GEMINI
8-M Telescopes
Project

TN-O-G0005

Optimum Final Surface Configuration of an 8-m Meniscus Mirror Using First and Third Order Spherical Aberrations

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ABSTRACT

A proper combination of the first order spherical aberration with the third order spherical aberration allows us to accomplish an optimum surface configuration. The optimum combination can be determined when the residual RMS surface error takes its least value from the active optics correction. The purpose of this study is to determine the optimum combination of these two spherical aberrations by parametric iterations.

INTRODUCTION

Finite element analysis was used to demonstrate the performance of an 8-m meniscus mirror. The current mathematic model, the one-half mirror model, comprises 318 nodal points and 294 plate bending elements. **Figure 1** shows the mirror model and its support system with a total of 97 axial supports.

The active optics system was established providing an optimum set of actuator forces. The active force set can be evaluated using either Least Square Fit or Pseudo Inverse scheme in the active optics system equation defined as:

$$[A]\,\{f\} = \{b\} \tag{1}$$

where [A] is a matrix whose components represent the displacement fields for each unit support force case, and the constraint conditions to satisfy the static equilibrium and the design requirements. [A] becomes in a short expression as:

$$[A] = \begin{bmatrix} D \\ C \end{bmatrix} \tag{2}$$

where [D] is the influence matrix and [C] is the constraint matrix. The influence matrix was established in terms of the optical surface displacements per unit support force based on a uniform grid of 40 by 40 over the optical surface. The constraint matrix includes the static equilibrium conditions and the design requirements in the active force set.

SURFACE DESCRIPTIONS

An optical surface can be commonly expressed in General Polynomials as:

$$w(r) = C_0 + C_1 r\cos(\theta) + C_2 r\sin(\theta) + C_3 r^2 + \ldots + C_{36} r^{12} \tag{3}$$

where $C_0,\ldots C_{36}$ are generic coefficients of the polynomials. For example, C_3 is the first order spherical aberration and C_8 is the third spherical term.

A surface defined by C_3 alone becomes

$$w(r) = C_3 r^2 \tag{4}$$

Similarly, a surface defined solely by C_8 is

$$w(r) = C_8 r^4 \tag{5}$$

The linear combination of above two expressions with unit magnitude of the coefficients can be written as:

$$w(r) = C_i r^2 + C_j r^4 \tag{6}$$

where parameters C_i and C_j are corresponding to the first order spherical term and the third, respectively.

The active optics system defined by Equation (1) was utilized to evaluate the surface errors for various combinations of C_i and C_j. The residual RMS surface errors are listed in **Table 1.** In the Table RMS and P-V are in wavelength (1 wave = 550 NM) and the magnitudes were calculated based on C_8 = 1.0 waves. The least RMS error was found when the ratio of C_3 to C_8 is 1.650. Therefore, the normalized optimum surface figure is:

$$w(r) = -1.650r^2 + r^4 \qquad (7)$$

A scaling factor was introduced to change the reference unit from 1.0 waves to 1.0 microns for the optimized optical surface. The final optimum surface configuration is illustrated by XFRINGE as shown in **Figures 2 and 3.** Note that the plots were made on the Zernike surface rather than the mathematical surface. A contour plot using CODE-V was also generated to make a cross check as shown in **Figure 4.** Maximum and minimum values in this plot are wavefront errors at a wavelength of 550 NM.

SUMMARY AND RESULTS

An active force set was calculated in order to minimize the optical surface defined by Equation (7) with properly scaled optimized parameters. The set of forces are required to conform to the object surface with minimum error variations. In order to perform this calculation a computer program was written with the 'llsqf' IMSL routine. The required active force distribution and summary of the results are listed in **Table 2.**

It was found that the RMS residual surface error for this case was 2.4 NM with a maximum required force of 14 lbs. The residual surface maps after correction are shown in **Figures 5 and 6.** A similar plot of CODE-V for the residual surface is also shown in **Figure 7.**

The RMS residual error of 2.4 NM is an interim result for the given support system as shown in Figure 1. There are many factors which impact the optical performances: the geometry of mirror, material properties of mirror blank, configuration of mirror, support system, and several other design parameters. The optical quality strongly depends upon the mirror back support system (number of supports and support pattern), especially for the active optics system.

ESO has made a similar study for the optimum ratio of the two spherical aberration (reference 3). The study observed that the ratio of 4.1 produced the optimum surface configuration with an RMS surface error of 1.0 NM.

REFERENCES

1. Cho, M. K. and Richard, R. M., "XFRINGE -- Optical Performance Program", RMR Design Group Inc, Tucson, Arizona, 1992.

2. "CODE V ", Optical Research Associates, Pasadena, California, 199 1.

3. Cui, N., Noethe, L., and Prat, S., "Axial Support System - Additional Calculations", ESO, 1992.

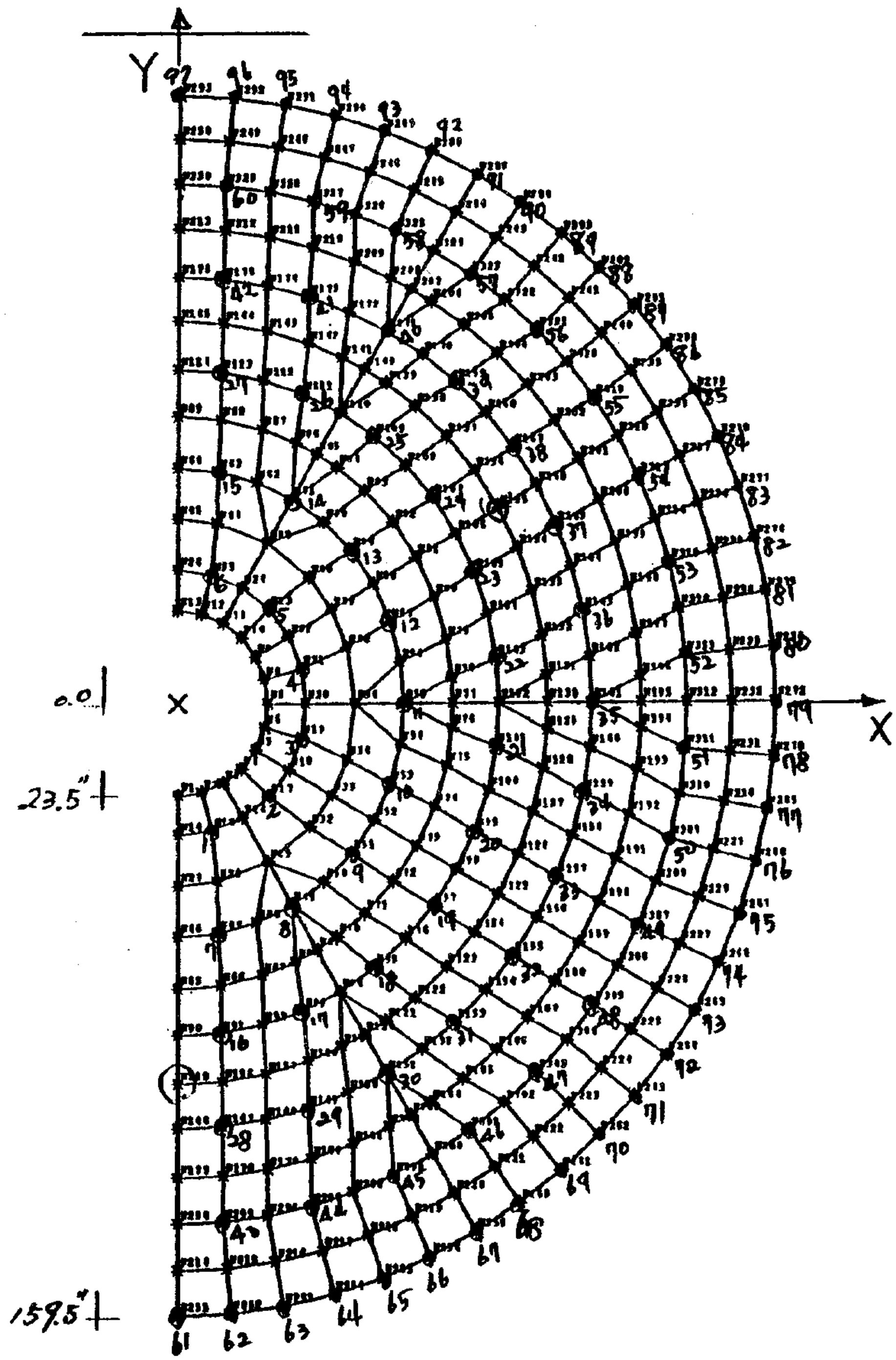

Figure 1. FE model and support system.

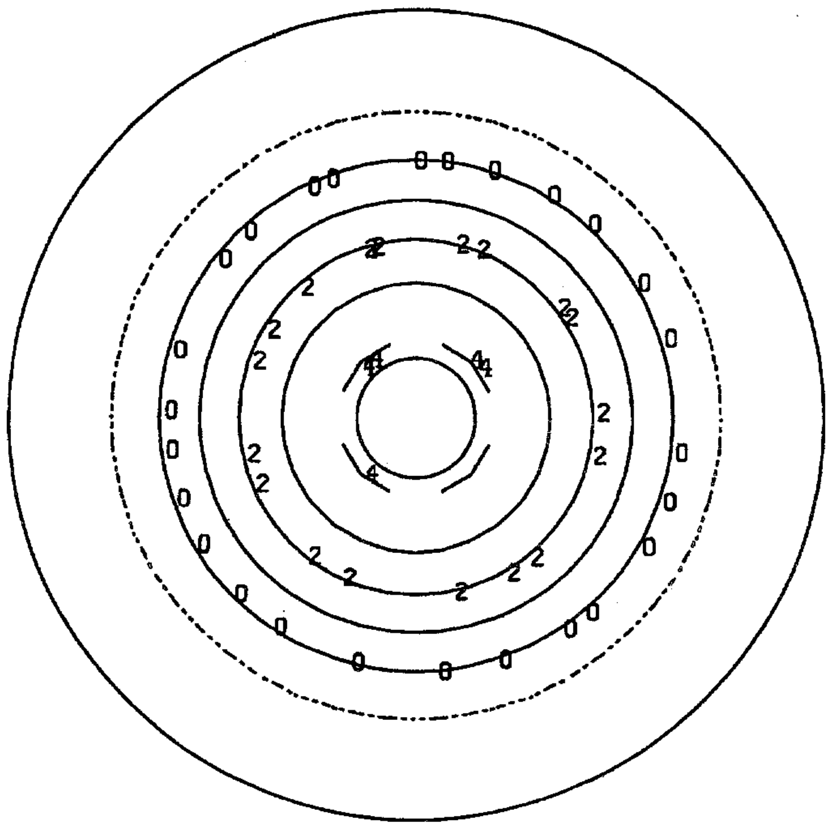

Figure 2. Contour map of the optimized surface.

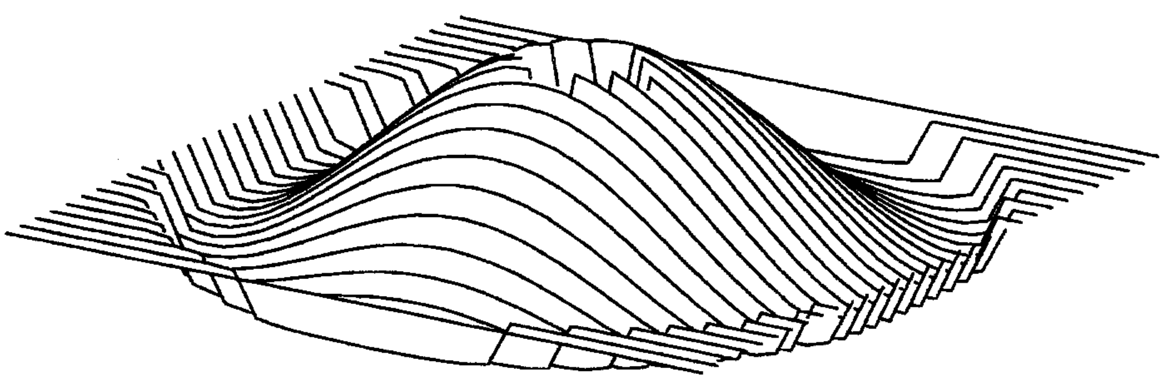

Figure 3. 3-D surface map of the optimized surface.

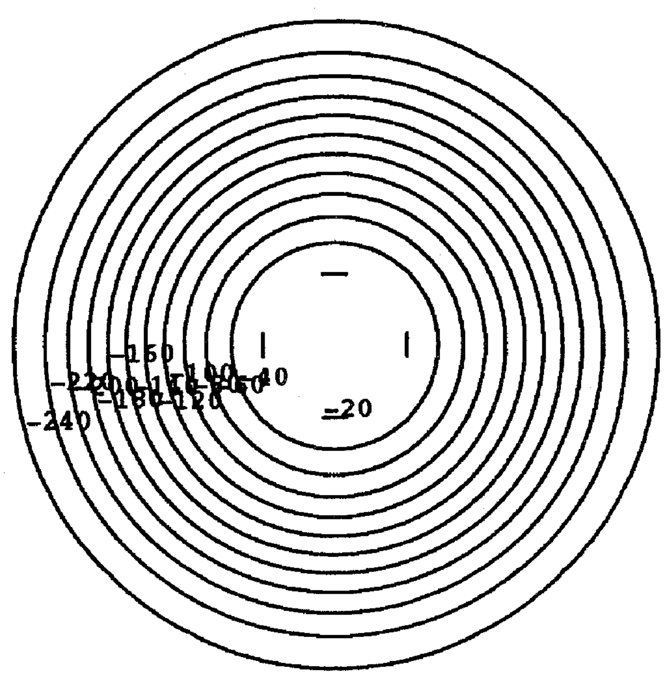

Figure 4. Contour plot from CODE-V.

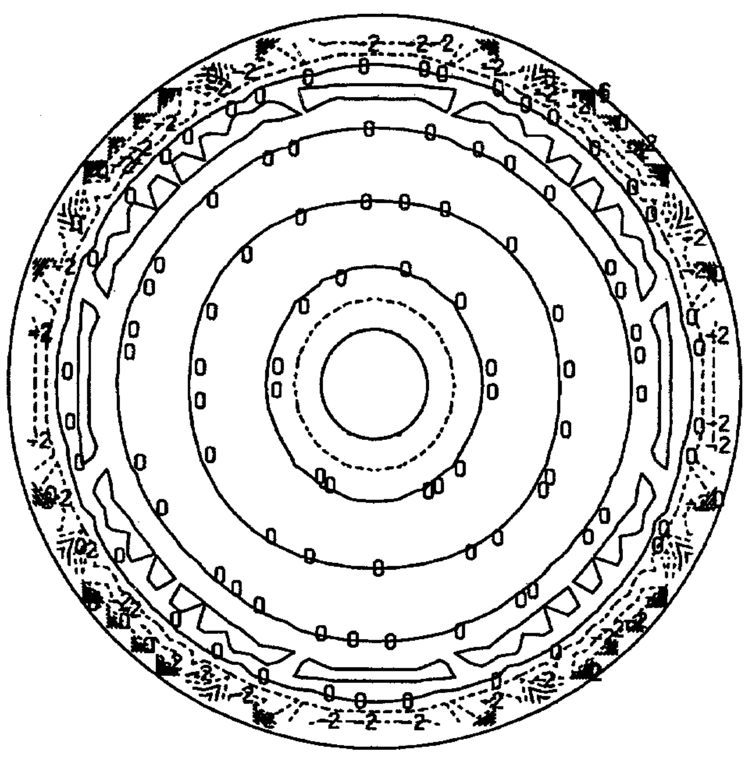

Figure 5. Contour map of residuals.

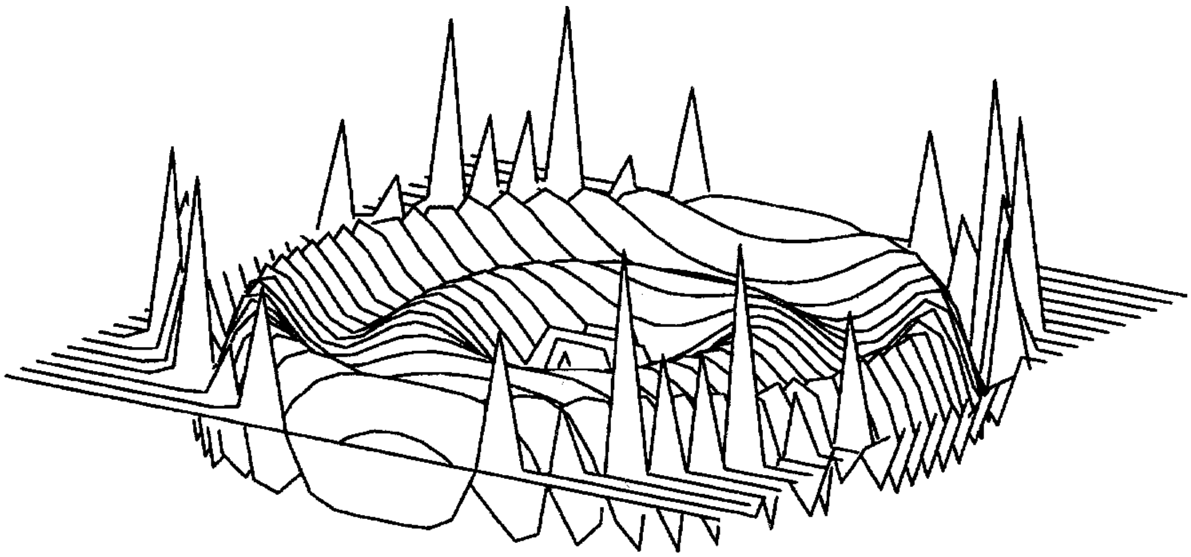

Figure 6. 3-D surface map of residuals.

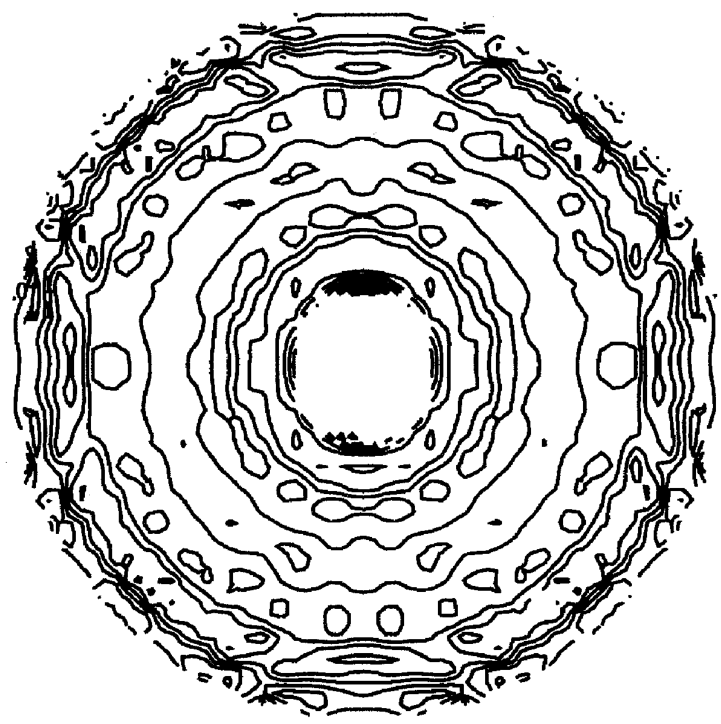

Figure 7. Residual map from CODE-V.

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Linear combination of C3 and C8:
  (RMS = Ci * R_C3 + Cj * R_C8)
```

ci	cj	P-V	RMS
-1.300	1.000	0.0181	0.00240
-1.350	1.000	0.0185	0.00239
-1.400	1.000	0.0189	0.00239
-1.450	1.000	0.0193	0.00238
-1.500	1.000	0.0197	0.00238
-1.550	1.000	0.0202	0.00237
-1.600	1.000	0.0206	0.00237
-1.650	1.000	0.0210	0.00237
-1.700	1.000	0.0214	0.00237
-1.750	1.000	0.0218	0.00237
-1.800	1.000	0.0223	0.00238
-1.850	1.000	0.0227	0.00238
-1.900	1.000	0.0231	0.00239
-1.950	1.000	0.0235	0.00240
-2.000	1.000	0.0239	0.00240

Table 1. Residual errors

```
port forces -- icase = 01 for msc38
```

supt. no	force (lbs)	isupt no.	force (lbs)
1	-7.2368	97	2.7044
2	-3.2798	98	-7.2387
3	-0.3835	99	-3.2784
4	-0.3384	100	-0.3837
5	-3.4443	101	-0.3386
6	-7.0828	102	-3.4445
7	4.9744	103	-7.0818
8	5.6495	104	4.9763
9	4.7283	105	5.6482
10	4.0223	106	4.7289
11	3.7109	107	4.0219
12	4.1421	108	3.7112
13	4.6739	109	4.1420
14	5.7060	110	4.6738
15	4.8315	111	5.7061
16	-1.6318	112	4.8309
17	-1.6807	113	-1.6313
18	-2.3040	114	-1.6813
19	-1.6989	115	-2.3035
20	-1.2999	116	-1.6992
21	-1.3115	117	-1.2999
22	-1.5355	118	-1.3112
23	-1.1954	119	-1.5361
24	-1.7688	120	-1.1951
25	-2.2183	121	-1.7688
26	-1.8871	122	-2.2185
27	-1.4260	123	-1.8866
28	4.6881	124	-1.4262
29	3.7565	125	4.6883
30	5.2978	126	3.7563
31	4.5808	127	5.2979
32	4.7898	128	4.5810
33	4.6275	129	4.7891
34	3.5969	130	4.6284
35	5.1988	131	3.5956
36	3.6175	132	5.2000
37	4.6551	133	3.6172
38	4.6863	134	4.6551
39	4.8044	135	4.6860
40	5.1792	136	4.8050
41	4.1953	137	5.1785
42	4.4120	138	4.1955
43	-10.0753	139	4.4177
44	-7.2571	140	-10.1755
45	-10.7975	141	-7.2571
46	-9.0086	142	-10.7976
47	-9.9139	143	-9.0088
48	-8-8884	144	-9.9139
49	-10.6384	145	-8.8881
50	-7.4187	146	-10.6386
51	-9.9691	147	-7.4183
52	-9.9952	148	-9.9688
53	-7.4011	149	-9.9963
54	-10.6367	150	-7.4007
55	-8.9786	151	-10.6368
56	-9.8387	152	-8.9780
57	-9.3080	153	-9.8396
58	-10.4639	154	-9.3073
59	-8.1179	155	-10.4638
60	-9.6346	156	-8.1184
61	2.3476	157	-9.6338
62	-0.1318	158	0.1317
63	10.8044	159	10.8042
64	-10.6045	160	-10.6043
65	13.6609	161	13.6610
66	-5.9989	162	-5.9995
67	11.5895	163	11.5907
68	-8.4644	164	-8.4659
69	13.1165	165	13.1181
70	-7.5638	166	-7.5650
71	13.7161	167	13.7174
72	-9.4009	168	-9.4029
73	12.1728	169	12.1757
74	-6.0916	170	-6.0949
75	13.7061	171	13.7088
76	-10.6497	172	-10.6516
77	11.0610	173	11.0616
78	-0.7123	174	-0.7124
79	3.4991	175	3.4992
80	-0.8788	176	-0.8785
81	11.3952	177	11.3940
82	-10.9947	178	-10.9919
83	13.8777	179	13.8746
84	-6.1406	180	-6.1386
85	12.1866	181	13.1856
86	-9.1917	182	-9.1915
87	13.0898	183	13.0895
88	-6.2675	184	-6.2673
89	11.1808	185	11.1819
90	-5.9092	186	-5.9118
91	8.1089	187	8.1111
92	-1.2755	188	-1.2765
93	9.3083	189	8.3083
94	-5.9042	190	-5.9038
95	8.5440	191	8.5440
96	0.3258	192	0.3255

summary of the axial force set (lbs):

max	min	p-v	rms
13.8777	-10.9947	24.8724	7.4956

summary of object displacement field (waves):

max	min	p-v	rms
-0.0920	-1.2374	1.1454	0.3439

summary of residual displacements (waves):

max	min	p-v	rms
0.0112	-0.0270	0.0382	0.0043