

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Technical Report 32-1167

*Nickel Plating of the 23-ft Collimating Mirror
for the JPL 25-ft Space Simulator*

M. R. Heilig

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Approved by:

George G. Goranson

G. G. Goranson, Manager
Space Simulators and
Facility Engineering Section

1 JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA *3*

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Abstract

The successful nickel plating of the 23-ft-diam aluminum collimating mirror for the JPL 25-ft space simulator is described. JPL specifications for the work included the following: (1) good optical polishing properties that would provide a surface with which the grind and polish vendor was familiar and also provide a hardness of 50 Rockwell C (Rc); (2) a sufficient adhesion to withstand the optical polishing process; (3) a suitable surface reasonably free of pits, blisters, and blemishes; (4) continuous nickel plating to at least a thickness of 0.008 in. minimum, and (5) minimum handling of the mirror. The electroplating process was selected over the Kanigen process because, in this project, the Kanigen process (1) would have cost more; (2) would not have provided a thick-enough plating; (3) would have required heat treating; and (4) would have necessitated more handling. The work was accomplished in three phases, which included the selection of grade II plating, experimentation with a 4-ft-diam mirror and plating of the 23-ft-diam mirror, itself. The third phase consisted of 11 operations, including pretreatment and final plating processes. The types of etching and rinsing solutions are described. Repairing pits and blemishes in the surface are also described. The use of a Magnagage and Dermatron to measure surface thicknesses is discussed, along with variances in thicknesses and problems encountered along the mirror edge. Further research is recommended to ensure uniform thicknesses and to reduce edge imperfections.

Nickel Plating of the 23-ft Collimating Mirror for the JPL 25-ft Space Simulator

I. Introduction

The objective was to nickel-plate the front face of a 23-ft aluminum mirror (Figs. 1 and 2). Specifications for the nickel plating included the following:

- (1) Good optical polishing properties that would provide a surface with which the grind and polish vendor was familiar, and a hardness of approximately 50 Rockwell C (Rc).
- (2) Sufficient adhesion to withstand the optical polishing process.
- (3) A suitable surface reasonably free of pits, blisters, and blemishes.
- (4) Continuous nickel plating to at least a thickness of 0.008-in. minimum.
- (5) Minimum handling of the mirror.

The first approach was to consider Kanigen coating, a type of electroless nickel plating that is the standard plating for aluminum mirrors. All of JPL's aluminum mirrors

in service were Kanigen-plated; the largest at that time was a 10-ft-diam mirror that had been plated with 0.007 in. of nickel by the use of a modified Kanigen plating process. The usual Kanigen process met practically all of JPL's specifications with the exception that there is usually too much mirror handling involved, the cost was excessive (Refs. 1 and 2), the maximum thickness that could be plated is 0.007 to 0.008 in., and to have gotten a hardness of 50Rc it would have had to be heat-treated at 375°F, which would have required additional handling and higher cost. With only 0.007- to 0.008-in.-thick nickel, there was a high risk involved in grinding and polishing the mirror, without going through the nickel. JPL's 10-ft mirror had been plated successfully, but workers did grind through the nickel in a small area at the edge.

Other electroless nickel plating processes and electroplated nickel were investigated and, based on small samples which were ground and polished, the electroless nickel processes had the same disadvantages as the Kanigen plating process. The electroplating process,

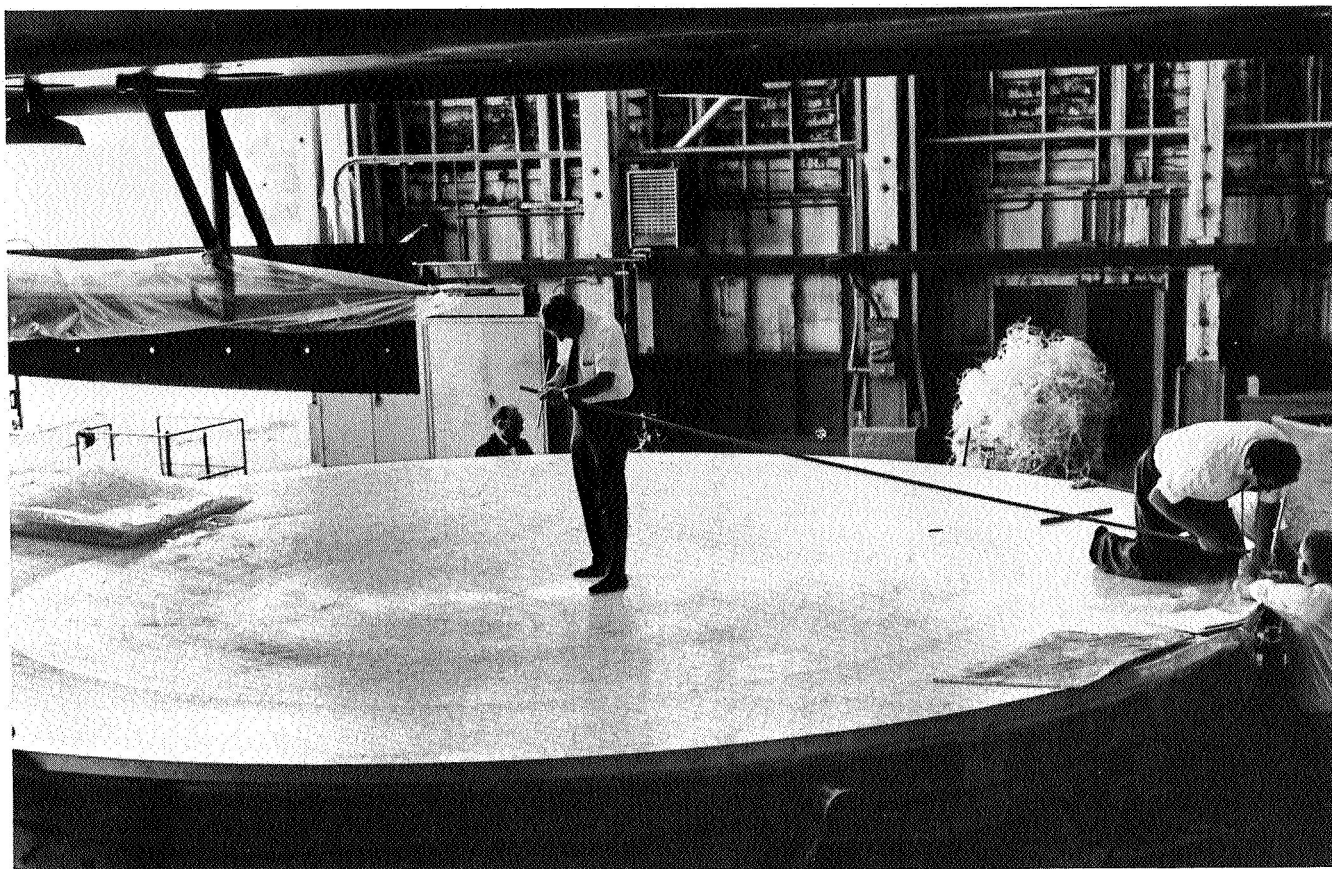


Fig. 1. Check of measurements at completion of machining

however, looked very promising. It could meet most of JPL's specifications. The process could be plated to any desired thickness and there would be no handling of the mirror — the plating could be accomplished with the mirror mounted on the grind and polish machine and no heat treating was required. This latter feature meant that, once the mirror was mounted on the grind and polish machine for rough grinding of the aluminum, it would not have to be moved until final shipment to JPL. However, there is a weight penalty with this method because the grind and polish machine must be capable of supporting both the mirror and the plating solution. The mirror weighed 15 tons and the 3000 gals of plating solution totaled 12 tons. Other disadvantages were that the optical polishing vendor did not have much experience with electroplated nickel and the proposed plating method had never been attempted, and would, therefore, require development effort.

Requests for quotations were sent to Kanigen, electroless nickel, and electroplating vendors. The Kanigen bids

exceeded \$200,000 (using a modified Kanigen process), the electroless nickel vendors submitted no bids, and the electroplating bid was \$58,000 (the final cost was actually \$85,000). All bids were cost-plus-fixed-fee (CPFF) — no one was willing to accept a fixed-price contract.

II. Technical Discussion

A three-phase CPFF contract was awarded to an electroplating vendor. The first phase consisted of making a choice between two different grades of electroplated nickel. The second phase consisted of demonstrating through laboratory tests and a scale-modeling program that the proposed plating method was feasible and giving the optical polishing vendor a large enough surface to further judge the optical polishing properties. Phase three consisted of plating the 23-ft-diam mirror.

In phase one, the electroplater plated two 12-in.-diam samples — one with grade II and the other with grade V



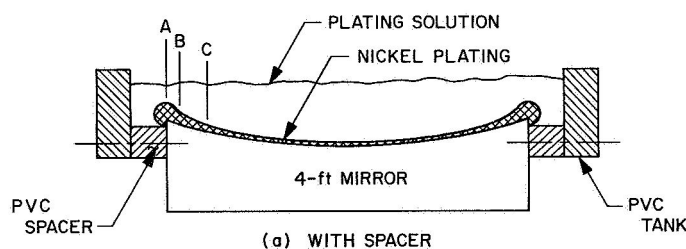
Fig. 2. Locating center of mirror

nickel (the samples were not rotated). The two were evaluated and no difference was found in adhesion or spectral reflectance. However, a difference in hardness was found: grade V was approximately 35 Rc and grade II was 46 Rc. The grind and polish vendor did not find enough difference in optical polishing properties to make a choice, but the electroplater said that he was more confident of meeting JPL specifications with grade II. Therefore, grade II was selected.

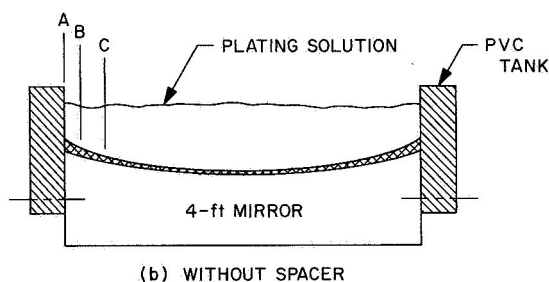
In phase two, the electroplater plated a 4-ft-diam mirror using the same techniques as would be used on the 23-ft mirror. During this phase, JPL experimented with different methods to repair porosity and inclusions in the aluminum substrate. It was found that after drilling out the inclusion or pit, it could be filled with conductive epoxy or aluminum dowel rod. Experiments were conducted to determine what size of pits needed repair and it was found that pits up to 0.010-in.-diam could be plated over with 0.025 in. of nickel and that larger pits

had to be drilled out and repaired with epoxy or dowel rod.

The typical problem with electroplated parts is the buildup of plating at the edge. Anode placement and other edge buildup problems were investigated. With a spacer between the mirror edge and the polyvinyl chloride (PVC) tank (Fig. 3a), the edge buildup was greater (0.060 in.) than without a spacer (0.040 in.), as shown in Fig. 3b. In both cases, the buildup occurred in the last 1 in. and the uniformity was very good (0.019 ± 0.0015), excluding the outer 1 in. The edges of the nickel anodes were directly above the edge of the mirror in these experiments. After experimentation, JPL submitted the plated 4-ft-diam mirror to the grind and polish vendor so that he could establish a complete grind and polish procedure to be used for the 23-ft-diam mirror. The vendor simulated the area ratio of the grinding tool to mirror and used different grinding compounds to establish removal rates.



THICKNESS, in.	LOCATION
~0.060	A (EDGE OF 4-ft MIRROR)
0.028	B (1/4 in. FROM EDGE)
0.020	C (1 in. FROM EDGE)



THICKNESS, in.	LOCATION
~0.040	A (EDGE OF 4-ft MIRROR)
0.028	B (1/4 in. FROM EDGE)
0.020	C (1 in. FROM EDGE)

Fig. 3. Differences in edge buildup (a) with spacer and (b) without spacer

After the successful completion of phase two, the third phase was begun, which was to nickel-plate the 23-ft mirror. When the rough grinding of the aluminum mirror was completed by the optical polishing vendor, the mirror remained mounted on the grind and polish machine and JPL made a visual inspection for defects in the surface. Repairs were made, using aluminum dowel rod (described earlier), which included one gouge (0.75 in. long, 0.040 in. wide and 0.010 in. deep), weld splatter (three 0.032-in.-diam spots), and nine pits (from 0.010 in. diam to 0.034 in. diam). There were other defects, but these were small enough to be plated over.

Next, an 8-in.-wide strip of PVC was attached to the edge of the mirror with epoxy and screws every 6 in. (Fig. 4), thus enabling the mirror to be its own tank. The different solutions required for cleaning, etching, and nickel plating were stored in tanks above and to the side of the mirror (Fig. 5). The solutions were transferred to the mirror tank by three methods: gravity-fed through a rubber pipe from one of the four tanks above

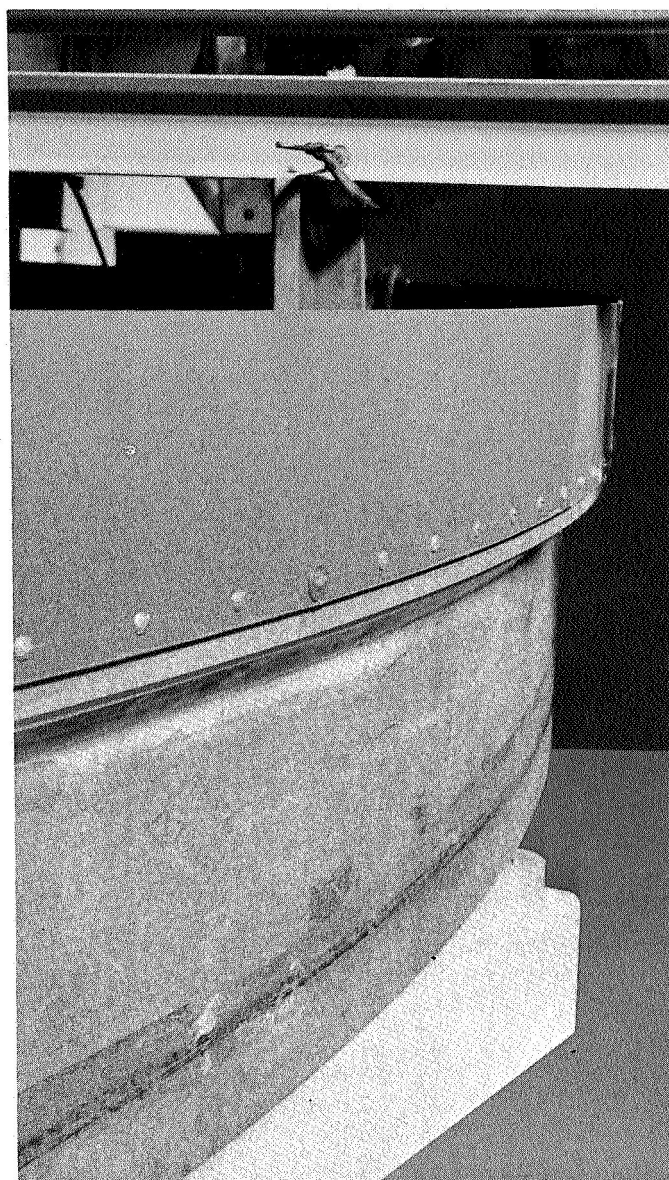


Fig. 4. Eight-in.-wide PVC strip attached to mirror

the mirror (Fig. 6), pumped up through a hose from tanks on the floor, or pumped through the circulation system (Fig. 7). The circulation system consisted of a pump, three filters in series, an input pipe that split into three pipes, which were at 120 deg and equal to the radius of the mirror. The pipes had a series of small holes along their length to permit fast wetting of the entire mirror surface. All solutions were removed from the mirror by a positive suction pump, through a pipe located at the center of the mirror. The solutions could either be returned to their storage tank or dumped. Figure 7 also shows the nickel anode rig and the copper anodes. The nickel anodes were wrapped in white filter



Fig. 5. Tanks containing cleaning, etching, and plating solutions

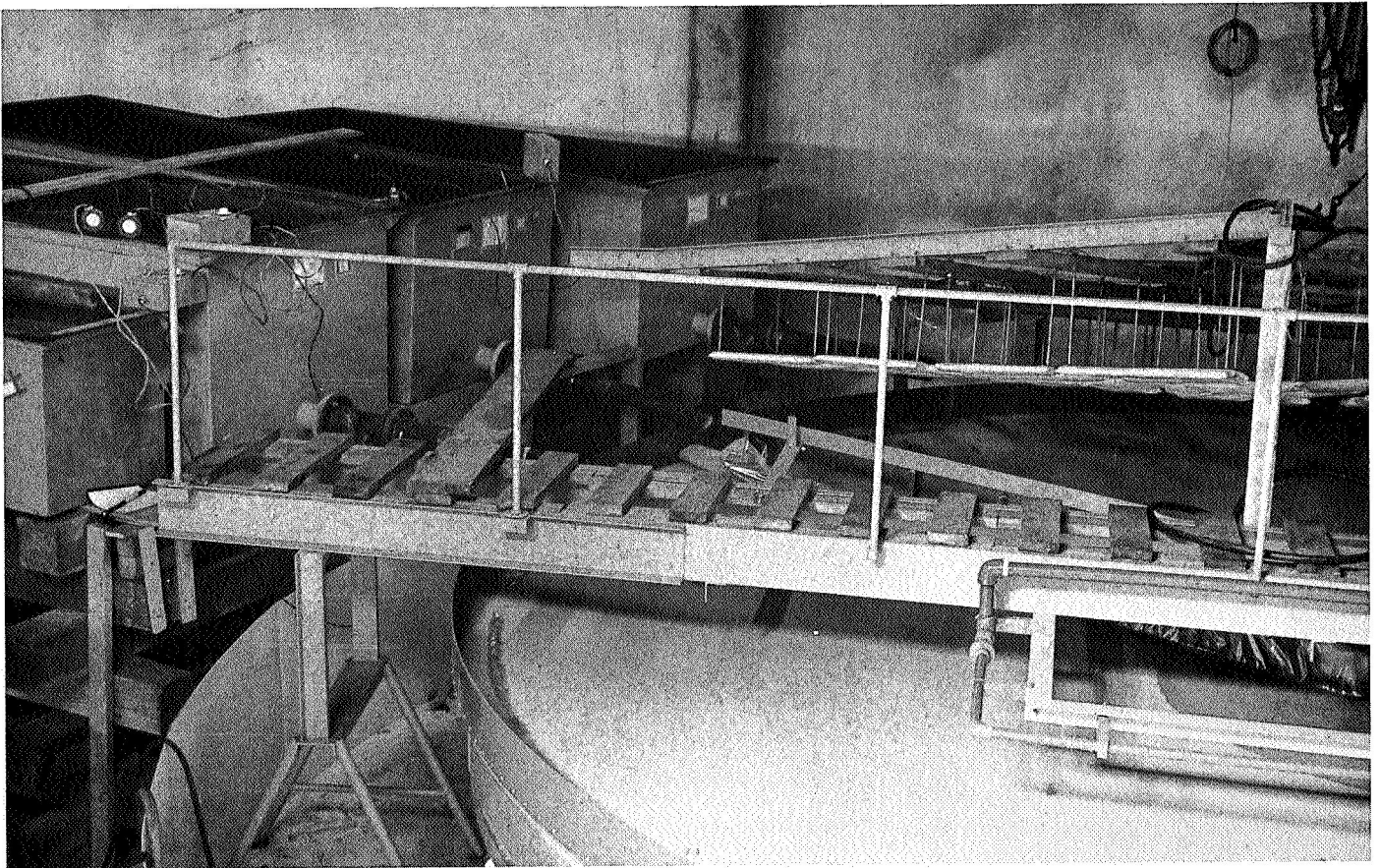


Fig. 6. Tanks used to gravity-feed solutions onto mirror

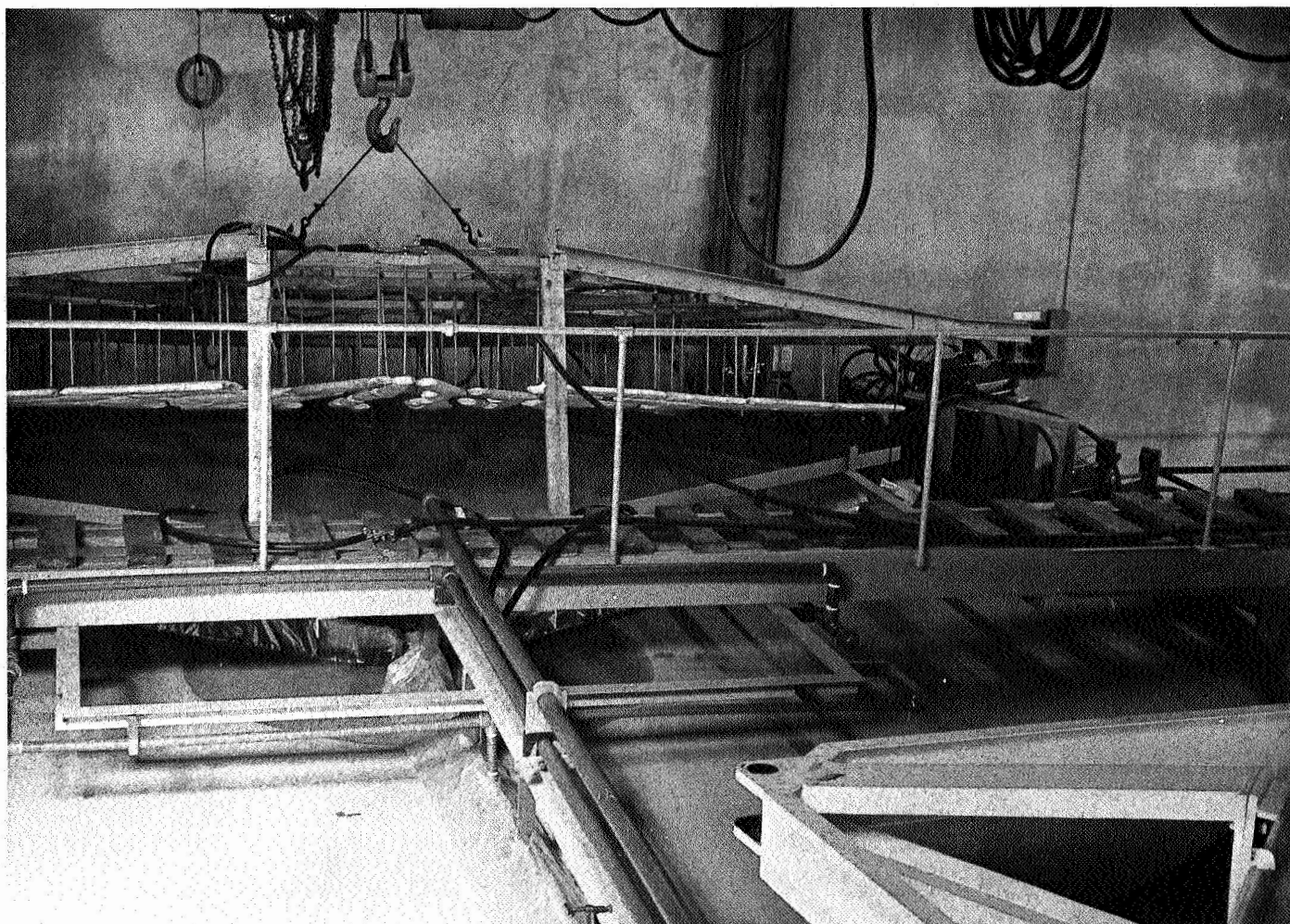


Fig. 7. Circulation system for applying solutions onto mirror

cloth and were hung from the support rig by titanium rods. There were four rows of anodes and the current density of 20 A/ft² was regulated by rheostats in order to maintain a constant current density over the entire surface (Fig. 8). The copper anodes were wrapped in plastic to protect them from the etching solutions. Depositing power was produced by seven rectifiers, six 500-A, 6-V and one 1500-A, 15-V (Fig. 9). A list of materials and equipment used is given in Table 1.

The operation sheet for pretreatment is shown in Table 2. Operation No. 2 included an alkaline solution to degrease the mirror surface. The mirror was covered with 600 gal of warm water (operation No. 1), and the concentrated alkaline cleaner was pumped onto the mirror from a small tank on the floor while the mirror was rotated at 5 rpm. After 15 min, the cleaner was pumped out with the center suction pipe and dumped. Next, the mirror was water-rinsed (operation No. 3). Operation No. 4 included a sulfuric acid etch that removed the aluminum oxide and other contaminants. The solution was

gravity-fed onto the mirror while the mirror was rotated at 5 rpm. After 1 h, with the mirror rotated at 5 rpm, the sulfuric solution was pumped out and the mirror was rinsed. Operation No. 6 included an etch with a solution of nitric acid and a smaller amount of hydrochloric acid. This solution removed the residue left by the sulfuric acid etch and also removed any silicate material. The nitric solution was pumped in through a hose from a drum on the floor while the mirror was rotated at 5 rpm. As soon as all of the nitric acid was pumped onto the surface, the solution was pumped off and the mirror was rinsed with water. Operation No. 8 included wetting the surface with a zincate solution. The solution was pumped on very quickly while the mirror was rotating at 5 rpm. As soon as all of the mirror surface was wetted with the zincate solution, it was pumped off. Then after another water rinse, the copper anodes were attached to the frame above the mirror. The mirror surface was kept wet with water until the copper cyanide was added by gravity feed. The copper strike took 15 min. During this time, the mirror rotated at 5 rpm. The copper cyanide

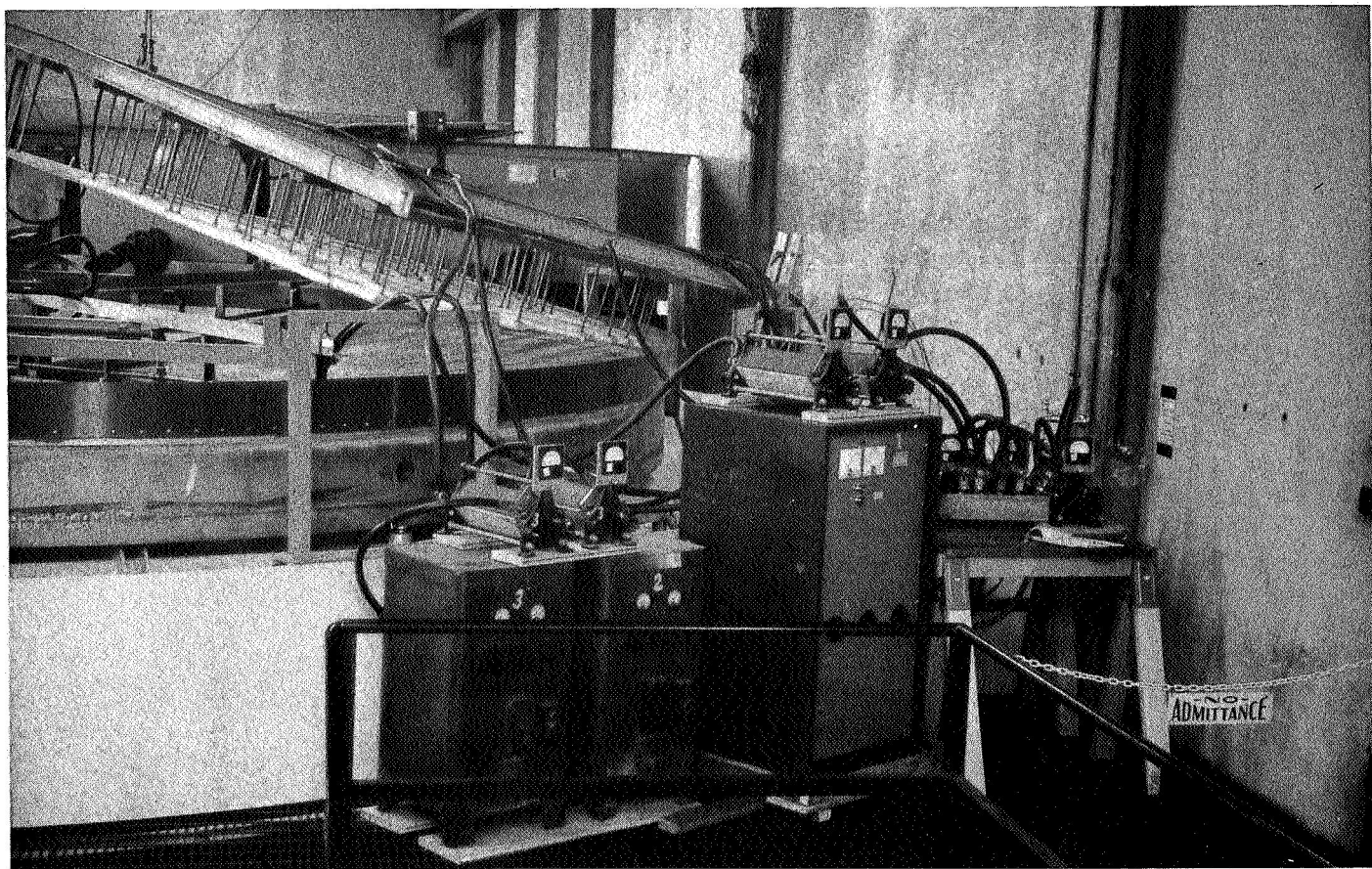


Fig. 8. Anodes and rheostats used to maintain a current density of 20 A/ft²

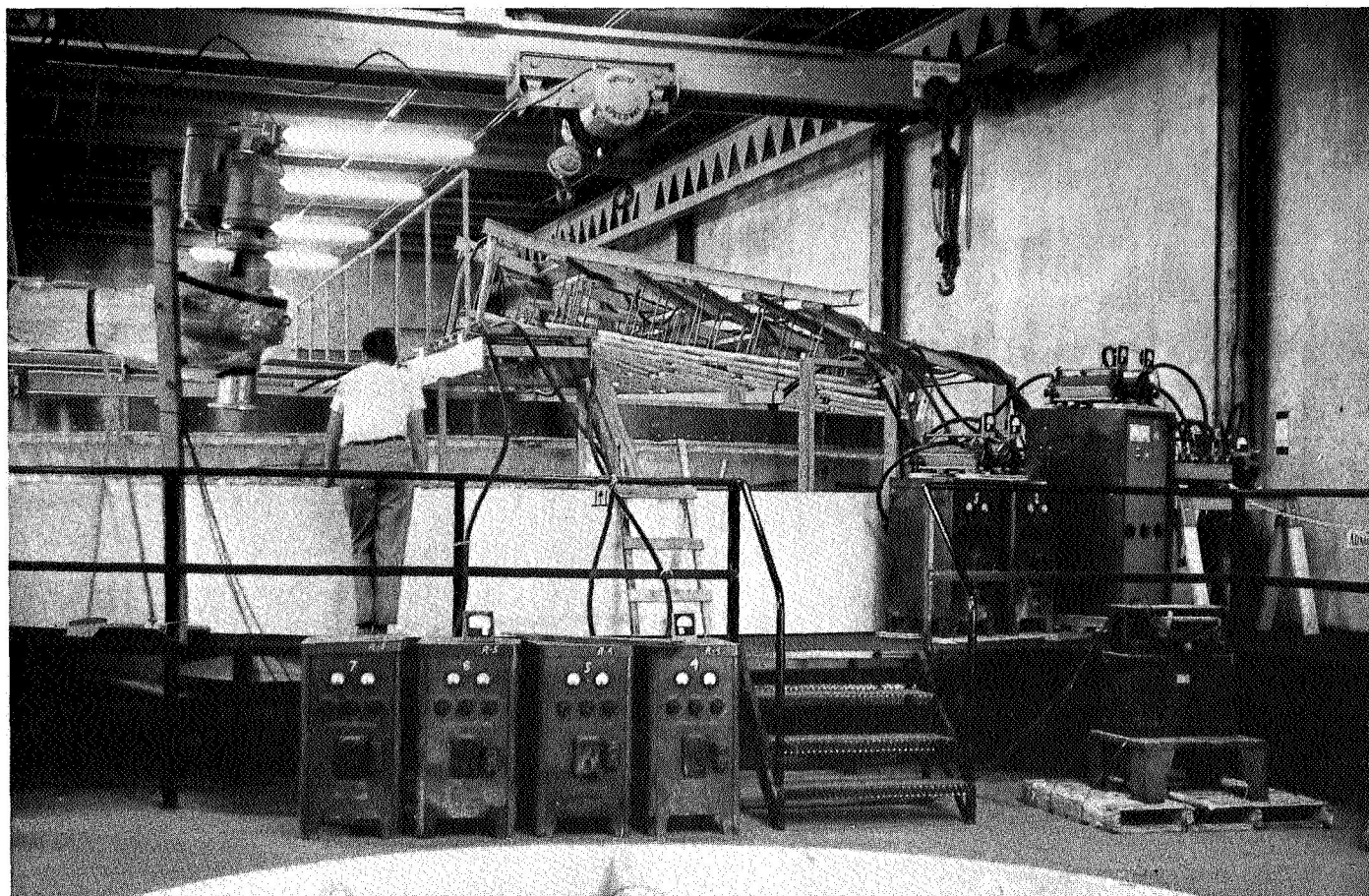


Fig. 9. Seven (six 500-A, 6-V, and one 1,500-A, 15-V) rectifiers used in depositing power

Table 1. Equipment and materials

Item No.	Quantity	Description
1	4	55-gal drums
2	1	0-10 A dc meters
3	2	0-100 A dc meters
4	8	0-500 A dc meters
5	7	Rheostats
6	4	Dacron uniforms
7	6 pr	Shoe covers
8	1	6-V starter solenoid
9	1	Heavy-duty power relay
10	400 ft	Cable
11	1	Glass tube
12	6	Valves
13	2	Garden hoses
14	1	X150 battery

Item No.	Quantity	Description
15	Misc.	Tubing and fittings of steel and PVC
16	Approx. 575 lb	Nickel
17	10 lb	Filter aid
18	10 lb	Pumice
19	48 fluid oz	Sealant
20	7	Pumps
21	4	Filters
22	7	Rectifiers
23	5	Tanks
24	5	Heaters
25	1	Anode structure
26	6	PVC rigid sheets
27	Misc.	Rubber hoses
28	Misc.	Maintenance equipment

Table 2. Pretreatment operation sheet

Operation No.	Tank No.	Operation	Rotation (rpm)	Time	Pump	Solution disposition
1		Add water and start rotation				
2	5	Alkaline clean	5	15 min	off	dump
3		Water rinse (cold)	$\frac{3}{4}$	"	on	dump
4	1	Sulfuric acid etch	5	1 h	off	save
5		Water rinse (cold)	$\frac{3}{4}$	"	on	dump
6	Drum	Nitric acid etch	5	2-5 min	off	dump
7		Water rinse (cold)	$\frac{3}{4}$	"	on	dump
8	3	Zincate	5	30-60 s	on	dump
9		Water rinse (cold)	$\frac{3}{4}$	"	on	dump
10	2 and 4	Copper strike	5	15 min	off	save
11		Water rinse (hot)	$\frac{3}{4}$	"	on	dump
" As required.						

was pumped out and a hot water rinse followed (approximately 180°F). The copper strike was inspected for adhesion and JPL found that the outer 3 ft had very little adhesive strength; so the rest of the copper had to be stripped off. Generally, JPL found that if the copper strike is not started soon enough, the zinc flash will oxidize and cause poor adhesion. It was determined that either the copper cyanide was not pumped in fast enough or else there was not enough copper anode area along the outer edge. To correct this, the plating vendor doubled the pumping capacity and rearranged the copper anodes. The second pretreatment run was successful: the copper had good adhesion. The nickel anodes were lowered into place, the nickel sulfate solution was pumped into the mirror, and the nickel plating was started. The nickel deposition continued as the mirror rotated at 2 rpm for 90 h. The deposition rate from the anodes was 0.001 in./h, but because the anodes only covered one-third of the mirror, the buildup on the mirror was 0.0003 in./h. After the mirror was plated, and before the nickel sulfate solution was pumped out, a low spot on the mirror (caused by the incorrect repair of a weld porosity) was spot-plated by placing a nickel anode over the spot and depositing for 4½ h. The solution was then pumped out and the anode assembly was removed for inspection. A visual inspection was made for surface defects — pits, blisters, and any other blemishes. There were six small defects (0.032 to 0.125 in.) and a few very small pits within the 22½-ft diam. The probable cause of these defects was dirt falling into the solution during the nickel

plating cycle. Agitation of the plating solution kept most of the particles moving, but if a particle was allowed to stick to the surface, a pit resulted. There were many blisters and other blemishes in the outer 2 or 3 in. along the edge. The poor adhesion along the edge was a serious problem because if there was any flaking of the nickel during polishing, it would have scratched the surface. To prevent this happening, all of the areas at the edge with questionable adhesion were ground out and filled with Devcon. This edge problem did not occur during the 4-ft experimentation. Also, there was a difference in timing between operations in the 4-ft and the 23-ft operations. The time between operations on the 23-ft mirror took much longer than had been anticipated. Another possible cause of the poor adhesion at the edge may have been that the crack between the PVC strip and the edge of the mirror trapped chemicals from previous operations and these chemicals could have seeped out during the plating operation.

Hardness was measured by three techniques. One technique included testing samples of nickel that were deposited during the plating of the mirror on special stainless-steel test specimens. Another technique was to test the hardness of the plating on the mirror with a portable hardness tester. The third technique was to test pieces that were chipped off the mirror during edge repairs. The latter, however, was not a planned testing procedure. The hardness ranged from 50 to 58 Rc.

Final nickel thickness measurements were made with a Magnagage and a Dermatron. The readings are given in Tables 3 and 4 and the data are shown in Figs. 10 and 11. There is a noticeable difference in the Magnagage and the Dermatron readings: the Dermatron readings were 0.038 ± 0.008 in. and the Magnagage was 0.033 ± 0.010 in., both neglecting the 3-in. outer edge. The problem with both of these instruments was that they were sensitive to many other properties of the nickel plating, such as surface finish, hardness, and probably the substrate properties. After subsequent grinding by the optical polishing vendor, JPL found that the Magnagage was the more accurate instrument.

Table 3. Magnagage readings

Point ^a	Nickel thickness, in.			
	W	E	S	N
Center	0.044	0.044	0.044	0.044
2	0.044	0.044	0.044	0.044
3	0.044	0.044	0.044	0.044
4	0.039	0.036	0.038	0.040
5	0.024	0.024	0.024	0.024
6	0.023	0.023	0.023	0.023
7	0.040	0.042	0.043	0.040
8	0.043	0.043	0.043	0.043
9	0.039	0.041	0.039	0.041
10	0.036	0.034	0.035	0.035
11	0.030	0.033	0.031	0.031
12	0.037	0.038	0.038	0.035
13	0.037	0.040	—	0.037
14	0.036	0.036	—	0.035
15	0.033	0.033	—	0.031
16	0.037	0.038	—	0.034
17	0.042	0.043	—	0.043
18	0.042	0.040	—	0.044
19	0.039	0.037	—	0.038
20	0.039	0.036	—	0.038
21	0.041	0.038	—	0.040
22	0.039	0.037	—	0.038
23	0.031	0.029	—	0.034
24	0.017	0.017	—	0.017

^aPoints spaced equally from center to edge.

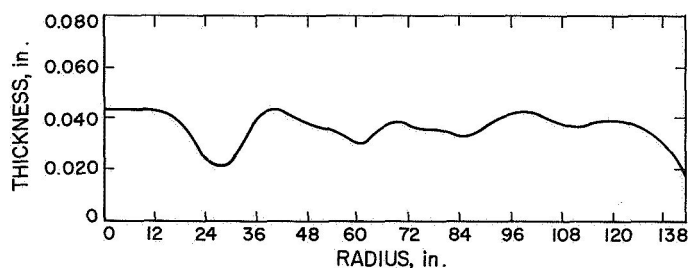


Fig. 10. Magnagage measurements of thickness along radius of mirror

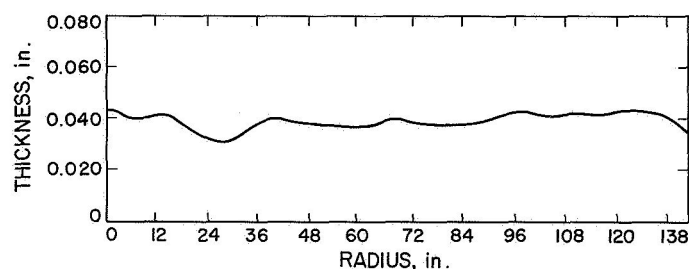


Fig. 11. Dermatron measurements of thickness along radius of mirror

III. Conclusions

Overall, JPL is pleased with the nickel plating. Initial setup started on September 12, 1966 and the mirror was plated by October 26, 1966. The process achieved the hardness and adhesion required for a good mirror surface and a plating thick enough to allow grinding the required curve. The surface was reasonably free of pits, blisters, and blemishes, excluding the outer 2 to 3 in. And, after the setup of the mirror on the grind and polish machine by the optical polishing vendor, the mirror did not have to be moved. From these favorable results, it is recommended that the discussed method of nickel plating be used for other large aluminum mirrors. It is also recommended, however, that development work be expended to ensure a more uniform nickel thickness and to reduce or eliminate edge imperfections. It is believed that a uniformity of $\pm 10\%$ of the thickness (0.030 ± 0.003 in.) could be achieved with only a little additional effort.

For more information on the 23-ft mirror see reports listed in Refs. 3 and 4.

Table 4. Dermitron readings

Point ^a	Nickel thicknesses, in.							
	A	B	C	D	E	F	G	H
Center	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044
2	0.042	0.040	0.040	0.040	0.040	0.040	0.041	0.042
3	0.042	0.042	0.043	0.040	0.042	0.044	0.042	0.042
4	0.038	0.040	0.038	0.039	0.040	0.041	0.037	0.036
5	0.032	0.032	0.032	0.032	0.032	0.034	0.035	0.034
6	0.032	0.032	0.032	0.032	0.032	0.032	0.031	0.030
7	0.040	0.040	0.040	0.039	0.038	0.040	0.036	0.038
8	0.040	0.040	0.040	0.041	0.042	0.041	0.040	0.040
9	0.038	0.040	0.040	0.039	0.039	0.042	0.038	0.038
10	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038
11	0.038	0.036	0.036	0.037	0.038	0.038	0.038	0.038
12	0.040	0.040	0.040	0.039	0.041	0.042	0.040	0.040
13	0.040	0.038	0.040	0.041	0.040	0.044	0.041	0.040
14	0.040	0.038	0.037	0.038	0.040	0.040	0.040	0.040
15	0.040	0.038	0.038	0.038	0.040	0.040	0.040	0.038
16	0.042	0.042	0.042	0.041	0.040	0.042	0.040	0.040
17	0.044	0.042	0.044	0.043	0.044	0.046	0.044	0.044
18	0.042	0.042	0.044	0.043	0.043	0.044	0.044	0.044
19	0.044	0.042	0.043	0.042	0.042	0.044	0.042	0.043
20	0.044	0.044	0.044	0.042	0.043	0.044	0.042	0.043
21	0.046	0.044	0.043	0.044	0.044	0.042	0.044	0.045
22	0.044	0.045	0.044	0.042	0.043	0.044	0.042	0.046
23	0.044	0.044	0.040	0.042	0.042	0.043	0.044	0.042
24	0.036	0.034	0.038	0.028	0.035	0.040	0.040	0.040

^aPoints spaced radially 6 in. apart.

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