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INTERFEROGRAM REDUCTION AND INTERPRETATION AS APPLIED TO THE OPTICAL ANALYSIS OF THE 10 KJ LASL LASER FUSION SYSTEM*

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ABSTRACT

The LASL 10 kJ Eight-Beam CO_2 Laser Fusion System, currently under construction, has approximately one hundred optical elements per beam. The nominal system is diffraction limited and degradations in performance are primarily caused by imperfect components as well as alignment errors. Consequently, analysis and predictions for the system are very much dependent on the proper description of the imperfect components.

The approach taken at LASL has been to characterize the components interferometrically. Briefly, interferograms of the various components are made at the 633 nm He-Ne wavelength. These are digitized, after visual examination, at appropriate sampling points along the fringes. The interactive semi-automatic computer program[1] developed at LASL is used to verify and if necessary correct the digitization. The correct digitization data is next input to the computer program FRINGE 2[2] and this program is used to generate, among other data, Zernicke polynomial coefficients at 10.6 microns for the wave front. The 36 Zernicke coefficients characterize the O.P.D. (optical path difference) at each manufactured surface and these are accepted by the diffraction propagation computer program LOTS[3] and the laser beam is thus propagated through the entire system and various parameters of interest such as Strehl ratio, intensity and encircled energy distributions are computed at stations of interest throughout the system.

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* Work performed under the auspices of the U. S. Department of Energy.
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An example of this procedure using an actual interferogram of a manufactured component will be presented and the various limitations will be discussed.

Analysis of the total system, based on expected component quality, has shown that spatial filters are very effective in removing aberrations and that only components after the final spatial filter are crucial to achieving near diffraction limited performance.[4] Further analysis of these components[5] has already shown the need to improve the optical quality of the large sixteen-inch diameter salt windows in the system.

The approach of interferometrically defining and characterizing the various manufactured optical components appears to be a powerful tool in the analysis and optimization of the optical parameters in the laser fusion system. Detailed results of the analysis for one complete leg of the Eight-Beam System will be presented.

References

1. CDFL - Computer Determined Fringe Locator - developed by W. S. Hall of Los Alamos Scientific Laboratory.
2. FRINGE 2 is an interferometric analysis code developed at the University of Arizona.
3. LOTS is a diffraction Propagation code tailered to LASL Laser Fusion System developed by George Lawrence of the University of Arizona in conjunction with the Laser Division of LASL.
4. "Optical Analysis of the LASL 10 KJ CO_2 Laser Fusion System" presented at the Annual Meeting of O.S.A. Toronto, Canada, . 13, 1977 by George Lawrence, I. Liberman and V. K. Viswanathan.
5. "Optical Analysis and Predictions for the LASL 10 kJ CO_2 Laser Fusion System" V. K. Viswanathan, submitted to the Topical Meeting on "Inertial Confinement Fusion," February 7-9, 1978. San Diego, CA.

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The LASL 10 kJ Eight-Beam CO_2 Laser Fusion System, currently nearing completion, has approximately one hundred optical elements per beam. Figure 1 shows the layout of the system. Each of the eight beams is expected to deliver 1.25 kJ within a nanosecond pulse.

The nominal system is diffraction limited and the degradations in performance are a consequence of imperfect components, alignment errors, etc. Hence, the analysis and predictions as well as attempts to optimize optical performance of the system are very much dependent on the proper description of the imperfect components.

The approach taken at LASL has been to characterize the components interferometrically. To describe the procedure briefly, Fizeau or Twyman-Green type interferograms of the components are made at 633 nm wavelength. These are digitized using one of two methods (to be described later). Zernike polynomial coefficients at 10.6 microns are generated and used to characterize the O.P.D. (optical path difference) at each manufactured surface. The wave front is propagated through the entire system, taking diffraction and O.P.D. modifications introduced at each component into account and

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various parameters of interest such as Strehl ratio, intensity and encircled energy distributions, amplitude and phase of the wave front are computed and displayed as desired.

The first method for digitizing the interferogram (either positive or negative) consists of processing the interferogram with a scanning display microdensitometer. The output is then "cleaned" and stored in a photostore file (which is a 512x512 matrix).

The computer program C.D.F.L.[1] which uses merger criteria in the x and y directions (for points to be considered to lie on the same fringe) prints the fringe pattern with all minima as shown in Figure 2. Next, the pattern is refined further to that shown in Figure 3 and operator intervention removes the discontinuities and ensures the correct ordering of the fringes as shown in Figure 4. These fringes are automatically digitized by proper sampling. The reduction described here is that of a noisy and marginal interferogram. If one traces over the negative with a Leroy '0' pen, the process actually works better and is considerably faster and very little operator intervention is necessary.

The second method is straightforward and consists of using a 4953 Graphics Tablet in conjunction with a Tektronix 4015 terminal; the sampled coordinates are directly stored in a file. Figure 5 shows a typical interferogram reduction using this method.

Actually, we had used a third method before we received the Graphics Tablet. This consisted of scotch-taping the interferogram film onto the face of the Tektronix terminal and then using the terminal cross hairs for the digitization process. Obviously, this is less accurate than using the tablet because of parallax errors, etc.

The first method is the most accurate and has the virtues of being compatible with automation as well as with several internal checks for possible errors. The second method is, however, easier to implement in practice (at least at LASL) and, as the original interferograms were taken at .633 microns and the results are desired at 10.6 microns, it is accurate enough and will not introduce errors in the representation of manufactured elements. It does suffer from the drawback that the operator has to make sure himself that no errors were introduced in sampling the points along the fringes.

The next stage consists of automatically transferring the data to the computer program FRINGE[2] and correctly orienting the element as well as ensuring the proper sign of the O.P.D. While we can access any of two versions of FRINGE available at LASL, and the program itself has a truly varied array of analysis outputs, the interest here is to fit the data to Zernike polynomials as closely as possible, and to get the Zernike coefficients at 10.6 microns as punched card output. Figure 6 shows a typical printed output. At present, a file ABR (which consists of the Zernike coefficients data for all the elements as they occur sequentially in the system) is created, but eventually we hope to make this process automatic.

The Diffraction Propagation Program LOTS[3] propagates the laser beam through the entire system, (using the Zernike polynomial coefficients to represent the manufactured surface); it allows for energy variations from saturating gain and loss intentionally placed in the optical path. Various parameters of interest such as Strehl ratio, intensity, encircled energy distributions, amplitude and phase are computed and displayed at stations of interest. Figure 7 shows the output at the target plane for one of the legs of the Eight Beam System.

Analysis of the total system, based on expected component quality, has shown that spatial filters of proper size are very effective in removing many troublesome aberrations and that only components after the final spatial filter are crucial to achieving near diffraction limited performance.[4] Further analysis of these components[5] has already shown the need to improve the optical quality of the large sixteen inch diameter salt windows in the system. Figure 8 shows the system performance in terms of Strehl ratio for one leg of the Eight Beam System based on compliance of mounted optical components, as well as the expected performance based on interferogram reduction of the actual manufactured components occurring after the final spatial filter in the system.

In conclusion, the approach of interferometrically defining and characterizing the various manufactured optical components appears to be a powerful tool in the analysis and optimization of the optical parameters in the laser fusion system. This technique could be used as an optical design, analysis, and assembly approach to these novel, and complex systems which appear to defy conventional approaches to optical systems design, optimization and analysis.

References

1. C.D.F.L. - Computer Determined Fringe Locator - developed by W. S. Hall of Los Alamos Scientific Laboratory.
2. FRINGE - Generic name for an interferometric analysis program developed at the University of Arizona.
3. LOTS is a diffraction propagation code tailored to LASL Laser Fusion System developed by George Lawrence of the University of Arizona in conjunction with the Laser Division of LASL.

4. "Optical Analysis of the LASL 10 kJ CO_2 Laser Fusion System" - Paper THB21 presented at the Annual Meeting of the Optical Society of America, Toronto, Canada, October 13, 1977, by George Lawrence, I. Liberman and V. K. Viswanathan.
5. "Optical Analysis and Predictions for the LASL 10 kJ CO_2 Laser Fusion System," paper #TuC4 at the Topical Meeting on Inertial Confinement Fusion, February 7, 1978 at San Diego, CA. by V. K. Viswanathan.

EIGHT BEAM SYSTEM OPTICAL SCHEMATIC

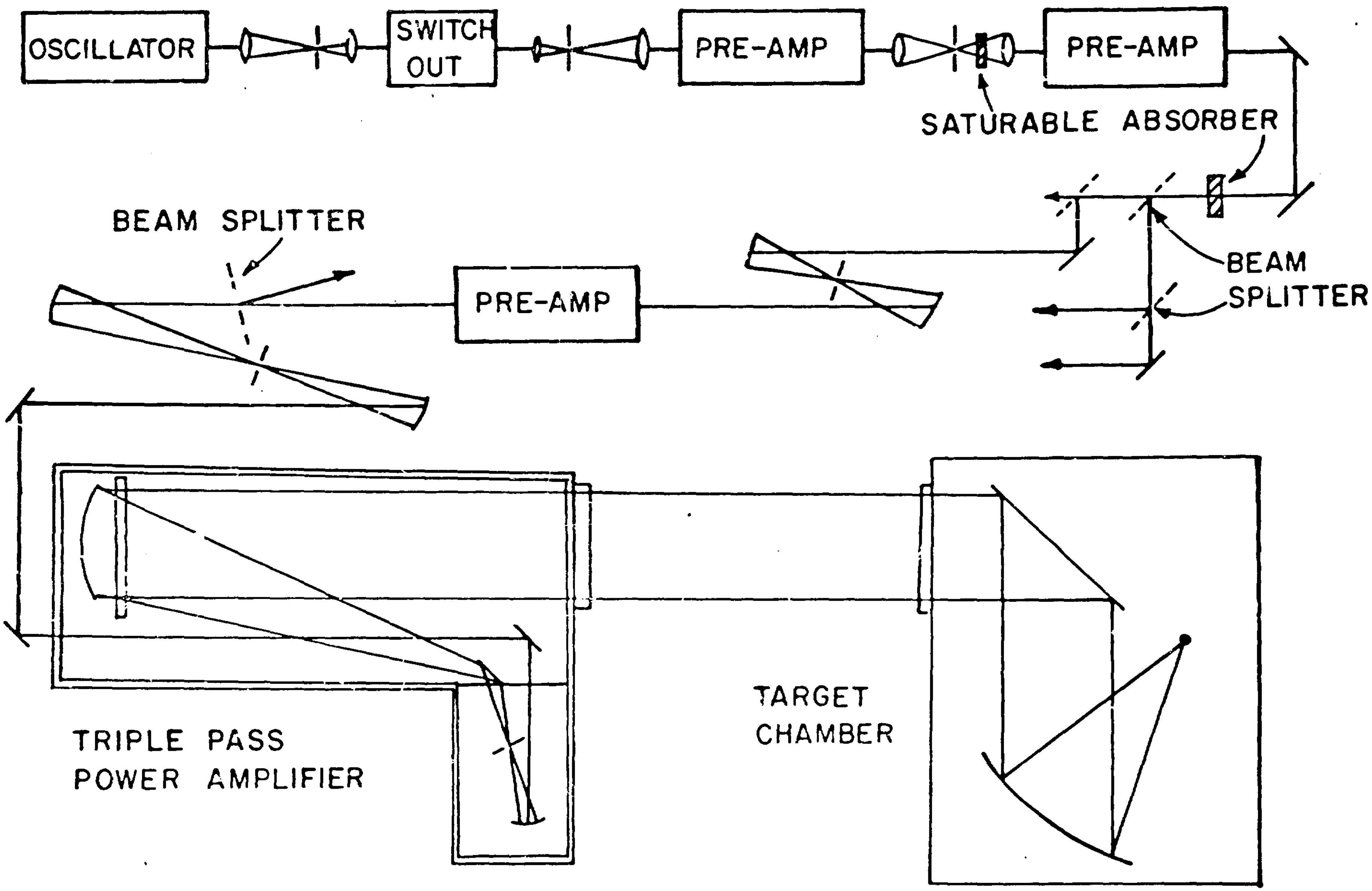


Figure 1

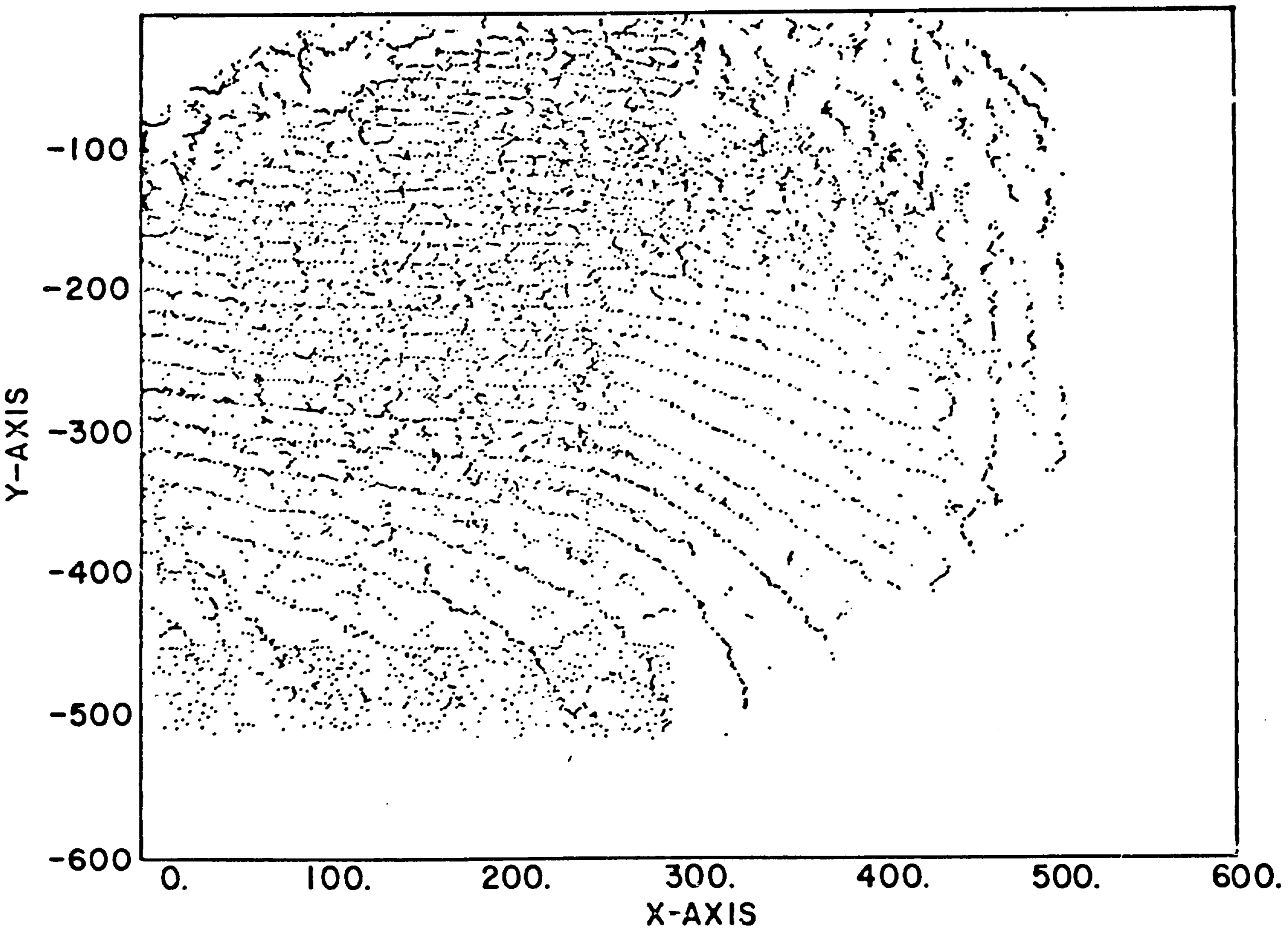
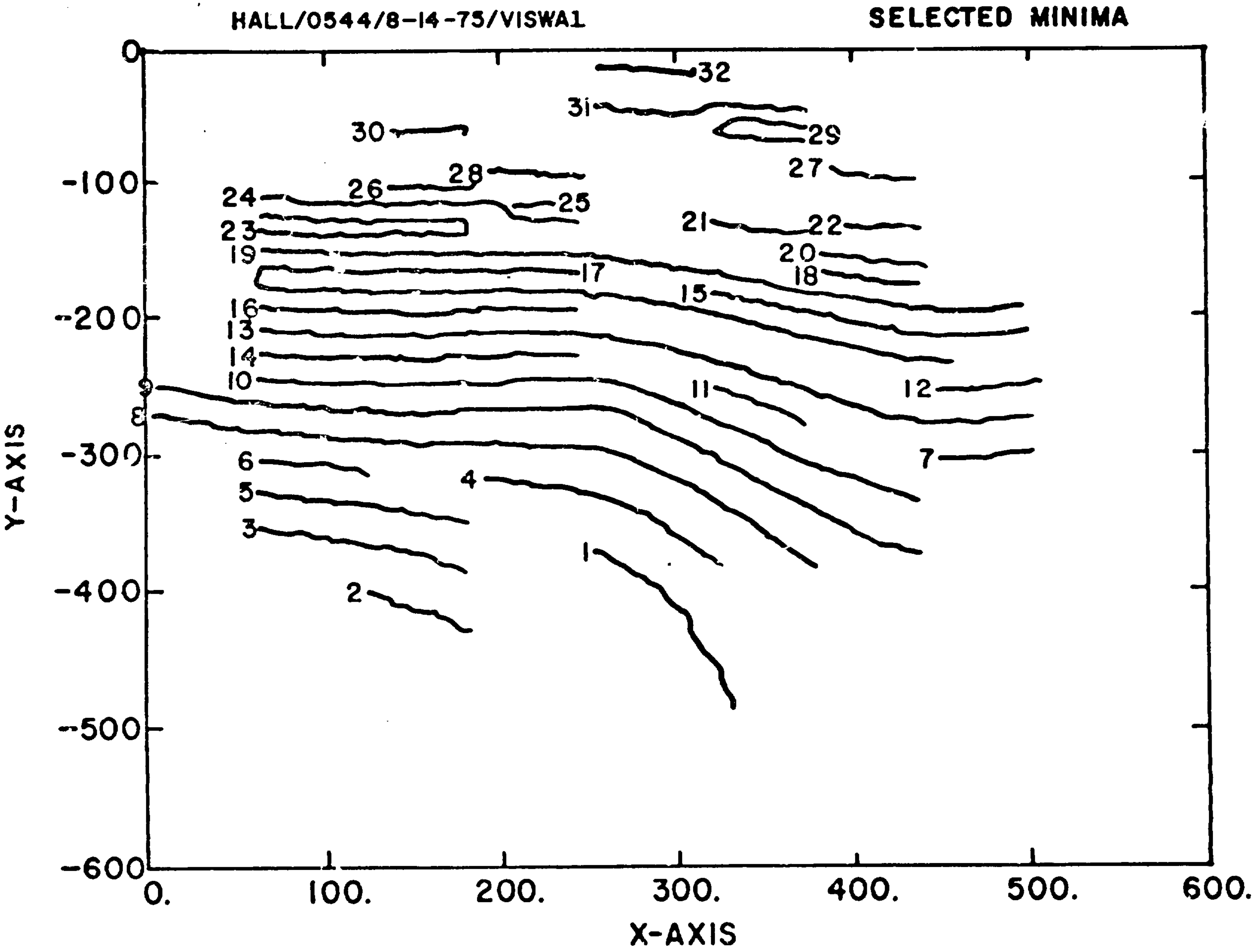


Figure 2


HALL/0544/8-14-75/VISWA1
SELECTED MINIMA
Y-AXIS
0
-100
-200
-300
-400
-500
-600
X-AXIS
0.
100.
200.
300.
400.
500.
600.
32
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17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1

Figure 3

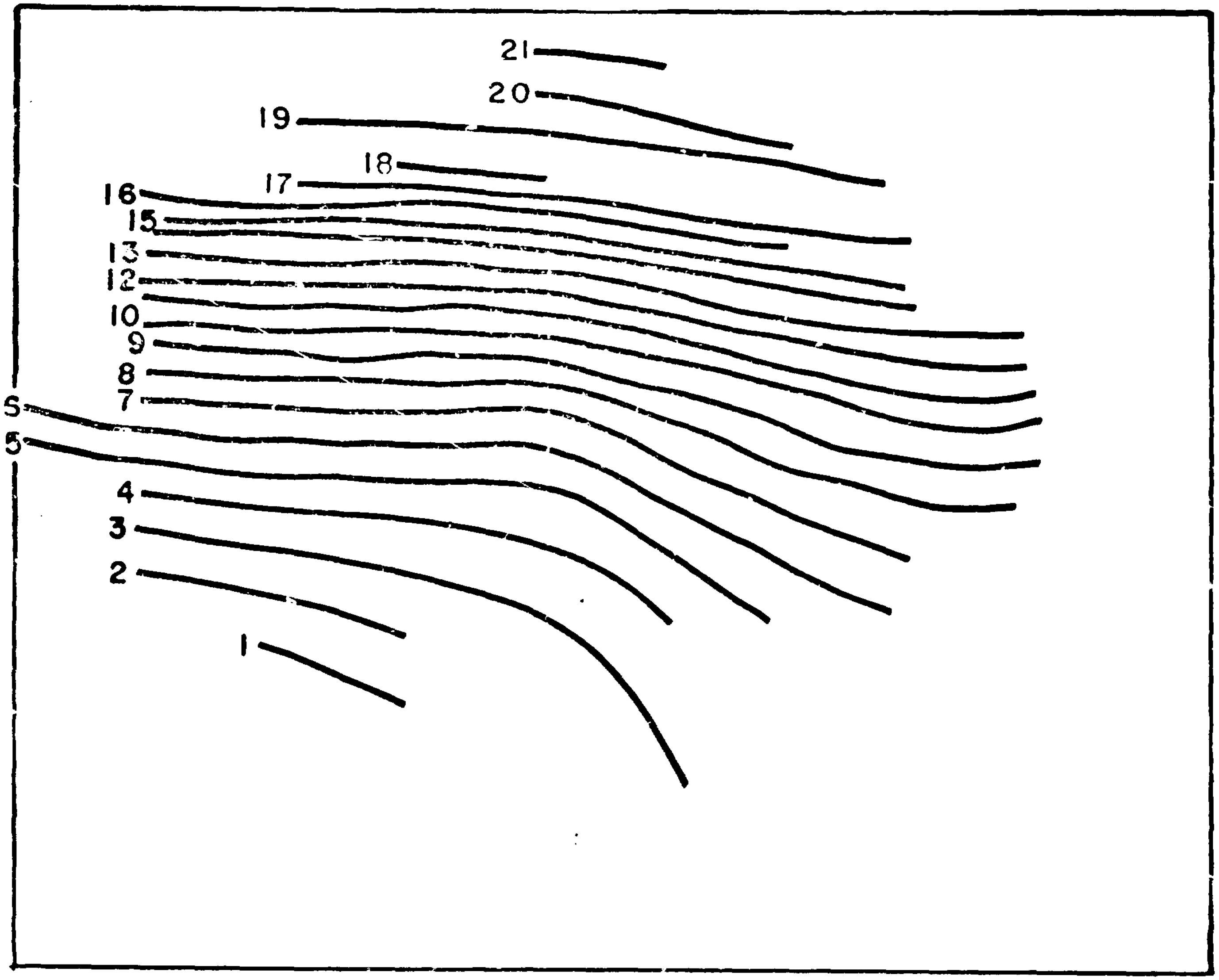
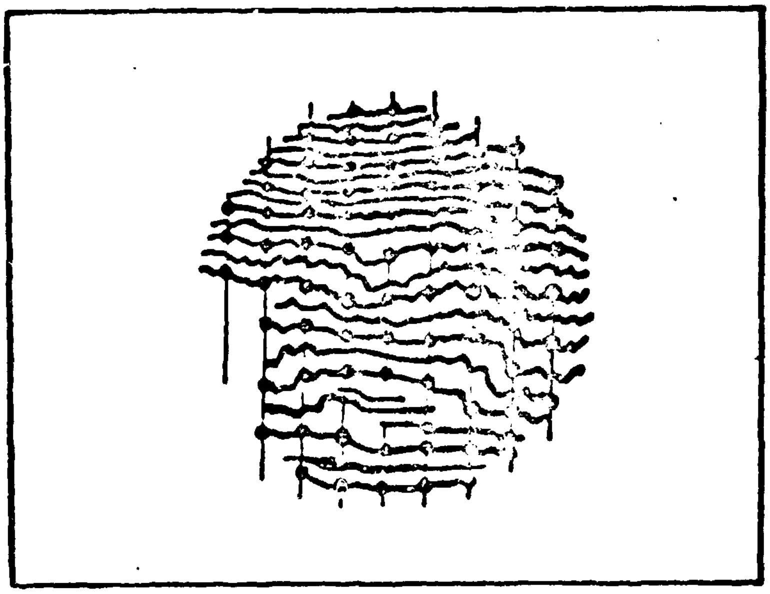


Figure 4



```
PUPIL RADIUS     17.780 CM          WAVELENGTH 10.600 MICRONS

DIFFRACTION ANGLE      7.5012  ARC SEC
  1 358 478     1 306 477     1 259 479     1 211 492     3 357 459
  3 305 455     3 259 462     3 211 472     3 163 492     5 406 458
  5 356 440     5 306 438     5 259 444     5 211 458     5 163 472
  7 404 430     7 357 421     7 305 419     7 261 428     7 213 435
  7 163 453     7 125 472     9 441 428     9 404 412     9 354 402
  9 306 400     9 259 410     9 213 419     9 161 435     9 117 455
 11 441 409    11 402 397    11 356 386    11 305 382    11 257 398
 11 239 408    11 161 416    11 117 435    13 441 391    13 404 378
 13 354 364    13 306 361    13 256 364    13 212 380    13 163 399
 13 117 415    13  77 438    15 470 385    15 401 372    15 401 356
 15 354 340    15 308 330    15 257 335    15 211 354    15 161 375
 15 117 395    15  73 420    17 477 364    17 439 300    17 402 332
 17 354 310    17 306 299    17 259 304    17 211 324    17 163 349
 17 119 372    17  72 397    19 475 343    19 441 324    19 402 308
 19 354 275    19 306 260    19 257 270    19 212 285    19 163 318
 19 117 346    19  72 376    21 475 320    21 440 298    21 402 271
 21 356 205    21 305 226    21 257 227    21 211 248    21 161 279
 21 117 317    21  74 352    21  37 380    23 475 293    23 439 270
 23 424 208    23 357 207    23 306 189    23 257 178    23 212 197
 23 161 231    23 117 276    23  73 323    23  32 359    25 475 263
 25 443 236    25 402 201    25 356 165    25 306 101    25 257  35
 25 209  49    25 160 177    25 116 221    25  72 282    25  34 327
 27 509 269    27 477 236    27 440 199    27 424 108    27 357  39
 27 345  13    27 159  26    27 117 158    27  73 235    27  32 299
 29 578 241    29 474 195    29 438 129    29 402  50    29 119  58
 29  74 199    29  30 271    29  10 306   999   0   0

128 TOTAL DATA POINTS        128 WITHIN UNIT APERTURE       DATA WILL BE ROTA
```

Figure 5

```
1         TPA COLL MIRROR 3-3-77-5 10.6                16:05:03 11/08/77  16:05:03 11/08/77

 WAVEFRONT DEVIATION IN UNITS OF WAVES
TILT AND DEFOCUS MEASURED FROM DIFFRACTION FOCUS

INTERFEROMETER USED A WAVELENGTH OF  0.633 MICRONS


               N       RMS
RAW            0      0.321
PLANE          2      0.062
                                          0.0339   -0.6026
SPHERE         3      0.051
                                          0.0230   -0.6044    0.0601
3RD ORDER      8      0.032
                                          0.0439   -0.6066    0.0517   -0.0096    0.0290    0.0193   -0.0348   -0.0288
               5      0.036
                                          0.0481   -0.6111    0.0535   -0.0098    0.0250


FIRST ORDER (GAUSS) DESCRIPTION

 MAGNITUDE     ANGLE      DESIGNATION
     WAVES       DEG
     0.635     -87.8      TILT
     0.120                DEFOCUS

STREHL RATIO 0.902


THIRD ORDER (SEIDEL) ABERRATIONS

 MAGNITUDE     ANGLE      DESIGNATION
     WAVES       DEG
     0.628     -85.9      TILT
     0.123                DEFOCUS
     0.238      81.8      ASTIGMATISM
     0.119     -61.2      COMA
    -0.125                3RD-ORDER SPHERICAL ABERRATION

FOLLOWING THIRD ORDER TERMS WERE SUBTRACTED-

     TILT      FOCUS

RESIDUAL  WAVEFRONT VARIATIONS FOR DATA

        AV        RMS        MAX        MIN       SPAN     STREHL
     0.005      0.052      0.110     -0.100      0.210      0.898

RESIDUAL  WAVEFRONT VARIATIONS FOR POLYNOMIAL

        AV        RMS        MAX        MIN       SPAN     STREHL
    -0.000      0.041      0.110     -0.127      0.237      0.935


ZERNIKE POLYNOMIAL COEFFICIENTS

   -0.0038   -0.0045    0.0018   -0.0098    0.0250    0.0193   -0.0348   -0.0288    0.        0.        0.        0.
    0.        0.        0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
    0.        0.        0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
```

Figure 6

```
ENERGY =        1122.76607 JOULES

STREHL RATIO     .47403

     PROFILE OF INTENSITY   JOULES/ SQ. CM.

 1.16E+00 1.17E+00 1.16E+00 1.15E+00 1.12E+00 1.11E+00 1.07E+00 1.13E+00
 8.55E-01 3.56E-01 0.       0.       0.       0.       0.       0.
 0.       0.       0.       0.       0.       0.       0.       0.
 0.       0.       0.       0.       0.       0.       0.       0.

1
FOCAL LENGTH IS     77.2600 CM

IMAGE, 1 UNIT =      .00060 CM

CLEAR APERTURE =      .02500 CM

STATION         0

ENERGY =       1122.05792 JOULES

PEAK INTENSITY =  95142580.81496 JOULES PER SQ. CM

     PROFILE OF INTENSITY   JOULES/ SQ. CM.

 9.51E+07 8.69E+07 5.57E+07 2.29E+07 4.64E+06 8.96E+05 2.54E+06 3.07E+06
 2.24E+06 1.73E+06 1.62E+06 1.13E+06 3.98E+05 5.52E+04 1.44E+05 2.28E+05
 1.58E+05 1.17E+05 1.94E+05 2.85E+05 2.93E+05 2.10E+05 9.55E+04 3.37E+04
 3.93E+04 5.56E+04 6.87E+04 1.08E+05 1.37E+05 9.26E+04 2.04E+04 1.06E+03
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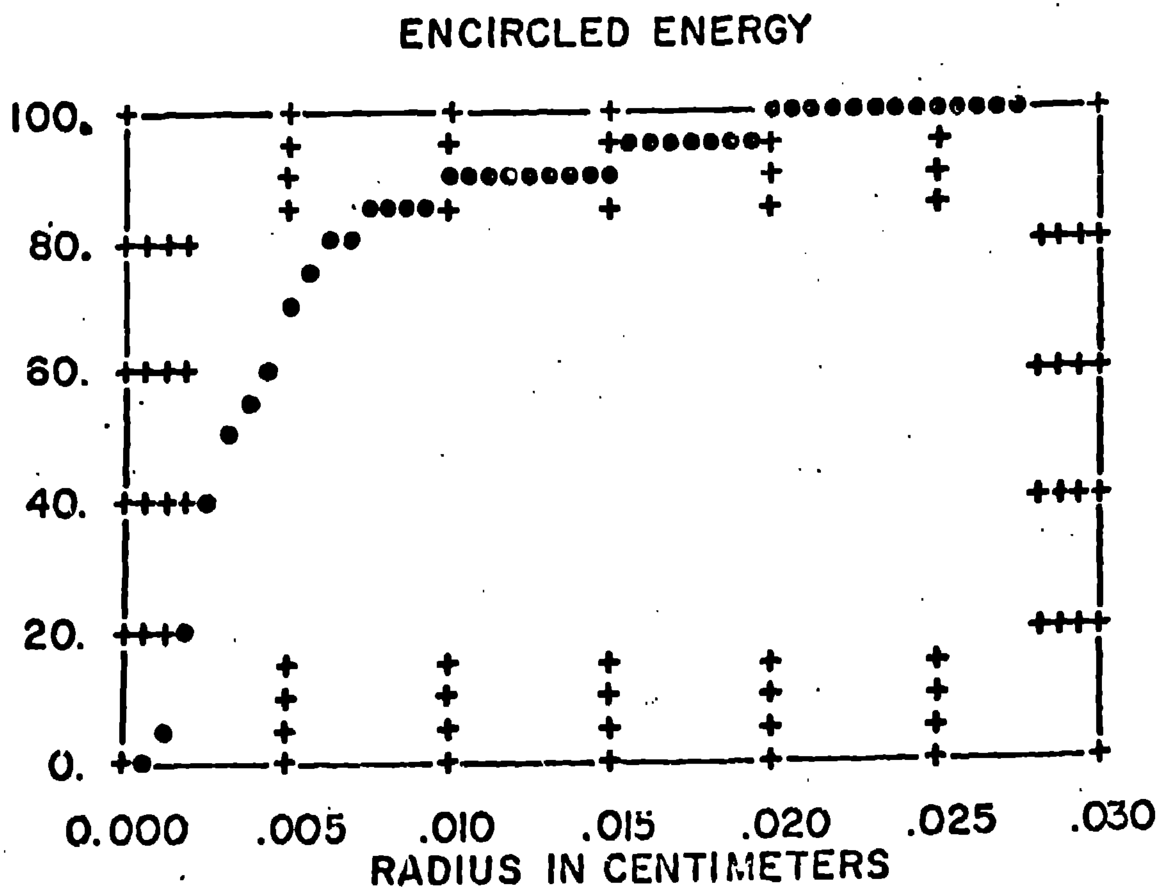

Figure 7

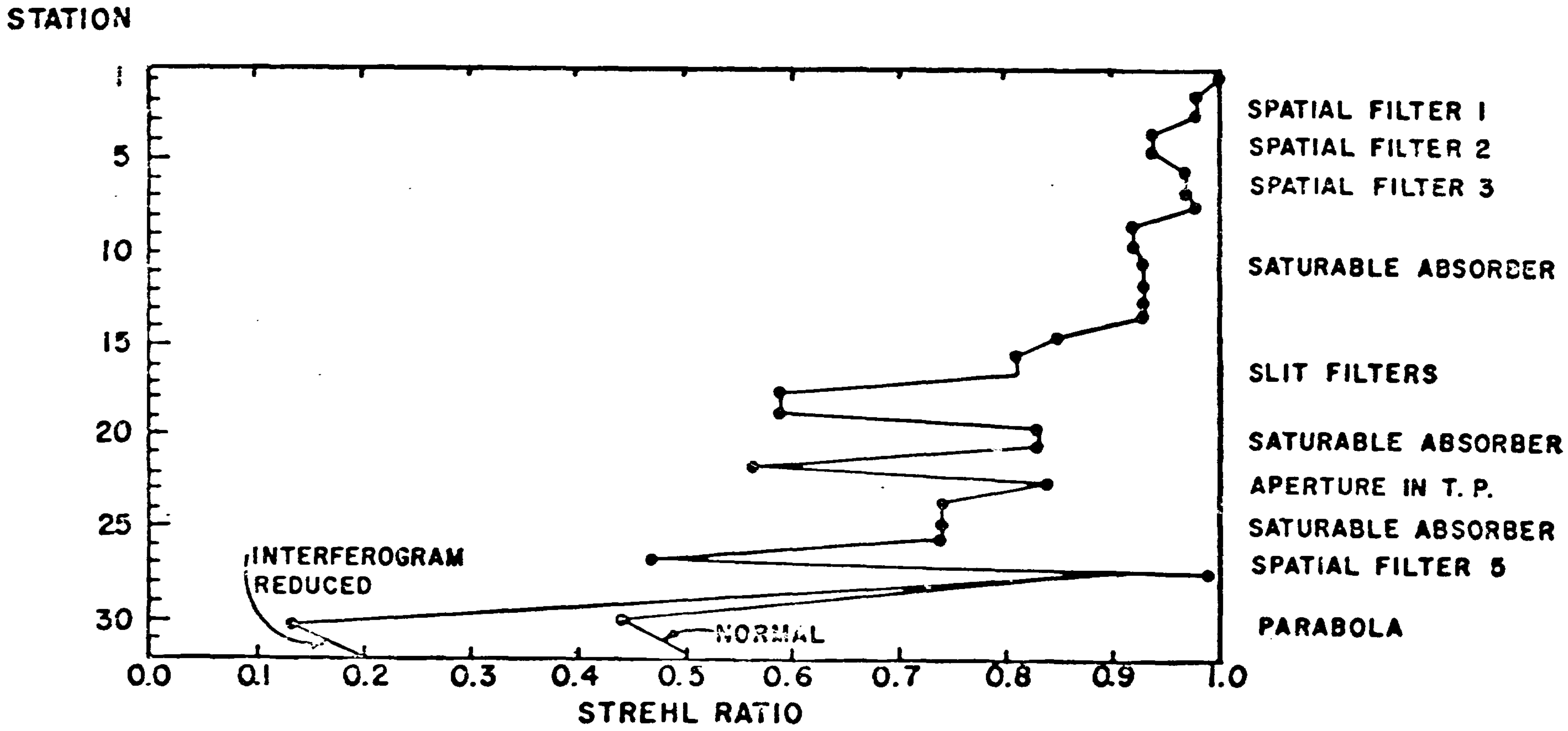
STATION
1
5
10
15
20
25
30
SPATIAL FILTER 1
SPATIAL FILTER 2
SPATIAL FILTER 3
SATURABLE ABSORBER
SLIT FILTERS
SATURABLE ABSORBER
APERTURE IN T. P.
SATURABLE ABSORBER
SPATIAL FILTER 5
PARABOLA
INTERFEROGRAM REDUCED
NORMAL
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
STREHL RATIO

Figure 8