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SPACECRAFT DEPARTMENT

MISSILE AND SPACE DIVISION

EVALUATION OF MOLYBDENUM GRAVITY GRADIENT RODS

FINAL REPORT

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EVALUATION OF MOLYBDENUM GRAVITY GRADIENT RODS FINAL REPORT

1 SEPTEMBER 1965 – 1 MAY 1966

CONTRACT NO. NAS 5-9666

FOR THE
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

APPROVED BY: R.J. KATUCKI, MANAGER
PASSIVE ATTITUDE CONTROL PROGRAMS

GENERAL ELECTRIC
SPACECRAFT DEPARTMENT
A Department of the Missile and Space Division
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FOREWORD

The Spacecraft Department of the General Electric Company has performed an evaluation of molybdenum as a material for gravity gradient rods for use on passively oriented earth satellites and other similar applications. The effort was performed under Contract NAS 5-9666 with the Goddard Space Flight Center of the National Aeronautics and Space Administration.

Many engineers and other technical personnel contributed to the work done under this contract. The chief contributors in their specific fields of interest were Dr. R. B. Gavert, E. M. Mazur, G. R. Bretts, H. W. Rosenberg, R. K. Knipe, D. B. Davies, and G. F. Groschke. The efforts of Mr. Groschke, Master Mechanic, and his associates were particularly outstanding in the design and fabrication of the Forming Machine. Mr. R. Fusco was the major contributor at GE Lamp Metals and Components Department.

This document is submitted as the final report and constitutes satisfaction of the contractual commitments of the General Electric Company in regard to this contract.

ABSTRACT

This document reports in detail the development efforts of the Spacecraft Department of the General Electric Comapny in the evaluation of molybdenum foil as a material for extensible rods for use in gravity gradient stabilized satellite systems and similar applications.

The report contains detailed descriptions of (a) the rolling processes for molybdenum foil as performed by the Lamp Metals and Components Department of the General Electric Company, (b) the forming of this foil into circular, overlapped rods of 1/2-inch diameter by the Spacecraft Department, (c) the construction of a deployer to demonstrate moly rod deployment characteristics, and (d) analysis and evaluation of moly rod material for its suitability (in long lengths) for gravity gradient rod and other similar applications.

As a result of this evaluation, it is concluded that molybdenum foil can be successfully formed and is deployable into a circular, overlapped 1/2-inch diameter rod, and that the resulting rod is suitable for long (1000 feet maximum) extensible rod applications. A relatively insignificant amount of growth (creep) was noted in five weeks of storage (on a 1-3/4 inch diameter drum) with one deployment being accomplished each week.

However, the final deployment gave indications that the growth rate had leveled off. It is believed that this growth can be compensated for by making the initial fabricated diameter smaller than that desired in orbit, thereby allowing for creep growth. Another approach is to fabricate the rod in a slightly larger size (3/4-inch diameter for example) such that the flattening stress levels are initially lower. Further development is required to obtain more exact data regarding creep and growth compensation.

A major problem with the 0.001-inch thick moly foil (used throughout the program) was the handling characteristics. Very slight finger pressure on the 0.001-inch thick rod produced a permanent indentation. As a final experiment in this program, a short length of 0.0015-inch moly rod was continuously formed very successfully. The handling characteristics and general appearance of this rod were far superior to any of the 0.001-inch moly rods previously formed. Therefore, it is recommended that 0.0015-inch minimum thickness be used in future moly investigations.

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SECTION 1

INTRODUCTION

On 4 June 1965, the General Electric Company submitted MSD Proposal No. N-20564B entitled A Proposal for Fabricating and Testing Molybdenum for Use in Gravity Gradient Rods. Generally, this document summarized the desirable characteristics of molybdenum as a material for use in fabricating long extensible rods. These desirable characteristics included high thermal conductivity, high stiffness, high ultimate tensile strength, high yield strength, low coefficient of thermal expansion, low solar absorptance and low weight per unit length. Evaluation of this material had been hampered because of the difficulty in obtaining pure, uniform and stress-free material and because of questions regarding the availability of suitable material in the length requirements foreseen. However, the Spacecraft Department pointed out in their proposal that the Lamp Metals and Components Department of the General Electric Company located in Cleveland, Ohio, had effectively overcome the problems associated with moly foil, and it was now available for evaluation as a rod material. It was also proposed to engage Yoder Engineering of Cleveland, Ohio as a subcontractor to develop the equipment for the continuous forming of molybdenum foil into rods.

Although the proposal originally defined several performance tests on the finished molybdenum rod including natural straightness, structural testing, etc., the contract as signed on 31 August 1965, restricted all testing to performing only the "Straightness-Under-Thermal-Deflection" test as described in Paragraph 3.4.3 of the proposal. This restriction is contained in Article I - Statement of Work of the negotiated contract.

After performing for several weeks prior to the signing of a final contract, Yoder Engineering Company withdrew from the effort because of their objections to certain contractual terms (government auditing) which are mandatory on all government contracts. On 28 January 1966, when it was apparent that the Yoder Company was going to stop all efforts, GE initiated a backup effort (in-house) to fabricate a continuous forming setup. All formed rods submitted to NASA under Contract NAS 5-9666 were fabricated using the GE forming

setup since no rods were ever fabricated by Yoder Engineering Company. The Yoder Company submitted a final report, 18 February 1966, covering all work done by them and returned all material and parts to GE on 2 March 1966. The final Yoder report is attached as Appendix A.

SECTION 2

TECHNICAL DISCUSSION

2.1 MOLYBDENUM FOIL

The molybdeunum foil used in this investigation was 99.99% pure powder metallurgy molybdenum foil (0.001 inch thick) produced by the General Electric Lamp Metals and Components Department. For the program, 500 feet of foil in minimum lengths of 100 feet were produced. In addition to this quantity of foil, six 3-foot lengths of the same foil were electroplated on one side with 100×10^{-6} (0.0001-inch) of silver by GE LM&CD.

To get a quantitative measurement of the effects of possible stress relief treatments on the strength of the foil, GE LM&CD performed early in the program a test matrix of stress relief times and temperatures from 500 to 750 ^{o}C and 5 to 30 minutes. Room temperature tensile tests were made of longitudinal and transverse specimens on flat, not formed, foil. This data, contained in Appendix B, indicates that optimum strength characteristics result in the 950 to 1125 ^{o}F temperature range.

2.1.1 ROLLING PROCESS AND EQUIPMENT

The 0.001-inch molybdenum foil used in the gravity gradient rod program was rolled from a pressed and sintered molybdenum ingot measuring 1 x 10 x 24 inches. A summary of the rolling schedule for a pressed and sintered molybdenum ingot (1 x 10 x 24 inches) is presented in Table 2-1, and the rolling schedule for an arc-vacuum-cast ingot (3 x 8 x 14 inches) is presented in Table 2-2.

TABLE 2-1. ROLLING SCHEDULE

(Pressed and Sintered Ingot 1 x 10 x 24 Inches)

A. Breakdown Rolling (from hydrogen atmosphere furnaces)

1. Initial breakdown of ingot by warm rolling to a thickness of 0.327 inch.
2. Recrystallize at 0.327 inch.

B. Intermediate Warm Rolling

1. Continue warm rolling from thickness of 0.327 inch to a thickness of 0.050 inch. This reduction process is also from a hydrogen atmosphere furnace.
2. Clean strip in hot caustic and acid.
3. Intermediate anneal and slit to 7 inches wide for cold rolling.

C. Final Cold Rolling

1. Cold roll from 0.050 inch to 0.007 inch.
2. Intermediate anneal at 0.007 inch and slit to 6.75 inches wide.
3. Final cold roll to 0.001 inch, clean and slit to width.

TABLE 2-2. ROLLING SCHEDULE

(Arc-Vacuum-Cast Ingot 3 x 8 x 14 Inches)

A. Breakdown Rolling (from hydrogen atmosphere furnaces)

1. Initial breakdown of ingot by warm rolling to a thickness of 1 inch.
2. Recrystallize at 1 inch.
3. Continue warm reduction to a thickness of 0.210 inch.
4. Recrystallize at 0.210 inch.
5. Clean 0.210 inch plate in hot caustic and acid. Condition grind if necessary.

B. Intermediate Warm Rolling

1. Continue warm rolling from thickness of 0.210 inch to 0.060 inch. This reduction again is from a hydrogen atmosphere furnace.
2. Clean strip in hot caustic and acid.
3. Intermediate anneal and slit to 7 inches wide for cold rolling.

C. Final Cold Rolling

1. Cold roll from 0.060 inch to 0.007 inch.
2. Intermediate anneal at 0.007 inch and slit to 6.75 inches.
3. Final cold roll to 0.001 inch, clean and slit to width.

The arc-vacuum-cast molybdenum ingot material is in the final development stages, and offers several advantages over the pressed and sintered material. These advantages include the following:

a. Arc-cast moly is more dense (has less porosity) which improves and enhances obtaining 1000-foot continuous lengths of perfect quality.

b. Higher as-rolled strength levels are possible.

c. Decreased porosity should reduce creep tendencies.

The equipment used for rolling molybdenum into a foil product is described below and shown in Figures 2-1 through 2-5. This description is keyed to the associated processes shown in Tables 2-1 and 2-2.

a. Breakdown Rolling - Initial warm breakdown rolling of the starting ingot is performed on the rolling mill illustrated in Figure 2-1. This mill is a 28 x 32-inch, 2-high reversing mill with a 900-hp drive capable of delivering 2000 hp intermittently with a separating force of 3 million pounds at the roll bite. The mill can cold roll at room temperature or hot roll at temperatures up to 1700°C. Hydrogen-atmosphere furnaces are used for all hot rolling.

b. Recrystallization - Recrystallization is accomplished in a hydrogen-atmosphere furnace capable of attaining 1850°C.

c. Intermediate Warm Rolling - Intermediate warm rolling is performed on the rolling mill shown in Figure 2-2. This mill can operate as a 2-high or 4-high reversing mill with available work roll diameters of 6, 12, or 28 inches. The mill is capable of warm rolling at temperatures up to 1200°C or cold rolling, under tension, in warm oil. Its finishing size capability ranges from 0.005-inch sheet to 0.250-inch plate. Sheet thickness control is maintained with continuous contact gauges accurate to 0.0001 inch.

d. Intermediate Cleaning - Intermediate cleaning is performed in molten caustic and mixed acid tanks. Molten caustic is used primarily to remove molybdenum oxide while the acid mix removes surface contaminants, such as iron, picked up in warm rolling.

e. Intermediate Annealing - Annealing is performed in a hydrogen-atmosphere, continuous-mesh-belt furnace. It can achieve a maximum temperature of 1150°C. The furnace portion of the annealer consists of three zones controlled to ±5°C. Zone temperatures are monitored continuously.

f. Cold Rolling - The cold rolling portion of the process is performed on two different mills. The first stage of cold reduction from 0.050 inch/0.060 inch to 0.007 inch is performed on a combination 2-high, 4-high reversing mill (shown in Figure 2-3).

This mill can operate with any of three sets of work rolls and has the capability to finish sheet in the thickness range of 0.001 to 0.025 inch. All rolling is performed under tension in warm oil. Sheet thickness control is maintained with continuous gauges accurate to 0.0001 inch.

g. Final Cold Reduction - Final cold reduction is performed on a 20-high, 12-inch wide Sendzimir cluster mill (shown in Figure 2-4). Finish size range capability of this mill is 0.00025 to 0.005 inch, with rolling being performed under tension in oil. The oil filtration system operates at a 5-micron level. Foil thickness control is maintained with non-contact beta-ray gauges equipped with continuous thickness chart recorders. Gauges are accurate to 0.000001 inch when measuring 0.001 inch and below. The mill is located in a temperature-and-humidity-controlled room equipped with an electrostatic air filtration system.

h. Final Slitting - Final width slitting is performed on a 12-inch wide Reusch foil gang slitter (shown in Figure 2-5). It is capable of producing accurate burr-free cuts in the foil thickness range of 0.00025 to 0.005 inch.

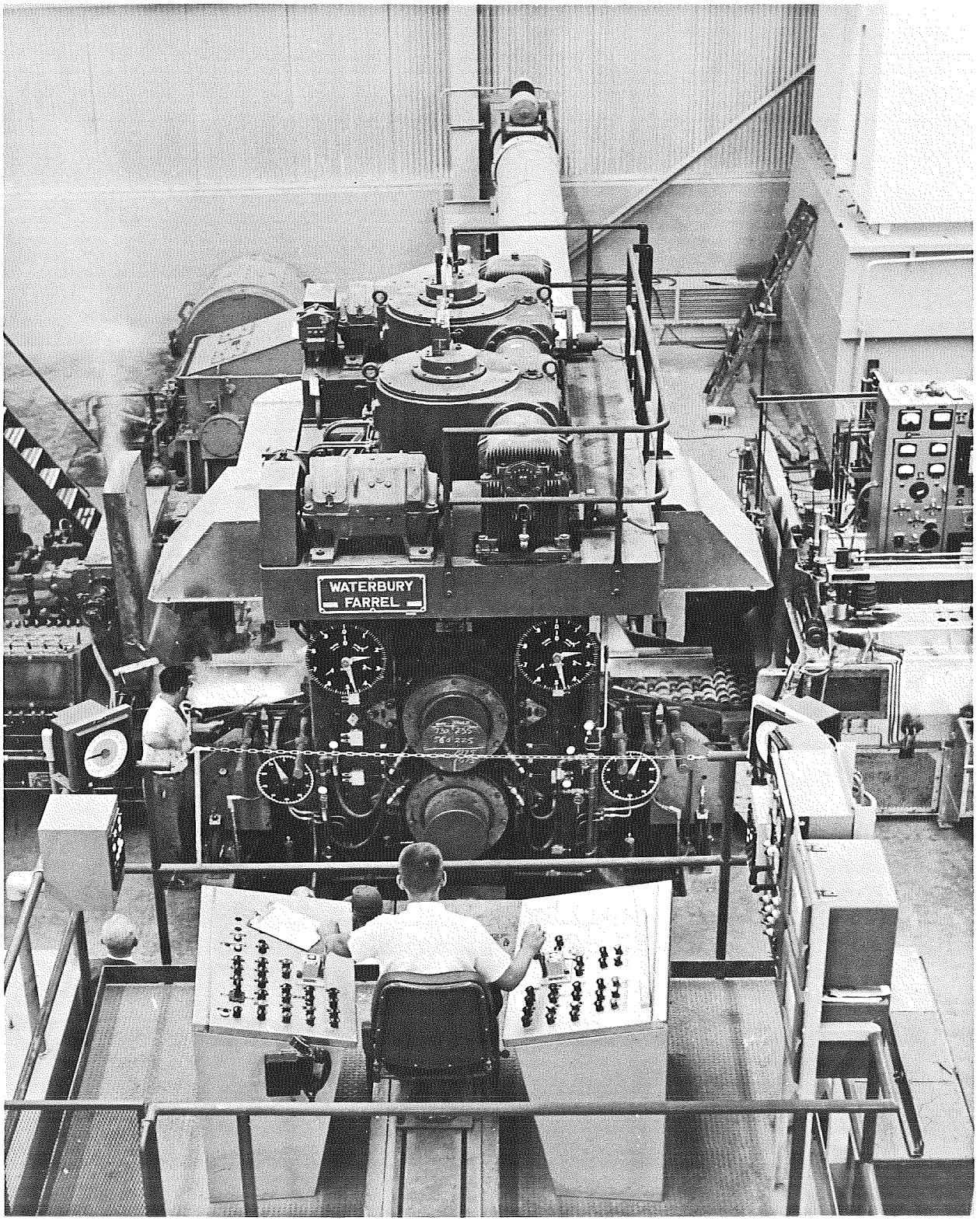


Figure 2-1. Breakdown Mill for Initial Rolling of Ingot

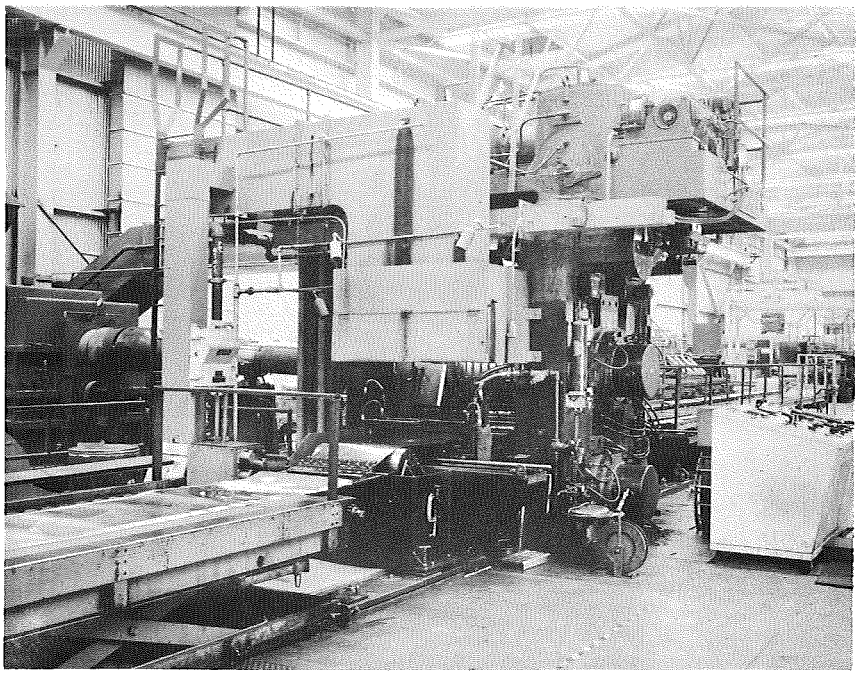


Figure 2-2. Intermediate Rolling Mill

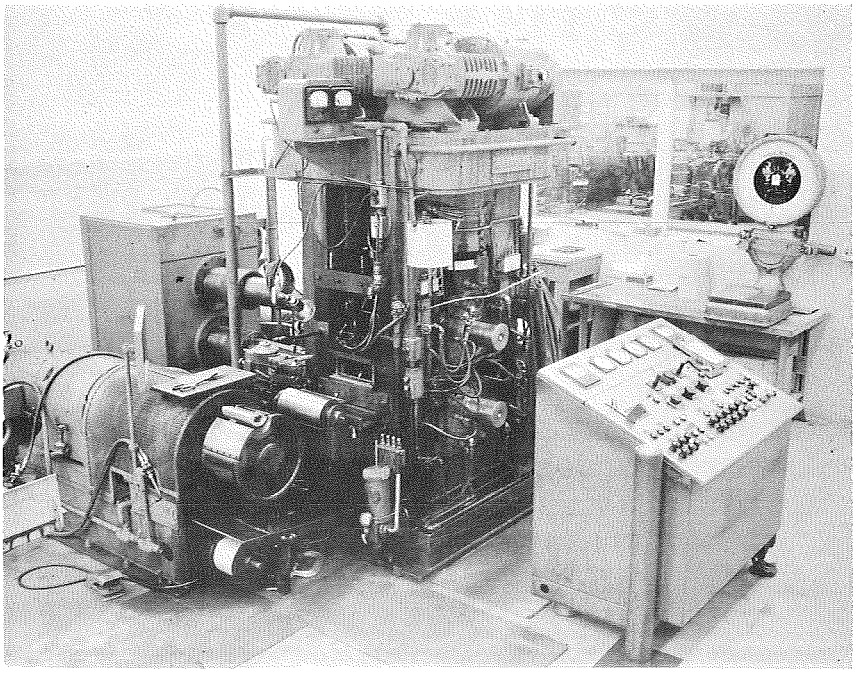


Figure 2-3. Cold Rolling Mill for First Stage of Cold Reduction

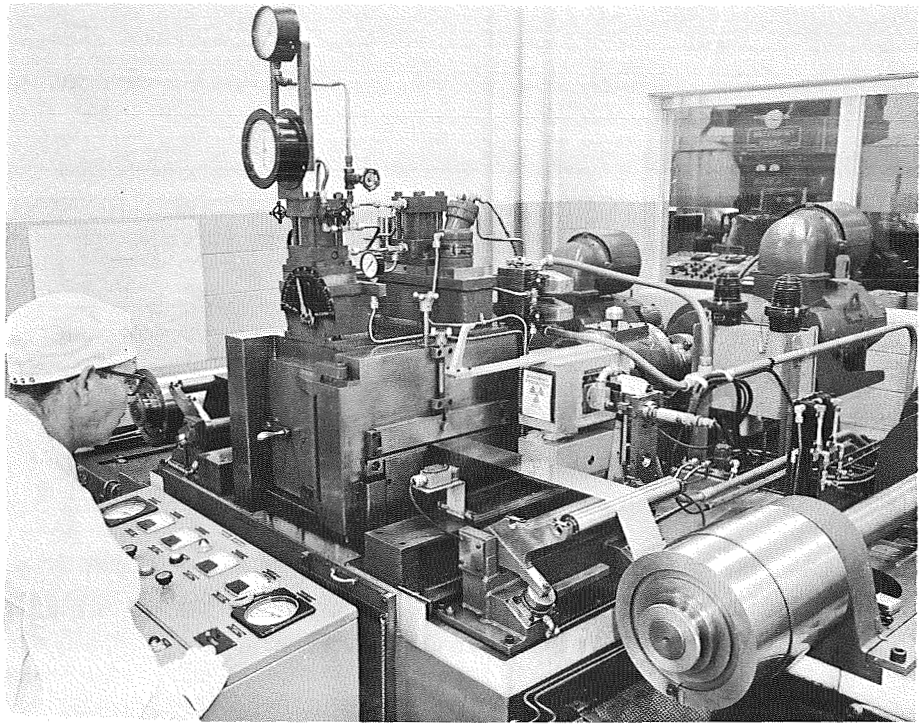


Figure 2-4. Sendzimir Cluster Mill for Final Cold Reduction

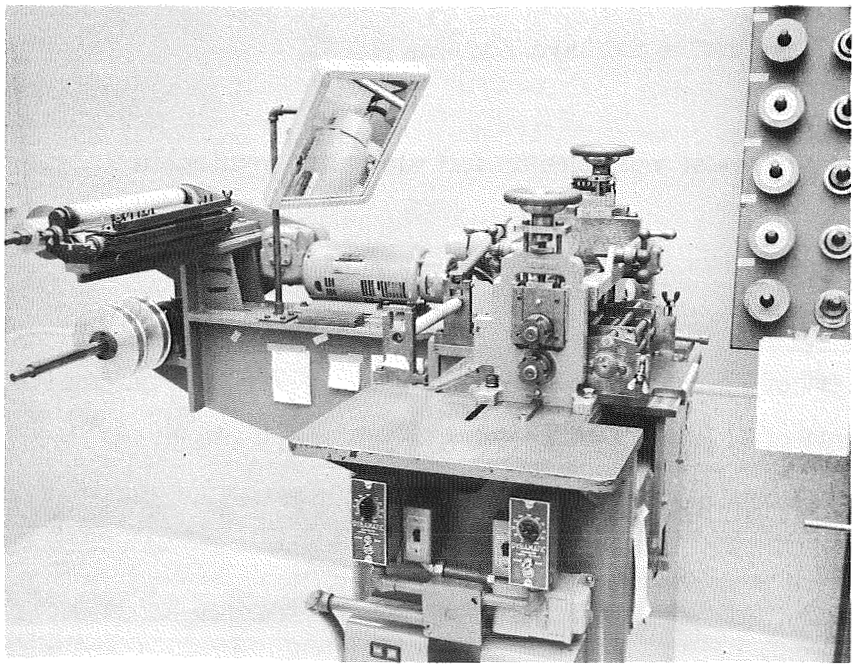


Figure 2-5. Reusch Foil Gang Slitter

2.1.2 AS-ROLLED PROPERTIES

The typical properties of cold-rolled, full-hard 0.001-inch thick molybdenum foil are shown in Table 2-3.

TABLE 2-3. AS-RECEIVED PROPERTIES OF COLD-ROLLED/ FULL-HARD MOLYBDENUM FOIL

Thickness	0.2% Yield Strength	Ultimate Strength	% Elongation in 2 inches
0.001 in.	201,900 psi	215,800 psi	2.5

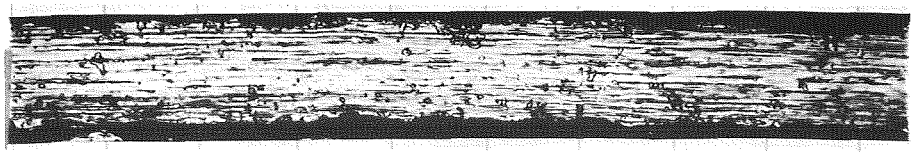
NOTE: Test was conducted at room temperature (70-80°F) at a strain rate of 0.005 inch/inch/minute until 0.6% offset, and 0.05 inch/inch/minute to fracture.

Appendix D shows the typical vendor chemistry for unalloyed power metallurgy foil.

The microstructure of the as-received molybdenum foil is shown in Figure 2-6. The figure shows a heavily worked fiber structure with little or no apparent grains or evidence of any recrystallization. The measured hardness was R_B 99.

Other physical properties of molybdenum foil which are applicable to gravity gradient rod design include:

Modulus of Elasticity, E	46×10^6 psi
Coefficient of Thermal Expansion	2.7×10^{-6} in./in./°F
Coefficient of Thermal Conductivity, K	84.5 Btu/hr/ft/°F



Etched With Murakamis Reagent
(10 gms each N_aOH and $K_3F_e(CN)_6$ dissolved in 100 ml H_2O
500X

Figure 2-6. Photomicrograph of Cold Rolled As-Received Molybdenum Foil

2.2 ROD MANUFACTURING DEVELOPMENT

2.2.1 FEASIBILITY STUDY - CONCEPT

Two possible process flow charts (Figure 2-7) for the forming were considered. In one, the foil would be cold formed into a shape, allowed to spring back to its minimum energy condition, then stress relieved without mechanical constraint. In the second process considered, the metal would be cold formed into shape, constrained to this shape and stress relieved with constraint in place.

Initially, it was believed that the molybdenum foil could be cold worked into the desired rod shape, and that this shape would be retained during the flattening and coiling steps. It was soon realized, however, that such a cold-working process would leave the metal with a residual stress level close to its yield point, and that the additional stress imposed by the flattening would cause the total stress to exceed the yield strength of the metal and, thus, create a permanent deformation resulting in inelastic behavior. Therefore, a stress relief anneal was required in the formed foil to lower the residual stress level to a sufficiently low level such that the superimposition of the residual and flattening stress would not exceed the yield strength. The practical implication in selecting the stress relief cycle was that induced forming stresses and induced rolling stresses would be reduced simultaneously.

The first flow chart, heat treatment without constraint, Figure 2-7 (A), had several disadvantages. The most significant of these was that to cold form a 1/2-inch diameter tube of molybdenum, the foil would have to be bent to a 1/16-inch radius of curvature so that the springback would yield the desired size. For a continuous forming die, this meant about five wraps of the foil. Tendency to crease, plus friction between the wraps, made the prospect of accomplishing this very difficult. A less significant, but still important, disadvantage of this approach was that further dimensional change would occur during the stress relief such that control of the intermediate shape and stress relief cycle would be extremely critical.

Several advantages accrue to heat treating the foil in a constrained tubular shape, Figure 2-7(B). The first of these was that the foil need not be cold formed nearly so severely as in the first case, 0.4-inch diameter vs 0.125-inch diameter. A second benefit was that the constraint during stress relief was in the form of a metal tube, and this tube aided in obtaining straight rod. The third advantage of this flow plan was that diameter control of the finished tube was easier with the constraint during heat treatment.

For the reasons just explained, the second flow plan, Figure 2-7(B), involving the use of constraining during stress relief was the approach adopted for continuous tube forming.

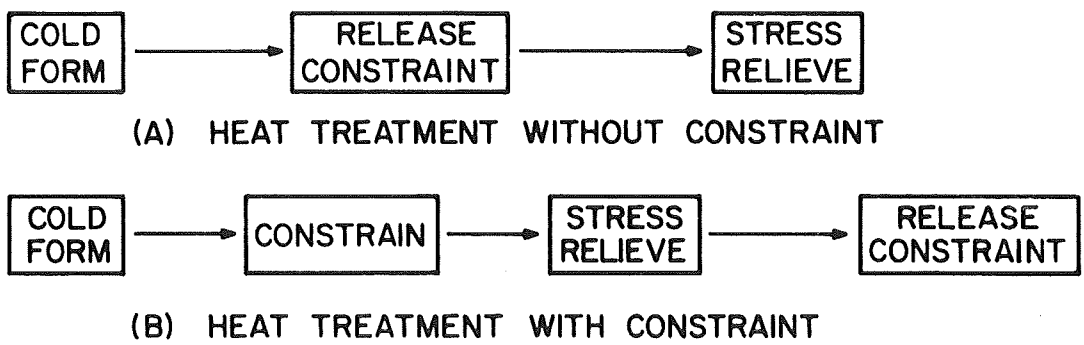


Figure 2-7. Rod Forming Process Flow Charts

2.2.1.1 Stress Relief

As mentioned above, it was determined that a stress relief anneal was required in the formed molybdenum foil to lower the residual stress level to a sufficiently low value such that the superimposition of the residual and flattening stresses would not exceed the yield strength.

The first objective of the stress relief anneal was to reduce the residual stress level in the formed tube to the lowest practical level while maintaining the yield and ultimate strength of the metal as high as possible. The second objective of the stress relief was to set the tubular shape into the foil. The inside diameter of the constraining tube during stress relief should be as large as possible to minimize difficulty in the forming die and to give the best possible control of diameter and roundness. As a practical consideration, the shortest possible stress relief time would facilitate the production of the rod.

To determine the stress relief time, temperature, and the shape (diameter) to be maintained during the stress relief (which in turn described the shape into which the forming die had to work the foil), a test matrix on batch samples involving stress relief temperatures between 400 and 700 $^{\circ}$C and constraining tube diameters during stress relief of 5/16 (0.312) inch, 3/8 (0.375) inch, and 1/2 (0.500) inch were evaluated by the Spacecraft Department. This work is reported completely in Appendix C. It was concluded that a 0.4-inch diameter rod stress relieved near 1200 $^{\circ}$F for 20 minutes would yield the desired 0.5-inch diameter finished tube. The choice of this forming diameter allowed sufficient latitude in stress relief time and temperature within a permissible range to enable the achievement of the desired shape.

Augmenting this preliminary survey of optimum stress relief times and temperatures, GE Lamp Metals and Components Department also ran tests on flat foil. The results are given in Appendix B.

2.3 CONTINUOUS FORMING EQUIPMENT DESCRIPTION

Upon completion of batch sample investigations, a pilot model of the forming equipment was developed and fabricated as shown in Figure 2-8. The forming set-up as shown is comprised of three zones. In the first zone (right hand portion of figure, the flat molybdenum foil is unwound from a feed spool and formed through suitable dies into a circular shape. In the second zone (furnace area) the tubular shaped foil is stress relieved. In the third zone (left hand portion of figure) the formed tube is reflattened and wound on a take-up spool. The

first and third zones are covered by a sealed plastic enclosure so that an inert argon atmosphere may be introduced around the molybdenum foil during forming. This inert gas protects the surfaces of the rod from oxidation during the stress relief cycle.

Details of the first zone are shown in Figures 2-9 through 2-17 (with sealed plastic cover removed). Figures 2-10 and 2-11 show details of the feed spool and the dies at Stations 1 and 2 which essentially transforms the shape of the flat foil into a U shape where it enters Station 3. Details of Stations 3 and 4 are shown in Figures 2-12 and 2-13. These dies close the U shaped foil into an overlapped oval shape. Also at a point between Stations 3 and 4, argon gas is introduced into the inner volume of the closing tubular foil and flows through the tube continuously during forming and the stress relief cycle. The dies at Stations 5 through 10 (Figures 2-13 through 2-17) gradually reduce the diameter and concomitantly increase the degree of overlap to that desired for the forming and heat annealing of the moly rod. The flat metal dies at Stations 4, 5, and 6 are floating with the tube alignment being controlled by the plexiglas ways between the stations. The circular dies at Stations 7 and 8 are also floating.

Figure 2-16 shows the entrance to the two-foot long electrically resistance heated furnace. A ceramic muffle lines the hot zone of the furnace. Centered within this ceramic muffler and extending about 8 inches from each end is a stainless steel constraining tube. The anchored entrance end of this constraining tube excludes air from the exterior surface of the foil during the stress relief cycle. The 1/4-inch diameter tube shown in Figure 2-18 is used for argon gas exhaust from the furnace area and Figure 2-22 shows the final exhaust tube and bubbler used for monitoring the flow of argon.

Figure 2-19 shows the reflattening and take-up zone of the forming machine. The stress-relieved foil with the desired shape set is flattened over a shaped tongue before passing over a tensioned idler drum used for monitoring foil speed, then the foil is wound on a motor-driven take-up reel. The idler drum is mounted in a rolling frame (shown in detail in Figure 2-20). The frame position is established by the tension exerted on it by the tensio-

TABLE 2-4. CONTINUOUS TIME/TEMPERATURE MOLY ROD DIAMETER DATA

RUN NO. 1

CONDITIONS	RESULTS					
	Heat Treat			Rod Dia (in.)		
0.430-in. I.D. Constraining Tube Die Sizes: #9 - 0.375 in. #10 - 0.375 in. #11 - o.420 in. #12 - 0.430 in.	Temp (°F)	Time (min.) per 2 ft	Line Rate ft/m	Max.	Min.	Avg.
	1000	15 14.4	8.3	0.585	0.554	0.572
	1000	10	12	0.579	0.569	0.572
	1050	15	8.3	0.562	0.545	0.553
	1050	10	12	0.561	0.544	0.555
	1100	15	8.3	0.522	0.516	0.519
	1100	10	12	0.541	0.533	0.536
	1150	15	8.3	0.502	0.497	0.499
	1150	10	12	0.508	0.504	0.505
	1150	fast 6.8	17.6	0.520	0.513	0.517
	1200	15	8.3	0.500	0.477	0.489
	1200	10	12	0.490	0.487	0.488
	1200	fast 6.8	17.6	0.497	0.492	0.494
	1250	fast 6.8	17.6	0.490	0.487	0.489
RUN NO. 2						
0.400-in. I.D. Constraining Tube Die Sizes: #9 - 0.375 in. #10 - 0.375 in. #11 - 0.380 in. #12 - o.400 in.	1000	10	12	0.539	0.529	0.535
	1000	6.8	17.6	0.547	0.540	0.544
	1050	10	12	0.516	0.504	0.512
	1100	10	12	0.502	0.494	0.498
	1100	6.8	17.6	0.509	0.499	0.505
	1150	10	12	0.497	0.465	0.481
	1150	6.8	17.6	0.506	0.472	0.487
RUN NO. 3						
0.375-in. I.D. Constraining Tube Die Sizes: #9 - 0.385 in. #10 - 0.375 in. #11 - 0.365 in. #12 - 0.375 in.	1000	10	12	0.548	0.518	0.529
	1000	6.8	17.6	0.538	0.528	0.532
	1050	10	12	0.505	0.490	0.488
	1050	6.8	17.6	0.520	0.503	0.512
	1100	10	12	0.486	0.476	0.480
	1100	6.8	17.6	0.488	0.485	0.486
	1150	10	12	0.465	0.456	0.460
	1150	6.8	17.6	0.469	0.454	0.461
	1200	6.8	17.6	0.470	0.451	0.459

Note: All runs were made using 0.0001 x 2 in. moly strip with the time/temperature condition constant over 4-foot lengths (approximately).

meter and the gage on the tensiometer provides a direct and constant control of tension on the foil. A counter and foil centering device (small light bulbs) are also mounted on the idler drum plate.

Figures 2-21 and 2-22 show details of the take-up spool and drive mechanism. Figure 2-23 is an overall view of the formed tube handling table on which several samples of formed moly rod are displayed. This table is adjacent to the forming machine.

2.3.1 TEMPERATURE/TIME/DIAMETER OPTIMIZATION

The final formed rod diameter is a direct function of the diameter of the constraining tube and the line rate, and an inverse function of the stress relief annealing temperature. A series of rod forming experiments were undertaken using GE's moly rod forming setup to determine the specific relationships using three sizes of constraining tube; 0.375-in. I.D., 0.400-in I.D. and 0.430-in. I. D. Line rates varied as follows: 8.3 ft/hr, 12 ft/hr and, 17.6 ft/hr corresponding, respectively, to approximate exposure times of 15 minutes, 10 minutes, and 6.8 minutes per incremental section. Temperatures were varied from furnace settings as low as 1000°F to as high as 1250°F. The average exposure temperature in the continuous furnace corresponded to the furnace setting; however, the peak temperature in the exact center of the furnace was 90 $\pm$ 10°F higher than the furnace setting. Table 2-4 shows the resulting rod diameter variations for the changing variables. The results showed that a 0.500 $\pm$ 0.020-inch diameter rod can be made in all three of the constraining tubes by increasing or decreasing the temperature. The line speeds chosen did not have a strong influence on the final diameter rod size. Tensile tests made on samples cut from the experimental rods showed that 0.2% yield strength values in excess of 170,000 psi can be obtained for a final 0.500-in. diameter by using a 1050°F stress relief anneal in a 0.375-inch I. D. constraining tube at a line rate of 12 feet/hour.

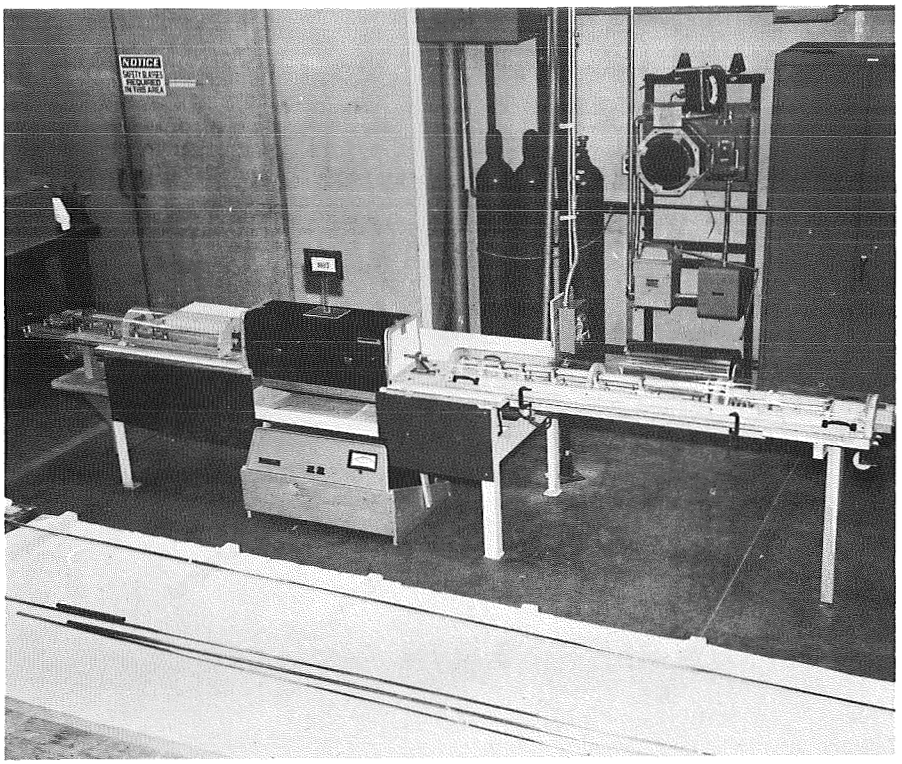


Figure 2-8. Overall View of Forming Machine

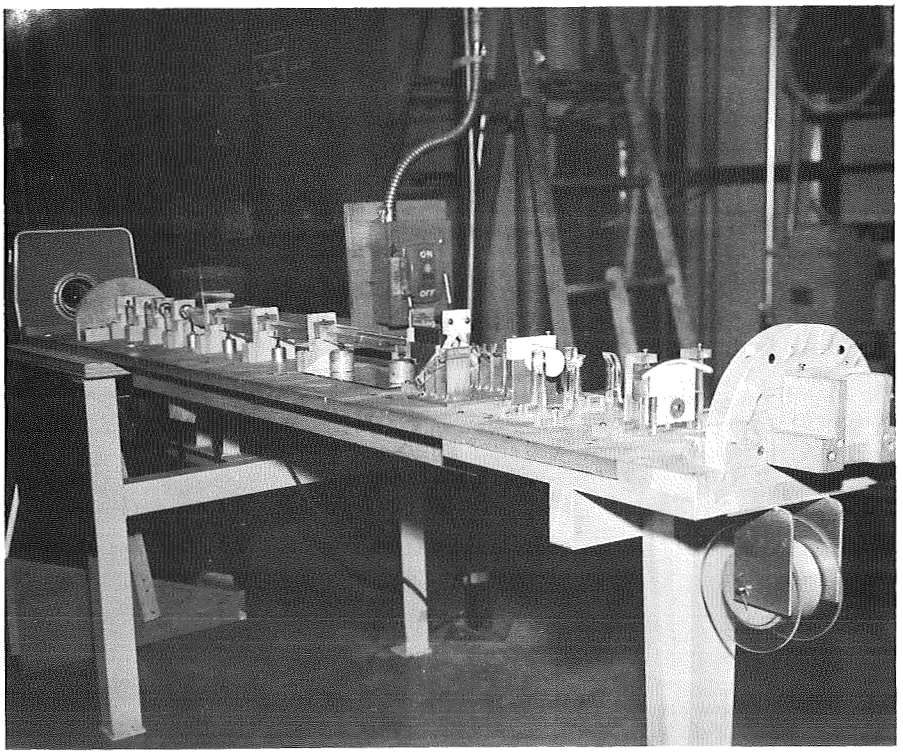


Figure 2-9. Close-Up Of Feed Zone

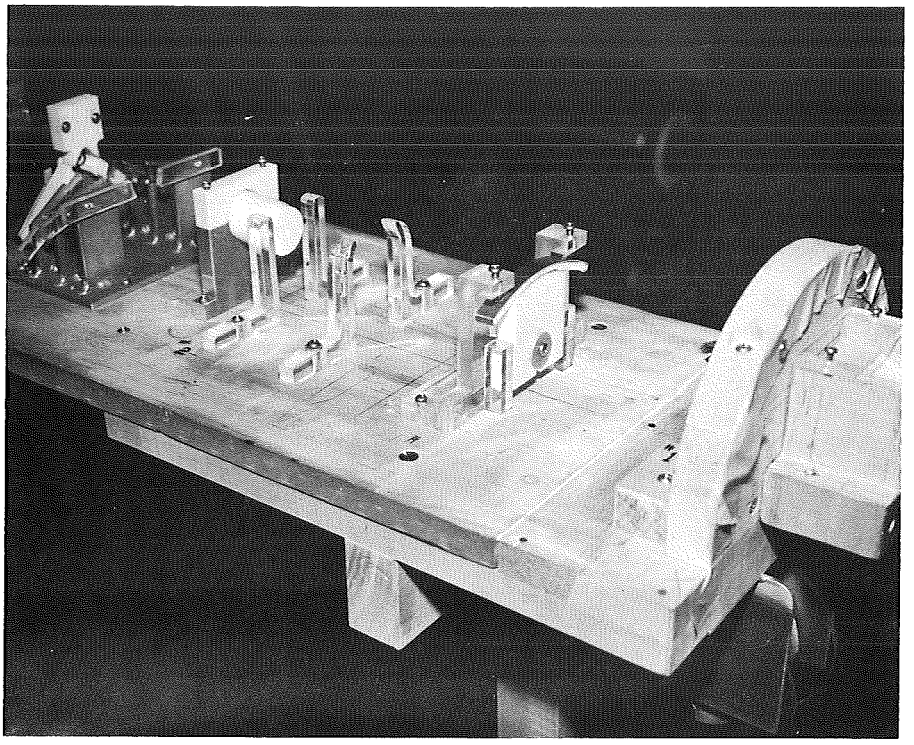


Figure 2-10. Close-Up of Stations 1 and 2

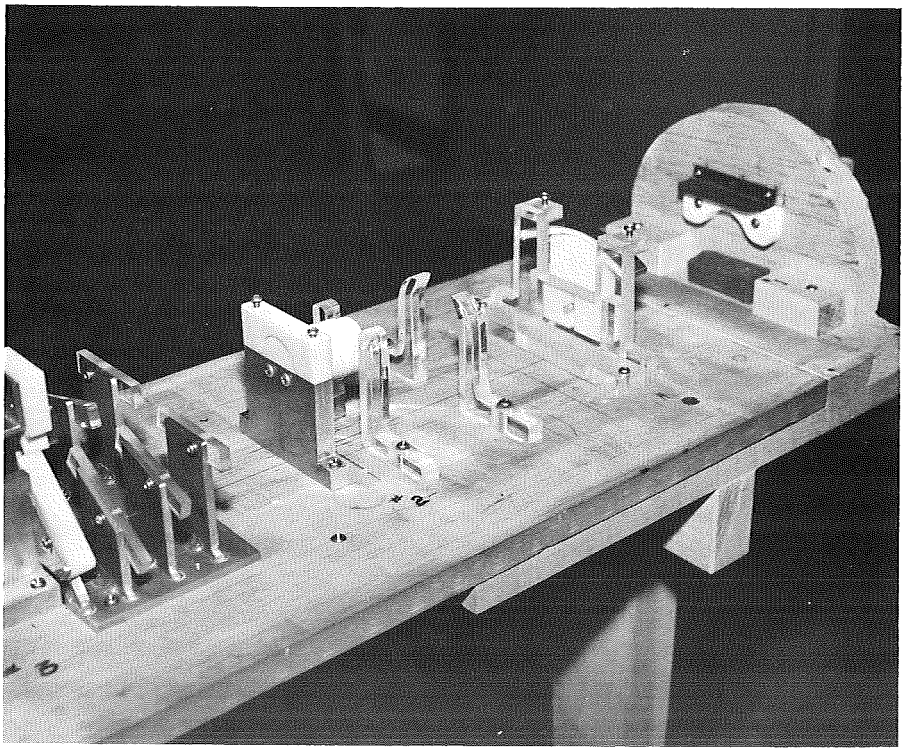


Figure 2-11. Opposite View of Stations 1 and 2

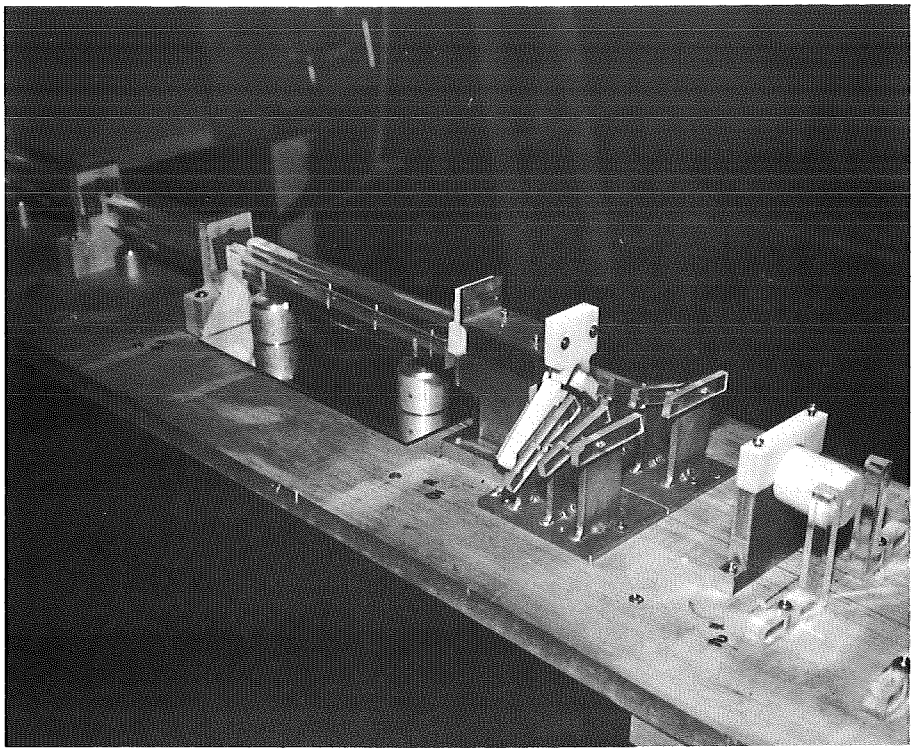


Figure 2-12. Close-Up of Stations 2, 3 and 4

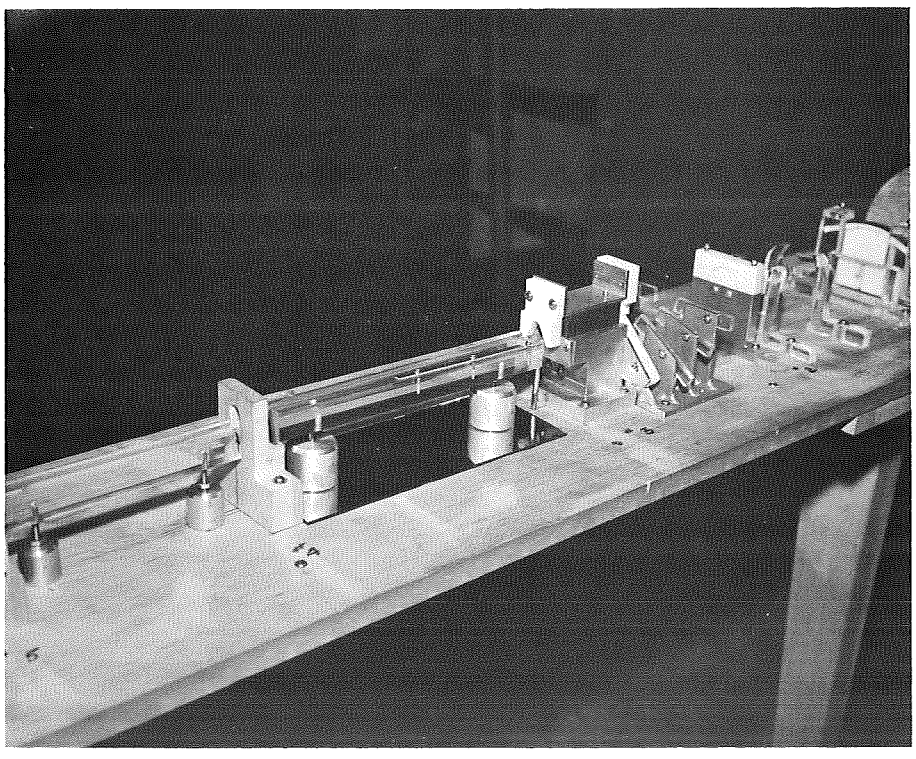


Figure 2-13. Opposite View of Stations 2, 3 and 4

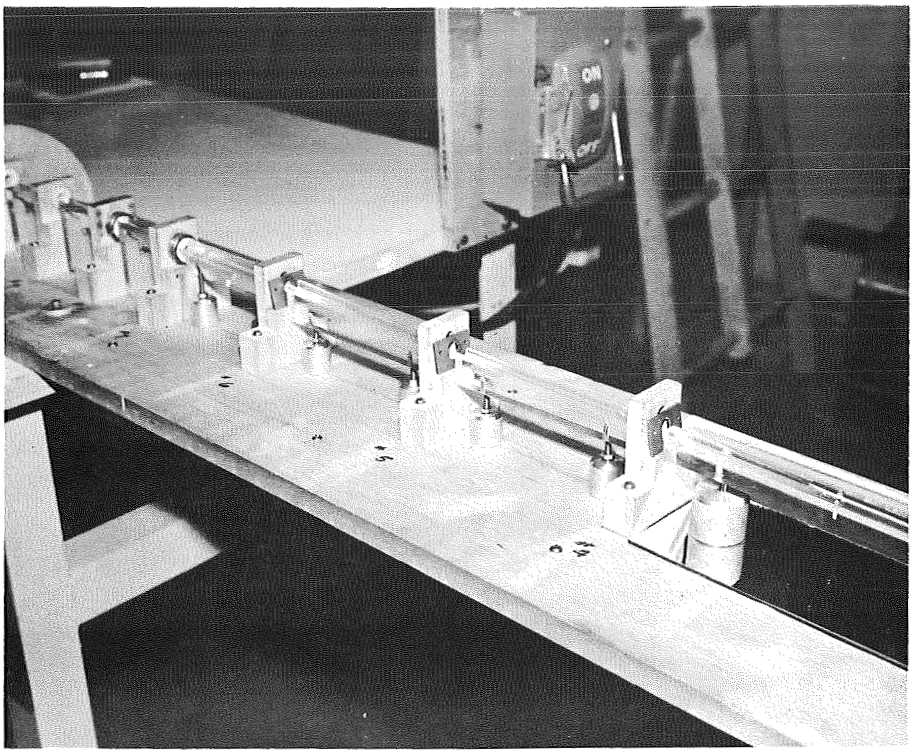


Figure 2-14. Close-Up of Stations 4 Through 9

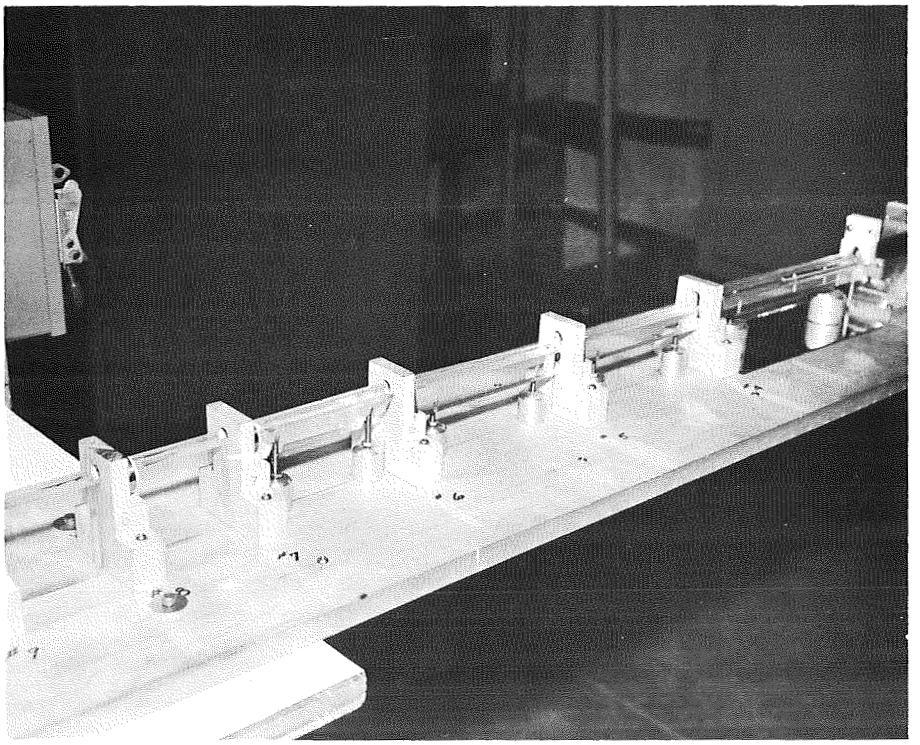


Figure 2-15. Opposite View of Stations 4 Through 9

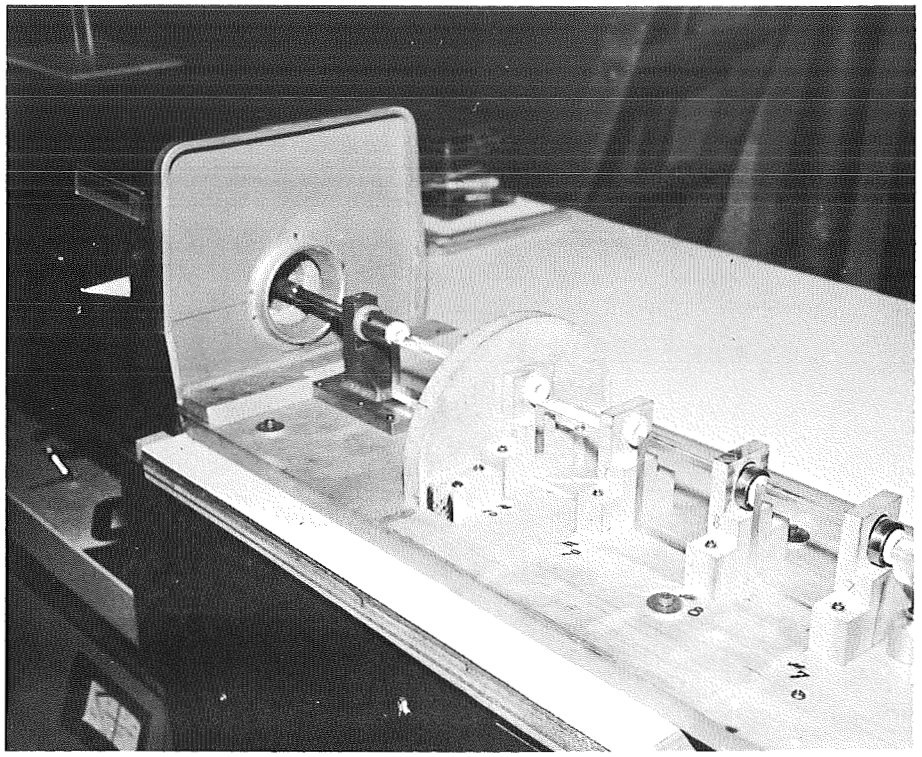


Figure 2-16. Close-Up of Entrance to Furnace

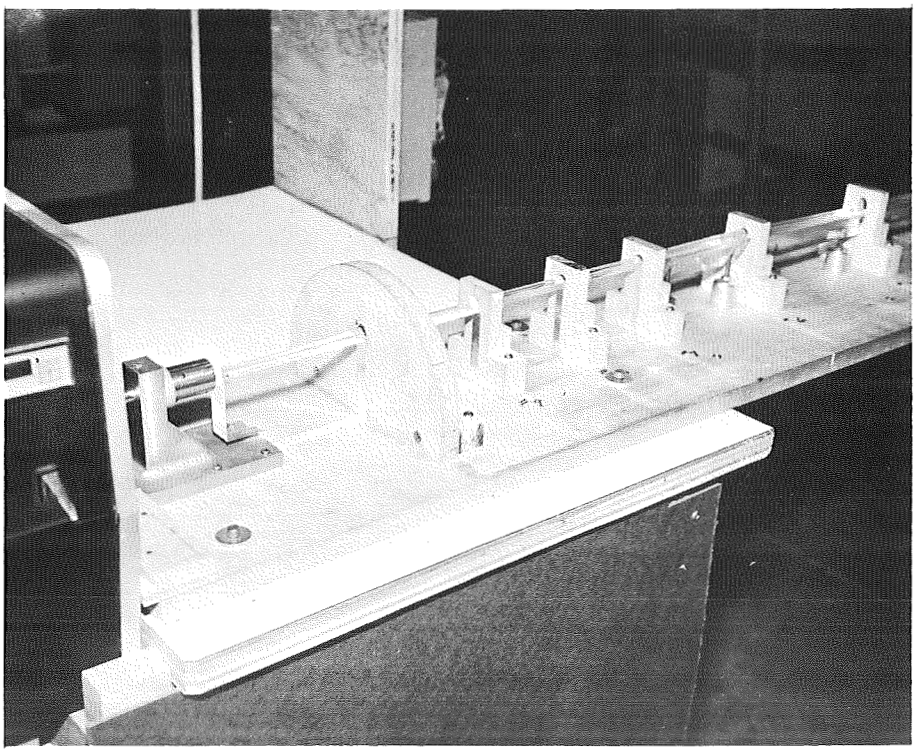


Figure 2-17. Opposite View of Entrance to Furnace

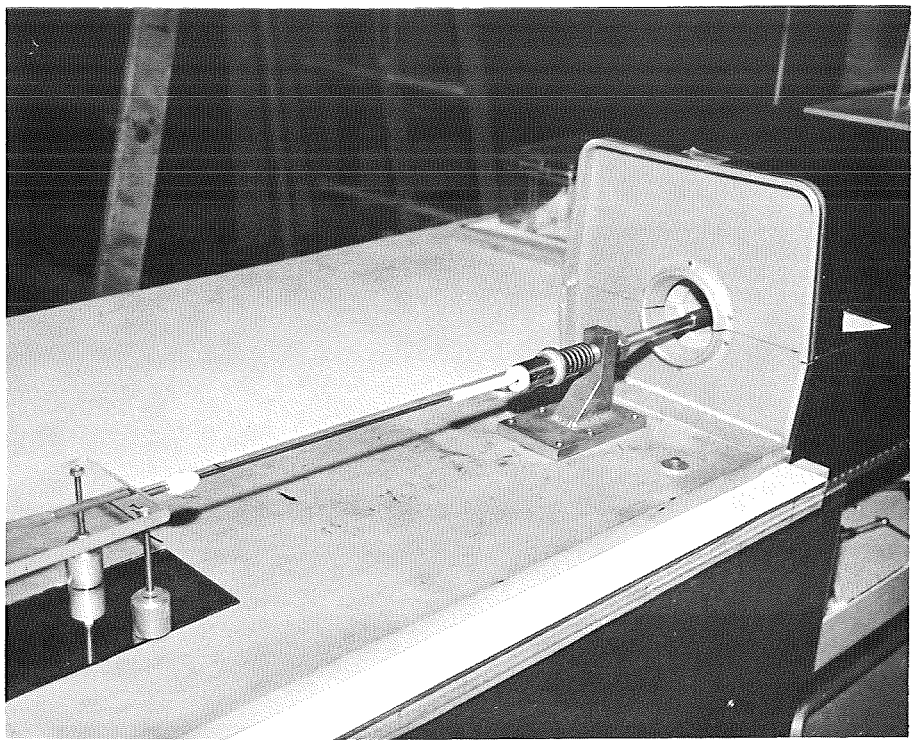


Figure 2-18. Close-Up of Furnace Exit

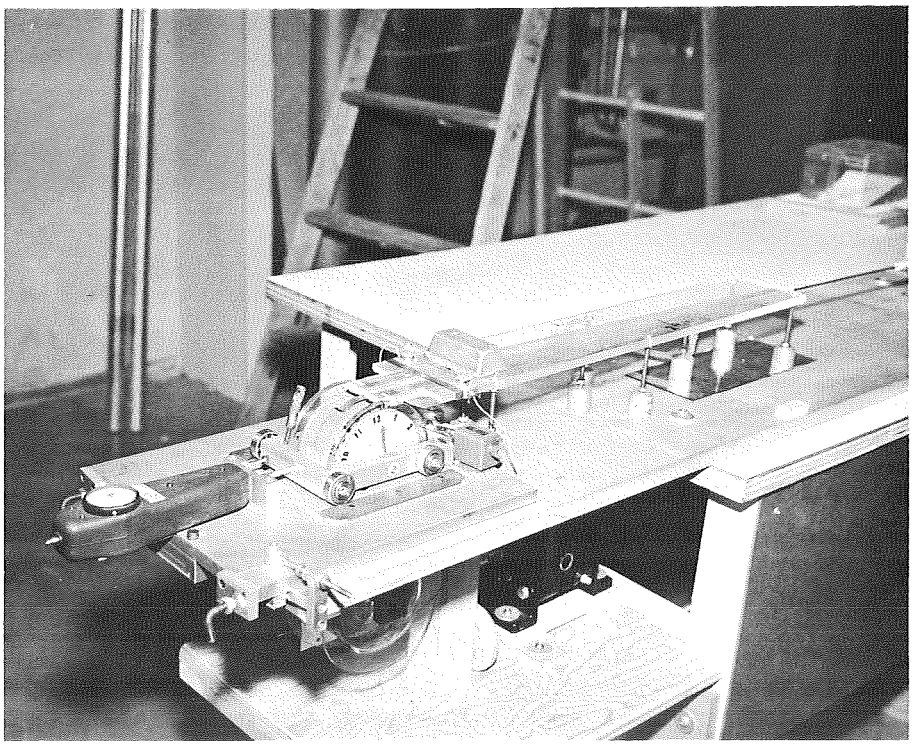


Figure 2-19. Overall View of Take-Up Zone

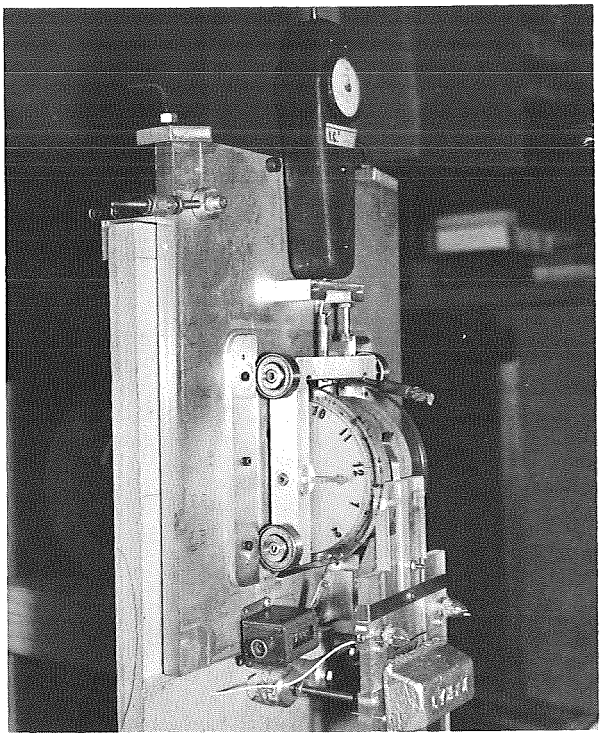


Figure 2-20. Close-Up of Idler Drum and Tensiometer

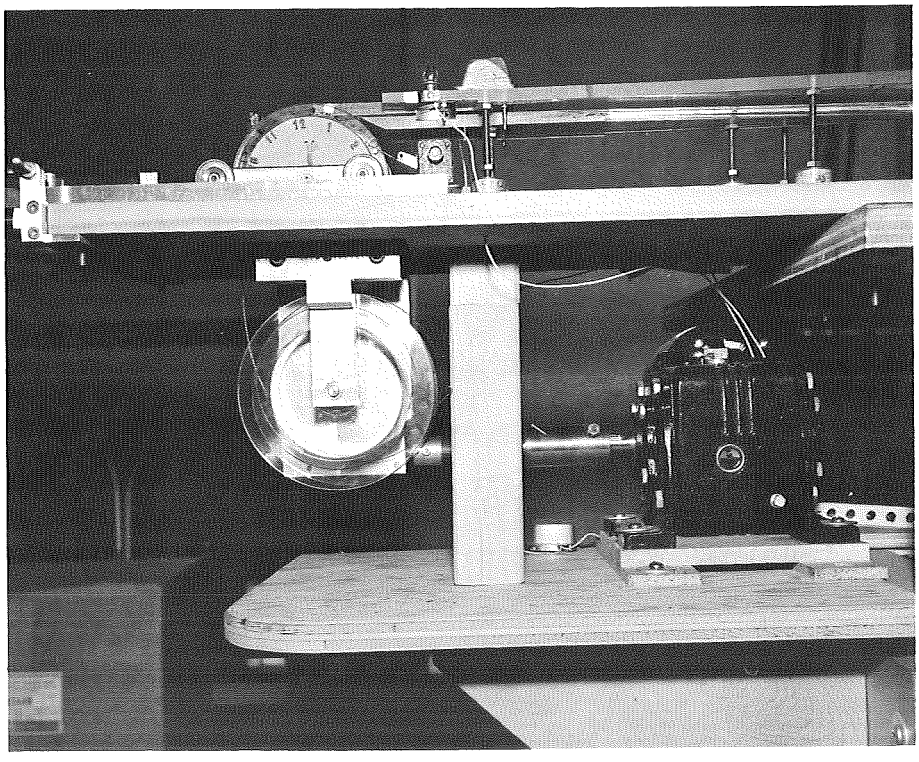


Figure 2-21. Drive Mechanism

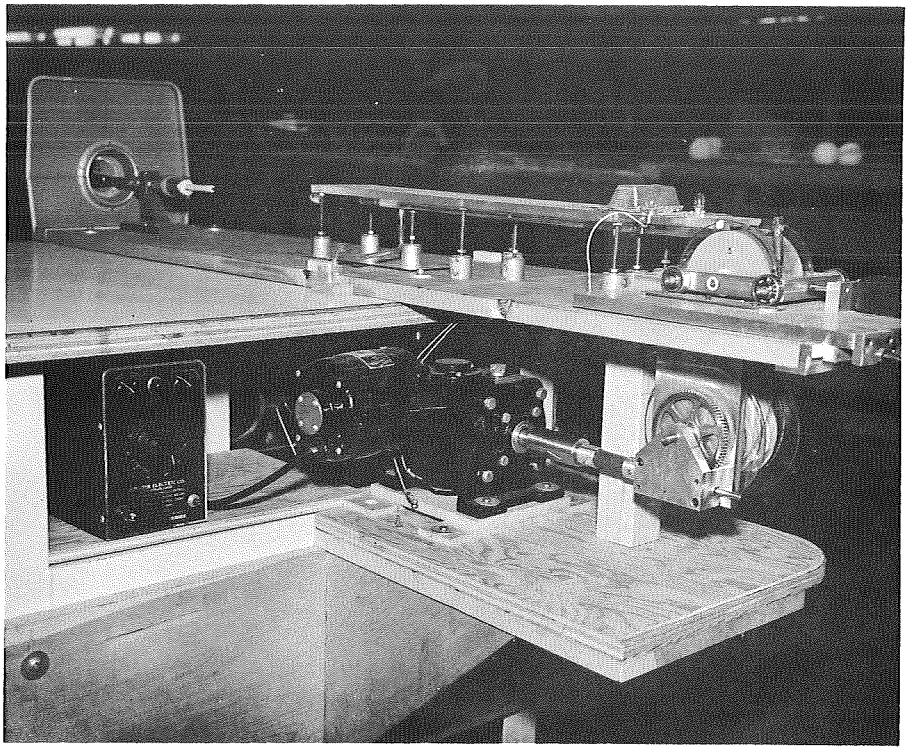


Figure 2-22. Opposite View of Drive Mechanism

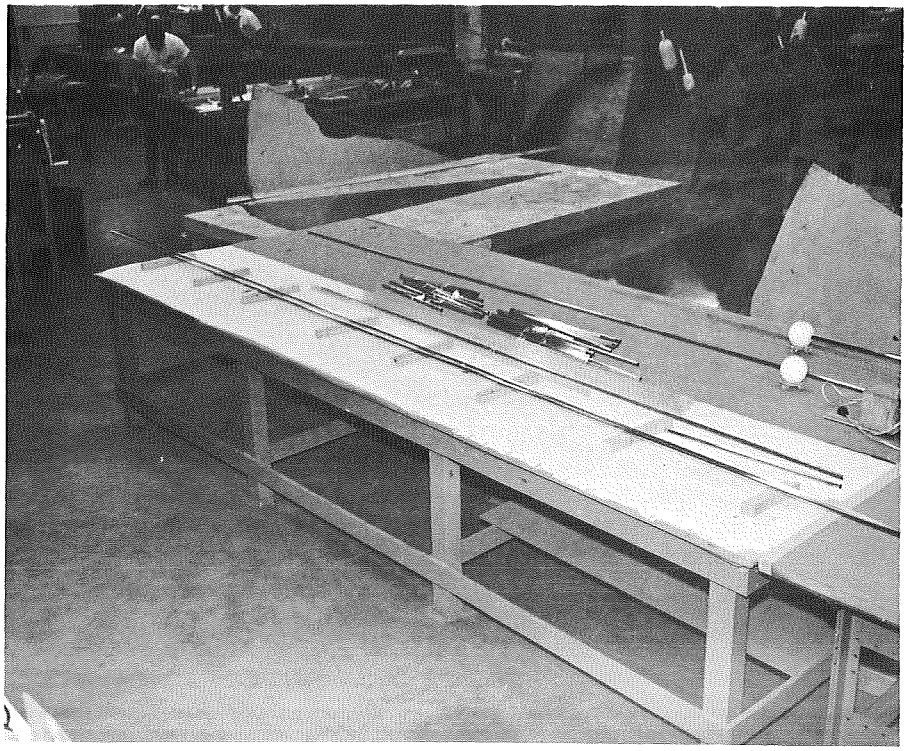


Figure 2-23. View of Display Table With Moly Rods

2.3.2 ELECTROPLATING AND VAPOR DEPOSITION

The solar absorptivity value for unplated molybdenum foil is 0.37. The absorptance can be reduced by plating or coating the molybdenum with materials such as silver or aluminum. With less absorptance, thermal bending can be further minimized. Table 2-5 shows the observed absorptivity values for silver and aluminum coatings.

TABLE 2-5. COATED MOLYBDENUM SOLAR ABSORPTANCES

Base Metal	Coating	α_s
Mo	100 microinches electroplated silver	0.097
Mo	1000A vapor-deposited silver	0.096
Mo	Commercial Silver, vapor-deposited (Schjeldahl Company)	0.074
Mo	1000A vapor-deposited aluminum	0.093

The coated samples exhibited poor surface adherence prior to forming. After forming, adherence was sufficiently improved to prohibit removal by scotch tape. The 1000A vapor coatings were too thin to prevent partial removal of the coating while passing through the forming dies. The samples supplied for thermal bending testing were electroplated by a batch process which included:

a. Scouring with low chlorine cleanser.
b. Surface activation with a KCN solution.
c. Nickel flash.
d. Silver strike.
e. Silverplate to 0.0001 inch with rinse steps between each sequence.

The coating adhered well after forming, and silver polishing with a whiting compound produced a high surface luster without any peeling of the plating. Scale-up efforts to produce a 50-foot continuous silver-coated foil were unsuccessful. Further research is necessary to obtain coating adherence over long lengths of foil.

2.4 DEPLOYMENT MECHANISM

As a part of the contract, a demonstration deployment mechanism was designed and fabricated (see Figures 2-24 and 2-25) to evaluate and demonstrate the behavior of the molybdenum rod during extension and retraction operations. This deployer is representative of the type of unit which could be developed into flight hardware and is capable of handling 200 feet of 0.002-inch thick tape as designed. The empty weight (without tape) of the demonstration unit is 3.5 pounds, and overall envelope dimensions are 4 x 4-1/2 x 9-1/2 inches including all protrusions, etc. The size and weight of the deployer can be reduced by further development of the design, and even further reduced if designed for a shorter or thinner tape.

The design can be broken down into five functions: storage, caging, drive, guidance and structure. The storage consists of a drum circumferentially wrapped except for an exit area by a continuous belt. The belt, as it comes off the drum, travels over a drive roller at one end and a takeup roller at the other. It returns over two idler rollers and one adjustable larger diameter combination idler and caging roller. The boom tape entering the storage after it is flattened by the guidance, is contained between the drum and the belt. As more wraps go on, the outside diameter of the coil increases, and the takeup roller adjusts accordingly to accommodate the coil and the belt. The takeup roller is supported on radius rods designed to locate the coil so that the point and angle of tangency of tape contact stay approximately fixed. This feature mitigates damage to the tape. The radius rods are loaded by adjustable torsion bar springs to maintain a tension on the belt. This type of spring fits the design with a minimum of complexity and space. The belt is guided at each roller by side plates.

To prevent damage from acceleration and vibration loads during launch and flight, caging of the tape and drum mass is accomplished by restraining the roll of tape between the drive roller, the adjustable idler and the takeup roller. The takeup roller is held against the roll of tape by adjustable stops against the radius rods. The adjustable idler is positioned to bear on the tape. The tape and drum are limited in axial motion by side rollers which are shimmed to give a small clearance.

The drive is effected through the drive roller which has over 180 degrees wrap by the belt. The tape is driven in either direction by the friction against the belt which also has over 180 degrees wrap. The drive roller is rotated by a PIC non-slip timing belt. The no-slip belt is driven by a gearhead motor through 2:1 reduction bevel gears. The battery operated motor used on the demonstration unit is not a space-qualified motor, but was readily available and, therefore, used. It is believed that a fully-qualified motor would occupy about the same volume and would weigh about the same. The idler on the drive belt allows the use of the minimum off-the-shelf length of no-slip belt and was included on the demonstration model to simulate a potentiometer which might be required on some units to indicate length of boom extended.

The guidance flattens the incoming boom and guides it into the storage unit. It guides the outgoing boom to give maximum pointing accuracy with short guidance length. The body of the guidance is a male and a female epoxy part spaced about 0.008 inch and developed from a cast of the ploy section of an actual boom. The boom tape runs in the 0.008-inch space. The close clearance inhibits crinkling (by not allowing space for a crinkle to form) and supports the boom against external bending. The tape is guided at each end by hardened plates shimmed to give close clearance on the edge of the tape. The guidance is supported in the deployer by bolts in oversized holes and by shims, such that alignment can be adjusted. The guidance is adjusted so that the tape runs true on the storage drum. The only other hard point the tape can touch is the side caging rollers. This minimum number of guide points will lessen the possibility of damage to the tape due to misalignment. The guidance is set as close as possible to the drive roller to cut down on the column length of unformed tape during the extension cycle.

The aluminum alloy structure consists of the two 1/8-inch thick side plates, two mounting lug plates, sheet metal bottom and end plates, motor mount and end plates. The two sheet metal plates are doweled and screwed in place and together with the motor mount and end plate maintain close alignment. The mounting plates and the guidance add to the rigidity of the complete structure. All parts are screwed together. The belt as installed on the demonstration unit is not required for flight models. Nylatron bushings are used at all working bearing points.

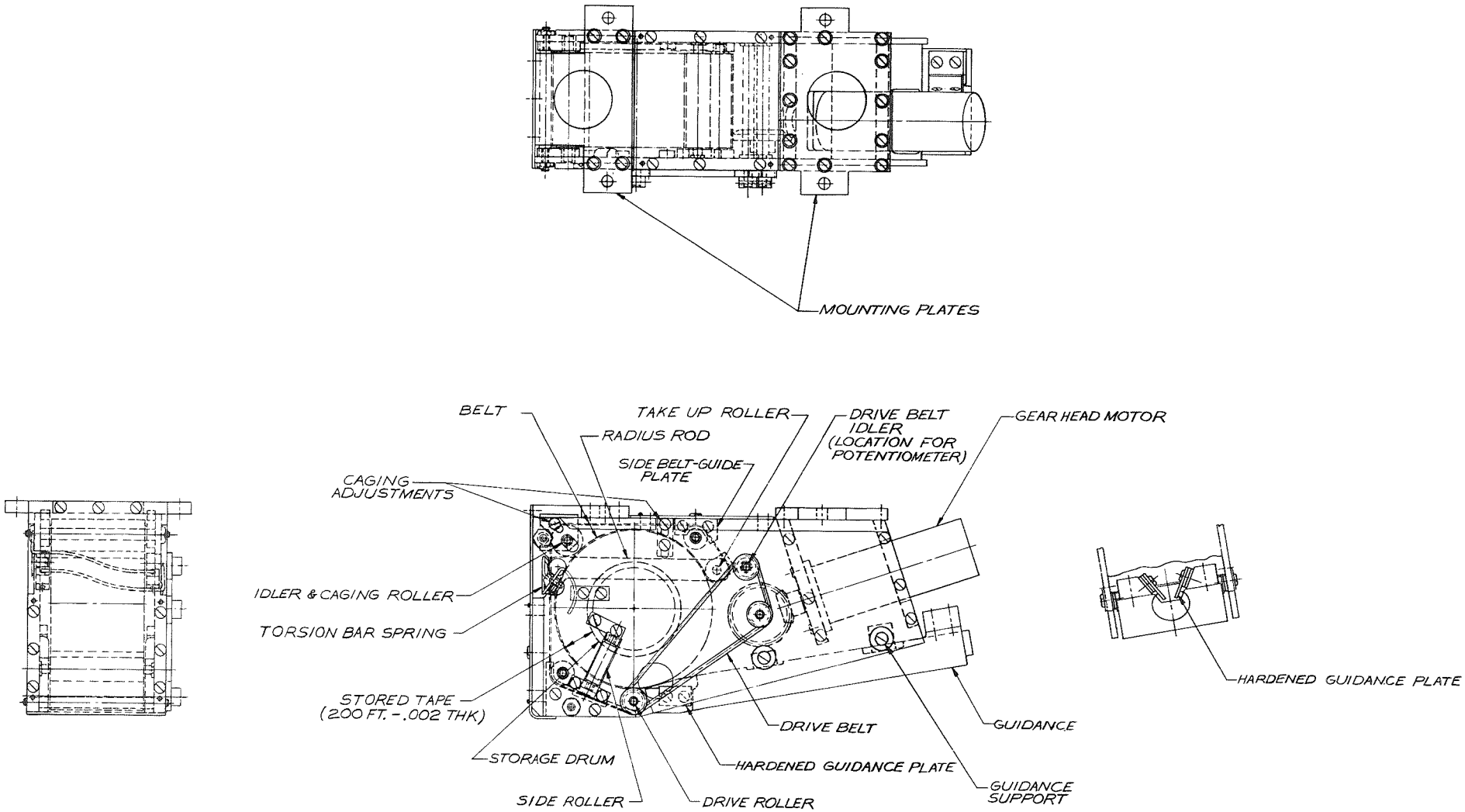


Figure 2-24. Layout-Demonstration Erection Unit

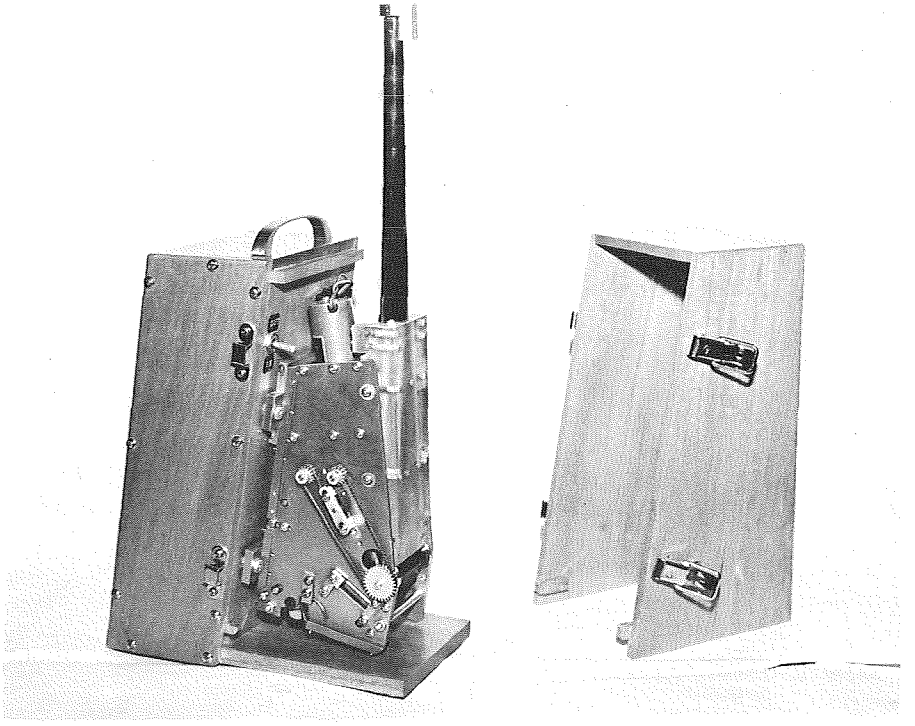


Figure 2-25. Demonstration Erection Unit

2.5 FORMED ROD CHARACTERISTICS

2.5.1 GEOMETRIC DESCRIPTION

Three geometric features influence the formed rod characterisitcs; (1) degree of roundness, (2) degree of twist, and (3) degree of lap tightness.

Roundness is measured by comparing two mutually perpendicular diameters of a formed rod. The difference in the two measurements represent the deviation from a true round condition. Measurements on early continuous formed rods varied from 0.018 to 0.025-inch difference in roundness. The degree of deviation is being reduced as more experience is gained in processing the tubing.

Twist is measured by observing the angular position of overlap seam relative to its starting position over a measured length of rod. Twist as great as 180 degrees over a length of ten feet has been observed in formed molybdenum rod. Further investigation is necessary to improve on the twist variation.

Lap tightness is measured by inserting shim material between the tube wall and the lap. The thickness of shim material then is a measure of lap tightness. Representative measurements vary from 0.004 to 0.008-inch. Processing experience should result in further lap tightness improvement.

Present continuous processing is capable of producing molybdenum rod reasonably free from crinkles or edge wrinkles.

2.5.2 FORMED ROD PROPERTIES

Early tensile data on samples cut from the formed rod showed 0.2% yield strength values of 150,000 psi with ultimate tensile strength of 165,000 psi at 1% elongation. Time temperature optimizations on the continuous forming line plus improved testing alignment has resulted in improved reported test values of yield strengths greater than 170,000 psi, ultimate strengths greater than 190,000 psi with elongation values at approximately 1% in a two-inch gage length.

The post forming microstructure showed little change from the as-received microstructure. The material still appeared highly worked with no evidence of recrystallization. The post forming hardness varied slightly dropping to between R_B 97 and R_B 98.

The rods formed during this program were very satisfactory even in this early experimental stage of development. Edge crinkle was practically non-existent, and the finished rod was generally quite smooth. The 0.001-inch thick moly foil was surprisingly sturdy after forming, but still required careful handling to prevent damage, particularly in the area of the overlapped free edge. When wound onto a spool through a guidance mechanism, the formed foil

was not damaged; however, winding by hand is not recommended. Also, interested bystanders have a tendency to want to open and flatten the rod by hand and several excellent samples were damaged due to such instances. To protect the formed samples, plexiglas storage tubes were ultimately introduced as a safeguard.

SECTION 3

PERFORMANCE TESTS

3.1 THERMAL DEFLECTION TESTS

The thermal test facility at NASA Goddard will be used to ascertain thermal deflections of a molybdenum silverplated rod in the near future. When test data and results are available, an addendum to this Final Report will be issued.

3.2 STORAGE AND CYCLING TESTS

Repeated deployment cycles have revealed an increase in rod diameter which is believed due to low temperature creep or pre-yield microstrain. Figure 3-1 shows the diameter growth change for a molybdenum sample backward wound on a 1-3/4 inch reel. Similar trials have been initiated on material formed at 1100°F for 8.6 minutes in a 0.375-inch constraining pipe. The material was stored on a 2-inch reel in a forward wound condition.

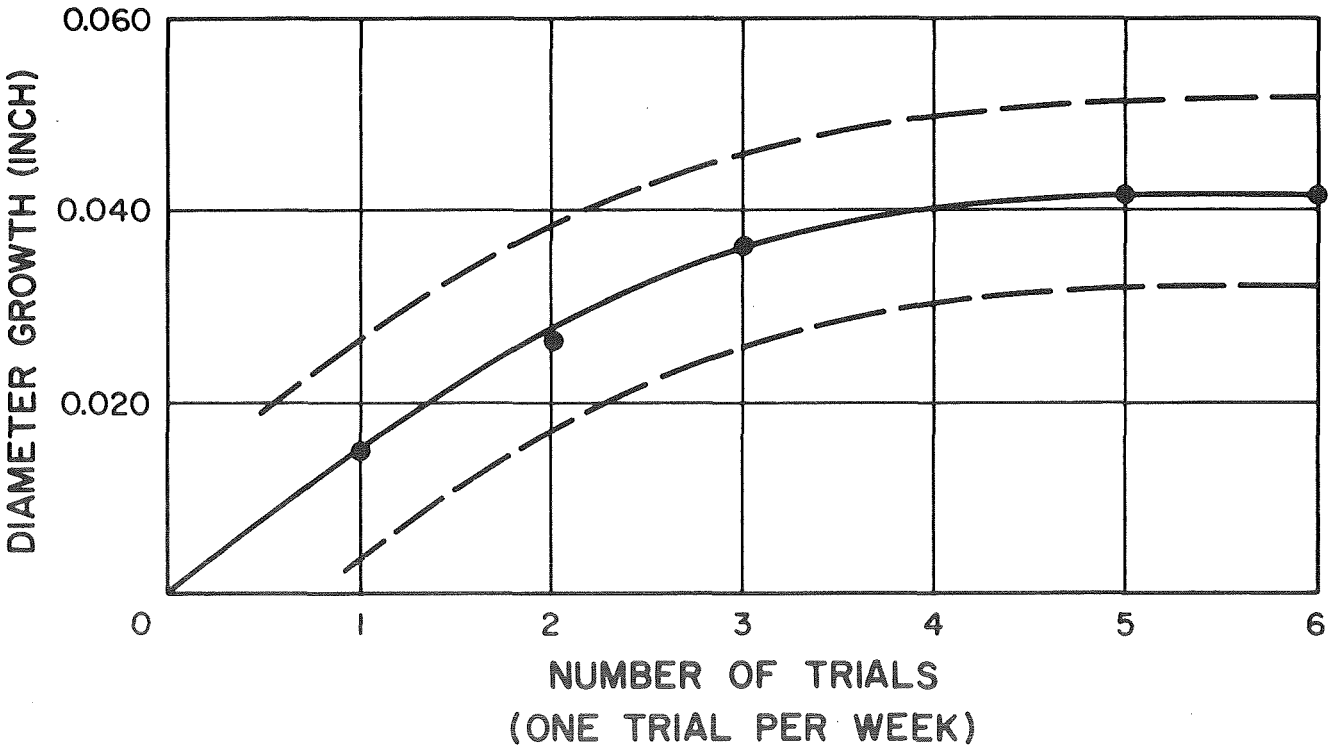


Figure 3-1. Rod Deployment Growth (1-3/4 Inch Spool)

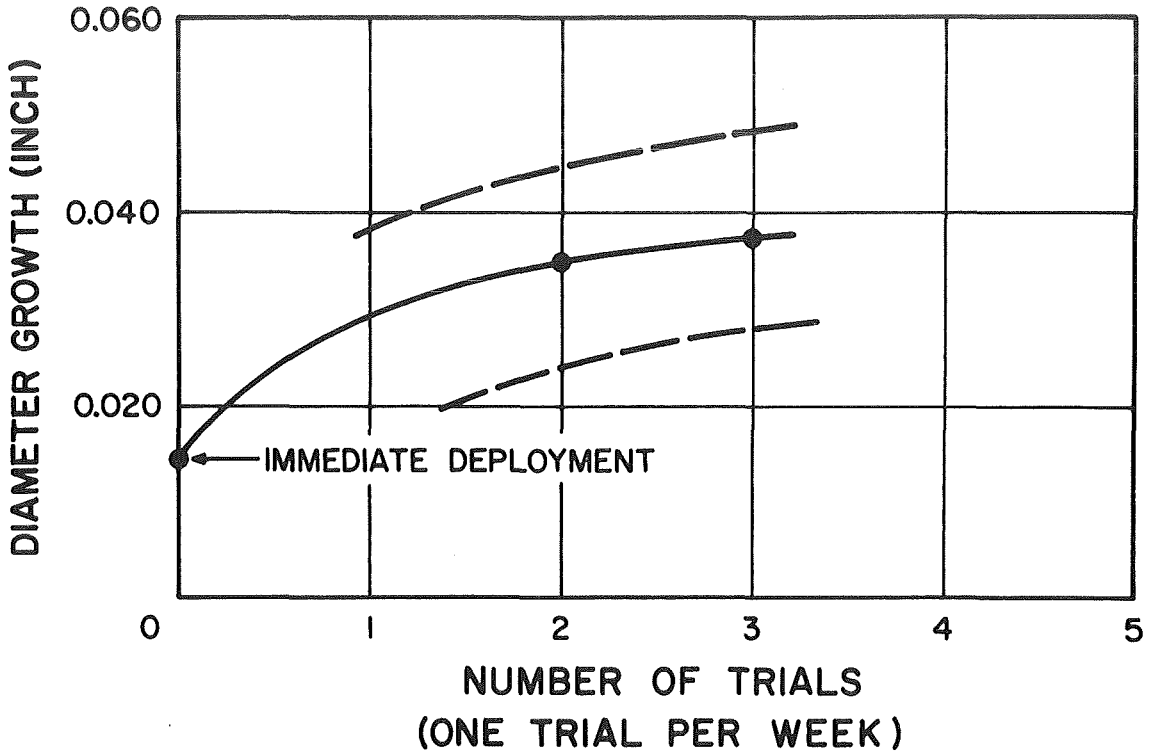


Figure 3-2. Rod Deployment Growth (2-Inch Spool)

Figure 3-2 shows the trend of the data for the molybdenum wound on the 2-inch reel. The data indicates that an approximate 0.50-inch diameter change limit is approached parabolically after a small number of deployment trials. The results suggest that the desired 0.500 ± 0.02-inch rod can be achieved by initially forming the rod to a diameter 0.050 inch smaller than the final desired rod size.

SECTION 4

PRODUCTION CONSIDERATIONS FOR 1000-FOOT RODS

4.1 ROLLING PROCESS FOR 1000-FOOT LENGTHS

In the opinion of General Electric Lamp Metals and Components Department, it is theoretically possible to roll 1000 feet of molybdenum strip on present equipment. However, lengths of this magnitude have not been attempted to date, and some development effort might be required to produce the high quality strip desired over such a long run. LM&CD recently completed the processing of a 400-foot roll of molybdenum strip, and they are planning to process a 1200-foot strip.

4.2 FORMING PROCESS FOR 1000-FOOT LENGTHS

The forming of 1000-foot long molybdenum rods is believed to be entirely feasible and could be performed on the pilot setup presently available if moly strip of this length were available. Of course, the time involved (assuming 12 ft/hr rate) to process a 1000-foot length would be approximately 83 hours (3.5 days) because of the single 2-foot furnace available in the present setup. Minor revisions for such an extended run would be required in the setup such as providing a manifold system for the argon gas supply such that argon bottles could be replaced without interrupting the flow. Also, larger feed and takeup spools would have to be provided and minor adjustments made during the run to provide proper tape takeup rates. On the low production scale currently required to meet the limited and sporadic demand for rods, it is believed the time involved to process 1000 feet of rod on the current setup is not a limiting factor. Table 4-1 compares the production time required as a function of furnace length. These numbers are based on a temperature/time requirement for moly rod of 1150°F for 10 minutes.

TABLE 4-1. ROD PRODUCTION TIME VS FURNACE LENGTH

Furnace Length (Ft)	Production Time Per 100 Ft of Rod (H2)
2	8.34
10	1.67
20	0.84
30	0.55
40	0.42

However, if a rod forming production facility were deemed necessary, and the demand for rods increased to the point where a production facility would be economically feasible, such a facility should pose few problems. Some development would be necessary to investigate the following potential problem areas:

a. Forming Friction - As furnace length is added to the line to speed up the processing time, the forming tube (inside the furnace) through which the moly tape travels during annealing must also become longer. It is believed that this increased length will require additional tension in the tape to overcome the friction forces generated. This additional tension may cause tape breakage problems of surface damage within the forming tube and possible die damage which would have to be resolved during a development phase.

b. Furnace Temperature Control - In the present pilot line forming setup, the furnace length is approximately two feet. Temperature data obtained by instrumenting the forming tube indicated that the temperature within the furnace varied over its length with the average temperature being approximately the same as the control setting. However, the peak temperature in the center of the furnace

was about eight percent above the control setting. If the length of the furnace were scaled-up for production, or if several furnaces were assembled in series, the effect on the tape properties of the temperature variations within the various furnace areas are unknown and would have to be investigated.

c. Adherence of Plating - Plating adherence is improved by the forming process in the current pilot line forming setup, and no damage such as peeling or scratching of the plated surface has been noted. However, in a longer forming tube where the plated surface is in contact with the walls of the forming tube for an extended period of time, problems may arise relative to the surface finish of the silverplated rod. Such problems, if real, would have to be resolved during the production development phase.

In view of the above listed potential problem areas, it is believed that the maximum furnace length for a production line for moly rods should be no more than 20 feet. This maximum length is recommended for the following reasons:

a. Friction problems in this length of forming tube are probably reasonable and readily solved.

b. Production rate of 1000 feet per working shift appears quite adequate to handle any forseeable demand. Additional lines can be installed as demand increases.

c. Forming tubes of various diameters are easy to procure and handle in 20-foot lengths. Straightness of the forming tube can be obtained and controlled with relative ease.

d. Furnace temperature variations are minimized.

Other considerations in setting up a production moly line would include:

a. Interchangeable die set assemblies at both the feed end and the takeup end of the line should be provided so that various diameters of rod can be produced through the single furnace assembly (forming tubes within the furnace area would also be interchangeable to match the die sets).

b. Furnaces should have the widest available temperature range to provide versatility in forming rods of other materials (including non-metallic rod material).

Figure 4-1 shows a schematic layout of a production molybdenum rod forming line.

Another consideration in planning a production facility for mass producing extensible rods, is whether to incorporate all potential operations (perforating, plating, cleaning, forming, etc.) in a single line, or make separate lines for each operation. The advantages of the separate line approach appear to outweigh by far the questionable practicality of the single-line approach in the following areas:

a. Versatility - With separate lines, maximum versatility is obtained. Various tape thicknesses, widths, materials, etc., can be easily adapted without affecting other processing operations.

b. Rate of Processing - The various processes may require very different tape for desired results. In a single line, it would be difficult to adjust the single tape rate to satisfy the various process rates. With separate lines, this would not be a problem.

c. Redundancy - A breakdown or problem in any section of a single line would shut down all production. With separate lines, processing could continue on all operations except the one with a problem. The investment required to build spare processing setups would be less with the separate-line approach.

Therefore, a production line consisting of separate setups for each necessary processing operation is recommended.

4.3 PLATING PROCESS FOR 1000-FOOT LENGTHS

Plating of molybdenum rods would be accomplished on the flat strip prior to forming. This procedure is recommended because the heat annealing process during forming (as experienced on batch samples) appeared to improve adherence of the plating to the moly surface very markedly. An additional reason for plating in the flat strip form is the ease of handling when compared with plating after forming.

Adherence of the silver plating to the molybdenum material appears to be a major problem area. Several attempts to plate sample strips using various baths and process variations have failed to produce a truly satisfactory product. Adherence of the plating to the unformed strip was quite poor and great care had to be exercised in handling the sample tapes prior to the forming process.

Once a satisfactory plating process is established, it is believed that continuous plating facilities for 1000-foot moly strips are quite feasible. The Dover, Ohio facility of General Electric Company is in the process of installing a continuous plating line which it is believed can be utilized in the near future for plating 1000-foot strips. Orbit Plating Company located in Bloomfield, New Jersey also has a continuous line and is presently performing trial plating runs on moly strip for GE.

4.4 PRELIMINARY SPECIFICATIONS

4.4.1 MOLYBDENUM FOIL MATERIAL PROCUREMENT SPECIFICATION

A preliminary specification for procurement of molybdenum strip material is attached as Appendix E.

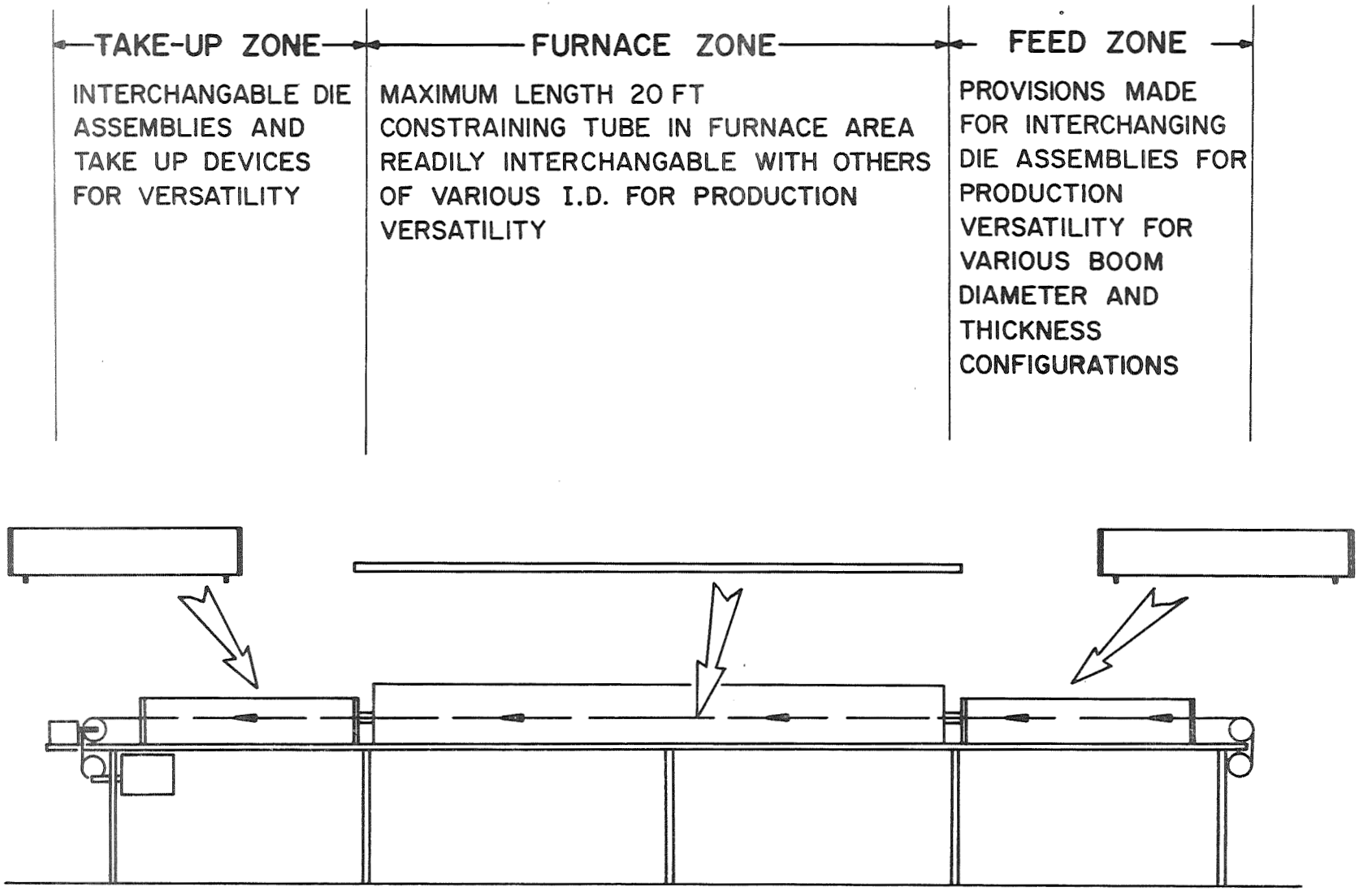


Figure 4-1. Production Molybdenum Rod Forming Line, Schematic

4.4.2 MOLYBDENUM ROD PROCUREMENT SPECIFICATION

Attached as Appendix F.

4.4.3 PROCESS SPECIFICATION - ROLLING OF MOLYBDENUM FOIL STRIP

Attached as Appendix G.

4.4.4 PROCESS SPECIFICATION - FORMING OF MOLYBDENUM OVERLAPPED ROD

Attached as Appendix H.

4.4.5 PROCESS SPECIFICATION - PLATING OF MOLYBDENUM FOIL STRIP

Attached as Appendix J.

APPENDIX A

FORMING OF THIN WALL MOLYBDENUM TUBING

(THE YODER COMPANY FINAL REPORT)

A.1 OBJECTIVE

This report is intended to cover the basic experimental work attempted to produce molybdenum gravity gradient tubes of 1/2-inch O.D., 0.001 inch thickness, and having about 100 degress of overlap.

A.2 DISCUSSION

There are two approaches to this project. One is to cold-form the foil, release it to its free state, and heat-treat it afterward. The other is to cold-form the foil, and heat-treat it while it is still restrained. In the early phase of the project, before heat treat equipment and information were made available by GE to Yoder, the first approach was taken to gain knowledge of working with light gauge foil.

Steel shim stocks of 0.001 and 0.002 inch thick were used instead of molybdenum foil. They were pulled through a series of epoxy funnels to overform to a small diameter so that they will settle to the objective size and shape.

The arrangement of this early experiment is shown in Figure A-1. Figure A-1 is broken down as follows:

a. Entry table, on which 2-inch wide foil was laid, foil was pulled through the forming. A rubber pad was clamped on a wire soldered on the tail end of the foil to produce back tension.

b. Open trough, where foil is confined more or less to a semi-circular shape as shown in section 1-1.

c. Semi-open funnel, funnel No. 2 as shown in Table A-1, foil still open, but more fully in contact with the cavity of funnel, edges of foil are guided by flat plastic plate. See section 2-2.

d. Closed funnel, tapered cavity where foil edges overlapped and diameter reduced. A taper of 1 degree included angle is most satisfactory. See Table A-1 for complete list of funnels.

e. A closed funnel with straight cavity of no taper which acts like a sizing pass in a tube mill.

f. Exit table and winding drum, the table is long enough to handle up to 10 feet of long tube for observation. A wire is soldered on the front

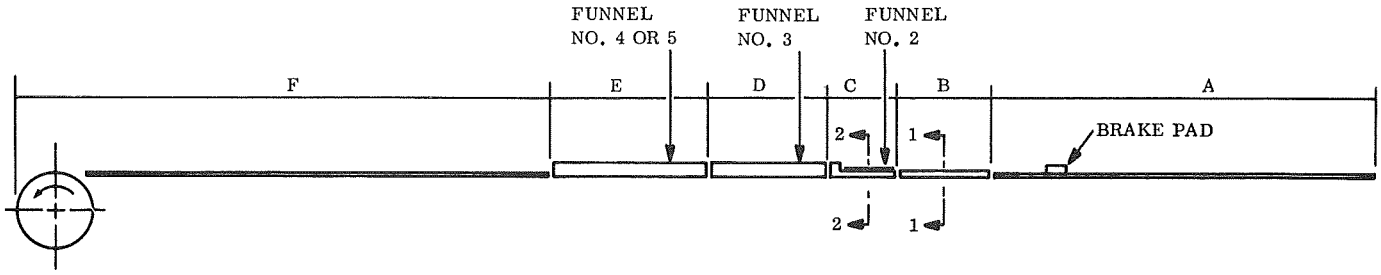


Figure A-1. Schematic Diagram of Experimental Line 1

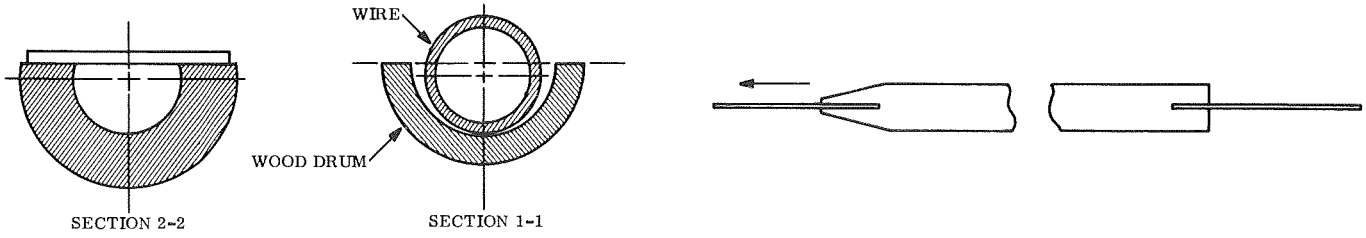


Figure A-2. Wire End

TABLE A-1 - FORMING TOOL

Funnel No.	Exit Diameter (Inches)	Entry Diameter (Inches)	Taper Total Included Angle (Degrees)	
1	0.187	1.250	3	
2	0.687	1.250	3	Semi open for edge guide
3A	0.275	0.625	1	
3B	0.275	0.625	1	
3C	0.320	0.625	1	
4	0.250	0.250	0	
5	0.281	0.281	0	Split in 2 halves
6	0.350	0.625	2	
7	0.340	0.625	2	
8	0.281	0.625	2	Transparent
9	0.348	0.625	2	
10	0.400	1.250	1	Impregnated with Moly-disulfide

end of foil as shown in Figure A-2. The other end of wire is wound on a wood drum which is rotated manually to supply the pulling force.

With the above crude setup, when steel shim stocks of 2 inches width were pulled through, tubes about 1/2-inch in diameter resulted. The cross-section had an ovality of 1.1. The overlaps tightly hugged each other and only small dimples, 1/8-inch long, 3/32-inches wide, and 1/32-inches deep, occurred on the edges of the outer layer at points 2 to 4 inches apart. Deviation from straightness was measured at 1/16 inch in 12-inch length.

In the beginning, the difficulties such as longitudinal creases, circumferential wrinkles, tears and breakages were numerous. To briefly summarize the result: Funnel of 1 degree taper is more satisfactory than 2 or 3 degrees. The alignments between the funnels are important. The space between funnels should be kept to a minimum. Some oil was used to reduce friction. Back tension is essential, and tends to increase overall longitudinal tensile stress of the foil to minimize the tendency of the edge to wrinkle.

To obtain 1/2-inch gradient tube of 0.002 inch thick shim stock requires overforming to about 1/4-inch O.D.. For 0.001 thick shim stock, overforming to less than 3/16-inch O.D. is necessary. This fact calls for a change to the second approach, i.e., heat treating the foil in line, while the tube is constrained circumferentially as well as longitudinally. In this case, overform to something a little less than 1/2 inch should be sufficient. The experience gained in the first phase will certainly help to cope with a less critical forming situation.

In the second phase, the experimental line is shown in Figure A-3.

a. Uncoiling stand - a drum about 4-inch diameter to unwind the foil, the drum shaft is provided with braking device for back tension.

b. Open trough - same as in Figure A-1.

c. Closed funnel (No. 10), 1-1/4-inch entering diameter, 0.4 inch exit diameter, 1 degree taper funnel is made of epoxy mixed with molybdenum disulfide.

d. Two furnaces, each has 24 inches effective heating length, stainless steel manifold of 65-inch length, 0.4 inch I.D., with connections for argon gas, mandrel made of stainless steel tube 0.375 inch O.D. inserted in the full length of manifold, mandrel has many 1/16-inch diameter holes to admit argon gas to the inside of molybdenum foil, the anchor of mandrel is at open trough. There are 3 supports for manifold and mandrel assembly.

e. Rewinding unit, rewinder drum of about 4-inch diameter driven through reducers by Reeves drive having pulling speed range of 1 to 6 inches per minute. A guide stand is provided in front of the drum.

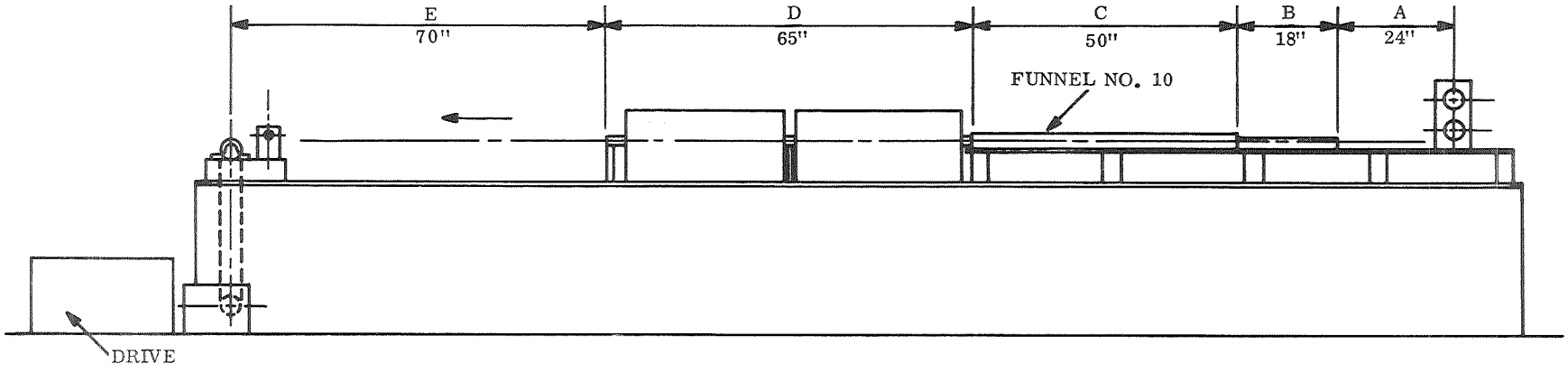


Figure A-3. Schematic Diagram of Experimental Line 2

Aside from tooling, the uncoiling, rewinding and driving units were converted from Yoder's standard tube mill stands and other laboratory equipment. All the units were lined up in 20 foot long line, and were ready to pull through the first molybdenum foil tube. At this point, the project was stopped. Nevertheless, the author is confident that a straight molybdenum tube free from wrinkles, good contact between overlapping layers, and having a length of over 50 feet can be successfully produced. The straightness of tube which is very important in the product application, can be controlled by the tension of the line inconjunction with the relative height of manifold to the entry and exit metal lines.

The author hopes that this report has outlined sufficient information for continuation of the project.

APPENDIX B

FLAT MOLYBDENUM FOIL TENSILE TEST DATA

Tabulated in Tables B-1 through B-5 are the results of a tensile test matrix generated by General Electric Lamp Metals and Components Department on 0.001-inch thick Molybdenum foil. All specimens were flat, no attempt being made in these tests to form the samples into a tubular shape. Tests were performed at room temperature with the samples at room temperature after they had been exposed to the temperatures and times specified.

TABLE B-1. AS-ROLLED TENSILE TEST RESULTS 0.001-INCH MOLYBDENUM FOIL

DIRECTION	CONDITION	0.2% YIELD STRENGTH (psi)	ULTIMATE STRENGTH (psi)
INGOT #569B3			
Transverse	As Rolled	179,200	197,100*
Transverse	As Rolled	179,200	191,800*
Transverse	As Rolled	179,200	193,500*
INGOT #1418B1A			
Longitudinal	As Rolled	211,500	225,800
Longitudinal	As Rolled	211,500	224,000
Longitudinal	As Rolled	211,500	225,800
Transverse	As Rolled	186,400	209,700*
Transverse	As Rolled	188,100	211,500*
Transverse	As Rolled	188,100	216,800

* Specimen broke before shift of 0.6% offset.

TABLE B-2. TENSILE TEST RESULTS AFTER EXPOSURE TO 500°C - INGOT #5695B3

DIRECTION	CONDITION		0.2% YIELD STRENGTH (psi)	ULTIMATE STRENGTH (psi)
	Temp. (°C)	Time (min.)		
Longitudinal	500	5	197,500	220,800
Longitudinal	500	5	192,100	215,400
Transverse	500	5	175,900	190,300*
Transverse	500	5	170,600	183,100*
Longitudinal	500	10	193,900	219,000
Longitudinal	500	10	197,500	222,600
Transverse	500	10	172,300	185,000*
Transverse	500	10	175,900	188,500*
Longitudinal	500	15	195,700	219,000
Longitudinal	500	15	183,000	208,200
Transverse	500	15	172,300	188,500*
Transverse	500	15	175,900	190,300*
Longitudinal	500	30	190,300	217,200
Longitudinal	500	30	183,100	211,900
Transverse	500	30	170,600	190,300*
Transverse	500	30	172,300	195,700*

* Specimen broke before shift of 0.6% offset.

TABLE B-3. TENSILE TEST RESULTS AFTER EXPOSURE TO 600°C - INGOT #5695B3

DIRECTION	CONDITION		0.2% YIELD STRENGTH (psi)	ULTIMATE STRENGTH (psi)
	Temp. (°C)	Time (min.)		
Longitudinal	600	5	174,100	201,100
Longitudinal	600	5	185,000	213,600
Transverse	600	5	172,300	188,500*
Transverse	600	5	170,600	186,700*
Longitudinal	600	10	168,800	197,500
Longitudinal	600	10	176,000	202,900
Transverse	600	10	167,000	181,300*
Transverse	600	10	168,800	186,700*
Longitudinal	600	15	175,900	202,900
Longitudinal	600	15	177,700	206,500
Transverse	600	15	163,400	190,300
Transverse	600	15	163,400	188,500
Longitudinal	600	30	168,800	186,700*
Longitudinal	600	30	172,300	201,100
Transverse	600	30	161,600	180,000*
Transverse	600	30	158,000	172,300*

* Specimen broke before shift of 0.6% offset.

TABLE B-4. TENSILE TEST RESULTS AFTER EXPOSURE TO 700°C - INGOT #5695B3

DIRECTION	CONDITION		0.2% YIELD STRENGTH (psi)	ULTIMATE STRENGTH (psi)
	Temp. (°C)	Time (min.)		
Longitudinal	700	5	156,100	181,300
Longitudinal	700	5	150,800	177,700
Transverse	700	5	156,100	172,300*
Transverse	700	5	157,900	174,100*
Longitudinal	700	10	154,400	179,500
Longitudinal	700	10	154,400	181,300
Transverse	700	10	158,000	185,000
Transverse	700	10	Sample Broke	
Longitudinal	700	15	150,800	175,900
Longitudinal	700	15	152,600	177,700
Transverse	700	15	152,600	167,000*
Transverse	700	15	150,800	174,100*
Longitudinal	700	30	136,400	158,000
Longitudinal	700	30	132,800	156,200
Transverse	700	30	147,200	168,800
Transverse	700	30	145,400	159,800*

* Specimen broke before shift of 0.6% offset.

TABLE B-5. TENSILE TEST RESULTS AFTER EXPOSURE TO 750°C - INGOT #5695B3

DIRECTION	CONDITION		0.2% YIELD STRENGTH (psi)	ULTIMATE STRENGTH (psi)
	Temp. (°C)	Time (min.)		
Longitudinal	750	5	158,000	186,700
Longitudinal	750	5	172,300	204,700
Transverse	750	5	165,200	185,000*
Transverse	750	5	165,200	195,700
Longitudinal	750	10	145,400	168,700
Longitudinal	750	10	147,200	172,300
Transverse	750	10	152,600	177,500
Transverse	750	10	152,600	179,500
Longitudinal	750	15	136,400	159,800
Longitudinal	750	15	134,600	156,200
Transverse	750	15	149,000	172,300
Transverse	750	15	149,000	172,300
Longitudinal	750	30	134,600	158,000
Longitudinal	750	30	145,400	170,500
Transverse	750	30	143,600	159,800*
Transverse	750	30	145,400	167,000

* Specimen broke before shift of 0.6% offset.

APPENDIX C

STRESS RELIEF TEMPERATURES, TIME AND SIZES FOR MOLYBDENUM ROD FORMING (BATCH SAMPLE TESTS)

C.1 SUMMARY

The stress relief at 700°C of 0.001-inch molybdenum foil elastically coiled inside a 3/8-inch tube will yield a 1/2-inch overlapped tube.

C.2 INTRODUCTION

In order to determine the stress relief conditions necessary to form 0.001-inch molybdenum foil into 0.500-inch diameter overlapped tube, a matrix of various initial overlapped dimensions and stress relief temperatures was evaluated. The temperatures were at one hundred degree intervals from 400 to 700°C inclusive. The geometries for the thermal treatment were obtained from tubular molds with inside nominal diameters of 5/16, 3/8, and 1/2 inch. The stress relief time was fifteen minutes. Some additional work was done with a 30-minute stress relief.

C.3 PROCEDURE

The equipment for the stress relief consisted of an electric resistance heated furnace with a Vycor muffle through which was passed dried argon. Three different molds were made from one-inch diameter steel bar stock. Each mold was two inches long. Holes of 5/16, 3/8, and 1/2-inch diameter were bored in the various pieces.

A two-inch length of GE -21 powder metallurgy molybdenum foil 0.001 inch thick and two inches wide was elastically coiled inside the molds and allowed to take a natural shape. The molds were placed inside the cold portion of the furnace muffle, after which the muffle was purged with dried argon. The molds were then placed in the hot zone of the furnace for the desired length of time. Time was measured from the moment of introduction of the mold

into the stabilized furnace, and not from a measurement of specimen temperature. At the end of the desired period, the molds were transferred to the cool portion of the muffle to cool before removal into the atmosphere.

All three mold sizes were used to prepare speciments at 400, 500, 600, and 700°C for a 15-minute stress relief. The 5/16 and 3/8 molds were used to prepare additional specimens at 600 and 700°C for a 30-minute stress relief.

C.4 RESULTS AND DISCUSSION

The diameter of the resultant shape of the molybdenum foil after removal from the molds is given in Table C-1.

The effect of stress relief on the cold worked molybdenum foil which has been elastically deformed into the mold shape is to reduce the level of the residual stress. The lower the residual stress level, the closer the conformity of the final shape achieved in the foil to the mold shape. Since the matrix study was to indicate the region of mold size and stress relief temperature necessary for a continuous process, exact values of time, temperature and mold size were not required. However, since the mold size is the least flexible parameter, it had to be chosen so that there was sufficient latitude in the other two parameters to accommodate the stress relief processing. From an examination of the information in Table C-1, it can be seen that the 3/8-inch mold yielded a 0.585 diameter at 600°C and a 0.496 diameter at 700°C for a 15-minute stress relief. Similarly, the same mold gave 0.472 and 0.415 at 600 and 700°C, respectively, for a 30-minute stress relief. A stress relief treatment will give lower residual stress levels by processing for long times at a low temperature rather than short times at a higher temperature if the final yield strength is maintained constant. For this reason, it appears that temperatures in the range of 600-700°C are the most desirable. Data to be provided by the GE Lamp Metals and Components Department will give actual tensile test data for various stress relief times over the same temperature range explored here. Once the temperature range is chosen, the forming mold size must be selected to give the desired final size, 0.500 inch.

Data in Table C-1 suggests that a 0.4-inch diameter form will yield a 0.500-inch tube for stress relief temperatures between 600 and 700°C for periods of 15 to 30 minutes.

TABLE C-1. DIAMETER OF TUBE FORMED BY STRESS RELIEF AT THE INDICATED TEMPERATURE AND MOLD SIZE

Temperature (°C)		400	500	600	700
Mold Diameter (in.)	Time (Min.)	Diameter of Tube (in.)			
5/16 (0.312	15	Open	0.66	0.485	0.444
3/8 (0.375)	15	Open	Open	0.585	0.496
1/2 (0.500	15	Open	Open	Open	0.596
5/16 (0.312)	30			0.392	0.344
3/8 (0.375	30			0.472	0.415

APPENDIX D

TYPICAL CHEMICAL COMPOSITION OF FINAL UNALLOYED POWDER METALLURGY MOLYBDENUM FOIL (GE LAMP METALS AND COMPONENTS DEPARTMENT)

General Electric's chemical composition, as stated here, is typical of the final unalloyed powder metallurgy molybdenum product, rather than the parent raw material form. Typical values shown are not intended to represent guaranteed or specification type composition.

TYPICAL SPECTROGRAPHIC ANALYSIS (1)

	Composition, ppm			Composition, ppm	
Element	Typical	Range	Element	Typical	Range
Aluminum	<8	<8 - 40	Potassium (3)	3	1 - 10
Calcium	15	<5 - 75	Manganese	10	8 - 20
Silicon	<15	10-50	Magnesium	<10	<10 - 10
Iron	50	40-75	Tin	10	<8 - 20
Chromium	10	<8 - 30	Lead	<10	<10-10
Nickel	8	5 - 40	Cobalt	<8	<8 - 10
Copper	8	4 - 30	Silver	<1	<1 - 10
Tungsten	80	<60-150	Titanium	<10	<10-10
Sodium (3)	8	5 - 10	Zirconium	<10	<10-10

99.9% Minimum Molybdenum Content (by difference)

TYPICAL INTERSITIAL ANALYSIS (1)

	Composition, ppm	
Element	Typical	Range
Carbon (4)	15	<10 - 50
Oxygen (5)	See Note (2)	15 - 70
Hydrogen (5)	1	1 - 20
Nitrogen (5)	2	15 - 50

NOTES

(1) The maximum range value reported, for both spectrographic and interstitial analysis, is such that it includes the normal variation between testing laboratories and the reproducibility of individual tests. This variation is known to approach ±40% of the reported value.

(2) Oxygen analysis will vary with sheet thickness due to surface area-to-volume ratio; i. e., apparent oxygen content increases as sheet thickness decreases. Foil thickness of 0.005 inch and under are typically 40 to 50 ppm oxygen, while 0.030-inch sheet and above are typically 15 to 25 ppm oxygen.

(3) Flame photometry analysis.

(4) Leco conductometric analysis.

(5) Vacuum fusion analysis.

Specification No. _____

PRELIMINARY

APPENDIX E

Specification for Pure

Molybdenum Foil

Prepared By _____ Date _____

Approved By _____ Date _____

Reviewed By _____ Date _____

PRELIMINARY

PRELIMINARY SPECIFICATION

PURE MOLYBDENUM FOIL

1.0 SCOPE

This document specifies the requirements of the as-rolled molybdenum foil strip for use in the manufacture of formed rods for use as gravity gradient rods, antennae and other similar applications.

2.0 FOIL SPECIFICATIONS

1. Material to be GE-21, powder metallurgy molybdenum foil of 99.9% purity.

2. Foil size - 0.001 inch thick x 2 inches wide (or as otherwise required).

3. Thickness tolerance - $\pm$0.00015 inch.

4. Width tolerance - $\pm$0.005 inch.

5. Camber tolerance - (maximum variation from best straight line) $\pm$1.25 inches per 100 feet of length, proportional for other lengths.

6. Length tolerance +1/32 inch, -0 inch per foot of length.

7. Typical ultimate tensile strength - 200,000 psi.

8. Typical 0.2% offset yield strength - 175,000 psi.

9. Typical modulus of elasticity - 47×10^6 psi.

10. Surface finish - standard bright, 4 microinches rms.

Specification No. _____

PRELIMINARY

APPENDIX F

Specification for Molybdenum
Rods for Gravity Gradient,
Antennae, and Other Applications

Prepared By _____ Date _____

Approved By _____ Date _____

Reviewed By _____ Date _____

PRELIMINARY

PRELIMINARY SPECIFICATION
MOLYBDENUM RODS FOR GRAVITY GRADIENT ANTENNAE, OR OTHER APPLICATIONS

1.0 SCOPE

This document specifies the requirements for extensible rods fabricated of molybdenum foil for use as gravity gradient rods, antennae, or other applications.

2.0 GENERAL

All rods will be of tubular cross section split longitudinally so that the cross section may be flattened and rolled up for storage. The free edges of the split tube will overlap upon deployment to increase strength.

3.0 FORMED ROD SPECIFICATIONS

1. Length - (as required) ± 6 inches/100 feet.

2. Diameter - 0.500 ± 0.020 inch.

3. Wall Thickness - 0.00100 ± 0.00015 inch.

4. Material - GE-21 powder metallurgy molybdenum foil of 99.9 percent purity.

5. Strip width - (as required) ± 0.005 inch (to 6 inches maximum).

6. Overlap - the overlap angle shall be (as required) ± 20 degrees.

7. Straightness - $\pm$ _____ inch per 100 feet from best straight line (approximately ± 6 inches per 100 feet is recommended).

8. Tensile strength of formed molybdenum rod - 175,000 psi minimum.

9. General Appearance - The formed rod shall be free from surface defects, indentations, edge wrinkles, burrs; or other imperfections which will be detrimental to the intended use.

Process Specification No. _____

PRELIMINARY

APPENDIX G

Process Specification
Rolling Flat Molybdenum Foil

Prepared by _____ Date _____

Approved by _____ Date _____

Reviewed by _____ Date _____

PRELIMINARY

PRELIMINARY PROCESS SPECIFICATION

ROLLING FLAT MOLYBDENUM FOIL

1.0 SCOPE AND CLASSIFICATION

1.1 Scope

This specification describes the processing and inspection requirements for rolling flat molybdenum foil.

1.2 Classification

The materials covered by this specification shall be classified as follows: molybdenum, powder metallurgy, unalloyed.

2.0 APPLICABLE DOCUMENTS

The following documents, of the issue in effect on the date of invitation for bids, form a part of this specification to the extent specified herein:

ASTM B-386-62T	Molybdenum and Molybdenum Alloy Strip, Sheet, Foil and Plate
ASTM E-8-61T	Tension Testing of Metallic Materials

3.0 REQUIREMENTS

3.1 General

To produce quality molybdenum foil for use in forming rod for gravity gradient or other aerospace purposes.

3.2 Equipment and Material

3.2.1 Equipment

Breakdown rolls associated with hydrogen furnaces for breakdown above the recrystalization temperature. Intermediate hot rolls with hydrogen furnaces or other heat sources such as hot oil or quartz lamp heaters. Cold rolls of the Sendzimir type. Hot slitting furnace.

3.2.2 Materials

Molybdenum powder metallurgy ingot.

3.3 Procedure

The rolling schedule shall include the following:

3.3.2 Breakdown Rolling (from hydrogen atmosphere furnaces).

a. Initial breakdown of ingot approximately 1 x 10 x 24 inches.

b. Recrystallize at 0.327 inch.

3.3.3 Intermediate Rolling

a. Continue hot rolling from thickness of 0.327 inch to 0.050 inch heating in hydrogen atmosphere furnace.

b. Clean strip in hot caustic acid.

c. Intermediate anneal and slit to 7 inches width for cold rolling.

3.3.4 Final Cold Rolling

a. Cold roll from 0.050 inch to 0.007 inch.

b. Intermediate anneal at 850 $\pm$ 100°C for one hour at 0.007 inch and slit to 6-3/4 inches wide.

c. Final precision Sendzimir cold rolling to a thickness of 0.001 inch. Clean and slit to width.

3.4 Post-Process Inspection

Samples shall be cut from the 0.001-inch foil and tensile tested for ultimate tensile strength, 0.2% yield strength and elongation in a 2-inch gage length. A minimum 0.2% yield strength of 185,000 psi and a minimum elongation of 1% shall be necessary for acceptance. Thickness of finished foil shall be 0.001 ± 0.0001 inch as measured with a standard micrometer. Width of the finished foil shall be 2 ± 0.005 inch as measured with a standard micrometer.

4.0 QUALITY ASSURANCE PROVISIONS

4.1 General Requirements

Unless otherwise required in the certificate of test requirements, the manufacturer or supplier shall be responsible for the performance of acceptance tests to determine conformance prior to submission of the material to the purchaser. MSD reserves the right to perform any test deemed necessary to assure compliance with the requirements of this specification. When there is a conflict between the vendor's results and MSD's, MSD shall have the authority for final disposition on acceptance or rejection.

4.2 Lot Acceptance Tests

Samples selected to represent a batch or lot shall be tested to determine conformance with the requirements stipulated in Section 3, and acceptance or rejection of the batch or lot shall be based on these test results.

4.3 Tests

4.3.1 Test Specimens

Tensile test specimens shall be machined (ground) from samples 1 x 8 inches according to ASTM E-8-61T. Samples shall be pulled at a strain rate of 0.005 inch/minute. Alternate tensile strength, 0.2% yield strength and percent elongation in a 2-inch gage length shall be reported.

4.4 Rejection

Failure of specimens representing a lot or batch to comply with all the requirements stipulated in Section 3 shall be cause for rejection. However, additional samples representing a rejected batch may be tested at the discretion of MSD to determine compliance with the requirements of this specification.

5.0 PREPARATION FOR DELIVERY

5.1 Certificate of Test

Unless otherwise requested, the manufacturer or processor shall submit promptly to the purchaser at the point of delivery a certificate of test in triplicate showing results of tests made to determine conformance to this specification. The certificate shall show this GE designation, the purchase order number and the lot number(s) with date of manufacture so that the certificate may be identified with the shipment.

5.2 Identification

The batch and/or lot number and date of manufacture or processing shall be indicated on each container.

5.3 Packaging

The foil shall be continuously wound on a 2-inch diameter reel with no sections taped, welded or otherwise joined together inside the roll and packaged so as to prevent contamination or damage during shipment.

6.0 NOTES

6.1 Description and Intended Use

The foil shall be used to form rods for aerospace applications.

6.2 Source of Supply

GE Lamp Metals Department, Euclid, Ohio.

Process Specification No. _____

PRELIMINARY

APPENDIX H

Process Specification
Forming Molybdenum Foil For
Gravity Gradient Rods

Prepared by_____ Date_____

Approved by_____ Date_____

Reviewed by_____ Date_____

PRELIMINARY

PRELIMINARY PROCESS SPECIFICATION

FORMING MOLYBDENUM FOIL FOR GRAVITY GRADIENT RODS

1.0 SCOPE AND CLASSIFICATION

1.1 Scope

This specification describes the processing and inspeciton requirements for forming molybdenum foil for gravity gradient rod applications.

1.2 Classification

The materials covered by this specification shall be classified as follows: Molybdenum foil, powder metallurgy, unalloyed.

2.0 APPLICABLE DOCUMENTS

The following document, of the issue in effect on the date of invitation for bids, form a part of this specification to the extent specified herein:

ASTM E8-6T Tension Testing of Metallic Materials.

3.0 REQUIREMENTS

3.1 General

This procedure covers the steps necessary to form molybdenum foil into gravity gradient rods by a stress relief anneal.

3.2 Equipment and Material

3.2.1 Equipment

Continuous forming line consisting of:

a. Dies for guiding the material into the forming tube.

b. Forming tube 0.375-inch inside diameter.

c. Furnace for service to $1500^{\circ}F$ (24-inch heat zone).

d. Inert gas protection assembly.

e. Dies to guide the formed rod onto the takeup reel.

f. Line tension assembly for pulling the foil through the forming line.

3.2.2 Materials

Molybdenum, powder metallurgy, unalloyed 0.001 ± 0.0001 inch x 2 $\pm$ 0.005 inches x coil length desired. Minimum yield strength 185,000 psi as rolled.

3.3 Procedure

a. Place coil onto payout reel.

b. Set furnace to desired temperature of $1050^{\circ}F \pm 50^{\circ}F$. Maximum center furnace temperature, $1150^{\circ}F$.

c. Feed lead material through pre-furnace die guides. Attach a pull-through wire to the foil and pull the lead end through the forming tube. Feed the lead material through the post-furnace die guides and connect the foil to the takeup drive assembly.

d. Set the speed control to a line speed of 12 ± 4 ft/hour.

e. Set the inert gas to 15 ± 10 cu ft/hour.

f. Set line tension at 20 ± 8 pounds.

g. Mark the material that is to enter the furnace.

h. Allow ten feet to pass through the furnace. When the desired material reaches the takeup reel stop the line and remove the ten-foot section for inspection. Tape the free end to the takeup reel and await insepction results.

i. Following satisfactory inspection results, the line shall be restarted after ten minutes to allow temperature and gas protection to reach steady state.

j. A mark shall be made on the material that is ready to enter the furnace. Allow 36 inches to pass through the furnace and then mark the lead end of the material to be the final product. The process shall continue without interruption until the desired length has been formed.

k. Upon completion of the desired length, the sample shall be give a post-process non-destructive inspection.

3.4 Post-Process Inspection

The ten feet of formed material shall be removed from the reel and allowed to take its tubular shape. It shall be inspected as follows:

a. The diameter shall be 0.5 ± 0.020 inch as checked with a standard micrometer.
b. The surface shall be free of oxidation or dirt and deleterious wrinkles, notches, burrs, kinks or other imperfections.
c. A tensile specimen shall be cut from the section per ASTM-DE 8-6T. The sample shall show a minimum yield strength at 0.2% offset of 170,000 psi.
d. The sample shall be placed in a water tank on suitable floats. Deviation of straightness shall not exceed ± 1/4 inch in ten-foot sections.
e. Coated samples shall have measured absorptivity of less than 0.100.

4.0 QUALITY ASSURANCE PROVISIONS

4.1 General Requirements

Unless otherwise required in the certificate of test requirements, the manufacturer or supplier shall be responsible for the performance of acceptance tests to determine conformance prior to submission of the material to the purchaser. MSD reserves the right to perform any test deemed necessary to assure compliance with the requirements of this specification. When there is a conflict between the vendor's results and MSD's, MSD shall have the authority for final disposition on acceptance or rejection.

4.2 Lot Acceptance Tests

Samples selected to represent a batch or lot shall be tested to determine conformance with the requirements stipulated in Section 3, and acceptance or rejection of the batch or lot shall be based on these test results.

4.3 Tests

4.3.1 Test Specimens

Tensile samples, three each, shall be cut longitudinally from the formed rod as strips 1 x 8 inches.

4.3.2 Test Procedures

a. The 1 x 8-inch samples shall be machined (ground) into tensile specimens per ASTM E-8-6T. The edges of the specimen shall be polished free of deleterious notches.

b. The specimen shall be pre-aligned prior to mounting into the jaws of the tensile test machine, alignment shall be re-checked once mounted.

c. Test shall be run under the following conditions: (1) room temperature - 70 -80°F, (b) strain rate - 0.005 inch/minute.

4.5 Rejection

Failure of specimens representing a lot or batch to comply with all the requirements stipulated in Section 3 shall be cause for rejection. However, additional samples representing a rejected batch may be tested at the discretion of MSD to determine compliance with the requirements of this specification.

5.0 PREPARATION FOR DELIVERY

5.1 Certificate of Test

Unless otherwise requested, the manufacturer or processor shall submit promptly to the pruchaser at the point of delivery a certificate of test in triplicate showing results of tests made to determine conformance to this specification. The certificate shall show this GE designation, the pruchase order number and the lot number (s) with date of manufacture so that the certificate may be identified with the shipment.

5.2 Identification

The batch and/or lot number and date of manufacture or processing shall be indicated on each container.

5.3 Packaging

The formed rod shall be stored flat (forward wound) on a 2-inch diameter reel and packaged so as to prevent damage during shipment and storage.

6.0 NOTES

6.1 Description and Intended Use

The formed molybdenum rod shall be used for gravity gradient rods to be deployed from a spool.

Process Specification No. _____

PRELIMINARY

APPENDIX J

Process Specification

Silverplating Molybdenum Foil

Prepared By _____ Date _____

Approved By _____ Date _____

Reviewed By _____ Date _____

PRELIMINARY

PRELIMINARY PROCESS SPECIFICATION
SILVERPLATING MOLYBDENUM FOIL

1.0 SCOPE AND CLASSIFICATION

1.1 Scope

This specification describes the processing and inspection requirements for batch silverplated molybdenum foil.

1.2 Classification

The materials covered by this specification shall be classified as follows: molybdenum, powder metallurgy, unalloyed, silverplated.

2.0 APPLICABLE DOCUMENTS

The following documents, of the issue in effect on the date of invitation for bids, form a part of this specification to the extent specified herein:

NONE

3.0 REQUIREMENTS

3.1 General

To batch plate 100 microinches of silver onto a 0.001-inch molybdenum foil with good adherance and low solar absorptivity.

3.2 Equipment and Material

3.2.1 Equipment

DC voltage source ammeters and voltmeter.

3.2.2 Materials

Laboratory beakers, silver anodes, N_1 anodes, alkaline cleaner, surface activator, silver and nickel, strike on plating, solutions, scotch tape.

3.3 Procedure

3.3.1 General

To Ag plate 100 microinches on molybdenum powder metallurgy, unalloyed foil 0.001 inch x 2 inches x 3 feet.

3.3.2 Surface Preparation

a. The surface shall be scrubbed with a low chloine scouring cleanser and then rinsed.

b. The surface shall be activated with an alkaline cleaner containing KCN and rinsed.

3.3.3 Application

a. A nickel flash shall be applied using a nickel sulfanate solution 500 ml/liter plus NiCl 6 gm/liter in a bath at 120°F with PH 3.5 to 4.2, current density 0.025 amp/sq in. for 20 seconds.

b. A silver strike shall be applied using 3 gm/liter AgCN, 120 gm/liter KCN, current density 0.01 amp/sq in. for 15 seconds.

c. A silver plate shall be applied using 120 gm/liter AgCN, 120 gm/liter KCN, current density 0.065 amp/sq in., rinse and dry.

3.4 Post-Process Inspection

a. The surface adherance shall be tested on a strip cut from the plated sample. The strip shall be heated for 10 minutes on argon at 105°F. If the coating after heat treatment is not removed by the test adhesive tape, the material will be accepted for adherance.

b. The coating thickness shall be measured electrolytically. The thickness shall be 100 ±25 microinches.

c. A piece of the heat-treated sample shall be given an absorptivity check. The measured (1-reflectivity) shall not exceed 0.100.

d. A sample shall be cut from the plated strip for tensile testing. The 0.27 yield strength shall be a minimum of 180,000 psi.

4.0 QUALITY ASSURANCE PROVISIONS

4.1 General Requirements

Unless otherwise required in the certificate of test requirements, the manufacturer or supplier shall be responsible for the performance of acceptance tests to determine conformance prior to submission of the material to the purchaser. MSD reserves the right to perform any test deemed necessary to assure compliance with the requirements of this specification. When there is a conflict between the vendor's results and MSD's, MSD shall have the authority for final disposition on acceptance or rejection.

4.2 Lot Acceptance Tests

Samples selected to represent a batch or lot shall be tested to determine conformance with the requirements stipulated in Section 3, and acceptance or rejection of the batch or lot shall be based on these test results.

4.3 Tests

4.3.1 Test Specimens

Specimens shall be cut into 1 x 8-inch strips and ground to tensile samples per ASTM E8-61T. Tensile testing shall be made at 0.005 in./min. The ultimate tensile strength, 0.2% yield strength and percent elongation in 2-inch gage shall be reported.

4.5 Rejection

Failure of specimens representing a lot or batch to comply with all the requirements stipulated in Section 3 shall be cause for rejection. However, additional samples representing a rejected batch may be tested at the discretion of MSD to determine compliance with the requirements of this specification.

5.0 PREPARATION FOR DELIVERY

5.1 Certificate of Test

Unless otherwise requested, the manufacturer or processor shall submit promptly to the purchaser at the point of delivery a certificate of test in triplicate showing results of tests made to determine conformance to this specification. The certificate shall show this GE designation, the purchase order number and the lot number(s) with date of manufacture so that the certificate may be identified with the shipment.

5.2 Identification

The batch and/or lot number and date of manufacture or processing shall be indicated on each container.

5.3 Packaging

The material shall be stored on a 2-inch minimum diameter spool and packaged so as to prevent contamination or damage during shipment.

GENERAL
ELECTRIC

SPACECRAFT DEPARTMENT
MISSILE AND SPACE DIVISION
VALLEY FORGE COMPLEX
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