MAGELLAN PROJECT

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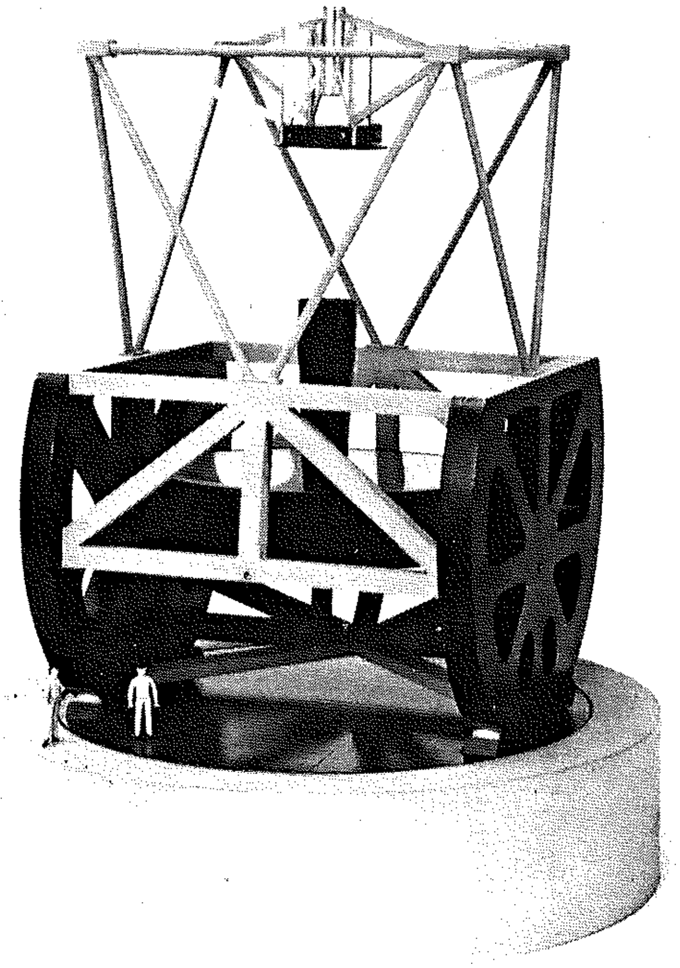

Mirror Coating Facilities

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The Observatories of the
Carnegie Institution of Washington
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INTRODUCTION

The 8-meter telescope of the Magellan Project proposed for the Las Campanas Observatory will require a mirror coating facility far beyond the capability of the Observatory's current coating system. A chamber approximately 29 feet (9 meters) in diameter will be required. As currently envisioned, the new mirror coating facility will be located in a building attached to or nearby the enclosure for the 8-meter telescope and will evaporate aluminum in a high vacuum from tungsten filaments onto the mirror substrate. This report describes the first draft concepts on this coating facility.

VACUUM CHAMBER

The coating facility is a modification of the scheme developed for aluminizing the 5-meter mirror in the Hale telescope where the mirror, in its cell, was placed in the vacuum chamber. The primary difference is in not placing the mirror and cell inside the vacuum system but making the cell, still carrying the mirror, part of the chamber sandwich. This leads, of course, to a somewhat smaller system than otherwise. Like the 5-meter facility there will be two separate volumes in the vacuum chamber, a "clean" one where evaporation will take place and a "dirty" vacuum that must be maintained to relieve differential pressure across the mirror. Figure 1 shows an early design concept for the vacuum chamber prepared by L & F Industries.

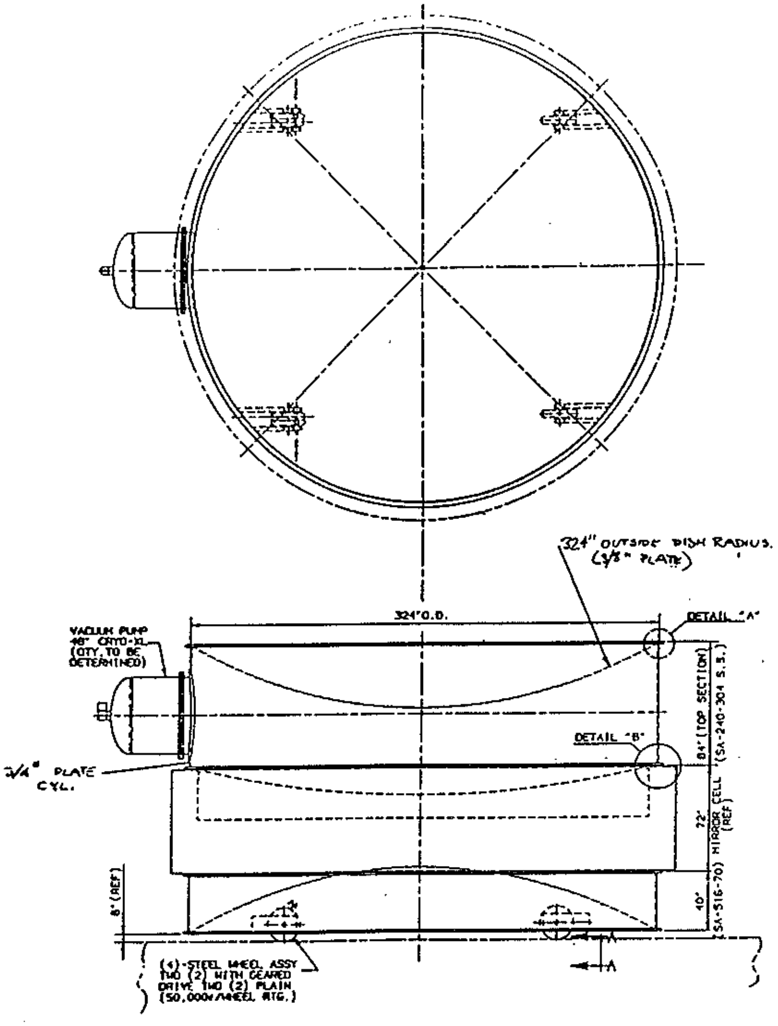


Fig. 1. - Preliminary vacuum chamber design.

The upper section of the tank, the section where the evaporation takes place, will be rigidly attached to the building structure. The cryopumps and roughing pump manifolds can be permanently attached to this section in order to eliminate the need for interrupting any high vacuum seals. The high current transformers for the evaporation filaments will be located above the top tank section. This section should be made of stainless steel to minimize outgassing.

The mirror cell will be the center section of the vacuum chamber. It must withstand the vacuum pressure loads and must mate and seal with the other two vacuum tank sections. The mirror cell is part of the "dirty" vacuum and can therefore be constructed of mild steel. Design of the mirror cell is currently the responsibility of the University of Arizona.

The lower section of the vacuum chamber also serves as the mirror cell handling cart. This cart must be capable of carrying the mirror and cell from the telescope to the coating facility. It must have a vertical motion so that it can rise to the level of the mirror cell and attach to and seal with the telescope in the zenith pointing position. After mirror preparation, the cart with mirror cell is moved under the high vacuum section where the cell is vacuum sealed to this fixed section. (In order to keep the vacuum chamber clean when not in use, the handling cart can also be sealed to the fixed, top section of the tank for storage.)

The vacuum tank has very demanding sealing requirements. The interfaces between the top tank section and the mirror cell and between the handling cart and the mirror cell will each require approximately 1100 linear inches (28 meters) of seal. In addition, a low differential pressure seal will be needed along the mirror edge and central hole to separate the clean and dirty vacuums. Viton is a preferred gasket material because of its low outgassing rate and permeability to atmospheric gases (O'Hanlon, 1980). Metal gasket seals would be useful for the approximately 50 electrical feedthroughs which are of small size and will rarely be dismounted.

EVAPORATION SYSTEM

We have set a requirement that the mirror coating system must produce an aluminum coating 800 - 1000 Å thick, with a uniformity of +/- 5% rms. Aluminum is to be evaporated in a high vacuum from resistively heated helical tungsten filaments. Figure 2 shows a distribution of 336 filaments which will produce a coating with the required uniformity on an 8-meter F/1.2 mirror.

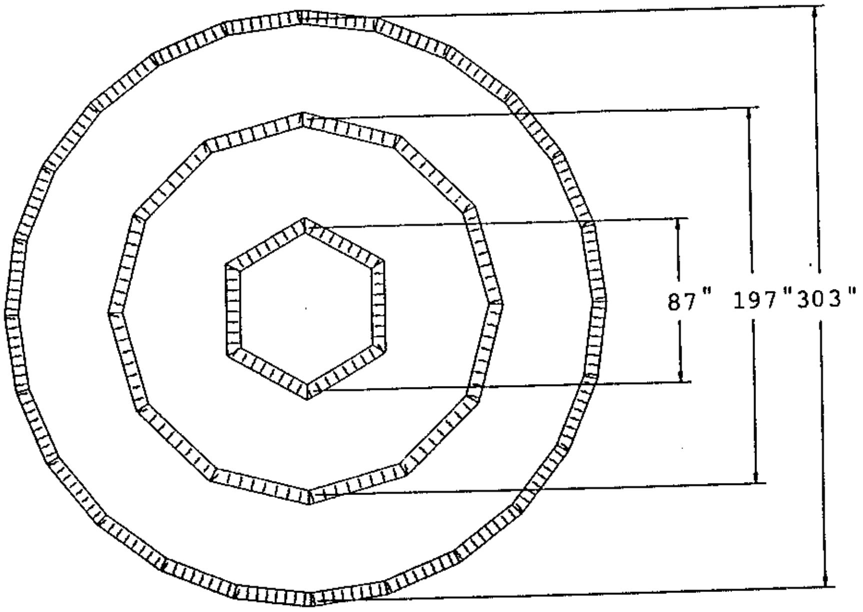


Fig. 2. - Filament distribution.

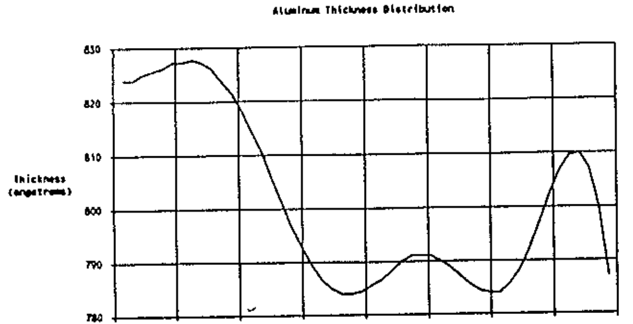


Fig. 3. - Aluminum thickness radial distribution; no baffling.

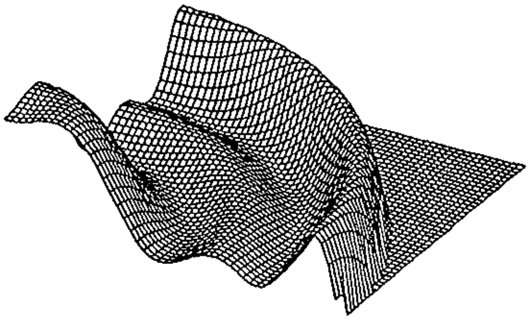


Fig. 4. - Aluminum thickness variation on mirror quarter section (vertical scale exaggerated to show variation).

The filaments are located in a plane 1 meter above the edge of the mirror. This configuration is based upon the 3-ring filament distribution suggested by the Columbus Project (Hill, Lesser, and Sabol, 1988), with the number of filaments scaled up by 25% and the geometry changed from 3 concentric rings to 3 concentric polygons of 6, 12, and 24 sides each. This configuration was numerically analyzed, with the filaments approximated as point sources. The results of this modeling are shown in Figures 3 and 4. The coating is uniform to within 2% rms along the radial direction. Figure 4 shows that the polygonal distribution of filaments allows good coating uniformity and is a sufficient approximation to the circular distribution.

In order to assure a more dense aluminum coat it is desirable to restrict the angle of vapor incidence to less than 50° as shown in Figure 5 (Brar, 1967). Otherwise the density of the coating becomes sufficiently low to produce a granular coating with a diffuse reflection. The filament geometry shown in Figure 2, with the filaments located 1 meter above the mirror edge has angles of incidence as high as 80°. Baffles may be used around the filaments to reduce the incidence angles without increasing the distance between the filament and the substrate. The 3-ring filament geometry of Figure 2 with baffling added to limit the angle of incidence to 50° does not produce a sufficiently uniform coating. It appears that it is necessary to use 5 filament rings and to add additional filaments to achieve the required uniformity with the 50° baffles. It is also possible that, by firing all filaments simultaneously, the need for baffling can be reduced or eliminated (Holland, 1958). Aluminum vapor atoms arrive at the substrate from many directions which may minimize the formation of surface irregularities that cause the diffuse reflection. Testing will probably be necessary to determine the need for baffling.

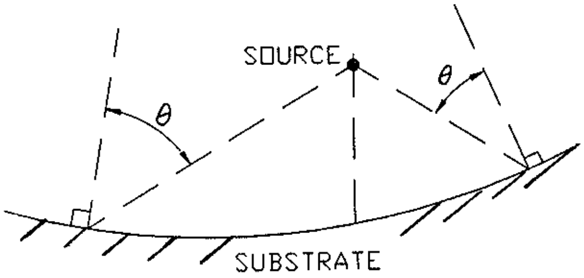


Fig. 5. - Angle of vapor incidence.

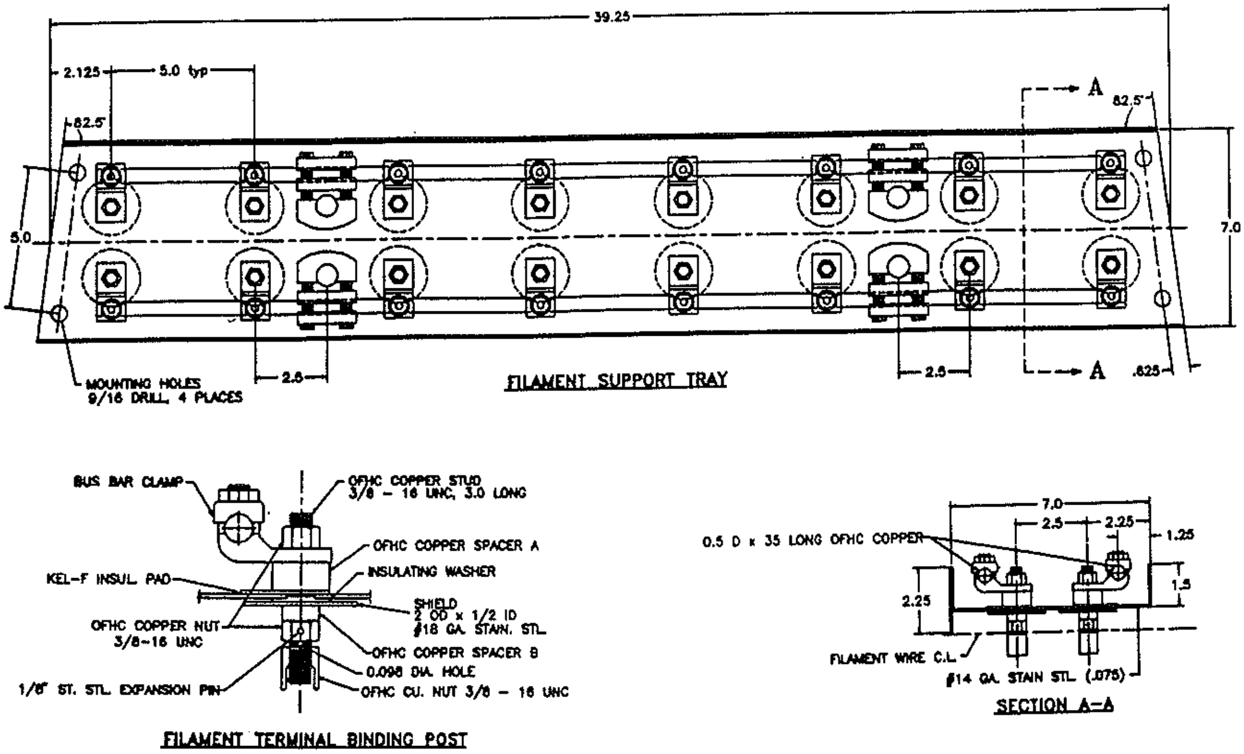


Fig. 6. - Filament tray assembly.

A preliminary design of a filament tray assembly for the outer filament ring is shown in Figure 6. The filament tray assemblies for the middle and inner rings are similar, essentially differing only in overall length. Each tray assembly has eight 2-strand, 7-loop tungsten filaments identical to the ones now used at Las Campanas. The tray itself is made from bent 304 stainless steel sheet. The electrical conductors are made of OFHC copper and the insulators are made of Kel-F or a similar material for minimal outgassing. Threaded fasteners and enclosed volumes are vented to prevent virtual leaks. Figure 7 shows the arrangement of the filament trays within the aluminization chamber.

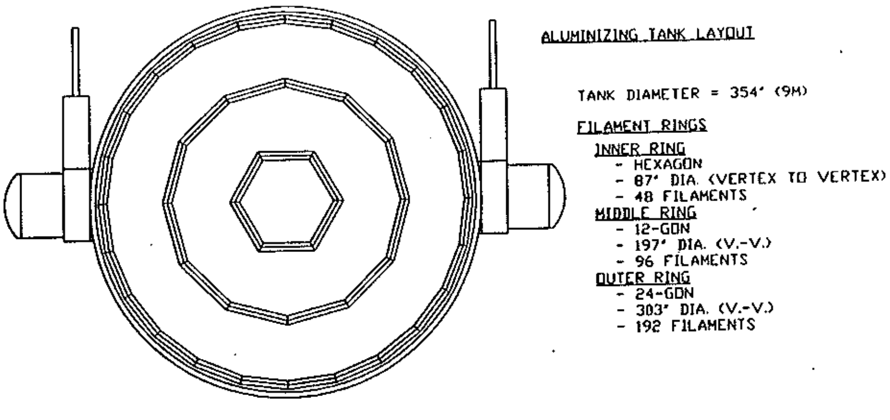
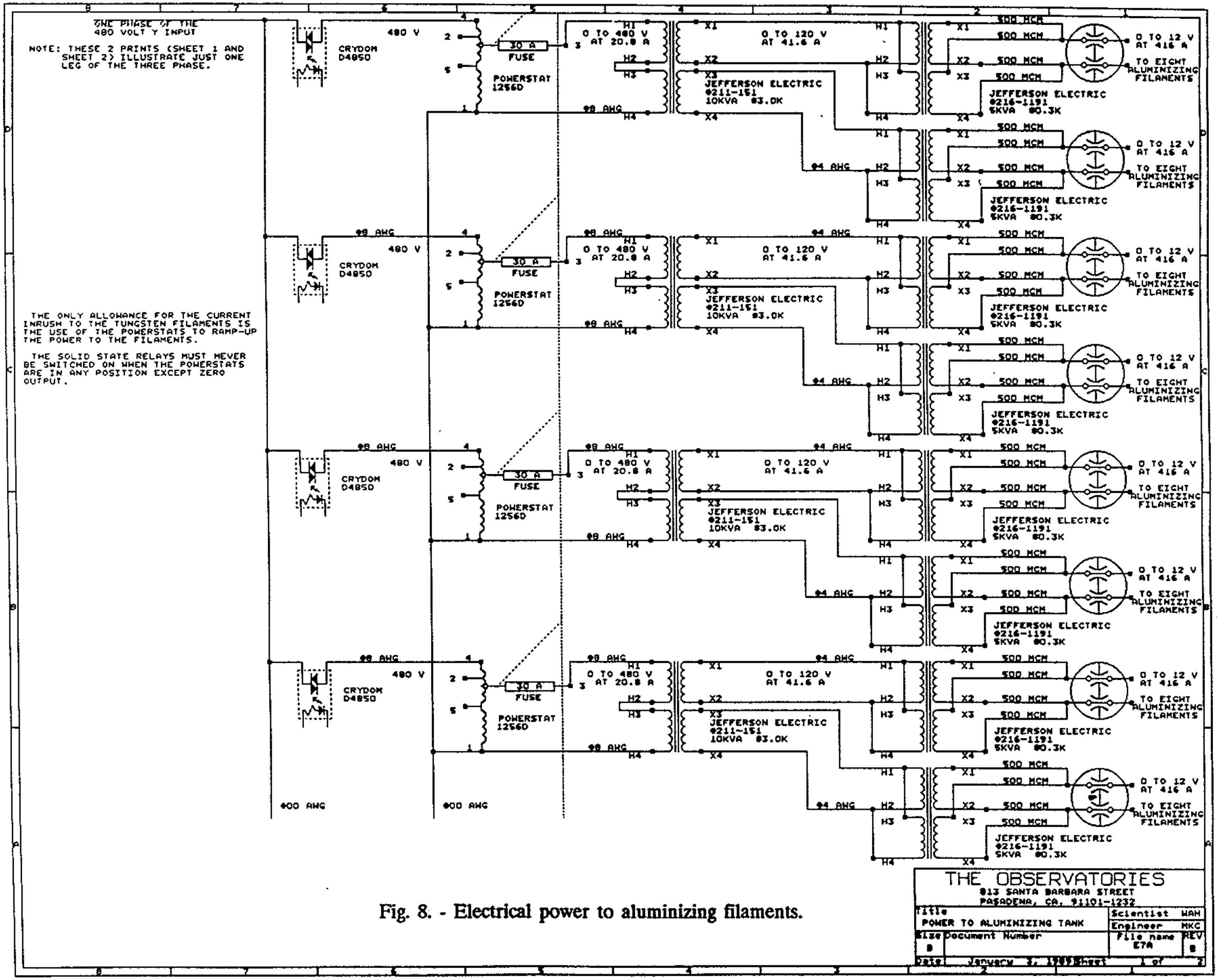


Fig. 7. - Filament tray arrangement within aluminization chamber.

The electrical power conditioning and distribution system is shown schematically in Figure 8. Over 210 kVA is required to simultaneously



ONE PHASE OF THE
480 VOLT Y INPUT

NOTE: THESE 2 PRINTS (SHEET 1 AND SHEET 2) ILLUSTRATE JUST ONE LEG OF THE THREE PHASE.

THE ONLY ALLOWANCE FOR THE CURRENT INRUSH TO THE TUNGSTEN FILAMENTS IS THE USE OF THE POWERSTATS TO RAMP-UP THE POWER TO THE FILAMENTS.

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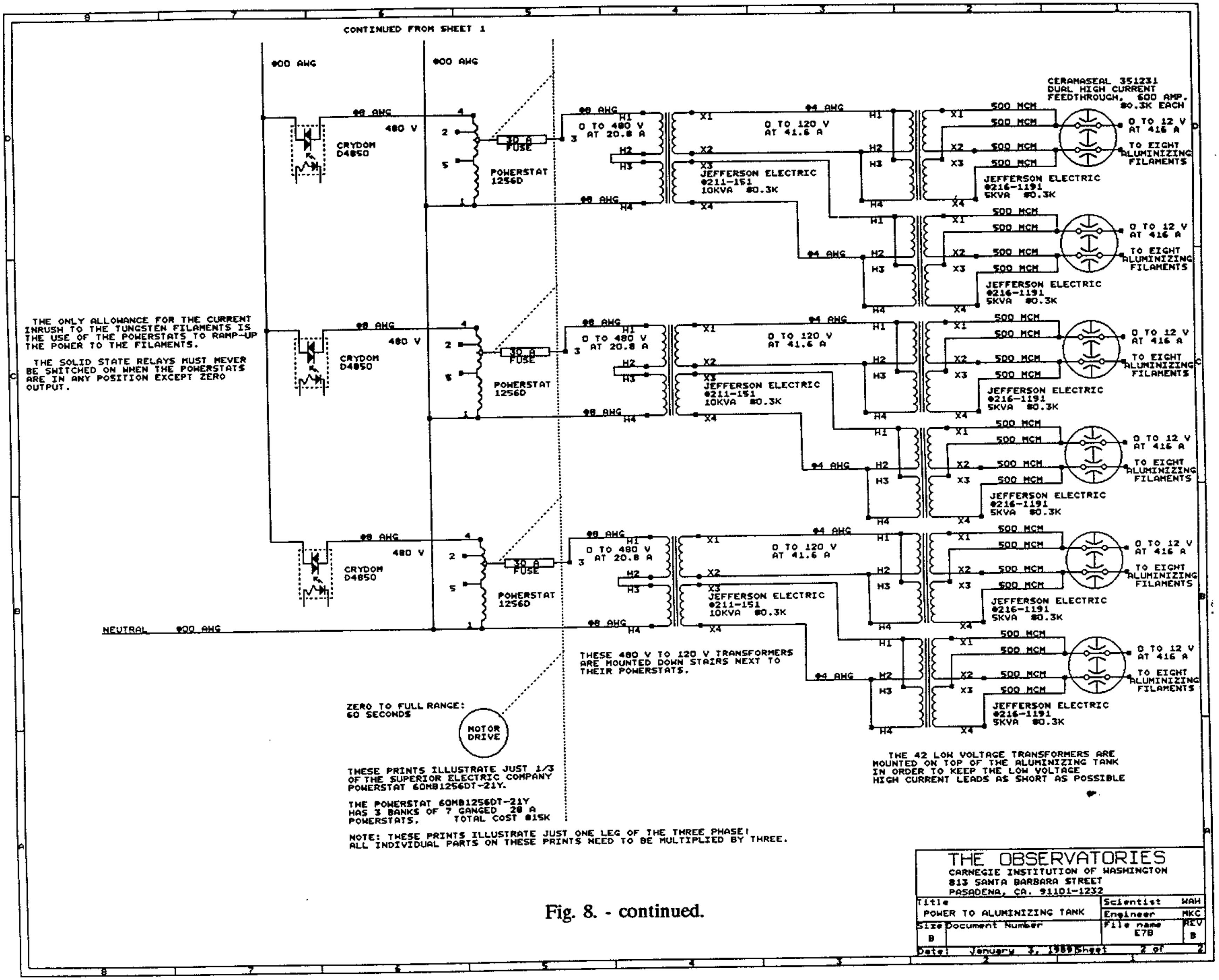
Fig. 8. - Electrical power to aluminizing filaments.



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THESE 480 V TO 120 V TRANSFORMERS ARE MOUNTED DOWN STAIRS NEXT TO THEIR POWERSTATS.

THE 42 LOW VOLTAGE TRANSFORMERS ARE MOUNTED ON TOP OF THE ALUMINIZING TANK IN ORDER TO KEEP THE LOW VOLTAGE HIGH CURRENT LEADS AS SHORT AS POSSIBLE

THESE PRINTS ILLUSTRATE JUST 1/3 OF THE SUPERIOR ELECTRIC COMPANY POWERSTAT 60MB1256DT-21Y.

THE POWERSTAT 60MB1256DT-21Y HAS 3 BANKS OF 7 GANGED 28 A POWERSTATS. TOTAL COST $15K

NOTE: THESE PRINTS ILLUSTRATE JUST ONE LEG OF THE THREE PHASE! ALL INDIVIDUAL PARTS ON THESE PRINTS NEED TO BE MULTIPLIED BY THREE.

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Fig. 8. - continued.

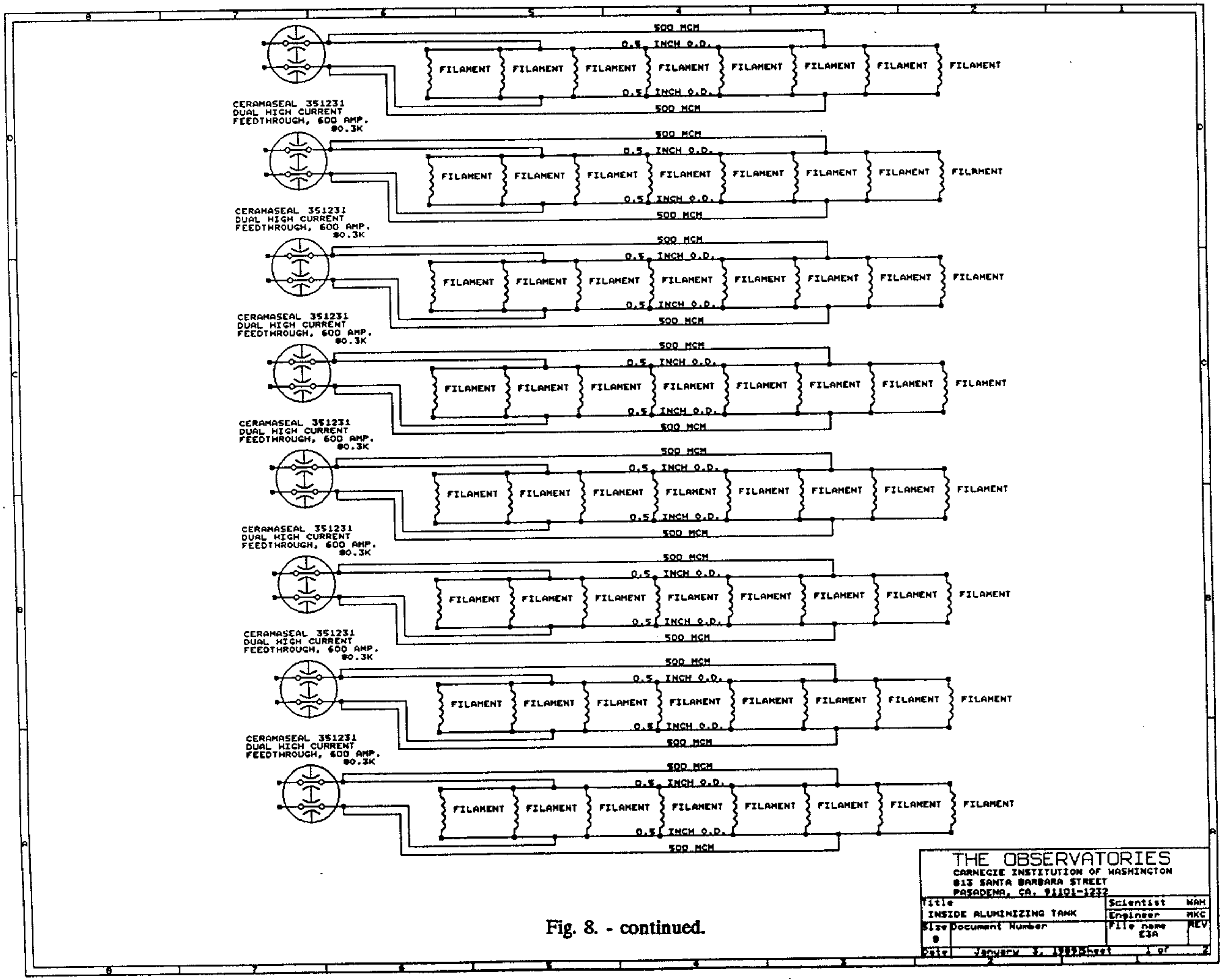

Fig. 8. - continued.

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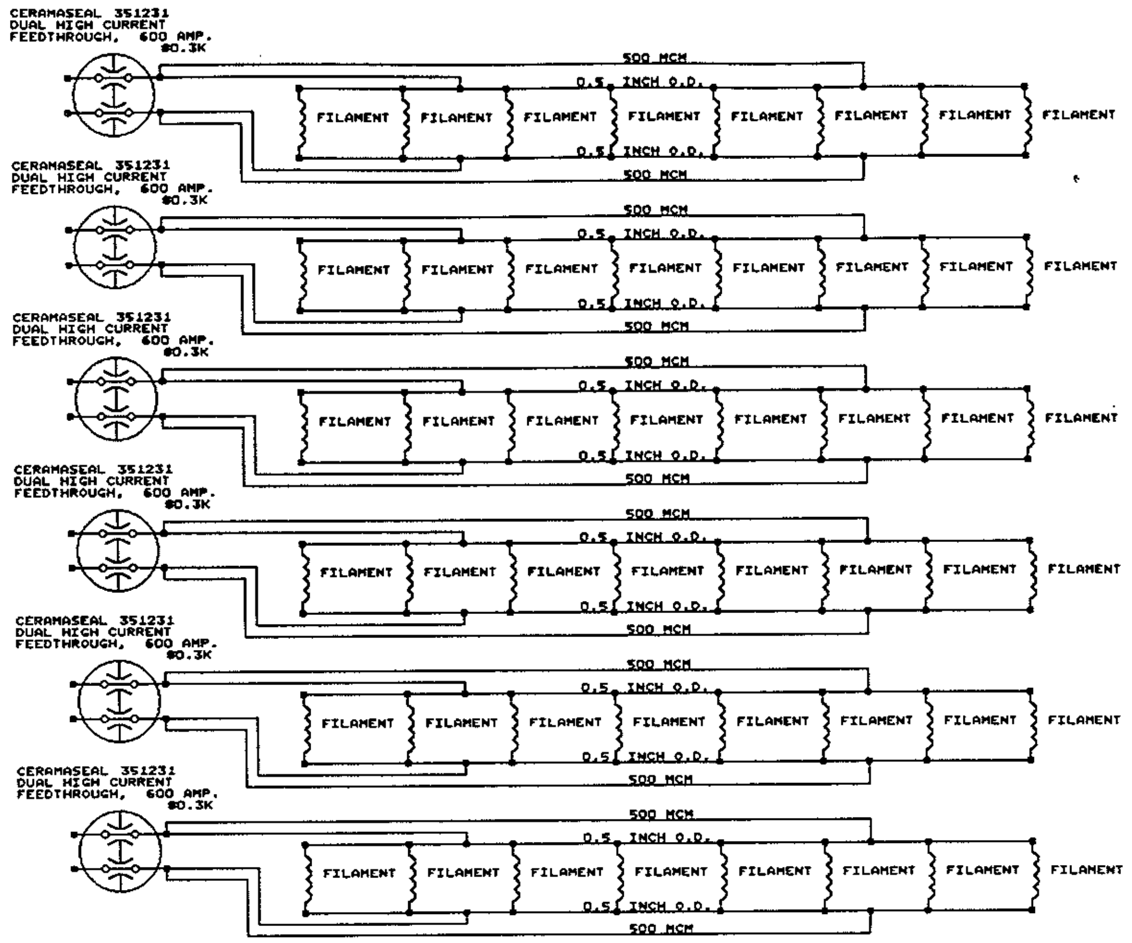

14 BANKS OF 8 FILAMENTS EQUALS 122 ON THESE PRINTS, TIMES 3 EQUALS 336 MAXIMUM.

NOTE: THESE PRINTS ILLUSTRATE JUST ONE LEG OF THE THREE PHASE!

ALL INDIVIDUAL PARTS ON THESE PRINTS NEED TO BE MULTIPLIED BY THREE.

Fig. 8. - concluded.

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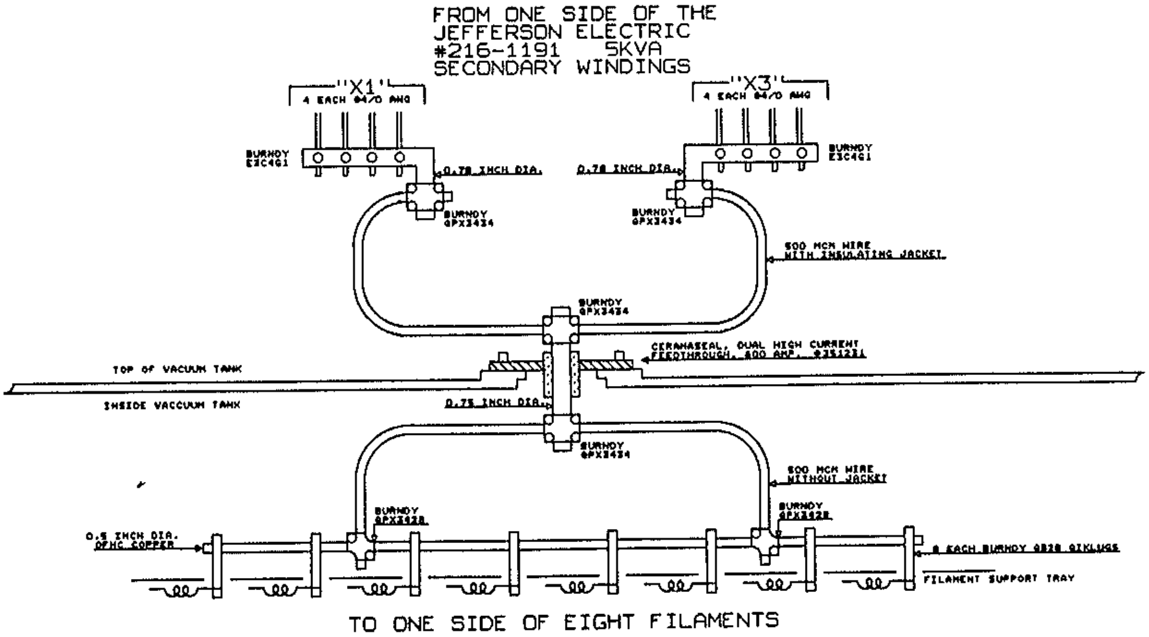


Fig. 9. - Filament tray wiring pictorial.

fire the 336 evaporation filaments as currently used at Las Campanas. A motor driven variable auto-transformer is used to control the high current inrush to the cold tungsten filaments. This Superior Electric motor driven (0 to 480 Volt AC) variable auto-transformer has 21 individual powerstats (3 banks of 7 ganged together) rated at 28 Amps each. Each input to the individual powerstats has a solid state relay (SSR) controlling it. The SSR will be interlocked to switch on only when the powerstats are in the zero output position. The SSR switches can also interrupt power the instant the aluminum film has reached the desired thickness. The outputs of the 480 Volt powerstats step down to the required 12 Volts through two readily available commercial transformers. The transformers with the 12 Volt, high current secondaries are mounted on top of the vacuum tank, near their dual vacuum feedthroughs. These, in turn, will be mounted above their individual filament tray assemblies. This arrangement permits short leads to the low resistance tungsten filaments loaded with aluminum. The power is finally distributed to the filaments by 0.5 inch diameter OFHC copper bus bars. The high current secondary distribution detail is shown pictorially in Figure 9.

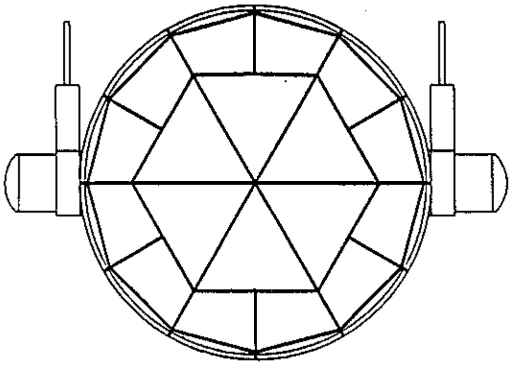


Fig. 10. - "Spider" support structure geometry.

The filament trays will be hung from a stainless steel "spider" support structure located inside the top section of the tank. Figure 10 shows the basic geometry of the support structure.

GLOW DISCHARGE SYSTEM

Following chemical removal of the old aluminum coating, a high voltage glow discharge system will be used for the final cleaning of the mirror surface immediately prior to aluminization. A 19 foot diameter, double bar discharge ring, scaled up from to that used in the du Pont aluminizing tank (Rule, 1972), will be used. It will operate at 3 Amps and 4800 Volts AC.

The glow discharge cleaning will take place in an oxygen and argon environment at 10^{-2} Torr. The Columbus Project has estimated that this process may last for more than 30 minutes (Hill, Lesser, and Sabol, 1988). The glow discharge will then be continued with only the argon supply, to remove the oxygen from the system. Immediately following the glow discharge, the chamber will be pumped down to the final pressure to begin evaporation.

The glow discharge assembly is shown in Figure 11. Two 228" diameter rings of 0.5" diameter bars will form the electrodes. The bars will be of high purity aluminum because of its very low sputtering rate. In addition, the glow ring is shielded from the mirror surface to avoid sputtering and direct electron bombardment of the substrate. The electrodes are also shielded from the evaporation sources to prevent aluminum from coating the ceramic high voltage insulators. For ease of manufacturing and assembly, the aluminum electrodes each consist of 24 segments, each 30" long and lap joined at the ceramic insulator posts, as shown in the detail of Figure 11. The stainless steel support and shielding structure will be made in 12 segments and attached to the main spider support structure inside the top tank section.

The power supply circuit for the glow discharge system is shown in Figure 12. A 15 kVA step-up transformer serves as the high voltage power supply. A variable transformer is connected to the primary side of the high voltage transformer to allow continuously variable voltage from 0 to 4853 Volts at 3 Amps.

VACUUM PUMPING SYSTEM

The success of the aluminization system is greatly dependent upon the capability of the pumping system to safely and rapidly achieve and maintain a high vacuum. A high speed pumping system will allow evaporation of aluminum to begin very soon after glow discharge cleaning is complete and will also make simultaneous firing of all the filaments possible while maintaining a good vacuum. A high vacuum during aluminization is necessary in order to keep the mean free path in the chamber as long as possible (at a pressure of 10^{-6} mm Hg, the mean free path is approximately 65 meters, seven chamber diameters).

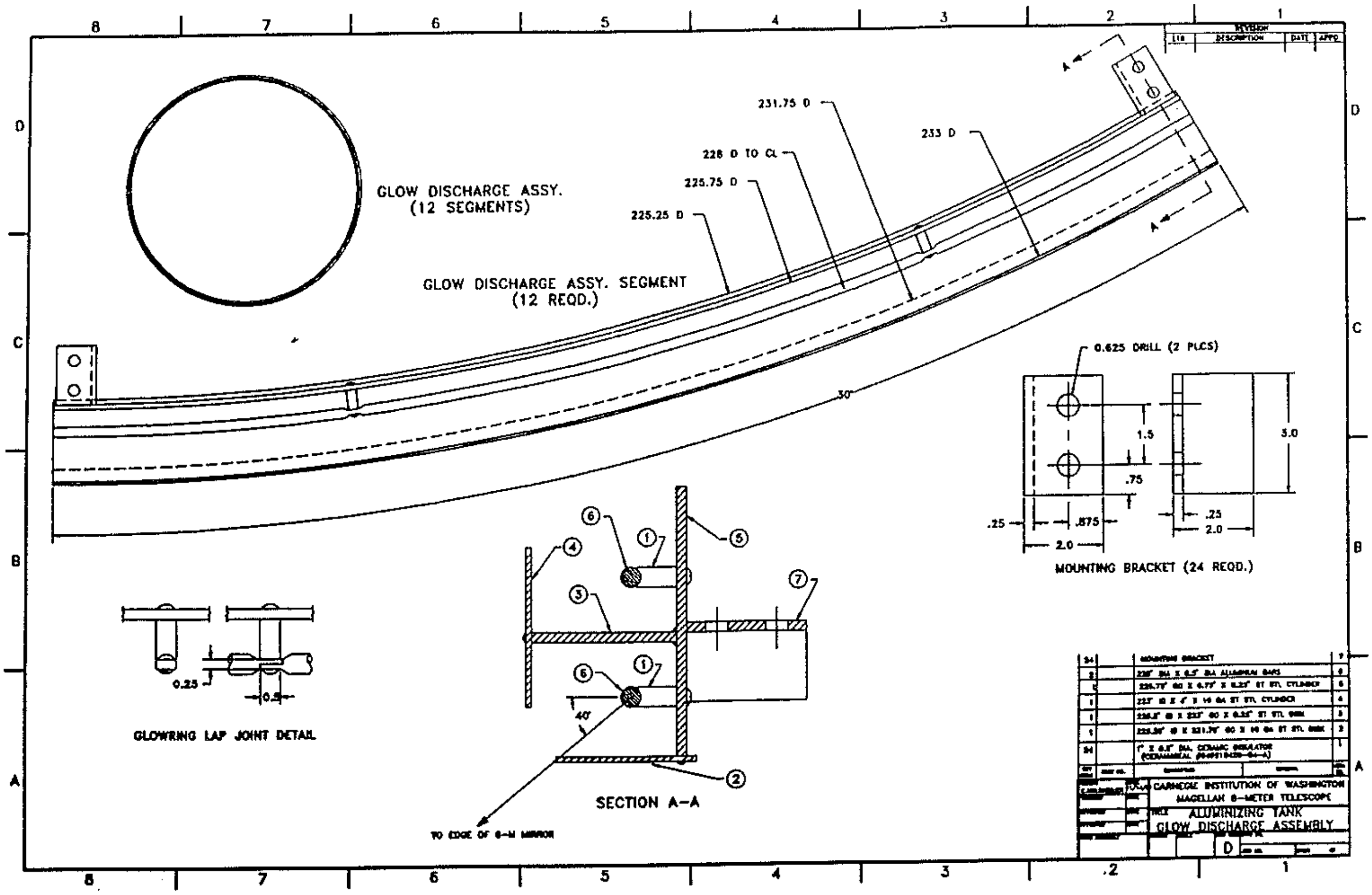
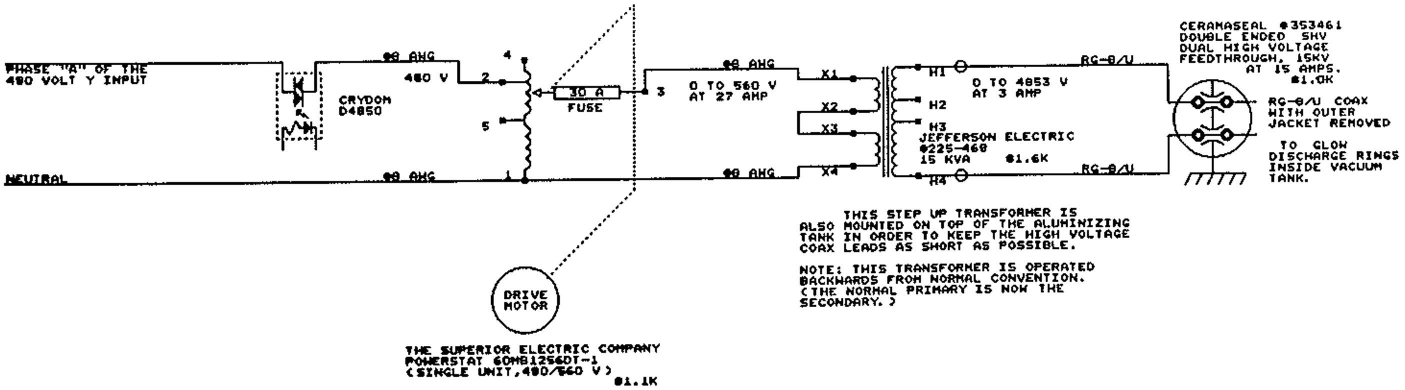


Fig. 11. - Glow discharge assembly.



THIS STEP UP TRANSFORMER IS ALSO MOUNTED ON TOP OF THE ALUMINIZING TANK IN ORDER TO KEEP THE HIGH VOLTAGE COAX LEADS AS SHORT AS POSSIBLE.

NOTE: THIS TRANSFORMER IS OPERATED BACKWARDS FROM NORMAL CONVENTION. (THE NORMAL PRIMARY IS NOW THE SECONDARY.)

Fig. 12. - Glow discharge power supply circuit.

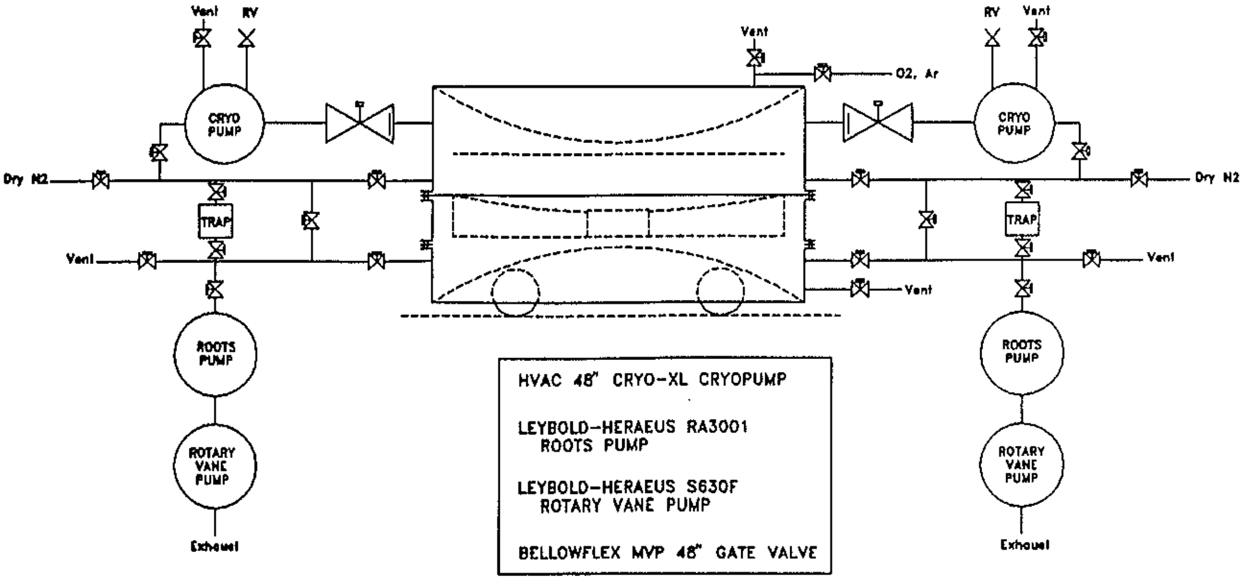


Fig. 13. - Vacuum system schematic.

A preliminary schematic of the vacuum pumping system is shown in Figure 13. The upper half of the vacuum tank is the "clean" section; the lower half (mirror cell and handling cart) is the "dirty" section. Both tank sections are rough pumped by two parallel sets of Roots blower and oil-sealed rotary vane pumps. The Leybold-Heraeus model S630F Rotary Vane pump and the Leybold-Heraeus model RA3001 Roots pump have been identified as potential candidates for this function. To prevent creating pressure differences across the mirror, the clean and dirty tank sections are rough pumped together. A cold trap, or possibly a catalytic trap, prevents any oil from backstreaming from the mechanical pumps and the dirty tank section into the clean tank section.

Final pumping of the clean tank section is performed by two large three-stage cryopumps. Cryopumps, while more expensive than traditional diffusion pumps, allow a contamination - free pumping system and offer very high pumping speeds. The Hi-Vacuum Corporation's 48" Cryo-XL pump, a candidate pump for this function, has the following pumping speeds: nitrogen-55,000 l/sec, argon-45,000 l/sec and water-175,000 l/sec. The cryopumps are attached to the upper section of the vacuum tank through large pneumatically operated gate valves, such as the Bellowflex 48" gate valve.

The effectiveness of the cryopump is shown in Figure 14 supplied by Leybold. Although the forepumps are different in capacity from those used in the analysis, the rapidity with which the cryopumps can reduce the pressure from greater than 10^{-2} Torr in the clean 9-meter chamber to less than 10^{-6} Torr is striking.

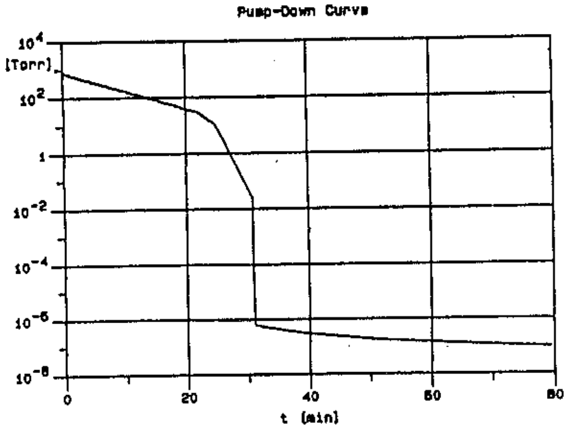


Fig. 14. - Tank pump-down curve.

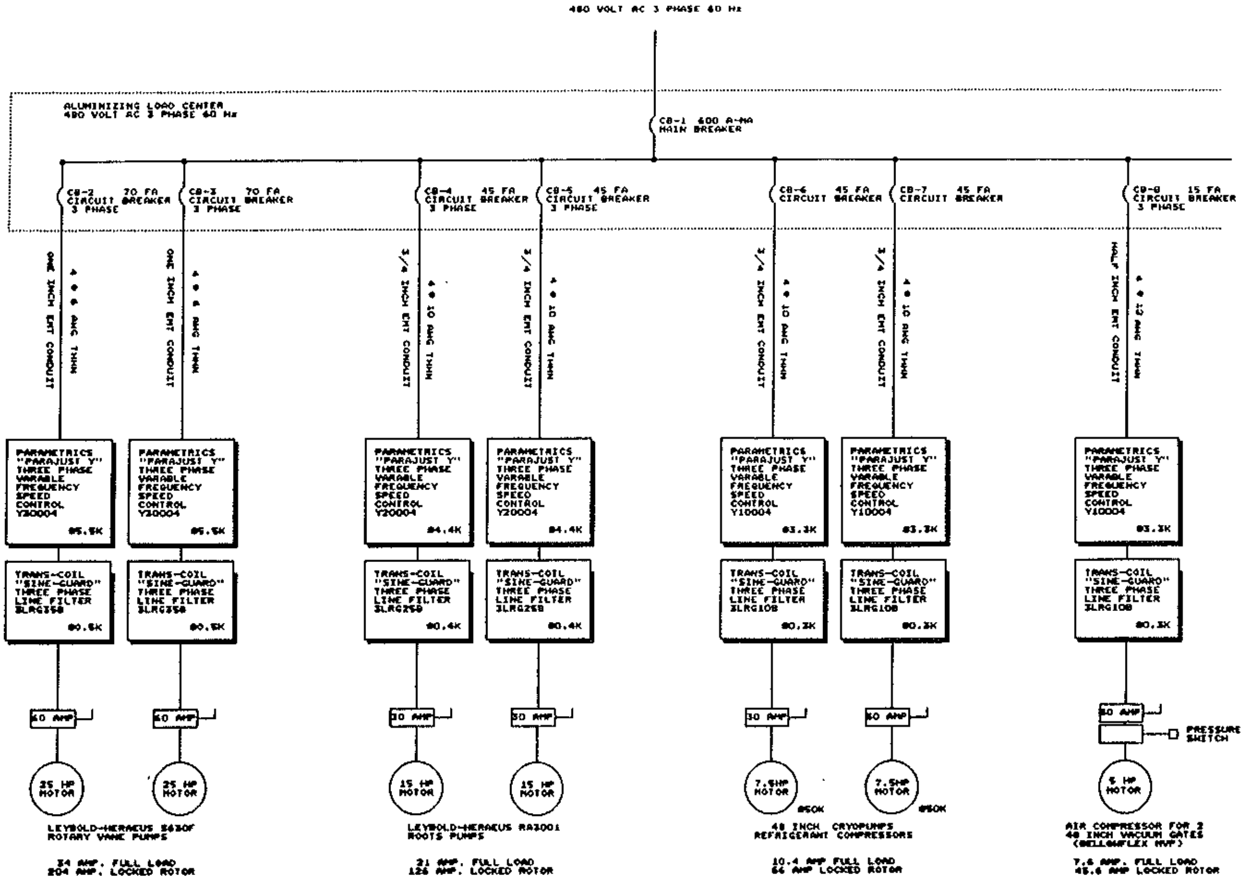


Fig. 15. - Vacuum pumping system electrical power requirements.

The electrical power requirements for the vacuum pumping system are shown in a one-line diagram in Figure 15.

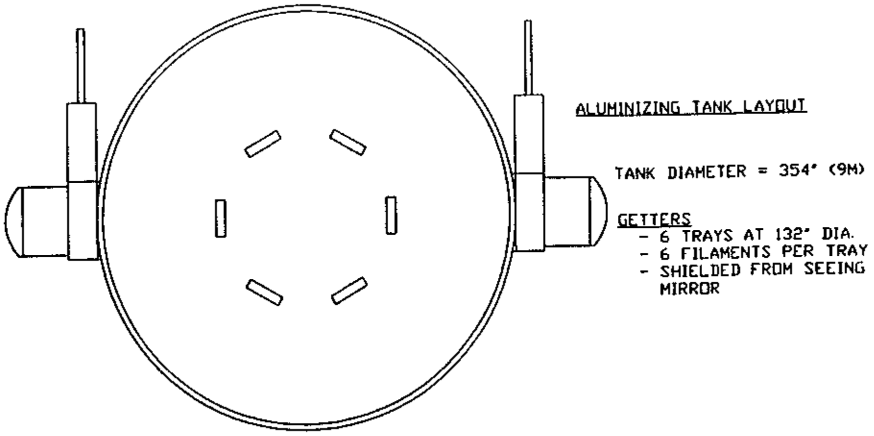
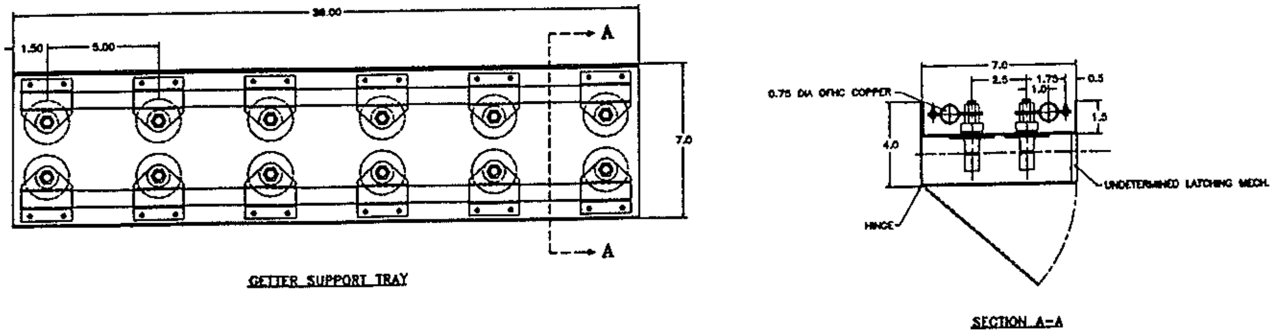


Fig. 16. - Getter tray arrangement

Getter pumping will be used to provide inexpensive additional pumping capacity. Aluminum will be deposited onto the walls of the clean vacuum chamber, acting as a large area surface getter. Thirty-six tungsten filaments to evaporate the aluminum will be located on six trays in the top section of the vacuum chamber, as shown in Figure 16. These filaments will be shielded to prevent depositing aluminum on the mirror surface. The getter filament



GETTER SUPPORT TRAY

SECTION A-A

Fig. 17. - Getter filament tray assembly.

tray assemblies, shown in Figure 17, will be similar to and have many parts in common with the aluminization evaporation system, making this a relatively inexpensive addition. The getters will have their own electrical power supply system, shown in Figure 18.

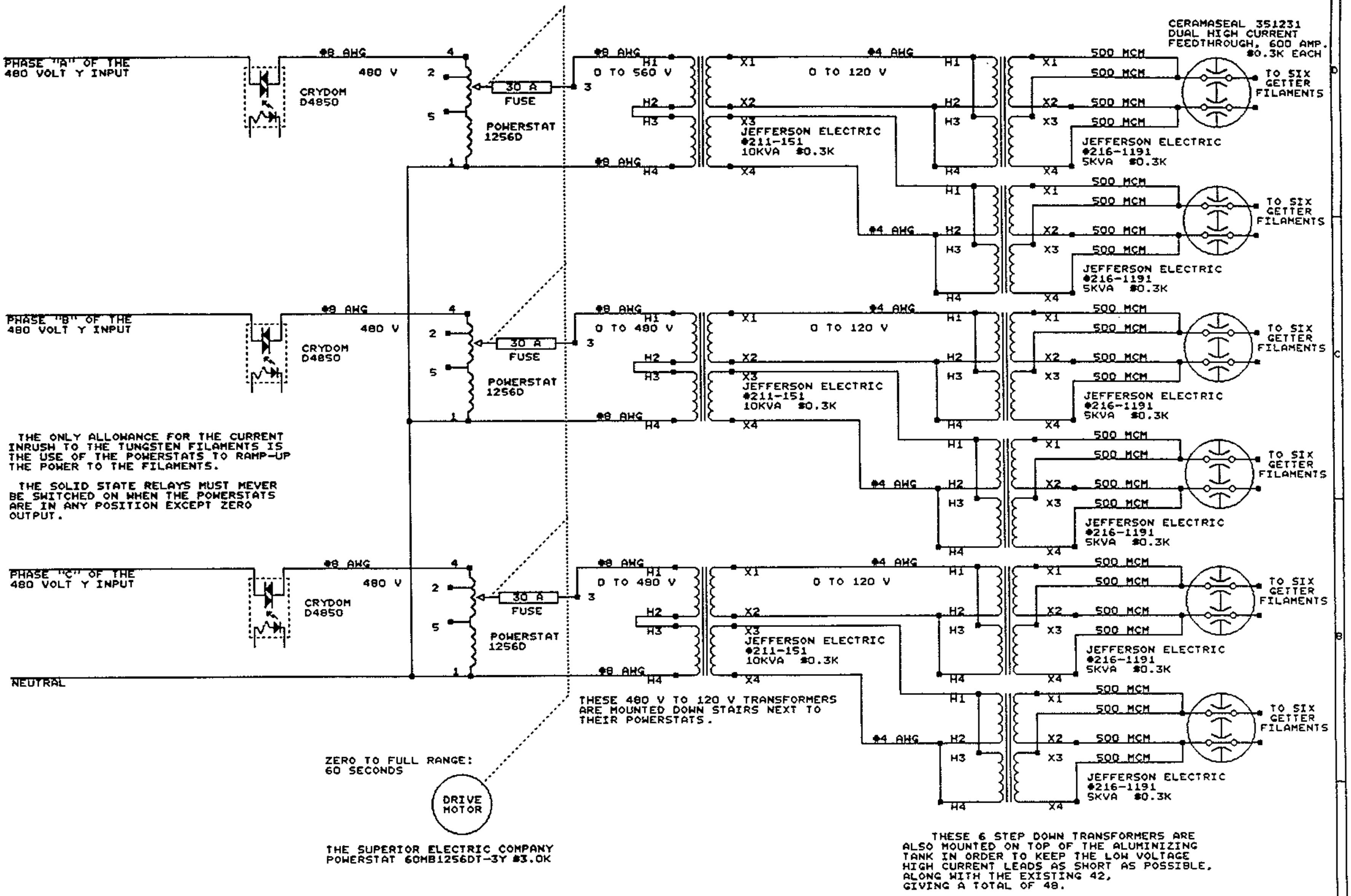
CONCLUSIONS AND ALTERNATIVES

We believe that the coating facility as now conceived and designed is capable of producing an excellent aluminum coat on the 8-meter mirror. However, with the upward looking mirror, the evaporation of other materials is severely limited. An ideal world would have the mirror looking downward so that materials could be evaporated from boats without the present restriction where one is basically limited to those materials that wet tungsten. Obviously, a downward looking mirror for coating purposes has been dismissed for a variety of reasons! As a possible alternative we have tentatively explored the sputtering process. This process allows a broader variety of coating materials and also can produce harder coats. However, the sputtering technology seems not to have progressed to the point where one can proceed with full confidence.

One should note that the choice of an evaporation process to coat the 8-meter mirror impacts the overall development of the project. The large power consumption during the short period of evaporation requires an additional power source on the mountain. Furthermore, the large sizes of the washing facility and coating chamber must be carefully planned. However, the work completed to date does not unearth any obstacle to implementing an excellent aluminum evaporation mirror coating facility. Details remain, of course, but the evaporation technology is so well established that no "show stoppers" are foreseen.

ACKNOWLEDGEMENTS

The authors would like to thank Mr. Frank Perez for his expert insights and advice on aluminization and to thank Dr. W. A. Hiltner and Ms. Kristin Theotokatos for their invaluable help in editing and producing this report.



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THE SOLID STATE RELAYS MUST NEVER BE SWITCHED ON WHEN THE POWERSTATS ARE IN ANY POSITION EXCEPT ZERO OUTPUT.

THESE 480 V TO 120 V TRANSFORMERS ARE MOUNTED DOWN STAIRS NEXT TO THEIR POWERSTATS.

ZERO TO FULL RANGE: 60 SECONDS

THE SUPERIOR ELECTRIC COMPANY POWERSTAT 60MB1256DT-3Y $3.0K

THESE 6 STEP DOWN TRANSFORMERS ARE ALSO MOUNTED ON TOP OF THE ALUMINIZING TANK IN ORDER TO KEEP THE LOW VOLTAGE HIGH CURRENT LEADS AS SHORT AS POSSIBLE, ALONG WITH THE EXISTING 42, GIVING A TOTAL OF 48.

Fig. 18. - Getter filament electrical power supply system.

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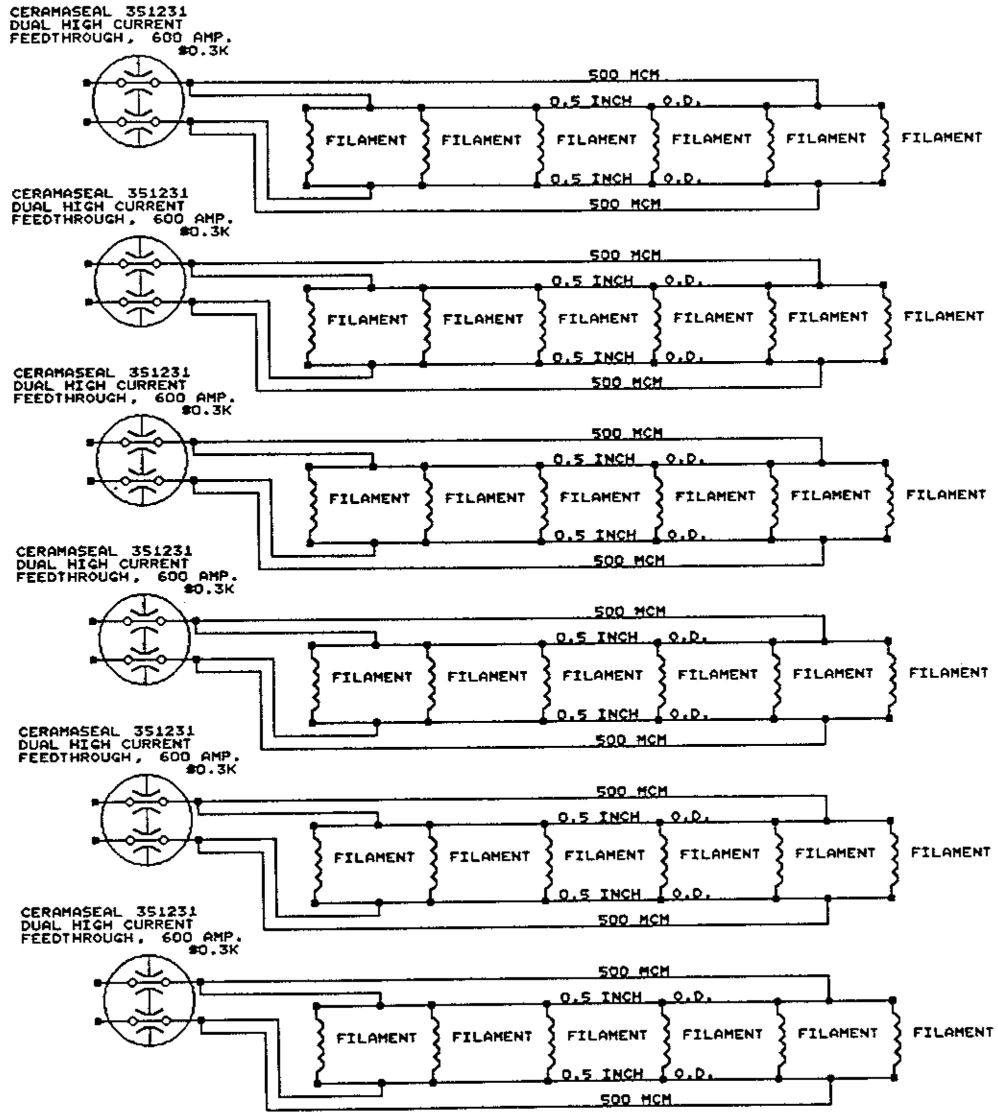

Fig. 18. - concluded.

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