 to 6 waves/inch flat, 1/8-inch thick) were used to observe the event. The mirrors were epoxied to plywood triangles that supported the mirrors perpendicular to the test stand. Because of the destructive nature of the tests, plywood boards were used for the test platforms.

The alignment of the event to the camera system is critical. If the charge lies above or below the optical axis of the camera lens, the image of the horizontal bands will appear curved. This is also true for any plane above or below the center of the view. The curvature is minimal for the bands when the charge is properly oriented and corrections are not required. An alignment fixture was constructed to allow proper alignment. The fixture has a horizontal scratch mark in front and back which can be aligned with the crosshair inside the camera. The stands were marked in pencil for the alignment of the mirrors and the test sample.

In the orientation of the image, care must be taken in properly aligning the direction of the detonation (as seen on the film) in the same direction as the image sweep speed (fig. 6). If this is not done, the image will be superimposed upon itself because as the detonation moves down the charge, the image sweep will bring the image up over the previously exposed film. When properly aligned, the image sweep will expand the image on the film. A prism image rotator was used to orient the detonation wave to the image sweep speed and to facilitate the final alignment of the images rotation without moving the charge.

The film results for the central initiation of TNT is shown in figure 7 and for the 1/4-inch off-center initiation in figure 8.
ANALYSIS OF FILM RESULTS

The analysis of the detonation wave form is long and tedious, requiring many repetitive calculations, using many data points, and a least-mean square technique. For this reason, a HP-86 personal computer interfaced with a Vanguard motion analyzer was used. A computer listing and flow charts of the program are included in the appendix. The following is a description of the analysis methods used.

By viewing the detonation with mirrors, three views of the charge are obtained: the front, right, and left sides. This allows analysis on almost 360 degrees around the explosive since the edges of the views are difficult to resolve.

The streak picture must be analyzed in order to obtain the position on the film in degrees and time. The position of each measurement is easily obtained by understanding that the projection of the cylinder upon the plane is equal to the radius times the sine of the angle. The scales must be properly applied to the problem in order to obtain the correct angle. The easiest method to calculate the angle is to use the diameter measured directly on the film. In determining the time at each point along a plane, the scaling factors between the film image, the image sweep rate, the precision analyzer, and the event must be known. Computation of the angles in the reflected view require adjustments to match the central view, (90 degrees on the left view and 270 degrees on the right view) and for the shift in directions (clockwise rotation on the charge appears as a counter clockwise rotation in the reflected images).

When measuring the position on points too close to the edge of a view, the measurements cannot be used. A small error in the measurement of the projection will yield a greater error in the computation of the angle measurement along the edges. The section near the rear of the charge (at 180 degrees) cannot be accurately measured because of the reduced resolution on the edges of each view. All other edges are covered in separate views.

Initially, a planar least-mean square analysis is computed on the bands using the positions as they appear on the film, then scaled using the conversion factors to a time in microseconds, not taking into account the change in positions due to the different heights of the film bands. The analysis is made by using multiple regression, determining the time at the bands by minimizing the sum of the squares between the actual and calculated values of time. The equations are readily available for three cartesian coordinates. For this reason the cylindrical measurements of angle are converted into the cartesian coordinate system. The normal equations for two independent variables are:

\[ t = n*bo + b1(\sum y) + b2(\sum x) \]
\[ xy = bo(\sum y) + b1(\sum y^2) + b2(\sum xv) \text{ and} \]
\[ xt = bo(\sum x) + b1(\sum xy) + b2(\sum x^2) \]
for the planar equation

\[ t = b_0 + b_1x + b_2y \]

where

\[ t = \text{time} \]
\[ x = \text{the x coordinate} \]
\[ y = \text{the y coordinate} \]
\[ b_0, b_1, b_2 = \text{the constants of the planar equation} \]

Once the planar, least-mean square analysis is obtained, a correction can be made for the height of each individual band. This is done by subtracting the height intercept from the height of the individual band, measured directly on the film, and scaled to microseconds. This correction will yield a correct planar equation in microseconds for each band. In the analysis, the scale on the diameter is not significant because any consistent scale will yield the same tilt. For convenience, the dimensions were not scaled but were left in the Vanguard motion analyzer's dimensions. In the computations, the time zero for the bands need only to be consistent for all of the bands. Only the times between the bands and the points on a individual band are necessary. For this reason, the upper section of the film is used for the zero point to allow a repetitive analysis if necessary. This plane is not used in any other portion of the computations because of the poor resolution obtained along this plane where the detonation wave is spreading out into the main charge from the smaller booster pellet.

The tests are being used to determine the wave tilt and orientation of the tilt. The wave tilt is defined as the angle the intersection of the detonation wave front with the charge perimeter would make with the intersection of a normal detonation (fig 9). The orientation is the angle between the leading edge of the detonation and the zero angle, which faces the camera in the central view. The film results directly yield only the arrival time of the detonation wave front around the perimeter of the charge within distinct planes and not the wave form at a distinct point in time. For this reason, assumptions must be made about the wave form in order to determine the wave tilt. It is assumed that the detonation wave form expands spherically at a constant rate into the nonreacted charge. The intersection between the spherical detonation wave front and the perimeter of the explosive charge will be an ellipse which lies in a plane. It is also assumed that the apparent vertical detonation velocity can be approximated as remaining constant between planes.

The analysis assumes the detonation velocity can be accurately measured vertically down the perimeter of the charge. This is an approximation since the detonation wave is expanding spherically into the charge and may be excessively tilted. For spherical expansion, this approximation is valid for the test sample geometries where the curvature of the detonation wave front is not changing rapidly. This occurs when a detonation wave front is allowed to travel down the charge, expanding considerably before measurement begins, to where the curvature
is not changing rapidly. This occurs in charges with a large length-to-diameter ratio.

For the centrally initiated test, it is possible to calculate the apparent detonation velocity along the perimeter of the charge at the film bands (fig. 10). By using the geometry of the test charge, the following ratios of apparent detonation velocity to detonation velocity can be determined:

<table>
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<tr>
<th>Band number</th>
<th>Apparent detonation velocity to detonation velocity</th>
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<tr>
<td>1</td>
<td>1.483</td>
</tr>
<tr>
<td>2</td>
<td>1.252</td>
</tr>
<tr>
<td>3</td>
<td>1.148</td>
</tr>
<tr>
<td>4</td>
<td>1.089</td>
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</table>

The tilt of the detonation wave front can be approximated for large wave tilts by using the apparent detonation velocity. This is true, because the apparent local detonation velocity is measured on the charge where it is used to compute the wave tilt.

The equations for the times the perimeter of the detonation wave front passes each band are obtained in three dimensions: time, x, and y coordinates. The equations will be transformed into two dimensional planar equations by using the coordinates of time and the cosine of the angle to determine the orientation of the wave tilt. The coordinates are rotated so that the side view of the plane will appear as a straight line. This will directly yield the orientation of the tilt from the rotation required to obtain a straight line.

The tilt of the detonation wave front is obtained from the height difference at the leading and trailing edges of the perimeter of the wave front and the charge diameter. The height difference is calculated from the time required for the perimeter of the detonation wave front to cross a plane and the local detonation velocity. The local detonation velocity is obtained from the known band separation divided by the time difference between the intercepts of the time equations for the perimeter of the detonation wave front. The intercept represents the average time for the detonation wave to pass each band.

RESULTS

The time-position graph for the centrally initiated tests (fig. 11) shows the least-mean square curve for each band, as well as the measured times for each band. The data were corrected for the offset caused by the different heights of the film-wrap bands. The graph shows the small variation in time along each band, as well as the close relationship to the measured points and verifies the least-mean square technique used. The height-position graph (fig. 12) shows a plot of the calculation detonation wave plane at the times that half of the
detonation wave has passed each band. This shows the position of the detonation wave around the perimeter of the charge as it is calculated from the least-mean square technique.

The polar graph of the tilt rotation of the detonation wave planes (fig. 13) shows the close grouping of the data and the random variation of the rotation of the planar wave tilt. This could be expected from the variations within the charge.

The computer printout of the test results for the centrally initiated test shows a planar wave. The maximum wave tilt was only 1.85 degrees with a minimum of 1.07 degrees. The detonation wave was first recorded on the bands between 157.2 and 120.2 degrees. This indicates that the detonation wave tilt rotated as it travelled down the charge. The rotation was probably due to the internal density variations within the charge.

A test was conducted with the initiation set off center in order to prove the validity of the analysis routine. The booster was offset 1/4-inch along 90 degrees from the center, positioned to the left as viewed by the camera. In an ideal charge, the detonation wave should first reach each band at 90 degrees. The printout shows that the detonation wave initially reaches the bands at a point greater than 90 degrees, up to 16 degrees greater. The range between the rotations was only 4.8 degrees. The consistency of this measurement indicates that the rotation was slightly larger than 90 degrees. This could be due to a large variation in density within the pellet; the detonation velocity decreases with density.

The time-position graph for the 1/4-inch off-center initiation (fig. 14) shows a greater variance between the least-mean square curve and the measured times. This was due to the large variation along each band. The time bands for the off-center initiation are at later times than for the centrally initiated case because of the larger distances the detonation wave travels at an angle through the charge. The position-angle graph (fig. 15) shows the plot of the calculated detonation wave at the time that half of the detonation wave passed each band.

The polar graph of the tilt rotation of the detonation wave front (fig. 16) shows the reducing wave tilt with a rotation of few changes. In an off-center initiation, the wave tilt can be expected to decrease as it travels down the charge; the longer the distance, the more time the detonation wave front has to become more planar. The rotation of the off-center initiation remains in the same range with little random variation. The off-center initiation effects the orientation to a much larger degree than normal internal variations within a charge.

The wave-tilt position graph (fig. 17) compares the wave tilts of the two test runs and shows the large variation between central and off-center initiation.
CONCLUSIONS

The inverse multiprofile streak technique was implemented by ARDEC to make a new measurement technique available to researchers. The method was used with on-center and off-center initiated explosive charges, confirming the viability of the test and analysis methods used. A computer program was developed to simplify the analysis and allow the use of a larger number of data points. This increases the quality of the results and reduces the change of computation errors in the analysis. The Vanguard motion analyzer was interfaced to a personal computer, allowing direct measurements on the test film to be used in the analysis. The inverse multiprofile streak technique is a valuable new tool in the study of detonation phenomena.
Figure 3. Rotating mirror streak cameras
Figure 4. Streak photographic test technique
Figure 5. Geometry of the multistreak technique
DISTANCE ON THE STILL PLUS THE SCALED TIME FOR THE DETONATION WAVE TO TRAVEL BETWEEN BANDS #1 AND #2, CAUSED BY THE IMAGE SWEEP SPEED.

Figure 6. Expansion of image on streak record
Figure 7. Streak picture for the central initiation
Figure 8. Streak picture for the 1/4-inch off-center initiation
Figure 9. Intersection between detonation wave front and cylinder
\[
R = B + A
\]

\[
\frac{dR}{dT} = 2B + 2R \frac{dB}{dT} + dO
\]

\[
\frac{dB}{dT} = \frac{R}{B} \frac{dR}{dT}
\]

Where:
- \(dR/dT\) = the detonation velocity
- \(dA/dT=0\), unchanging geometry
- \(dB/dT\) = the apparent detonation velocity

Figure 10. Apparent detonation velocity
Figure 11. Planar least-mean square times, central initiation
Figure 12. Position of wave form, central initiation
Figure 13. Wave tilt and rotation, central initiation
Figure 15. Position of wave form, 1/4-inch off-center initiation
Figure 16. Detonation wave tilts and rotation, 1/4-inch off-center initiation
Figure 17. Wave tilts
REFERENCES


APPENDIX

PERSONAL COMPUTER PROGRAM
**Program Listing**

10 REM MAIN ROUTINE FOR DETERMINING WAVE TILT ON 1" DIA. CHARGE
20 GOSUB RETRIAL
30 DISP "DATA HAS BEEN RETRIEVED"
40 REM RETRIEVES DATA FROM VANGARD MOTION ANALYZER
50 GOSUB SCALES
60 REM DETERMINES THE SCALE USED LATER IN THE PROGRAM
70 GOSUB VIEWS
80 REM DETERMINES THE ANGLES AND HEIGHTS OF THE BANDS PHOTOGRAPHED
90 REM FROM THE THREE VIEWS MEASURED
100 GOSUB LMS
110 REM DETERMINES THE LEAST MEAN SQUARE TILT OF THE WAVE
120 GOSUB ANGLES
130 REM DETERMINES THE ANGLE OF TILT AND ITS ORIENTATION
140 END

150 REM ***************************t**

160 RETRIAL:

170 REM ***************************

180 REM ** RETRIAL SUBROUTINE OBTAINS DATA FROM THE MOTION ANALYZER

190 MO=1
200 N=0

210 REM COUNTS THE TOTAL NUMBER OF READINGS TAKEN FOR LATER USE
220 PAGESIZE 24
230 REM INCREASES DISPLAY TO ALLOW 24 LINES TO BE DISPLAYED
240 CLEAR
250 REM CLEAR DISPLAY
260 PRINTER IS 501

270 REM SELECTS ADDRESS CODE TO THE PRINTER, 5— GPIB, 01 PRINTER
280 DIM H(200),X(200),Y(200),TH(4,200),X1(4,200)
290 DIM BO(4),B1(4),B2(4),AL(4),DL(4)
300 REM DIMENSIONS VARIABLES USED IN PROGRAM
310 REM H,HEADER X,X DIRECTION Y,Y DIRECTION TH,ANGLE X1, HEIGHT
320 REM TI, TILT ANGLE, BO,B1,B2,AL,DL PLANAR COEFFICIENTS
330 DISP "THE FIRST DIAL ON THE HEADER MUST BE SET TO A NON-ZERO NUMBER"
340 DISP "UNTIL THE LAST READING, ZERO SIGNALS THAT THE DATA ACQUISION"
350 DISP "HAS BEEN COMPLETED" 360
360 DISP "SET THE POSITIVE DIRECTIONS ON THE VANGARD MOTION
ANALYZER"
370 DISP "RIGHT AND UPWARDS ARE THE POSITIVE DIRECTION"
380 REM
390 DISP "NEXT INSERT THE STILL FILM SUCH THAT THE EMULSION IS FACING
UP"
400 DISP "AND TOP OF DETONATION TO THE RIGHT"
410 REM SETS THE SIDE OF THE FILM BEING MEASURED
420 DISP "ZERO THE SMALL MOTION ANALYZER ALONG THE BASE AND CENTRAL
VIEW"
430 REM ALLOWS FOR CHECKING THE DATA AT A LATER POINT
440 DISP "ENTER THE FILM SPEED IN R.P.S."
450 INPUT U
460 U=U/250 1 mm/s
470 PRINT "FILM SPEED ";U;" mm/s"
480 REM ENTERS FILM SPEED IN R.P.S. WHICH IS THEN CONVERTED TO mm/s
490 REM OF IMAGE SWEEP RATE ACROSS THE FILM
500 DISP ""
510 DISP ""
520 DISP ""
530 DISP ""
540 DISP ""
550 DISP "INPUT THE DATA IN THE FOLLOWING FORMAT"
560 DISP "READINGS 1 & 2 THE SCALE OF 4 FILM DIVISIONS (SPROCKETS)"
      " FROM LEFT TO RIGHT"
570 DISP "READINGS 3 & 4 THE SIZE OF THE CENTER VIEW FROM TOP TO
BOTTOM"
580 DISP "READINGS 5 & 6 THE SIZE OF THE TOP VIEW FROM TOP TO BOTTOM"
590 DISP "READINGS 7 & 8 THE SIZE OF THE BOTTOM VIEW FROM TOP TO
BOTTOM"
600 DISP "READINGS 9 & 10 THE SCALE OF THE BANDS ON THE PICTURE"
610 DISP "FROM RIGHT TO LEFT"
620 DISP ""
630 DISP ""
640 DISP "INSERT STREAK RECORD EMULSION FACE UP, DETONATOR TO
THE RIGHT"
650 DISP "ZERO ON THE CENTRAL AXIS OF THE CENTRAL VIEW ALONG THE"
660 DISP "RIGHT HAND SIDE"
670 REM INSURES THE STREAK AND STILL RECORD ARE READ FROM THE SAME SIDE
680 IF MO=1 THEN 830
690 DISP ""
700 DISP "ENTER THE STREAK BANDS USING THE HEADER IN THE FOLLOWING MANNER"
710 REM THE HEADER IS A THUMB WHEEL USED BY THE OPERATOR TO IDENTIFY
720 REM THE READING BEING TAKEN
730 DISP "ENTER DATA FROM TOP TO BOTTOM AND RIGHT TO LEFT"
740 DISP "THE VERTICAL BANDS ARE NUMBERED FROM ONE TO THREE,"
750 DISP "BAND NUMBER ONE IS ON THE FAR RIGHT"
760 DISP ""
770 DISP "THE VIEWS ARE NUMBERED FROM ONE TO THREE, VIEW ONE ON TOP,"
780 DISP "VIEW TWO IN THE CENTER, AND VIEW THREE ON THE BOTTOM"
790 DISP "THE HEADER MUST BE SET APPROPRIATELY FOR EACH READING"
800 DISP "THE VIEW IS SET ON HEADER DIAL #4 AND THE BAND ON DIAL # 5"
810 MO=0 @ GOTO 880
820 REM MO IS USED TO ROUTE THE PROGRAM THROUGH THE INSTRUCTIONS
830 Z(1)=5.799
840 Z(2)=8.4201
850 Z(3)=11.28
860 Z(4)=14.691
870 REM ACTUAL SIZE OF BANDS MEASURED IN mm
880 PRINT
890 PRINT
900 PRINT "HEADER", "X DIRECTION","Y DIRECTION"
910 PRINT
920 DISP
930 DISP
940 DISP "HEADER", "X DIRECTION","Y DIRECTION"
950 DISP
960 REM TITLES THE DATA APPEARING ON THE SCREEN AND PRINTER SEPARATELY

35
970 ENTER 10 USING "*,8A,3X,7A,X,7A,3X"; HS,XS,YS
980 N=N+1
990 REM INCREMENTS N
1000 REM ENTERS DATA OVER RS-32
1010 REM $, NO CARRIAGE RETURN 8A, 8 DIGIT STRING, 3X, THREE SPACES NO ENTRY
1020 REM 7A, 7 DIGIT STRING, X ONE SPACE, 7A, 7 DIGIT STRING, 3X, THREE SPACES
1030 REM HS,XS, & YS ARE STRING CHARACTERS THAT ARE IN INVERSE VIDEO
1040 REM, NUMBERS ON A LIGHT BACKGROUND AND CANNOT BE USED IN MATH FUNCTIONS
1050 FOR J=1 TO 8 ! 8 DIGIT STRING
1060   B1$[J,J]=CHR$ (NUM (HS[J,J])-128)
1070 NEXT J
1080 B(N)=VAL (B1$)
1090 REM CONVERTS B1$ INTO A NUMBER VARIABLE
1100 REM -128 IS THE ASC-2 OFFSET FOR THE INVERSE TO NUMERIC VARIABLE SHIF
1110 REM VAL FUNCTION CONVERTS NUMBERS IN STRING INTO NUMERIC VARIABLES
1120 REM AND SETS H INTO MATRIX
1130 FOR J=1 TO 7 ! 7 DIGIT STRING
1140   X1$[J,J]=CHR$ (NUM (XS[J,J])-128)
1150   Y1$[J,J]=CHR$ (NUM (YS[J,J])-128)
1160 NEXT J
1170 X(N)=VAL (X1$)
1180 Y(N)=VAL (Y1$) ! REM VANGARD DIVISIONS
1190 REM CONVERTS X & Y STRING VARIABLES INTO NUMERIC VARIABLES
1200 REM AND SETS X & Y INTO MATRIX
1210 DISP H(N);" ";" ";X(N);" ";Y(N)
1220 PRINT H(N);" ";" ";X(N);" ";Y(N)
1230 IF N=10 THEN MO=2
1240 REM SETS MO TO 2 AFTER INITIALIZING DATA IS OBTAINED
1250 IF MO=2 THEN 680
1260 REM ROUTES PROGRAM AFTER OBTAINING SCALES
1270 A=NUM (B1$)
1280 IF A=48 THEN RETURN
REM RETURNS TO MAIN PROGRAM IF THE FIRST DIGIT IN THE HEADER EQUALS ZERO
REM SIGNIFYING THE DATA ACQUISITION IS FINISHED
REM ASC-2 CODE OF 48 IS EQUIVALENT TO ZERO
GOTO 970
REM ***************************************************************
SCALES:
REM ***************************************************************
REM SCALES SUBROUTINE DETERMINES THE SCALE FUNCTIONS REQUIRED
REM IN DETERMINING THE TILT
SC=ABS (4*4.75/(X(1)-X(2))) 1 UNITS mm ON FILM / VANGARD DIVISION
REM THERE ARE 4.75 mm BETWEEN SPROCKETS ON THE FILM
REM ALLOWS THE SCALING OF FILM SPEED FROM THE VANGARD MEASUREMENTS
PRINT "SC= ";SC;" mm ON FILM / VANGARD DIVISION"
DIA=ABS (Y(3)-Y(4)) 1 VANGARD DIVISIONS
REM MEASURED DIA OF CENTRAL VIEW ON FILM IN VANGARD DIVISIONS
R=DIA/2
REM RADIUS OF CENTRAL VIEW
S=(X(9)-X(10))/8.892*SC
REM S IS THE SCALE OF mm ON FILM / mm ACTUAL
REM 8.892 IS THE ACTUAL SIZE OF THE BANDS IN mm
REM S IS DETERMINED FROM THE VERITICAL SCALE ON THE BANDS
PRINT "S= ";S;" mm ON FILM / mm ACTUAL"
RETURN
REM ***************************************************************
VIEWS:
REM ***************************************************************
REM THIS SUBROUTINE DETERMINES THE ANGLES OF EACH READING
REM AND SETS UP A TWO DIMENSIONAL MATRIX USING BANDS AND
REM THE COUNT ON THE BAND TO DEFINE THE ANGLES AND HEIGHTS
REM OF EACH READING
E1=0
E2=0
E3=0
REM E1 THROUGH E4 ARE THE COUNTS ON THE INDEPENDENT BANDS
1640 M=N-1
REM LAST READING LEAVES THE DATA ACQUISITION ONLY, NO DATA
1660 FOR J=11 TO N
REM FIRST 10 READINGS WERE FOR SCALING
1680 BS=VAL$ (H(J))
REM PUT HEADER INTO STRING VARIABLE BS
1700 B=VAL (BS[5,5])
REM PLACES 5TH NUMBER IN BS INTO VARIABLE B
1720 REM WHICH IS THE BAND NUMBER
1730 IF B=1 THEN E1=E1+1 @ E=E1
1740 IF B=2 THEN E2=E2+1 @ E=E2
1750 IF B=3 THEN E3=E3+1 @ E=E3
1760 IF B=4 THEN E4=E4+1 @ E=E4
REM DETERMINES COUNTS ON EACH BAND AND PLACES COUNT INTO TEMPORARY VARIABLE
1770 REM VARIABLE E
1780 REM VARIABLE V
1790 V=VAL (BS[4,4])
REM DETERMINES THE 4TH VARIABLE IN THE HEADER, THE VIEW NUMBER
1800 IF V=1 THEN VO=(Y(5)+Y(6))/2 @ G=PI / 2 @ YA=-1
1810 IF V=2 THEN VO=(Y(3)+Y(4))/2 @ G=0 @ YA=-1
1820 IF V=3 THEN VO=(Y(7)+Y(8))/2 @ G=3*PI / 2 @ YA=-1
1830 REM ANGLE IS DETERMINED FOR EACH VIEW FROM ITS CENTER
1840 REM THEN THE REFLECTED VIEWS ARE ROTATED TO THE CENTRAL VIEWS
1850 REM VIEWS ZERO ANGLE, THROUGH G
1860 REM THE MIRROR IMAGES ARE REVERSED SO YA IS USED TO
1870 REM CORRECT THE ANGLES, YA=-1 FOR REFLECTED VIEWS
1880 T(B,E)=ASN (YA*(Y(J)-VO)/R)+G
1890 REM DETERMINES THE ANGLE FROM THE CENTER OF THE CENTRAL VIEW
1900 REM AND PLACES IT INTO THE MATRIX
1910 REM NOTE THE DIMENSIONS ARE IN VANGARD DIVISIONS
1920 IF T(B,E)<0 THEN T(B,E)=T(B,E)+2*PI
1930 REM ANGLES ARE ROTATED UNTIL THE EQUIVALENT POSITIVE ANGLE IS OBTAINED
1940 XI(B,E)=X(J)
1960 REM PLACES HEIGHT INTO MATRIX
1970 PRINT "THETA (";B;E;")= TH(B,E)*360/(2*PI )
1980 PRINT " AT THE HEIGHT ";XI(B,E)
1990 NEXT J
2000 RETURN
2010 REM ***********************************************
2020 LMS:
2030 REM ***********************************************
2040 FOR B=1 TO 4
2050 IF B=1 THEN E=E1
2060 IF B=2 THEN E=E2
2070 IF B=3 THEN E=E3
2080 IF B=4 THEN E=E4
2090 REM COUNT ON INDIVIDUAL BAND IS PUT INTO E
2100 BM=0 @ CM=0 @ FM=0 @ ET=0 @ H2=0 @ AM=0 @ CM=0 @ DM=0
2110 REM INITIALIZING VARIABLES REUSED FOR EACH BAND
2120 FOR J=1 TO E
2130 REM LEAST MEAN SQUARE ON EACH BAND
2140 YL=R*SIN (TH(B,J))
2150 XL=R*COS (TH(B,J))
2160 ZL=XI(B,J)*(SC/U)*(-1)
2170 REM SCALE SC/U CONERTS XI INTO THE TIME SCALE, ..
2180 BM=BM+YL
2190 CM=CM+XL
2200 BM=FM+YL*XL
2210 ET=ET+YL*XL
2220 H2=H2+XL*2
2230 AM=AM+ZL
2240 GM=GM+XL*ZL
2250 DM=DM+YL*ZL
2260 NEXT J
2270 REM DETERMINES THE VARIABLES NEEDED TO DETERMINE A LEAST MEAN
2280 REM SQUARE PLANE
2290 L1=(AM/E-GM/CM)/(BM/E-FM/CM)
2300 L2=GM*BM/CM-DM
2310 L3=BM*FM/CM-ET
REM B IS A COEFFICIENT OF PLANAR EQUATION
REM L^S ARE USED ONLY TO SPLIT THE LONG EQUATIONS USED
REM L VARIABLES WILL BE REUSED WHEN NEEDED

LI=DM-BM*GM/CM
L2=BM*H2/CH-FM
B1(B)=-(LI+L2*B2(B))/L3
REM NOTE LI IS THE SAME VARIABLE USED BEFORE
L1=AM/BM-DM/ET+B2(B)*(FM/ET-CM/BM)
L2=E/BM-BM/ET
BO(B)=LI/L2
REM THE COEFFICIENTS BO,B1,B2 FOR THE PLANAR EQUATION
REM HAVE NOW BEEN DETERMINED FOR THE PRESENT BAND ON THE
REM PRESENT COUNT
REM THE EQUATION IS OF THE FORM
T=BO+B1*Y+B2*X
REM NOTE THE DIMENSIONS ARE AGAIN IN VANGARD DIVISIONS
REM SINCE THE BANDS ARE INITIALLY SEPARATED THE TIME PLANE
REM MUST BE CORRECTED FOR THE INTERCEPT, BO
REM THE METHOD FOR DOING THIS IS TO SUBTRACTED THE SCALED
REM HEIGHT OF THE BAND AT THIS POINT
BO(B)=BO(B)-Z(B)*(S/U)
REM S/U IS THE SCALE FACTOR TO CONVERT m ACTUAL TO u#
PRINT "AT BAND NUMBER ";B;" THE PLANAR EQUATION IS ";BO(B);" + ";B1(B);" *Y+ ";B2(B);" *X"
NEXT B
RETURN

REM ANGLES:
REM THE PROBLEM NOW IS TO FIND THE ANGLE BETWEEN THE PLANE
REM AND THE FORM PLANE, TIME =BO
FOR B=1 TO 4
DL(B)=ATN (B1(B)/B2(B))
AL(B) = -(R*B2(B)/COS(DL(B)))

REM A COORDINATE TRANSFER IS REQUIRED TO CYLINDRICAL COORDINATES

REM THE FORM OF THE INTERSECTION OF THE PLANAR EQUATION DESIRED

REM IS TIME = BO + AL*COS(TH + DL), WHERE DL IS THE ANGLE OF ROTATION

REM TO REDUCE THE SIN TERM OF THE TRANSFORMATION TO ZERO

REM THE ABOVE EQUATIONS ARE THE CONSTANTS FOR THE TRANSFORMATION

REM NOTE THE DIMENSIONS ARE IN VANGARD DIVISIONS

PRINT "ZERO ANGLE FOR BAND "; B " IS "; DL(B)*360/(2*PI); " DEGREES"

PRINT "AT BAND "; B

PRINT "TIME = "; BO(B); " + "; AL(B); "COS(TH + "; DL(B)*360/(2*PI); "")"

NEXT B

PRINT " "

PRINT " "

TI(1) = ATN(((Z(2)-Z(1))/(BO(2)-BO(1))*(AL(1)*2)/25.4)

PRINT "" 

PRINT "TILT ONE = "; TI(1)*360/(2*PI); " DEGREES"

PRINT " AT A ROTATION OF "; DL(1)*360/(2*PI); " DEGREES"

TI(2) = ATN(((Z(3)-Z(1))/(BO(3)-BO(1))*(AL(2)*2)/25.4)

PRINT "" 

PRINT "TILT TWO = "; TI(2)*360/(2*PI); " DEGREES"

PRINT " AT A ROTATION OF "; DL(2)*360/(2*PI); " DEGREES"

TI(3) = ATN(((Z(4)-Z(2))/(BO(4)-BO(2))*(AL(3)*2)/25.4)

PRINT "" 

PRINT "TILT THREE = "; TI(3)*360/(2*PI); " DEGREES"

PRINT " AT A ROTATION OF "; DL(3)*360/(2*PI); " DEGREES"

TI(4) = ATN(((Z(4)-Z(3))/(BO(4)-BO(3))*(AL(4)*2)/25.4)

PRINT "" 

PRINT "TILT FOUR = "; TI(4)*360/(2*PI); " DEGREES"

PRINT " AT A ROTATION OF "; DL(4)*360/(2*PI); " DEGREES"

REM THIS SEGMENT CALCULATE THE WAVE TILT USING THE
2990 REM TIME RELATIONSHIPS ALREADY CALCULATED
3000 REM THE LOCAL DETONATION VELOCITY IS CALCULATED BY COMPUTING
3010 REM THE TIME THE CENTER OF THE WAVE CROSSES THE BAND
3020 REM PLANES (THE CHANGE IN HEIGHT, Z, DIVIDED BY THE
3030 REM CHANGE IN TIME, BO).
3040 REM THE TIME IT TAKES THE WAVE TO PASS AN INDIVIDUAL
3050 REM BAND PLANE IS ALSO NEEDED, 2*AL. THE FACT IS
3060 REM MULTIPLIED BY 2 TO OBTAIN THE FULL TIME SINCE
3070 REM THE TIME EQUATION, TIME = BO+AL*COS(TH+DL)
3080 REM IS LINEAR IN THE TIME AND COS(TH+DL) COORDINATES.
3090 REM GOING FROM COS(0)+COS(180) IS EQUAL TO 1+1 OR TWO
3100 REM THE WAVE TILT IS THEN CALCULATED FROM THE
3110 REM DETONATION VELOCITY AND THE TIME REQUIRED TO PASS
3120 REM A PLANE IS THEN USED TO CALCULATE THE WAVE TILT.
3130 REM THE ROTATION OF THE WAVE WAS CALCULATED EARLIER.
3140 BEEP @ BEEP @ BEEP
3150 RETURN
## COMPUTER PRINTOUT FOR CENTRAL INITIATION

**FILM SPEED** 5.872 mm/µs

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\[ \Theta (1, 1) = 50.5204 \]  
AT THE HEIGHT -.325

\[ \Theta (1, 2) = 60.2039 \]  
AT THE HEIGHT -.311

\[ \Theta (1, 3) = 75.3397 \]  
AT THE HEIGHT -.303
\[
\text{THETA ( 1, 4 )} = 91.2379 \\
\text{AT THE HEIGHT } -.303 \\

\text{THETA ( 1, 5 )} = 105.7597 \\
\text{AT THE HEIGHT } -.291 \\

\text{THETA ( 1, 6 )} = 129.4795 \\
\text{AT THE HEIGHT } -.29 \\

\text{THETA ( 1, 7 )} = 44.9743 \\
\text{AT THE HEIGHT } .326 \\

\text{THETA ( 1, 8 )} = 27.7781 \\
\text{AT THE HEIGHT } .338 \\

\text{THETA ( 1, 9 )} = 9.2355 \\
\text{AT THE HEIGHT } -.346 \\

\text{THETA ( 1, 10 )} = 350.4059 \\
\text{AT THE HEIGHT } -.359 \\

\text{THETA ( 1, 11 )} = 332.8198 \\
\text{AT THE HEIGHT } -.361 \\

\text{THETA ( 1, 12 )} = 315.7707 \\
\text{AT THE HEIGHT } -.358 \\

\text{THETA ( 1, 13 )} = 262.9083 \\
\text{AT THE HEIGHT } -.362 \\

\text{THETA ( 1, 14 )} = 279.4147 \\
\text{AT THE HEIGHT } -.384 \\

\text{THETA ( 1, 15 )} = 295.9936 \\
\text{AT THE HEIGHT } -.373 
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\theta (1, 16) = 308.7955 \\
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\]

\[
\theta (2, 1) = 308.7955 \\
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\[
\theta (2, 2) = 296.7832 \\
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\[
\theta (2, 3) = 278.3408 \\
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\[
\theta (2, 4) = 265.2198 \\
\text{at the height } -0.771
\]

\[
\theta (2, 5) = 253.3193 \\
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\[
\theta (2, 6) = 236.886 \\
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\[
\theta (2, 7) = 224.0168 \\
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\[
\theta (2, 8) = 310.0545 \\
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\[
\theta (2, 9) = 329.1797 \\
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\[
\theta (2, 10) = 345.1569 \\
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\[
\theta (2, 11) = 3.0076 \\
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\[
\begin{align*}
\theta (2, 12) &= 17.0502 \\
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\theta (2, 13) &= 32.0638 \\
& \text{at the height } -0.768 \\
\theta (2, 14) &= 45.2248 \\
& \text{at the height } -0.768 \\
\theta (2, 15) &= 128.560 \\
& \text{at the height } -0.715 \\
\theta (2, 16) &= 109.6588 \\
& \text{at the height } -0.709 \\
\theta (2, 17) &= 97.4481 \\
& \text{at the height } -0.708 \\
\theta (2, 18) &= 88.5851 \\
& \text{at the height } -0.713 \\
\theta (2, 19) &= 78.6073 \\
& \text{at the height } -0.724 \\
\theta (2, 20) &= 61.6205 \\
& \text{at the height } -0.735 \\
\theta (2, 21) &= 49.1318 \\
& \text{at the height } -0.759 \\
\theta (3, 1) &= 48.1896 \\
& \text{at the height } -1.15 \\
\theta (3, 2) &= 72.7647 \\
& \text{at the height } -1.144
\end{align*}
\]
\text{THETA} (3, 3) = 100.3122
\text{AT THE HEIGHT} -1.105

\text{THETA} (3, 4) = 116.7832
\text{AT THE HEIGHT} -1.097

\text{THETA} (3, 5) = 131.5734
\text{AT THE HEIGHT} -1.092

\text{THETA} (3, 6) = 43.2501
\text{AT THE HEIGHT} -1.131

\text{THETA} (3, 7) = 16.4961
\text{AT THE HEIGHT} -1.146

\text{THETA} (3, 8) = 2.1225
\text{AT THE HEIGHT} -1.114

\text{THETA} (3, 9) = 343.8723
\text{AT THE HEIGHT} -1.136

\text{THETA} (3, 10) = 327.9361
\text{AT THE HEIGHT} -1.149

\text{THETA} (3, 11) = 312.7292
\text{AT THE HEIGHT} -1.162

\text{THETA} (3, 12) = 237.9361
\text{AT THE HEIGHT} -1.145

\text{THETA} (3, 13) = 251.8365
\text{AT THE HEIGHT} -1.15

\text{THETA} (3, 14) = 266.1065
\text{AT THE HEIGHT} -1.168
\text{THETA (3, 15)} = 283.0210 \\
\text{AT THE HEIGHT -1.167}

\text{THETA (3, 16)} = 302.0638 \\
\text{AT THE HEIGHT -1.172}

\text{THETA (3, 17)} = 312.7665 \\
\text{AT THE HEIGHT -1.157}

\text{THETA (4, 1)} = 312.7665 \\
\text{AT THE HEIGHT -1.648}

\text{THETA (4, 2)} = 296.1905 \\
\text{AT THE HEIGHT -1.646}

\text{THETA (4, 3)} = 280.6719 \\
\text{AT THE HEIGHT -1.644}

\text{THETA (4, 4)} = 257.7039 \\
\text{AT THE HEIGHT -1.635}

\text{THETA (4, 5)} = 242.4215 \\
\text{AT THE HEIGHT -1.627}

\text{THETA (4, 6)} = 230.9771 \\
\text{AT THE HEIGHT -1.615}

\text{THETA (4, 7)} = 314.7751 \\
\text{AT THE HEIGHT -1.635}

\text{THETA (4, 8)} = 331.6205 \\
\text{AT THE HEIGHT -1.643}

\text{THETA (4, 9)} = 347.5229 \\
\text{AT THE HEIGHT -1.644}
\[ \Theta(4, 10) = 6.5573 \]
\[ \text{at the height } -1.641 \]

\[ \Theta(4, 11) = 22.5020 \]
\[ \text{at the height } -1.65 \]

\[ \Theta(4, 12) = 40.8681 \]
\[ \text{at the height } -1.635 \]

\[ \Theta(4, 13) = 128.7955 \]
\[ \text{at the height } -1.566 \]

\[ \Theta(4, 14) = 110.6006 \]
\[ \text{at the height } -1.157 \]

\[ \Theta(4, 15) = 97.0916 \]
\[ \text{at the height } -1.592 \]

\[ \Theta(4, 16) = 83.6206 \]
\[ \text{at the height } -1.613 \]

\[ \Theta(4, 17) = 72.0225 \]
\[ \text{at the height } -1.626 \]

\[ \Theta(4, 18) = 58.767 \]
\[ \text{at the height } -1.646 \]

\[ \Theta(4, 19) = 49.5978 \]
\[ \text{at the height } -1.65 \]

At Band Number 1 the planar equation is
\[ \text{Time } = 0.2088 + 0.1090 \times y + 0.0636 \]

At Band Number 2 the planar equation is
\[ \text{Time } = 0.5769 + 0.0884 \times y + 0.1361 \]
AT BAND NUMBER 3 THE PLANAR EQUATION IS
TIME = .9098 + .0698 *Y + .537

AT BAND NUMBER 4 THE PLANAR EQUATION IS
TIME = 1.3301 + .0458 *Y + .1092

ZERO ANGLE FOR BAND 1 IS 59.7555 DEGREES AT BAND 1
TIME = .2088 + .0409 * COS(TH + 59.7555)

ZERO ANGLE FOR BAND 2 IS 33.0268 DEGREES AT BAND 2
TIME = .5769 + .0526 * COS(TH + 33.0268)

ZERO ANGLE FOR BAND 3 IS 52.4504 DEGREES AT BAND 3
TIME = .9098 + .0285 * COS(TH + 52.4504)

ZERO ANGLE FOR BAND 4 IS 22.7668 DEGREES AT BAND 4
TIME = 1.3301 + .0384 * COS(TH + 22.7668)

TILT ONE = 1.5790 DEGREES
AT A ROTATION OF 120.2444 DEGREES

TILT TWO = 1.859 DEGREES
AT A ROTATION OF 146.9731 DEGREES

TILT THREE = 1.0718 DEGREES
AT A ROTATION OF 127.5495 DEGREES

TILT FOUR = 1.4049 DEGREES
AT A ROTATION OF 157.2331 DEGREES
**COMPUTER PRINTOUT FOR 1/4 inch OFFCENTER INITIATION**

**FILM SPEED 6.336 mm/μs**

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SC = 6.0394 mm on film/vangard divisions
S = .2010 mm on film/mm actual

\[ \text{THETA (1, 1)} = 54.9534 \]
\[ \text{AT THE HEIGHT -1.077} \]

\[ \text{THETA (1, 2)} = 66.5165 \]
\[ \text{AT THE HEIGHT -0.846} \]

\[ \text{THETA (1, 3)} = 76.4173 \]
\[ \text{AT THE HEIGHT -0.616} \]

\[ \text{THETA (1, 4)} = 94.7801 \]
\[ \text{AT THE HEIGHT -0.559} \]

\[ \text{THETA (1, 5)} = 111.4169 \]
\[ \text{AT THE HEIGHT -0.58} \]

\[ \text{THETA (1, 6)} = 126.9784 \]
\[ \text{AT THE HEIGHT -0.699} \]

\[ \text{THETA (1, 7)} = 133.5821 \]
\[ \text{AT THE HEIGHT 0.857} \]
\[ \text{THETA} \left( 1, 8 \right) = 39.2964 \]
 \[ \text{AT THE HEIGHT } -1.207 \]

\[ \text{THETA} \left( 1, 9 \right) = 26.4524 \]
 \[ \text{AT THE HEIGHT } -1.367 \]

\[ \text{THETA} \left( 1, 10 \right) = 12.2466 \]
 \[ \text{AT THE HEIGHT } -1.581 \]

\[ \text{THETA} \left( 1, 11 \right) = 358.0897 \]
 \[ \text{AT THE HEIGHT } -1.794 \]

\[ \text{THETA} \left( 1, 12 \right) = 345.7913 \]
 \[ \text{AT THE HEIGHT } -1.923 \]

\[ \text{THETA} \left( 1, 13 \right) = 334.8972 \]
 \[ \text{AT THE HEIGHT } -2.039 \]

\[ \text{THETA} \left( 1, 14 \right) = 317.4869 \]
 \[ \text{AT THE HEIGHT } -2.207 \]

\[ \text{THETA} \left( 1, 15 \right) = 269.1318 \]
 \[ \text{AT THE HEIGHT } -2.391 \]

\[ \text{THETA} \left( 1, 16 \right) = 285.4660 \]
 \[ \text{AT THE HEIGHT } -2.345 \]

\[ \text{THETA} \left( 1, 17 \right) = 299.0025 \]
 \[ \text{AT THE HEIGHT } -2.281 \]

\[ \text{THETA} \left( 1, 18 \right) = 309.9728 \]
 \[ \text{AT THE HEIGHT } -2.21 \]

\[ \text{THETA} \left( 2, 1 \right) = 309.9728 \]
 \[ \text{AT THE HEIGHT } -2.577 \]
THETA ( 2, 2 ) = 299.4003
AT THE HEIGHT -2.628

THETA ( 2, 3 ) = 281.5349
AT THE HEIGHT -2.671

THETA ( 2, 4 ) = 251.8128
AT THE HEIGHT -2.672

THETA ( 2, 5 ) = 316.0572
AT THE HEIGHT -2.556

THETA ( 2, 6 ) = 333.7413
AT THE HEIGHT -2.433

THETA ( 2, 7 ) = 345.0737
AT THE HEIGHT -2.314

THETA ( 2, 8 ) = 358.7845
AT THE HEIGHT -2.185

THETA ( 2, 9 ) = 11.0058
AT THE HEIGHT -2.031

THETA ( 2, 10 ) = 24.9111
AT THE HEIGHT -1.852

THETA ( 2, 11 ) = 139.6515
AT THE HEIGHT -1.402

THETA ( 2, 12 ) = 129.8596
AT THE HEIGHT -1.19

THETA ( 2, 13 ) = 105.1959
AT THE HEIGHT -1.158
\[
\begin{align*}
\text{THETA ( 2, 14 )} & = 76.5958 \\
& \text{AT THE HEIGHT -1.262} \\
\text{THETA ( 2, 15 )} & = 51.7059 \\
& \text{AT THE HEIGHT -1.534} \\
\text{THETA ( 3, 1 )} & = 53.2385 \\
& \text{AT THE HEIGHT -2.032} \\
\text{THETA ( 3, 2 )} & = 63.8381 \\
& \text{AT THE HEIGHT -1.917} \\
\text{THETA ( 3, 3 )} & = 78.7287 \\
& \text{AT THE HEIGHT -1.804} \\
\text{THETA ( 3, 4 )} & = 104.4775 \\
& \text{AT THE HEIGHT -1.755} \\
\text{THETA ( 3, 5 )} & = 128.9607 \\
& \text{AT THE HEIGHT -1.831} \\
\text{THETA ( 3, 6 )} & = 46.4058 \\
& \text{AT THE HEIGHT -2} \\
\text{THETA ( 3, 7 )} & = 33.8883 \\
& \text{AT THE HEIGHT -2.153} \\
\text{THETA ( 3, 8 )} & = 21.5101 \\
& \text{AT THE HEIGHT -2.33} \\
\text{THETA ( 3, 9 )} & = 4.6930 \\
& \text{AT THE HEIGHT -2.527} \\
\text{THETA ( 3, 10 )} & = 347.9309 \\
& \text{AT THE HEIGHT -2.666}
\end{align*}
\]
\[
\begin{align*}
\text{THETA ( 3, 11 )} & = 322.4762 & \text{AT THE HEIGHT} & -2.845 \\
\text{THETA ( 3, 12 )} & = 267.2209 & \text{AT THE HEIGHT} & -2.961 \\
\text{THETA ( 3, 13 )} & = 288.7362 & \text{AT THE HEIGHT} & -2.952 \\
\text{THETA ( 3, 14 )} & = 309.5211 & \text{AT THE HEIGHT} & -2.867 \\
\text{THETA ( 4, 1 )} & = 309.5211 & \text{AT THE HEIGHT} & 3.362 \\
\text{THETA ( 4, 2 )} & = 396.8409 & \text{AT THE HEIGHT} & -3.443 \\
\text{THETA ( 4, 3 )} & = 278.5391 & \text{AT THE HEIGHT} & 3.485 \\
\text{THETA ( 4, 4 )} & = 249.2344 & \text{AT THE HEIGHT} & 3.478 \\
\text{THETA ( 4, 5 )} & = 320.7035 & \text{AT THE HEIGHT} & -3.34 \\
\text{THETA ( 4, 6 )} & = 332.7692 & \text{AT THE HEIGHT} & -3.257 \\
\text{THETA ( 4, 7 )} & = 347.9309 & \text{AT THE HEIGHT} & -3.116 \\
\text{THETA ( 4, 8 )} & = 5.2159 & \text{AT THE HEIGHT} & -2.976
\end{align*}
\]
\[ \theta(4, 9) = 21.1374 \]
\[ \text{at the height } -2.846 \]

\[ \theta(4, 10) = 34.9406 \]
\[ \text{at the height } -2.73 \]

\[ \theta(4, 11) = 137.5510 \]
\[ \text{at the height } -2.43 \]

\[ \theta(4, 12) = 107.5486 \]
\[ \text{at the height } -2.326 \]

\[ \theta(4, 13) = 64.9931 \]
\[ \text{at the height } -2.509 \]

\[ \theta(4, 14) = 45.4513 \]
\[ \text{at the height } -2.634 \]

AT BAND NUMBER 1 THE PLANAR EQUATION IS
TIME = 1.2415 + 2.3746 \* Y + .6858

AT BAND NUMBER 2 THE PLANAR EQUATION IS
TIME = 1.5888 + 2.0897 \* Y + .5543

AT BAND NUMBER 3 THE PLANAR EQUATION IS
TIME = 1.8958 + 1.6766 \* Y + .4716

AT BAND NUMBER 4 THE PLANAR EQUATION IS
TIME = 2.3183 + 1.5808 \* Y + .3173

ZERO ANGLE FOR BAND 1 IS 73.8908 DEGREES AT BAND 1
TIME = 1.2415 + .8156 \* \cos (\theta + 73.8908)

ZERO ANGLE FOR BAND 2 IS 75.1444 DEGREES AT BAND 2
TIME = 1.5888 + .7134 \* \cos (\theta + 75.1444)
ZERO ANGLE FOR BAND 3 IS 74.2885 DEGREES AT BAND 3
TIME = 1.8958 + .5747 * COS(TH+ 74.2885)

ZERO ANGLE FOR BAND 4 IS 78.6503 DEGREES AT BAND 4
TIME = 2.3183 + .5320 * COS (TH+ 78.6503)

TILT ONE = 25.8610 DEGREES
AT A ROTATION OF 106.1091 DEGREES

TILT TWO = 25.2008 DEGREES
AT A ROTATION OF 104.8555 DEGREES

TILT THREE = 21.2575 DEGREES
AT A ROTATION OF 105.7114 DEGREES

TILT FOUR = 18.6898 DEGREES
AT A ROTATION OF 101.3496 DEGREES
Flow Chart

Main Routine

START

SUBROUTINE RETRIEVAL

SUBROUTINE RETRIEVAL OBTAINS MEASUREMENTS FROM VANGUARD MOTION ANALYZER

SUBROUTINE SCALES

SUBROUTINE SCALES DETERMINES THE SCALES BETWEEN THE FILM, THE VANGUARD MEASUREMENTS, AND THE TEST SETUP

SUBROUTINE VIEWS

SUBROUTINE VIEWS ARRANGES THE DATA FROM THE THREE VIEWS INTO HEIGHT AND ANGLE MEASUREMENTS

SUBROUTINE LMS

SUBROUTINE LMS DETERMINES THE PLANAR LEAST-MEAN-SQUARE OF THE TIME THE DETONATION WAVE PASSES THE FILM PLANES
SUBROUTING ANGLES DETERMINES THE WAVE TILT AND ORIENTATION OF THE DETONATION WAVE AT EACH FILM PLANE
SUBROUTINE RETRIEVAL

START

MO = 1

N = 0

DIMENSION H(200), X(200), Y(200), TH(4,200), X1(4,200), BD(4), B1(4), B2(4), AL(4), DL(4)

INPUT U

ENTERS, FROM THE KEYBOARD, THE ROTATION, IN R.P.S., OF THE ROTATING MIRROR WITHIN THE STREAK CAMERA
U = U/250

Determines the film speed of the rotating mirror, streak camera, in \( \text{mm/ms} \)

DISPLAY OPERATING INSTRUCTIONS

Displays instructions on the monitor for inputting the scales from the stills

MO = 1

Routes program to bypass the operating instructions required later

MO = 0

Sets MO to 0 variable to facilitate the routing of the program

Displays instructions for inputting the data from the streak record
Initializes the measured heights, in m, of the band on the file wrap.

Displays the headings for the print out of the measured points.

Inputs $H\$, the header, $X\$, the x value, and $Y\$, the y value, in string format.

Increment the count on the readings taken.
The eight characters in the header must be converted from string variables to numeric variables individually.

\[ \text{FOR } J = 1 \text{ to } 8 \]

\[ H1S(J,J) = \text{CHR} \left( \text{NUM}(H1S(J,J)) - 128 \right) \]

The characters ASCII codes are offset by 128. This statement sets the code to the correct individual characters.

\[ \text{NEXT } J \]

\[ H(N) = \text{VAL}(H1S) \]

Sets the string character of H1S to a numeric variable.
The seven characters in the x and y directions must be converted from string variables to numeric variables individually.

\[ \text{FOR } J = 1 \text{ TO 7} \]

\[ X(\text{J}, J) = \text{CHR$(\text{NUM}(X(\text{J}, J) - 128))} \]

The characters ASCII codes are offset by 128. These statements set the codes to the correct individual characters.

\[ Y(\text{J}, J) = \text{CHR$(\text{NUM}(Y(\text{J}, J) - 128))} \]

\[ \text{NEXT J} \]

\[ X(N) = \text{VAL}(X(\text{J})) \]

Sets the string character of \( X(\text{J}) \) to a numeric variable.
Y(N)=VAL(Y1S)

Sets the string character of Y1S to a numeric variable

DISPLAY
H(N),X(N),
Y(N)

Displays measured data points

N=0

Routes the program. After ten readings from the still picture, the data is then obtained from the streak photograph.
Determines the ASCII code for H1S, if H1S is equal to zero the corresponding ASCII code is 48. A header reading of zero is used to end the data acquisition.
SUBROUTINE SCALES

START

SC = ABS \( \frac{4 \times 4.75}{X(1) - X(2)} \)

PRINT SC

DIA = ABS \( Y(3) - Y(4) \)

R = DIA / 2

Determines the scale factor between the vanguard divisions and the film dimensions obtained from the standard sprocket hole separation, 4.75mm. Units on SC are 

Prints scale factor SC

Determines the scaled diameter from readings 3 and 4, in vanguard divisions

Determines the scaled radius
$S = \frac{(X(9) - X(10))}{8.692 \times SC}$

Determines the scale factor between the film and the test measurements. Units on $S$ are mm on film/mm actual.

Prints the scale factors.
SUBROUTINE VIEWS

START

E1 = 0
E2 = 0
E3 = 0
E4 = 0

Initialize variables E1 through E4, the counts on individual bands

N = N - 1

Reduce the count on the data by one to account for the last reading, which was used the end data acquisition

FOR J = 11 TO N

The first 10 readings were used as scale factors, reading number 11 began the data acquisition of the streak records

8
B$ = VAL$(H(J))

B$ = VAL (B$ 4, 4)
V$ = VAL (B$ 5, 5)

Places header variable into string variable B

Determines the value of the fourth and fifth characters, the band and view values

B = 1
YES - E1 = E1 + 1
E = E1
NO

B = 2
YES - E2 = E2 + 1
E = E2
NO

B = 3
YES - E3 = E3 + 1
E = E3
NO

B = 4
YES - E4 = E4 + 1
E = E4
NO

9

Increments the individual band counts
9

V=1 YES \[V= (Y(5)+Y(6))_{12}\]
   NO \[G= P112\]

V=2 YES \[G= 0\]
   NO \[V= (Y(7)+Y(6))_{12}\]

V=3 YES \[G= 3*P\]

TH(B,E)+2*PI

IF TH(B,E) THEN

Sets central angle, rotation, and central view
Determines the angle of the reading
Sets all angles to a positive rotation
Sets the $x$ variable to the matching two dimensional of the angle

Displays the angle

Displays the $x$ value

RETURN
The count on the bands is incremented from 1 to 4.

Sets to proper count on the readings taken on each individual band into variable E.
B.m-0, CM-0, FM-0, ET-0, HZ-0, AH-0, CM-0, DM-0

Initializes variables used in the least-mean-square technique

FOR J=1 TO 8

YL=R*S/N(TH(B,U))

Determines the Y variables from the angle

XL=R*COS(TH(B,U))

Determines the x variables from the angle
ZL = -XL(B,U)*(SL/U)  
Determines the time of the reading

BM = BM + YL  
Sums the Y values along the individual band

CM = CM + XL  
Sums the x values

FY = FY + XL*YL  
Sums the product of x and y

EI = ET + YL^2  
Sums the x square of the y values
H2 = H2 + XL^2

Sums the square of the x values

AM = AM + ZL

Sums the time values

GM = GM + XL*ZL

Sums the product of x and time values

DM = DM + YL*ZL

Sums the product of y and time values

NEXT J

F
Determines the x coefficient of the planar equation

**B2 =**

\[ \frac{A^y - C^m}{E} - \frac{B^m}{CH} \frac{E}{A^y - C^m} \]

\[ \frac{B^m F^m}{E} - \frac{C^m}{E - F^m} \frac{E}{E - C^m} \]

\[ \frac{H^2 - C^m}{C^m} E - \frac{F^m - H^2}{E - C^m} \frac{B^m}{E} \]

\[ \frac{B^m F^m}{E - C^m} \frac{E}{B^m F^m - E} \]

**Determines the y coefficient of the planar equation**

**B1 =**

\[ \frac{A^y - C^m}{E} - \frac{B^m}{C^m + C^m B^m} - D^m \]

\[ H^2 B^2 \]

\[ \frac{B^m F^m}{C^m} - E \]

**Determines the x intercept of the planar equation**

**B0 =**

\[ \frac{A^y - D^m}{E} - \frac{F^m}{B^m} - \frac{C^m}{E - B^2} \frac{B^m}{E} \]

\[ \frac{B^m}{E - B^m} \frac{B^m}{E} \]

**Determines the intercept of the planar equation**
Determines the proper intercept, correcting for the variation in band heights

BO(B) = BO(B) - 2BS/U

Prints the least-mean-square coefficients obtained

NEXT J

RETURN
SUBROUTINE ANGLES

START

FOR B = 1 TO 4

DL(B) = ATN(B1(B) / B2(B))

Determines the zero angle for the intersection between the cylinder and the time plane

AL(B) = \(-A \times E2(B) \) / \( \cos(DL(B)) \)

Determines the slope for the intersection between the cylinder and the time plane

PRINT AL, BL

Print: AL & BL

16
\[ T(1) = \text{ATN}((Z(2)-Z(1)) / (B0(2)-B0(1))) + \text{AL}(1) + 21 \text{.} \]

Determines the tilt in the first film plane, in radians

\[ \text{PRINT} \frac{T(1) \times 360}{2 \pi} \]

Prints the tilt in the fast film plane, in degrees
$T(2) = \text{ATN}((Z(3) - Z(1))/BO(3) - BO(3) - BO(1))1 * (AL(2)*21/25.4)$

Determines the tilt in the second film plane in radians

PRINT $T(2)*360/2$

Prints the tilt in the second film plane in degrees

$T(3) = \text{ATN}(Z(3) - Z(2))/BO(4) - BO(2) * (AL(3)*2)/125.4)$

Determines the tilt in the third film plane in radians

PRINT $T(3)*360/2$

Prints the tilt in the third film plane in degrees
\( I(1) = \text{Determines the tilt in the fourth film plane in radians} \)

\[ T(4) + \text{ATK}((2(4) - 2(3))/\text{BO}(4) - \text{BO}(3)) \times \text{AL}(4) \times 2 \]

\( 125.4 \)

\[ \text{PRINT 360} \]

\[ \frac{T(4)}{2} \]

\[ \text{Prints the tilt in the fourth film plane in degrees} \]

\[ \text{RETURN} \]
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