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MFTF

MIRROR FUSION TEST FACILITY

**SUPERCONDUCTING MAGNET SYSTEM
COST ANALYSIS**

Prepared by
EG&G Task Force

JULY 1977

obs

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APPENDIX A TASK FORCE

APPENDIX B 200-TON TROLLEY HOIST

1. PURPOSE

At the request of Victor Karpenko, Project Manager for LLL's Mirror Fusion Test Facility, EG&G has prepared this independent cost analysis for the proposed MFTF Superconducting Magnet System.

The analysis has attempted to show sufficient detail to provide adequate definition for a basis of estimating costs.

2. PRIMARY SYSTEM REQUIREMENTS

SUPERCONDUCTING MAGNET SYSTEM

Dr. Vadim Kopytoff
Project Engineer for MFTF Magnet System

Primary System Requirements

The primary MFTF magnetic system requirements result directly from the type of plasma physics experiments to be performed. MFTF scientific requirements specify the magnetic field intensity (B), general field configuration and physical size, duration of the field, and access requirements for neutral beam injection and diagnostics. These primary requirements are:

1. Minimum- $|B|$ mirror-field configuration; the magnetic field intensity increasing in all directions outward from the plasma center (magnetic center).
2. Field intensity at the plasma center of 2.0 T (20 kG).
3. Field intensity at the mirror points (on axis) of 4.0 T (40 kG); a longitudinal mirror ratio of two.
4. Nominal distance between magnetic mirror points of 3.4 m.
5. Field duration of several seconds at a constant level.
6. Accommodations for neutral beam injection from a minimum of 48 source modules.

An example of a minimum- $|B|$ field configuration is shown in Fig. 1, where contours of constant $|B|$ and magnetic field lines are indicated. The curvature of the field lines exhibits the characteristic "fan" shape of the minimum- $|B|$ mirror field. The field intensity (on-axis) is shown in Fig. 2, where the ratio of the peak field to the central field ($z = 0$) is the mirror ratio.

Although there are several magnet configurations that satisfy the above field requirements, the so-called Yin-Yang geometry is the most efficient and offers the best plasma access for the experimentalist. The Yin-Yang configuration requires two coils of identical shape acting in unison. Figure 3 shows such a magnet pair and the "flux tube" formed by magnetic field lines passing through the plasma at the center of the coil system.

The required field duration of "several seconds" is necessary to guarantee a minimum of 0.5 s for the actual duration of each experimental shot. Tradeoff studies of a conventional (resistive) magnet versus a superconducting magnet for MFTF indicate that a superconducting system is less expensive. An added benefit, of course, is steady-state operation allowing future, longer pulse, operation of the system with no added costs for upgrading the magnet.

Magnet Description

The specific coil configuration has been selected from parametric studies of alternate Yin-Yang geometries. Three-dimensional field analysis was employed to determine the attributes of candidate geometries. The MFTF coil geometry is defined in Fig. 4. The major radius of each coil is 2.5 m, and the minor radius is 0.75 m. The center of curvature of each coil is displaced 0.8 m to yield an effective half-length of 1.7 m, or 3.4 m mirror-to-mirror. In effect, the coils are designed oversize, then displaced to produce the desired length of 3.4 m. The result is improved access for neutral beam injection, at the expense of additional conductor. A trapezoidal winding cross-section is also used to increase access space for beam injection.

The high magnetic field intensity results in large induced forces on the windings. These forces are depicted in Fig. 5 as resultants of the distributed load resolved into XYZ components. The dominant force is ~ 100 MN ($\sim 22 \times 10^6$ lb) tending to open up each coil into a circular loop. A massive stainless-steel structure will be needed to restrain the windings. The structure must exhibit high strength and toughness at ~ 4 K, therefore a material such as alloy 21-6-9, which has a yield strength of 1350 MPa (196 ksi) at 20 K will be used. The structure consists of two main elements: a casing surrounding each coil, and four interconnecting members that bridge between the two coils. In effect, one

coil acts as a C-clamp for the other. This arrangement is shown in Fig. 6. Note that the casing has an enlarged cross-section for added stiffness.

A three-dimensional, finite-element stress analysis code (SAPIV) has been utilized to analyze the complex geometry. An independent analysis was also performed by Boeing Engineering and Construction Co. with the NASTRAN computer program. The results of these analyses indicate that a casing thickness of ~75 mm (3 in.) is required to provide structural integrity. Great care is required to insure that the magnet structure does not impede access for neutral beams and other penetrations to the plasma region. Three-dimensional computer graphics codes are being utilized to integrate the structural design with the requirements of the injection system, as shown in Fig. 7.

The magnet design is based on established technology insofar as practical, in order to minimize extrapolations from known performance. The superconductor is niobium-titanium stabilized with copper. A special conductor configuration is required to achieve an operating current of 5-7 kA, consistent with the size of the magnet. The special conductor consists of a near-standard core of NbTi filaments in a copper matrix, but with additional copper added having internal cooling channels. The net result is a 13 mm square conductor (Fig. 8) with greater-than-normal cooling surface area to increase the heat transfer rate to liquid helium. (The operating current of the superconductor is limited by the heat transfer capacity of the copper surface to the bath of liquid helium.) The conductor is cryostatically stabilized so that small regions which may go normal (become non-superconducting) due to perturbations during charging will recover and not cause the magnet to quench.

Each coil will consist of about 1200 turns wound in pancake fashion. The complex shape of the coils precludes a continuous, or solenoidal, winding. The pancake winding pattern will require splicing of the conductor at the inner and outer edge of each layer. Each coil will have approximately 120 field splices. Individual turns will be separated by "buttons" of fiberglass-epoxy laminate about 1 mm thick. Perforated sheets of laminate will be used to separate layers. These insulating spacers will occupy about half the space between conductors, leaving the other half available for pool boiling liquid helium at approximately one atmosphere. The conductor will be wound under nominal tension with sufficient clamping to maintain a compact bundle. The winding

mandrel will be the inner portion of a stainless-steel jacket that completely encloses the winding. Once the coil bundle is wound, jacket segments will be welded around the winding to complete a vacuum-tight shell. The jacketed coils will then be assembled within the structural casing. The clearance space between coil and case will be partially shimmed; the remaining void space will be dynamically vacuum-pumped during magnet operation. This is an important feature, in that it keeps helium leakage (from the coil bath) from contaminating the plasma region just outside the case. A conceptual drawing of the jacketed-coil and structure is shown in Fig. 9.

Magnet Parameters

Magnet parameters are summarized in Table I. Most of these values are tentative until the results of magnet development tasks are complete. Some of the major technical issues are listed below:

1. Characteristics of the superconductor will need to be well defined to insure operation at the design level. This requires evaluation of the proposed conductor in a test coil.
2. Adequate instrumentation for detecting the onset of quench must be designed into the magnet.
3. A circuit which can extract the majority of the energy stored in the magnet and dump it in an external resistor in the event that the coil does quench will be required.
4. Cryogenic design must minimize liquid helium consumption, and the internal structure of the windings must be designed against vapor-blocking of the helium flow path.
5. Conductor splices must be absolutely reliable with respect to an open-circuit failure mode.
6. Barrier insulation between the coil and jacket (ground) must withstand a discharge potential of ~ 1 kV.
7. A guard vacuum feature must be provided to protect against helium leakage from the winding to the external plasma region.
8. The magnet structure must not interfere with access for neutral beam injection, plasma end-loss, diagnostics and vacuum pumping.

9. The structural material must be non-magnetic, and exhibit high strength and toughness at the operating temperature (~4 K).

Magnet Development

Several aspects of the magnet system are under development this fiscal year, in preparation for construction approval for MFTF.

The development of the superconductor for the magnet is being performed by the Magnet Development Group at LLL. They are working closely with industry to adapt a near-standard niobium-titanium/copper superconducting "core" for use in the special conductor. Additional effort is underway to demonstrate the manufacturing feasibility of adding the copper stabilizer. A test coil (1 m bore solenoid) will be fabricated at LLL with conductor samples from industry to determine the actual operating characteristics of the MFTF conductor at fields near 7.5 T.

A large two-axis coil winding machine (Fig. 10) is being purchased this fiscal year. The design and fabrication have been subcontracted to industry. A conductor-reel-support machine has been designed by LLL and is now being built. These large machines will be installed at LLL this fall to begin trial winding operations and final tool development.

Much of the tool design relating to magnet winding is occurring this year, such as clamping mechanisms to maintain conductor-bundle compactness during winding. Splice forming tools must either be designed or purchased, depending on results from the Magnet Group. The insulating spacers for the coils require unique shapes of fiberglass-epoxy laminate: local vendors are supplying this material for the test coil. We are also performing weld tests to define the procedures required to weld both the coil jacket and the massive support structure.

Table I. MFTF Magnet Parameters

Geometry	
Magnet type	Yin-Yang pair (minimum- B)
Major radius	2.50 m
Minor radius	0.75 m
Half-displacement	0.80 m
Lobe sweep half-angle	75°
Mean winding length (per coil)	17.8 m
Coil section ^a	0.34 × 0.75 m
Field Characteristics	
Mirror-to-mirror length ^b	3.4 m
Vacuum central field	2.0 T
Mirror field	4.0 T
Mirror ratio	2
Total stored energy	~500 MJ
Conductor Characteristics	
Superconductor	Cu-stabilized NbTi
Maximum conductor field	7.5 T
Design current	6.3 kA
Heat flux to liquid helium	0.25 W/cm ²
Dimensions	13 mm square
Cooling	LHe bath @ 1 atm
Conductor quantity	43 km (27 mi)
I·ℓ product	2.7 × 10 ⁸ A·m (8.8 × 10 ⁸ A·ft)
Winding Characteristics	
Winding style	Pancake wound
Insulation material	Fiberglass-epoxy laminate
Spacing between turns	≥ 1 mm
No. of turns per coil	1200
No. of splices per coil	~120
Winding mandrel (jacket)	Austenitic stainless steel

(continued)

Structure	
Nominal lobe force	100 MN (22×10^6 lb)
Maximum magnetic pressure	31 MPa (4500 lb/in ²)
Casing and intercoil members	Austenitic stainless steel (21-6-9)
Nominal case thickness	75 mm (3 in)
Operating temperature	~4 K

Mass	
Superconductor	65.0×10^3 kg (140×10^3 lb)
Insulation	5.2×10^3 kg (12×10^3 lb)
Jacket	13.0×10^3 kg (29×10^3 lb)
Case	95.0×10^3 kg (210×10^3 lb)
Intercoil members	18.0×10^3 kg (39×10^3 lb)
Total	196.0×10^3 kg (430×10^3 lb)

^aEquivalent rectangular dimensions.

^bNominal length measured on coil.

Fig. 1. Minimum- $|B|$ mirror field; dotted lines represent contours of constant $|B|$, field lines are shown solid.

Fig. 2. Magnetic field intensity on-axis.

Fig. 3. Yin-Yang magnet windings with relative plasma shape.

Fig. 4. MFTF coil geometry.

Fig. 5. Resultant forces due to the distributed magnetic pressure.

Fig. 6. MFTF magnet with its supporting structure.

Fig. 7. Magnet structural design must accomodate neutral beam injection.

Fig. 8. Conductor design.

Fig. 9. Coil assembly.

3. TECHNICAL DESCRIPTION OF THE BASELINE DESIGN

To satisfy the primary system requirements, as described by Dr. Vadim Kopytoff, Engineering will continue to perform in-depth analyses to optimize the Superconducting Magnet System. The final product must satisfy the following essential design requirements:

1. Operational Performance Requirements
2. Structural Requirements
3. System Configuration and Essential Features
4. Reliability, Quality Assurance and Safety Requirements
5. Applicable Codes and Standards
6. Instrumentation and Control Requirements
7. Design Life
8. Interfacing Systems Functions and Services
9. Maintenance Requirements

3.1 Operational Performance Requirements

The magnet system will feature a large coil pair in the proven Yin-Yang configuration. This geometry provides the required magnetic field shape with sufficient access for the neutral-beam injection perpendicular to the direction of the field.

A unique niobium-titanium superconductor with a copper matrix has been developed specifically for MFTF. The magnet will be cooled to the superconducting state by pool-boiling of liquid helium at near atmospheric pressure. The superconductor windings will be confined in a vacuum-tight structure (also cooled to liquid-helium temperatures) to withstand the large forces (6.5 million pounds) generated when the magnet is energized. The magnet system will generate a continuous magnetic field of 2 Tesla (20 thousand gauss) at the center of the plasma with the field increasing to 4 Tesla (40 thousand gauss) at the ends, or mirrors, to provide a mirror ratio of 2. The effective length of the field is 3.4 meters (11.2 feet). The coils will store 500-million joules of energy in the field. The operational performance requirements are summarized as follows:

1. Center Field	2T
2. Mirror Field	4T
3. Mirror Ratio	2
4. Mirror to Mirror Length	3.4 M
5. Total Energy Store	500 MJ
6. Max. Conductor Field	7.5 T
7. Design Current	6.3 kA
8. Operating Temperature	4°K

Operational performance of the MFTF Superconducting Magnet System will be measured and compared against the initial design criteria prior to experimental testing. LLL's previous experience in the design and development of the Baseball and 2XIIB superconducting magnets has shown that the final operational performance was predictably accurate to the system's stated design criteria.

3.1.1 Auxiliary Equipment

In addition to the items listed under Auxiliary Equipment in Document 142* it is recommended that the following be considered:

1. Primary welding and handling fixture: This equipment will be used to support the coil and jacket assembly while the structural case is added. Secondly, it will provide some variations to fixed position welding for the case construction phase. The fixture will have the ability to rotate the completed assembly about its centroidial axis. The fixture shall also be capable of transporting one completed coil assembly to the unloading area. The fixture will support the coil assembly to be lifted from the support dolly and lowered onto the structural mounting base. (Refer to conceptual design in Appendix B.)
2. Coil case shipping cradles: Shipping cradles must be able to load and unload the large sections of the coil structural case. These items can be constructed by the same vendor supplying the coil cases.

*"MX Major Project Proposal," LLL-Prop-142, Lawrence Livermore Laboratory, Livermore, California.

3.2 Structural Requirements

The proposed MFTF structure has no previous counterpart; thus, the engineering design involves some pioneering effort. Established techniques of stress analysis will be applied, but some code development is necessary for the unique Yin-Yang configuration. Much analytical effort will be necessary to insure structural integrity of the magnet. Structural design experience gained on LLL's superconducting Baseball magnet will be a valuable asset to the MX project. Before beginning a detailed structural analysis of the coil case and mounting structure, several design factors must be discussed.

3.2.1 Selection of Structural Materials

The desirable properties of the structural material are well known. Briefly, LLL requires high strength and toughness at liquid He temperature and low magnetic permeability after working. The material must be available in large bars and plates, and must be weldable as well as workable with conventional fabrication techniques. Common 300-series stainless steels do not exhibit sufficient yield strength. In addition, martensite precipitation, which is cumulative with cold cycling, can raise the permeability to prohibitive levels.

The tentative choice of materials for the magnet jacket and case has been made. Armco's Nitronic 40, a high-chrome, high-manganese stainless steel is the best candidate. Armco has indicated that they do not roll this plate. It must be procured from G. O. Carlson, Incorporated. The present price for large quantities of the steel, in the as-rolled annealed condition, is \$1.315/lb. Therefore, the estimate of \$1.35/lb. is valid. Shipping charges must be added.

Armco Bulletin S54 presents some interesting data relative to the physical properties of this steel. The strength is good at 4°K as is the toughness of the parent metal.

Armco is presently under contract with ERDA via the Tokamak Program to determine the weld physical properties of Nitronic 40. The data for the simulated heat affected zone (HAZ) is not valid. This material was sensitized for a corrosion study and does not simulate the HAZ of a welded structure. Mr. Harry Espy of Armco has discussed the present state-of-the-art of Nitronic 40 during a telephone conversation on 5/25/77.

The major problem area is the weld metal. Nitronic 40 is a nitrogen-strengthened stainless steel. Two phenomena result from this constituent: The yield strength and ultimate strength go up as the temperature is reduced and the metal has low permeability at low temperature. Metals like 304 stainless behave differently; i.e., the yield strength remains about the same while the ultimate strength goes up and they increase in permeability. Therefore, in large welds such as will be required for this case, the joints will exhibit significantly lower yield strength and higher permeability than the parent plate. Toughness, however, will be increased.

In addition to the above, Mr. Espy discussed two other areas. First, none of the slag types of processes should be used if the toughness is to remain high. Inert gas processes, such as spray, short or pulsed arc should be used. Secondly, E. B. Welding is not acceptable even if the equipment was available. The problem centers about the nitrogen. It boils out, and the weld nugget is not only lower in strength but is porous. E. B. Welding (in air) was considered because of the small weld nugget and HAZ, as well as shorter welding time.

It is apparent that careful consideration of joint location must be made so that the radial joints are made in low stress fields. A study to determine properties of the toughness of welded structures at 4°K should be made. As received, material should be checked against the accumulated data. Mr. Espy has indicated that NBS recommends against attempting Charpy tests at 4°K, as the specimen heats up too quickly. Testing at -320°F is used for screening with further testing at -423°F for those materials that show promise. A study of the data presented in the Armco S54 Bulletin shows a significant change in toughness from -110°F to -310°F, but only slight changes from -310°F to -423°F. It is not apparent that 3-inch plate is available for such a study. Note should be made that a more appropriate material has not been located. Cost of the above study is 4 man-years.

3.2.2 Welding

The development of welding specifications and procedures is dependent upon the above recommended study. However, due to the massive welds required for this structure, low heat input processes are appropriate. In addition, semiautomatic processes should be used wherever possible in order to provide maximum weld quality. The initial choice is the pulsed-arc Gas Metal Arc process. Because of the distortion aspects of stainless steel and due to the "one-sided" weld problem, block welding should be used. Appropriate welding engineering techniques will provide sound welds with minimal distortion.

3.2.2.1 Joint Design. It is assumed that all welds must be full penetration. However, due to the inaccessability of some of the welds, sound metal cannot be obtained throughout the nugget. The basic joint design must consider the problem of lamellar tearing which results from rolled plate having weak through-thickness properties. This requires that the corner joints be designed such that the weld nugget covers the thickness of the plate. Bevel cuts will be utilized where possible in order to allow "flame" cutting rather than milling edge preparation. However, it is also important that the nose of the weld preparation be accessible to the arc so that maximum penetration is obtained. Modified J-groove preparations and quarter J-grooves will be used on milled edges. The total mill time is estimated to be 842 hours for the case. No mill time is expected for the jacket as the lamellar problem is reduced because of plate size.

3.2.2.2 Capital Equipment. The above problem will require the following equipment:

1. Four pulse-arc welding machines - Airco PA3
water cooled or equivalent, for final fabrication at LLL	\$16,000
2. One welding positioner - 15 ton	} Assumed to be
on hand at
fabricator's
facility
3. One plasma-arc cutting machine or one
propane powder cutting torch	
4. One horizontal mill, 5-inch spindle min.	

3.2.2.3 Qualification and Certification. The welders and welding procedures would have to be qualified according to ANSI N45.2 - 1971. A minimum of six welders should be qualified. The welding procedure would serve to qualify all of the machines and one welder. Estimated time would be 8 man-weeks.

3.2.3 Magnet Structure

A major restriction on the coil structure is free access to the plasma. The unreinforced winding offers access between the magnet lobes and between the two coils (in the 45° plane). The goal is to minimize encroachment on this area; for example, by avoiding tension members that span the lobes. Our approach is to reinforce the magnet casing and provide a connecting member between the two coils so that one restrains the other.

The thickness of the casing is tentatively 76 mm, and in certain sections the casing width is increased to achieve sufficient stiffness. This is shown in Figure 3-1*(a), where the casing width at the center of the major radius is twice that required to span the coil bundle. Additional cross section is also added around the minor radius, both for strengthening that section of the coil and for reinforcing the base for the interconnecting cone. The cone transmits the high lobe force (F_X) to the other magnet, which acts as a C-clamp. In addition, the cone counteracts the F_Z force that tends to drive the two coils together.

To furnish input to the structural analysis, the magnetic forces generated by large mirror coils must be calculated. It is also important to determine the distribution of forces so that one may fully comprehend the nature of the loading. We use a version of MAFCO that computes the $\vec{I} \times \vec{B}$ product for short straight-line-segment approximations to continuous filaments.

A detailed structural analysis using three-dimensional stress analysis codes is still to be performed. Our first computer model of the coil structure will consist of three-dimensional beam elements. This model, although not absolutely accurate, enables us to make an efficient series of calculations for a parametric study.

*Figure 14, "MX Major Project Proposal", LLL-Prop-142, Lawrence Livermore Laboratory, Livermore, California.

Figure 3-1. Magnet structure, showing strengthening provided by (a) casing width, (b) additional cross section around the minor axis, and (c) reinforcement of the base.

With the information obtained from the above analysis, we shall proceed to a detailed design of the coil structure, using the SAPIV finite-element computer code. In this design, the structure will be modeled with three-dimensional plate and shell elements. The required SAPIV input data for this phase is quite complicated. Therefore, a computer program has been written to generate (from minimal input) plate, shell, and boundary element data for a Yin-Yang magnet. In addition, this generator will accept force output from EFFI and will produce load data appropriate for a shell analysis in SAPIV. The use of extra manpower and computer time is warranted here because this analysis will give us the final analytical assurance of the integrity of the coil structure. Here, we allow for the possibility of another iteration should another previously undiscovered critical-stress area be discovered. This identification is facilitated by use of the program SAMPP, which will graphically display SAPIV input and output.

This approach of using a simple but fast computer model for initial design and an accurate but relatively expensive model to complete the design is an efficient way of solving the structural problems of superconducting magnets.

3.2.4 Magnet Support Structure

The design of the support structure will be completed in two steps. Step 1 will provide a preliminary design based on hand calculations (or very simple math models). This step will provide the rough size for all members. Step 2 will provide a detailed finite element analysis of the preliminary structure. This phase will fill in all details for the final design.

The analysis of the structure will consider the effects of the following loading conditions:

1. The static load from the weight of the structure.
2. The pressure loads that result from the chamber being evacuated.
3. The thermal loads produced from low-temperature service. Areas to be investigated will include:
 - a. Material selection.
 - b. Thermal isolation and the effect, if any, on the response of the structure to the various loads.
 - c. Thermal stresses that might result in the magnet, support structure, and vacuum chamber.

4. The seismic loads (Figure 3-2) that may be generated during an earthquake. Items to be considered are foundation-structure interaction, effects on magnet and magnet support structure, and effects on the vacuum chamber.
5. Other miscellaneous loads that the facility could experience during its expected lifetime such as the handling loads caused during assembly and the magnetic loads from magnet.

3.3 System Configuration and Essential Features

The magnet system will employ a superconducting magnet in a Yin-Yang configuration. A Yin-Yang mirror pair was chosen to provide the minimum- $|B|$ well for two reasons: This configuration is efficient in terms of field production, and it provides access for neutral-beam injection perpendicular to the local magnetic field. The major decision as to whether the magnet should be a superconducting magnet or a conventional room-temperature magnet involved many factors, the more important being: time duration of the field; external heat sources on the coil (e.g., neutron heating); intrusion upon the plasma region by shields or liners; complexities of a low-temperature environment; and the need for large, high-power, energy-conversion systems. The superconducting magnet would also furnish technological experience with reactor-like designs, accelerate component development, and, especially, address steady-state-problems. Consideration of all these factors led to the choice of a superconducting magnet. NbTi conductors, whose technology will not require extraordinary development, will be used in the magnet. However, the large size of the coil will require some detailed conductor development prior to magnet construction. Since MX will require many liquid-helium (LHe) condensation pumps, the additional cryo-plant capacity required for the coil adds little complexity to the system. Table 1 lists key system parameters.

Magnet design began with parametric studies of various Yin-Yang coil geometries and with the evaluation of field characteristics. The choice was restricted to Yin-Yang minimum- $|B|$ configurations because of their successful employment in 2XII and 2XIIB. A regular Yin-Yang was employed in 2XII and a slanted Yin-Yang is used on 2XIIB.

A displaced Yin-Yang coil is actually a regular Yin-Yang designed for a mirror length of 5 m, but with the two windings displaced axially inward.

Of overriding importance in choosing a magnet geometry is providing access for neutral-beam injection, diagnostic apparatus, and vacuum pumping. The displaced Yin-Yang pair offers the greatest access, in both the 45° planes and the orthogonal planes (through the magnet lobes). For this reason, a displaced Yin-Yang pair was chosen for MFTF. Figure 6, Section 2, illustrates this general configuration.

Figure 3-2. LLL earthquake design criteria.

Table 1. MFTF magnet parameters.

<u>Parameter</u>	<u>Design Value</u>
Type of field	Minimum- B mirror
Magnet type	Displaced Yin-Yang pair
Major radius (mean)	2.5 m
Minor radius (mean)	0.75 m
Axial half-displacement	0.80 m
Coil section	0.34 x 0.75 m
Mirror-to-mirror length*	3.4 m
Vacuum central field	2.0 T
Mirror field	4.0 T
Mirror ratio	2.0
Conductor field near mirror points	6.4 T
Maximum conductor field	7.5 T
Conductor type	Cu-stabilized NbTi
Conductor current	6.3 kA
Overall current density	3400 A/cm ²
Number of turns	1200
Ampere turns	7.56 MA
Conductor quantity (both coils)	330 x 10 ⁶ A·M
Conductor mass (both coils)	65 x 10 ³ kg (140 x 10 ³ lb)
Total mass of coils with structure	196 x 10 ³ kg (430 x 10 ³ lb)
Total stored energy	~ 500 MJ
Maximum allowable plasma radius	120 cm

*This is the nominal length, based on the distance between the centroids of current.

3.3.1 Magnet Installation

The mass of the magnet assembly represents an installation problem. Existing crane capacity at the machine site is only 60 tons. The weight of one coil (including case) is ~100 tons and the total weight of the coil assembly is ~215 tons. During magnet installation, there must be enough crane capacity to hoist the individual coils, or about a 100-ton load. LLL has considered upgrading the existing crane, but although possible, this requires reinforcing the rail supports of the bridge (building structure) as well as adding a second bridge. A more economical solution is to hire a rigging contractor with a high-capacity mobile crane. This is indeed feasible, but does require dismantling a portion of the concrete-block shielding wall.

The actual installation sequence of the magnet is demonstrated in Figure 3-3. The first step [Figure 3-3(a)] is the attachment of the base of the main chamber to its support columns. The magnet support columns penetrate the bottom cover of the main chamber with a large metal bellows that makes the vacuum joint by connecting the magnet supports to the base. This joint mechanically uncouples the magnet from the main chamber vessel. Next [Figure 3-3(b)], two of the four interconnecting cones are attached to the support columns with a temporary stabilizing fixture. The bottom coil is then moved into position [Figure 3-3(c)] and attached to the two existing cones. The upper magnet is similarly lowered into place [Figure 3-3(d)], and the upper cones are attached between the two windings. Finally [Figure 3-3(e)], the temporary fixture is removed and the main cylinder and top cover are added.

3.4 Reliability, Quality Assurance and Safety Requirements

3.4.1 Reliability

The magnet system is the one critical element of the MFTF which does not have a back-up or redundant counterpart. System reliability is viewed as a paramount requirement to the success of the project.

3.4.2 Quality Assurance

Engineering will prepare a quality assurance (QA) plan for every detail in the assembly and manufacturing sequence to assure magnet performance and compliance to the engineering specifications. A technical support staff will be employed throughout the entire procurement and assembly cycle to execute the QA plan. Testing and reporting will be an ongoing requirement for the QA staff. Engineering will continue to be an integral part of this effort to further assure the success of the final magnet assembly.

*Figure F-17, "MX Major Project Proposal," LLL-Prop-142, Lawrence Livermore Laboratory, Livermore, California.

Figure 3-3. Magnet installation sequence, showing (a) attachment of base to support columns, (b) attachment of interconnecting cones to support fixture, (c) bottom coil moved into position and attached, (d) upper magnet lowered into place and upper cones attached, and (e) temporary fixture removed and main chamber cylinder and top cover added.

3.4.2.1 Quality Assurance Plan. The QA plan will provide the following:

1. A qualified technical staff responsible to Engineering.
2. 100 percent inspection for all outside procurements.
3. Validated testing procedures for all critical elements.
4. Responsive reporting and documentation.
5. A centralized records and filing system.
6. An effective means for handling discrepancies.
7. A fault-free analysis.

3.4.2.2 Technical Areas of the QA Plan.

1. Installation and checkout of the coil winding machinery.
2. Superconductor procurement.
3. Superconductor joining.
4. Joint integrity.
5. Electrical/mechanical testing of joints.
6. Insulation procurement.
7. Preparation and cleanliness.
8. Monitoring conductor tension.
9. Jacket and case procurement and fabrication.
10. Welding procedure and certifications.
11. Destructive and non-destructive testing of weld joints.
12. Vacuum leak testing.
13. Fastner (procurement and testing).
14. Special tooling (calibration and test).
15. Torque verifications and identification.

16. Weight, balance and C.G. checks.
17. Certified special lifting fixtures and rigging.
18. Safety equipment and interlocks.
19. Load testing of all lifting equipment.

3.4.3 Vacuum Integrity of the Magnet

Although this topic has not been discussed previously, it represents a critical area in attaining reliable magnet operation. The prime concern is that small vacuum leaks, undetectable at room temperature, might become prohibitively large when the coil is cooled down to LHe temperature. These "cold leaks" are extremely difficult to detect and locate and can severely hamper the overall construction schedule. We propose to investigate this problem area and develop a reliable technique or design for the vacuum integrity as part of the preconstruction development. Two obvious areas of pursuit are:

1. To develop ultrasensitive methods of leak detection at room temperature that are applicable to internal pressurization of the magnet container.
2. To provide a guard vacuum space as an integral part of the structural design. The guard vacuum would be designed with enough helium pumping capacity to limit the gas load on the plasma region to a tolerable level.

3.4.3.1 Vacuum Leak Test Plan. The leak detecting technique to be utilized in answering the vacuum integrity of the MFTF magnet system will consist of two phases. This will be true for both the superconductor jacket and the structural jacket. To reduce the amount of weld joints which must be checked after final assembly, a method of localized evaluation will be used prior to final assembly. All weld joints of the individual components will be checked by this method. Once the entire assembly is completed, a leak check will be performed on only those welds incurred during final assembly.

The localized method of leak detection will consist of a flexible rubber-sealed component similar to the rug attachment of a vacuum cleaner. This component must be designed and fabricated. It will be placed over a length of weld (approximately 2 or 3 feet) and attached to a leak detector. The component will be evacuated and helium introduced to the weld seam from the opposite side. This will allow verifying the vacuum integrity of welded joints prior to being in the final configuration.

During the final assembly of the magnet system, several welded joints around the entire inner and outer perimeter of the magnet structure must be made. To detect any leaks in these welds and any others incurred during final assembly the completed vessel will be evacuated. There are existing vacuum systems at the North Las Vegas Facility which can perform this task.

It seems advisable to conduct another system check after liquid helium has been circulated through the superconductors. This would insure that no damage has been caused by the introduction of the cryogenic fluid.

3.5 Safety Requirements

The safety requirements deal with the protective devices and procedures necessary to assure the safe operation of the magnet system. General personnel and equipment safety will be everyone's responsibility with the assistance of a full-time LLL Safety Officer.

One area of concern is a rapid thermal change in the coils which would drop the magnet out of the superconducting state. This obviously could destroy the magnet system and case structure with a stored energy in excess of 500 MF. The magnet system will be safeguarded from this type of accident as part of the electronic safety control.

Earthquake protection will be provided in the design of the magnet structural base and foundation mounting.

4. PROJECT SCHEDULE

MFTF **SUPERCONDUCTING MAGNET** **ASSEMBLY SCHEDULE**

Altes 6/30/77

5. MAGNET ASSEMBLY NETWORK

A first step in the development of an integrated program plan is to generate an accurate project assembly flow network. The assembly network shows the sequence of major engineering, fabrication, and assembly tasks necessary for completion of the MFTF superconducting magnet system. The major tasks will be further broken down and analyzed for cost estimating purposes.

10/1/77

25

MFTE
superconducting
magnet system
assembly

6. COST ANALYSIS

MFTF

SUPERCONDUCTING MAGNET

COST ESTIMATE SUMMARY

<u>ITEM</u>	<u>ESTIMATED COST</u> <u>\$000</u>
Magnet Coil Materials	\$2,300.
Coil Jacket and Structure Materials	1,065.
Magnet Coil Winding Labor	660.
Magnet Assembly and Installation	730.
Tooling	<u>1,119.</u>
 Fabrication Total*	 \$5,874.
 Engr./Design @ 25%	 <u>1,469.</u>
 TOTAL COST	 \$7,343.

*Includes no contingency.

PROJECT MTF - SUPERCONDUCTING MAGNET

JOB NO. B-380-02 BY ALTES

CHECKED DATE 7/20/77 SHEET 1 OF 1

ITEM	DESCRIPTION	QTY.	UNIT	MATERIAL		LABOR		TOTAL ITEM COST, \$
				UNIT COST	TOTAL \$	UNIT MAN HOURS	TOTAL MAN HOURS	
900	SUPERCONDUCTING, MAGNET STR.							
1100	MAGNET COIL MATERIALS	1	lot	—	2193	4,259	107	2300
1200	COIL TACKET & STRUCTURE	1	lot	—	786	11,172	279	1065
1300	MAGNET COIL WINDING LABOR	1	lot	—	—	26,400	660	660
1400	MAGNET ASSY, INSTL. & TEST.	1	lot		294	17,438	436	730
1500	POWER SUPPLIES			BY OTHERS.				
1600	EXCH. / DESIGN	1	lot			58,760	1469	1469
1700	TOOLING	1	lot	—	1089	1164	30	1119
TOTAL					4362		2981	7343

① BASED ON \$25/HR.

MAGNET COIL MATERIALS.

MT-F -

PROJECT

JOB NO. B-380-02 BY ALTS

CHECKED

DATE 5/25/77

SHEET

7 OF

[illegible]

ENGINEERING NOTE

1100

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PAGE

SUBJECT

MFTF - SUPERCONDUCTING MAGNET

NAME

OLSON

DATE

5/25/77

GENERAL

THE FOLLOWING ESTIMATES ARE FOR TWO MAGNETS AND BASED ON THE HORIZONTAL WINDING CONFIGURATION. I FEEL THERE WOULD BE LITTLE OR NO COST CHANGE FOR MATERIALS & TOOLING TO WIND THE MAGNETS IN A VERTICAL CONFIGURATION. HOWEVER, THE NUMBER OF CONDUCTOR JOINTS WOULD BE ABOUT HALF IN THE VERTICAL CONFIGURATION. THIS IS A SIGNIFICANT ADVANTAGE AND SHOULD BE EXAMINED IN MORE DETAIL.

ENGINEERING NOTE

1110

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SUBJECT

MFTF - MAGNET COIL MATERIALS

NAME

W. OLSON

DATE

5/18/77

ITEM 1110 MAGNET COIL MATERIALS ESTIMATES

LATEST CONDUCTOR COST ESTIMATES ARE AS STATED IN MOST RECENT LLL REPORT. THIS WAS CONFIRMED BY DR KOPYTOFF DURING HIS VISIT TO EG & G MAY 18, 1977.

1110 CONDUCTOR

1111 NbTi CONDUCTOR - $3.3 \times 10^8 \text{ A}\cdot\text{M}$ @ $\$0.0044/\text{A}\cdot\text{M}$ \$1452K
SECT. 1.11 OF L³ REPORT

1112 STABILIZING COPPER - $1.33 \times 10^5 \text{ lb}$ @ $\$1.50/\text{lb}$ 200K
SECT 1.12 OF L³ REPORT

1113 PREFAB INTO COMPOSITE - $1.7 \times 10^5 \text{ ft}$ @ $\$1.60/\text{ft}$ 272K
SECT 1.14 OF L³ REPORT

1114 SHIPPING (FROM P 2/2) 14K

1115 SCRAP LOSS3% OF 1111 $\rightarrow$ 1113 $(.03)(1924 \text{ K}) \approx$

60K

TOTAL

=

\$1998K

ENGINEERING NOTE

1110

PAGE

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SUBJECT

MFTF - MAGNET COIL MATERIALS

NAME

ASN

DATE

5/19/77

ITEM 1110 MAT'L ESTIMATES

1114 SHIPPING

CONDUCTOR

CONDUCTOR IS ASSUMED TO BE SHIPPED ON REELS
WITH THE FOLLOWING STATISTICS:

134" O.D. = 11'-2" O.D.

126" HUB DIA. = 10'-6" HUB DIA.

40" OUTSIDE WIDTH = 3'-4" O.W.

11000 lb WEIGHT

INCLUDES 8500 lbs CONDUCTOR

2500 lbs WOOD REEL

TOTAL QUANTITY OF 24 REELS

OR 264,000 lbs.

ACTUAL SHIPPING WT. WILL PROBABLY RUN UP TO
300,000 lbs.

∴ SHIPPING COST FROM AIRCO, MURRAY HILL,
NEW JERSEY TO LLL IS;

PER ANDY ANDERSON OF SOUTHERN PACIFIC RAILROAD

@ A RATE OF \$4.43/CWT WITH 80,000 lbs MINIMUM
 $3 \times 10^5 \text{ lbs} \times \$0.043/\text{lb} = \$14 \text{ K}$

SUBJECT

MFTF - MAGNET COIL MATERIALS

NAME

OLSON

DATE

5/19/77

ITEM 1130 MATL ESTIMATES

1130 INSULATION

1131 CASE

ASSUME A HIGH VOLTAGE MYLAR .010" THK IS USED. SINCE EACH MAGNET HAS $\sim 600 \text{ ft}^2$ AND FIGURING 100% EXTRA.

$$600 \times 2 \text{ MAG.} \times 2 \quad @ \$12/\text{ft}^2 = \$288 - \approx \underline{\underline{\$3 \text{ K}}}$$

(2400 FT²)

1132 INTER-TURN

OVERALL CONDUCTOR LENGTH IS $48.6 \times 10^3 \text{ M} = 1.6 \times 10^5 \text{ ft}$
 $= 1.91 \times 10^6 \text{ in.}$

IF 7/16 DIA BUTTONS ARE STUCK ON .5" WIDE x .005 THK MYLAR TAPE, THE NUMBER OF BUTTONS REQ'D (N_B) TO COVER 50% OF THE CONDUCTOR IS;

$$N_B = \frac{\text{AREA OF CONDUCTOR } (A_C)}{2 \times \text{AREA OF BUTTONS } (A_B)}$$

$$A_C = .5" \text{ WIDE} \times L = .5(1.91 \times 10^6 \text{ in}) = 9.567 \times 10^5 \text{ in}^2$$

$$A_B = .1503 \text{ in}^2$$

SUBSTITUTING,

$$N_B = \frac{9.567 \times 10^5 \text{ in}^2}{2 (.1503 \text{ in}^2)} = \underline{\underline{3.182 \times 10^6 \text{ BUTTONS}}}$$

THE SPACING BETWEEN BUTTONS (d) IS;

$$d = \frac{L}{N_B} = \underline{\underline{.601"}}$$

COSTS

3.2×10^6 1/32" THK x 7/16" DIA GLASS-EPOXY

BUTTONS (G-10) @ \$3.84/M

\$12.3K

$1.6 \times 10^5 \text{ ft.}$ OF .005 THK x .5" WIDE MYLAR TAPE

@ \$11.75 / M ft

1.9K

COST TO PUT BUTTONS ON TAPE

@ \$20 / M ft

3.2K

TOTAL COST OF INTER-TURN INSULATION

\$17.4K

THIS REPRESENTS \$.109 / ft

RAW MATERIAL COST WAS OBTAINED FROM PLASTIC CENTER, INC.

ENGINEERING NOTE

1130

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SUBJECT

MFTF - MAGNET COIL MATERIALS

NAME OLSON

DATE 5/19/77

ITEM 1130 MAT'L ESTIMATES

1133 INTER-LAYER

THE QUANTITY OF INTER-LAYER INSULATION
RAW $\frac{5}{16}$ SHEET STOCK IS;

$$40 \text{ LAYERS} \times \frac{15" \text{ WIDE}}{12 \frac{1}{4}"} \times 20.6 \text{ M} \left(3.28 \frac{\text{ft}}{\text{M}} \right) \times 2 \text{ MAG.} \times 2 (\text{SCRAP}) = 13,520 \text{ #}^2$$

$$\text{WEIGHT} = 13,520 \text{ #}^2 \left(.772 \frac{\text{#}}{\text{#}^2} \right) \text{ FOR G-10 GRADE GLASS-EPXY} \\ = \underline{10,436 \text{ #}}$$

RAW MAT'L COST (GRADE G-10)

$$11000 \text{ #} @ \$2.28/\text{#}$$

\$25K

LABOR TO PUNCH SLOTS IN SHEET - 40% SHEET
AREA TO BE SLOTS.

$$\sim 100 \text{ #}^2/\text{HR} \rightarrow \underline{136 \text{ HRS}}$$

THIS REPRESENTS $\sim$. ' LINEAR FEET/MINUTE OF A
3 FOOT WIDE SHEET.

LABOR TO CUT SHEET FOR ONE LAYER

$$\sim 8 \text{ HR/LAYER} \times 80 \text{ LAYERS} = \underline{640 \text{ HRS}}$$

RAW MAT'L COST FROM PLASTIC CENTER, INC.

1134 RAMPS

120 RAMPS REQ'D FOR 2 MAGNETS MACHINED FROM 1" THK
GLASS-EPXY SHEET. APPROX. MAT'L WEIGHT IS

$$1" \text{ THK} \times 2" \times 24" \times 120 \text{ PLS.} \times \frac{1}{144} \text{ in}^2 @ 10 \frac{\text{#}}{\text{#}^2} = 400 \text{ #}$$

$$\text{COST OF } 400 \text{ # G-10 SHEET} @ \$2.30/\text{#} = \underline{\$1 \text{ K}}$$

LABOR TO MACHINE RAMPS @ $\sim 4 \text{ HRS EACH}$ IS

$$120 \times 4 \Rightarrow$$

480 HRS

ENGINEERING NOTE

1130

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SUBJECT

MFTF - MAGNET COIL MATERIALS

NAME

OLSON

DATE

5/19/77

ITEM 1100 MAT'L ESTIMATES1135 GLUE BLOCKS

MAT'L REQ'D

.5" x 10" G-10 GLASS-EPOXY SHEET

2 MAG. x 30 TURNS x 20.6 M = 1236 M → 4056 ft

WEIGHT = .5 x 4056 / 12 x 10 x 2 (SCRAP) ≈ 3400 #

COST OF 3400# G-10 SHEET @ \$2.20/#

7.0K ←

MAT'L TO BE PURCHASED IN SHEET FORM, THEN CUT.
LABOR TO CUT & FORM BLOCKS IS ESTIMATED
AT 30 HRS PER TURN.

LABOR = 30 HRS (30 x 2) ⇒ 1800 HRS ←1136 ENCAPSULATING MAT'L

SURFACE AREA OF COIL IS

$$A = \frac{(17" + 14" + 15\sqrt{2})}{12"/ft} \times 21 M \times 2 \text{ MAGNETS} \times 3.281 \frac{ft}{M}$$

$$A = 600 \text{ ft}^2$$

ASSUMING COIL IS COVERED BY 1" OF EPOXY & GLASS MAT'L.
VOLUME OF MAT'L IS

$$V = 600 \times \frac{1}{12} = 50 \text{ ft}^3$$

FIGURING 50% ADDITIONAL REQ'D FOR WASTE, ETC.

$$V = 75 \text{ ft}^3 \text{ OR } 563 \text{ GAL}$$

MAT'L COSTSG-10 SHEET 50 ft² x 1.5' x 120#/ft² @ \$2.20/#\$20.6K ←

300 GAL. CONAP K-22 @ \$30/GAL

\$9K ←LABOR TO CUT & FIT MAT'L @ 500 HRS/MAGNET 1000 HRS

RAW MAT'L COSTS FROM PLASTIC CENTER, INC. & ADVANCED
ELECTRIC SALES.

SHEET 1 OF 1

[illegible]

ENGINEERING NOTE

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SUBJECT

MFTF - SUPERCONDUCTING MAGNET

NAME

ALTES

DATE

5/25/77

COIL MONITORING INSTRUMENTATION

STRAIN GAGES

THERMOCOUPLES

NO • READ-OUT EQWP. INCLUDED

• WIRE TO CONTROL CENTER

ASSUME \$10,000

ENGINEERING NOTE

1170

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SUBJECT

NETF - MAGNET COIL MATERIALS

NAME R. ALTES

DATE 5/23/77

TRIAL WIND MATERIAL

ASSUMES • TRIAL WIND IS MADE

- MATERIAL USED IS 5% OF MATERIAL REQUIREMENTS FOR 2 FULL COILS.

MATERIAL

SUPERCONDUCTOR

$$1998K (.05) \approx 100K$$

INSULATION

$$81.1 (.05) = \underline{4K}$$

\$104K

LABOR

INSULATION

$$4056 (.05) = \underline{203 \text{ MHS.}}$$

PROJECT NI-TF - COIL JACKET AND STRUCTURE

[illegible]

Fig. 9. Coil assembly.

ENGINEERING NOTE

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1215

SUBJECT

MTEF COST ESTIMATION (coil Jacket)

NAME Y CHANG

DATE 5-20-77

coil Jacket is used to provide frame for coil winding and vacuum seal for He coolant.

QTY: 2 REQUIRED.

Unit:

MATL Nitronic 40 (21-6-9)

PREFAB
LABOR

INCLUDED IN SECTION 1400

Above Labor cost is to cover the pre-fab parts.
It does not include the assembly cost.

ENGINEER Labor:
(SEC 1100)

PROBLEM EVALUATION & ANALYSIS	60 MH
CONCEPTUAL DESIGN & CALCULATION	80 MH
DRAFTING	6 DRAWINGS (E) (240 MH)

ENGINEERING NOTE

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SUBJECT

MFT MAGNETS (CEIL JACKET W/ Estimation)

NAME Y CHAN

DATE 5-17-77

Note: total jacket should be made of 20 units. 20 per magnet Radius sides. 4 for minor radius side Each unit is made of pre-fabricated side plates as shown in sketch. PT 1 should be 1" thick made in "L" shape PT 2 should be 1" $\frac{3}{4}$ " plate made in "L" shape PT 3 should be 3" plate shape PT 1 is bolted with cell MT Adapter prior to test winding.

ENGINEERING NOTE

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1215

NAME ALTES

DATE 5/24/77

SUBJECT METE COST EST (COIL JACKET)

MATERIALS ALUMINUM 40 (.28 LB/IN³) FINISH WT

INNER FORM (SEE L³ DWG AAA76-112235-00)
(LARGE RADIUS LAYOUT)

$$W_T = \pi (114.62^2 - 76.5^2) \times \frac{2 \times 75}{360} \times (.28) = 2670 \text{ LB EA.}$$

$$\text{EDGE R.} = \frac{1}{2} \times 2" \times 150^\circ$$

$$W_T = 2\pi (.77)(.5)(2) \left(\frac{360}{150}\right) (.28) = 56$$

$$\frac{2726 \text{ LB EA.}}{56}$$

INNER FORM - (SEE L³ DWG AAA76-112236-00)
(SMALL RADIUS)

$$W_T = 2\pi (21.76 + .5)(1)(360) \left(\frac{360}{150}\right) (.28) = 620 \text{ LB.}$$

$$\text{EDGE R.}$$

$$W_T = 2\pi (23)(.5)(.9) \left(\frac{360}{150}\right) (.28) =$$

$$\frac{641 \text{ LB EA.}}{21}$$

ENGINEERING NOTE

1215

PAGE

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SUBJECT

MFTF COST EST. (COIL JACKET)

NAME ALTES

DATE 5/24/77

MATERIAL - CONT'D.FINISH WT.COVER - LARGE RADIUS L/O.L³ DWG - AAA'6-112233-00PLATE : $\frac{1}{2}$ " THK.

$$AREA = 38 \times \left(\frac{25 + 16.69}{2} \right) = 792 \text{ IN}^2$$

$$+ 16.69 \times \sim 24 = 400$$

$$+ 18 \times \sim 20 = 360$$

$$\overline{1552} \times \frac{1}{2} = 776 \text{ IN}^3$$

$$WT \text{ EA.} = 776 \times .28 = \underline{217 \text{ LB.}}$$

NO. REQ'D: 24/COIL.

COVER - LARGE RADIUSL³ DWG, AAA'6-112234-00PLATE : $\frac{1}{2}$ " THK.

NO. REQ'D : 10/COIL.

ENGINEERING NOTE

1215

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SUBJECT

META COST EST (COIL JACKET)

NAME

ALTB3

DATE

5/24/77

MATERIAL - CONT'D.

FINISH WT.

COVER LARGE RADIUS - CONT'D.

$$WT = \pi (38^2 - 22.26^2) (.5) (.28) \left(\frac{36}{3600} \right) = 42 \text{ LB}$$

$$+ \sim 42 \text{ LB}$$

$$+ \sim 42$$

126 LB.

TOTAL JACKET WT/COIL.

$$WT = 2 \times 2726 = 5452$$

$$+ 2 \times 641 = 1282$$

$$+ 24 \times 217 = 5208$$

$$+ 10 \times 126 = 1260$$

$$\text{FINISH WT/JACKET} = 13,202 \text{ LB EA.}$$

$$\text{SCRAP LOSS } 30\% \approx 4,000 \text{ LB.}$$

$$\text{STOCK WT/JACKET} = 17,202 \text{ LB EA JACKET}$$

ENGINEERING NOTE

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SUBJECT

NIFTE COST ESTIMATE (COIL JACKET)

NAME

ALTES

DATE

5/25/77

MATERIAL -

SCRAP ALLOWANCE

REF: INNER FORM - LARGE RADIUS LAYOUT
L³ DWG NO. AAA 70-11235-00

$$\begin{aligned}\text{FINISH PART WT} &= \pi(114.62^2 - 76.50^2) \times 1 \times \left(\frac{150}{360}\right) \times .28 \\ &= 2670.3 \text{ LB.}\end{aligned}$$

$$\begin{aligned}\text{STOCK WT.} &= [2(48 \times 96) + (48 \times 120)] \times (.28) \\ &= 4193.28\end{aligned}$$

$$\begin{aligned}\text{SCRAP WT} &= 4193 - 2670 \\ &= 1523 \text{ LB.}\end{aligned}$$

$$\text{SCRAP AS \% OF FINISH WT} = \frac{1523}{2670} = 57\%$$

$$\text{SCRAP AS \% OF STOCK WT} = \frac{1523}{4193} = 36\%$$

ASSUME FOR ALL NITRONIC 40 FABRICATIONS
THAT EFFICIENT LAYOUT WILL LIMIT SCRAP LOSS
TO 30% OF FINISH PART WT.

ENGINEERING NOTE

1215

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SUBJECT

MFTF - MAGNET COIL ESTIMATE

NAME

ALTES.

DATE

5/25/77

MATERIAL COST. -

NITRONIC 40

PER : ART RINIER

G.O. CARLSON STL. CO.

COATSVILLE PENN.

- NITRONIC 40 PROPRIETARY TO ARMCO
- ARMCO SUPPLIES INGOTS TO CARLSON STL. CO. FOR ROLLING INTO PLATE. MILL IS IN PENN.

COST FOR STEEL DELIVERED TO L³ IS
AS FOLLOWS.

PLATE COST AT PENN. MILL.

\$1.315 / LB.

(~ 500,000 LB. QUANTITY)

* STORAGE (REF P.9)

ASSUME PLATE IS ROLLED & HELD
FOR SHIPMENT TO SPECIFIC
FABRICATORS.

STORAGE FEE \$4.50/100 WT

.045 / LB.

* SHIPPING

MILL TO WEST COAST FABRICATOR
(ESTIMATE)

.05 / LB.

TOTAL COST / LB = 1.410 / LB.

* ADDITIONAL HANDLING & SHIPPING CHARGES
AS ESTIMATED BY ALTES

ENGINEERING NOTE

1215

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SUBJECT

NITE - MAGNET COST ESTIMATE.

NAME

ALTES

DATE

5/25/77

FREIGHT RATES. - LATE '76 PRICES.

PER: ALKE MONROE EG&G PURCHASING
PRICES FOR STEEL STOWL SHIPMENTS
VIA RAIL.

HOUSTON → S.F. VIA SOUTHERN PACIFIC.

40,000 LB.	\$ 3.68/100 WT
80,000 LB	3.44/ L L
120,000 LB	3.32/ L L

EAST COAST (PENN. TO S.F.)

100,000 LB.	\$ 4.57/100 WT.
-------------	-----------------

ALL PRICES INCLUDE LOAD & UNLOAD AT BOTH
ENDS.

PRICES DO NOT INCLUDE WAREHOUSE
STORAGE OR HOLDING, FOR ANY LENGTH OF TIME

ENGINEERING NOTE

1215

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SUBJECT

MFTK - MAGNET COST ESTIMATE

NAME ALTES

DATE 5/25/77

WAREHOUSE RATES.

PER: ALICE MONROE, EG&G PURCHASING.

EG&G PURCHASES MATERIALS THAT ARE HELD
IN STORAGE BY AM CASTLE IN SAN FRANCISCO.

THIS MATERIAL IS SHIPPED ON DEMAND

COST FOR

STORAGE

ADMINISTRATION

INVENTORY

MARKING

CERTIFICATIONS

\$ 4.50/100 LOT

ENGINEERING NOTE

1215

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SUBJECT

METF - MAGNET COST ESTIMATE

NAME R. ALTES

DATE 5/25/77

FREIGHT RATES - RAIL

PER : SOUTHERN PACIFIC
S.F. OFFICE
JANIE DANIELS
392-4284

HOUSTON TO S.F. - PLATE, ROLLED SHAPES.
90,000 LB MIN. RATE \$3.22/100 WT.

COATSVILLE, PENN. TO HOUSTON

80,000 LB MIN RATE \$1.72/100 WT

ENGINEERING NOTE

1215

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SUBJECT

MFTF - MAGNET COST

NAME

ALTES

DATE

5/25/77

COIL JACKET.

COST SUMMARY.MATERIAL COST. PER JACKET. (REF P. 5)

$$17,202 \frac{\text{LB}}{\text{JACKET}} \times \$ \frac{1.41}{\text{LB}} = \$ 24,255$$

$$\text{SHIPPING @ } \$.05 / \text{LB} \times 17,202 = 660$$

SHIP COMPLETED
PREFAB PARTS

24,915

USE \$ 25,000 / JACKET.

FABRICATION IN SECTION 1400

② COST OF SHIPPING PREFAB Pcs. TO L³

① COST INCLUDES SHIPPING R; MILL TO FABRICATOR

ENGINEERING NOTE

1220

PAGE

SUBJECT

MFTF (COIL CASE & MOUNTING STRUCTURE STUDY)

NAME Y CHANG

DATE 5-18-77

THE MAGNETIC FORCE IN Y AXIS IS 4.1×10^6 #
of "YING"
ASSUME ALL THE LOAD ON X AXIS IS APPLIED TO OTHER
MAGNET (YANG) ALONG Y AXIS. THEN THE MAX.
POSSIBLE FORCE ALONG Y AXIS COULD BE

$$(4.1 + 22) \times 10^6 \# = 26.1 \times 10^6 \#$$

WHICH IS 250 CM FROM THE MAX. BENDING SECTION
98.4 in

$$M = 26.1 \times 10^6 \times 98.4 \text{ in} = 2.56 \times 10^9 \text{ in-}\#$$

THE YIELD STRENGTH OF Nitronic⁴⁰ (21-6-9) (COLD WORKED) IS

180,000 PSI (AT ROOM TEMP.)

ULTIMATE STRENGTH IS 202,000 PSI (AT ROOM TEMP.)

USE $\frac{S.F.}{U.T.} = 4$

$$\frac{202 \times 10^3}{4} = \frac{2.56 \times 10^9}{I/C}$$

$$I/C \geq 50 \times 10^3 \text{ IN}^3$$

MAJOR RADIUS

LOAD ALONG X AXIS. GIVES BENDING MOMENT AT
MINOR RADIUS.

$$M = (22 \times 10^6 \times 29.5 \text{ IN}) = 0.65 \times 10^9 \text{ in-}\#$$

$$I/C \geq 13 \times 10^3 \text{ IN}^3$$

MINOR RADIUS

* 22×10^6 # ALONG X AXIS IS QUESTIONABLE. SHOULD BE AROUND 8×10^6 #.

ENGINEERING NOTE

1210 - 1220

PAGE

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SUBJECT

MFTF (MAG. CASE MOUNTING ARRANGEMENT)

NAME Y CHANG

DATE 5-18-77

ROT. 90° ABOUT
VERTICAL AXIS

SUBJECT

MFTF (COIL CASE & MOUNTING STRUCTURE STUDY)

NAME

Y CHANG

DATE

5-18-77

FOR MAJOR RADIUS (AT MAX BENDING SECTION)

Centroid:

$$\bar{x} = \frac{\sum A \cdot x}{\sum A} \quad \bar{y} = \frac{\sum A \cdot y}{\sum A}$$

$$\bar{y} = \frac{63 \times 2 + 232 \times 42 + 202 \times 44 + 59 \times 61.5 + 22.5 \times 11.5}{63 + 232 + 202 + 59 + 22.5} = 41.86"$$

$$I = \sum I_u + \sum A d^2$$

$$= \left\{ \begin{array}{l} \frac{21(2)^3}{12} + 63(40)^2 \\ \frac{3(202)^3}{12} + (202)(2)^2 \\ \frac{3(232)^3}{12} + (232)(0.5)^2 \\ \frac{22.5(3)^3}{12} + 22.5(40)^2 \end{array} \right.$$

$$= 47 + 110900 + 2060602 + 3121792 + 36000 = 5.3 \times 10^6 \text{ in}^4$$

$$\frac{I}{c} = 2 \times \frac{5.3 \times 10^6}{40} = 2 \times 132 \times 10^3 \text{ in}^3 = 264 \times 10^3 \text{ in}^3$$

Compare to $50 \times 10^3 \text{ in}^3$ minimum

Required Section Modulus.

Plate with 100 cm crown. (extended radius beyond jacket is sufficient.)

if appears 3" THICK

There are two of this sections on coil CASE. Total I/c should be $2 \times 132 \times 10^3 \text{ in}^3 = 264 \times 10^3 \text{ in}^3$

ENGINEERING NOTE

1220

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SUBJECT

MFTF (WT. Estimation of MAG. COIL CASE)

NAME

Y CHANG

DATE

5-19-77

MATERIAL: FINISH WT. EST.

$$\textcircled{1} \quad 4 \times \left[\frac{(120)^2 \pi}{2} \cdot \left(\frac{150}{180} \right) + 2 \cdot 40 \cdot 120 - \frac{(70)^2 \pi}{2} \cdot \left(\frac{150}{180} \right) \right]$$
$$= 88141 \text{ in}^2$$

$$\textcircled{2} \quad (2 \times 38.5 \times \pi + 2 \times 18 \times \pi) (137 - 70 - 6)$$
$$= 21655 \text{ in}^2$$

$$\textcircled{3} \quad (2 \times 120 \times \pi + 2 \times 70 \times \pi) \times (21 - 6)$$
$$= 17907 \text{ in}^2$$

$$\textcircled{4} \quad 2 \times [(38.5)^2 \pi - (18)^2 \pi]$$
$$= 7277 \text{ in}^2$$

$$\textcircled{5} \quad 2 \times 118.5 \cdot \pi (21 - 6)$$
$$= 11168 \text{ in}^2 \quad \sim 10,000 \#$$

① AREA of 4
FACET PLATE
ON MAJOR
RADIUS.

② AREA of INNER
& OUTER SIDE
PLATE ON MINOR
RADIUS.

③ AREA of inner
& OUTER SIDE
PLATE ON MAJOR
RADIUS.

④ AREA of facet
plate on MINOR
RADIUS.

⑤ intermediate
partition.

$$\text{total AREA: } 146148 \text{ in}^2$$

$$\text{Volume: } 3 \times 146148 = 438444 \text{ in}^3$$

$$\rho = .29 \text{ #/in}^3$$

$$\text{WT.} = 127 \times 10^3 \text{ # per CASE}$$

MAT'L Nitronic 40 (21-6-9) stainless steel

ENGINEERING NOTE

1220

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SUBJECT

MFTF (wt. estimation of NAB coil cable)

NAME

Y CHANG

DATE

5-23-77

$$(2 \times 98.5 \times \pi \times \frac{15}{18} + 30 \times 2\pi) [57.8"] = 706.578 = 407050 \text{ in}^3$$

$$\text{sp wt} = .29 \text{ #/in}^3$$

$$\text{total wt. } 110 \times 10^3 \text{ #}$$

THIS ESTIMATION DOES NOT INCLUDE
(THE PORTION WHICH EXTEND BEYOND
THE MAJOR RADIUS).

ABOVE FIGURE IS TO VERIFY THE
WT. ESTIMATION OF COIL CABLE.

ENGINEERING NOTE

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SUBJECT

MF TF MAGNET COST ESTIMATE

NAME ALTES

DATE 5/25/77

COIL CASE.

COST SUMMARY

MATERIALS. (PER CASE)

NITRONIC 40

127,000 ^{LB}
CASESCRAP @ 30% $\approx$

40,000

167,000 LB.COST @ L⁴¹ ^① =

235,470

SHIPPING - FAB TO L³

\$.05/LB x 127,000 =

6350

\$ 241,820

USE \$242,000 / COIL CASE

FABRICATION IN SECTION 1400

② COST OF SHIPPING PREFAB FLS. TO L³

① COST INCLUDES SHIPPING FL, MILL TO FABRICATOR

ENGINEERING NOTE

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SUBJECT

MFTF COST ESTIMATION (COIL CASE)

NAME

Y CHANG

DATE

5-24-77

QTY: 2 units REQ.

Unit:

MTRL: Nitronic 40 (21-6-9)

3" plate, in various sizes.

Total AREA: 1012 sq ft.

Total WT. 127 x 10³ #.PRE FAB
LABOR:

prefab welding (SECTION 1400)

MACHING MISC. 360 M-H

CUTTING (SECTION 1400)

Drilling, Taping 240 MAN-HR

(For fittings, pipes, gaskets etc.)

600 MH

REF
SEC 1420

ENGINEERING NOTE

LIFT (at estimation of indicated members)

SUBJECT

NAME

Y CHANG

DATE

5-23-77

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Indicated members

Contact Load: 26×10^6 # between rails

The contact pressure should be less than 100,000 psi. (Fr 246-9)
 A/in. AREA REQ:

$$26 \times 10^6 / 1.10 \times 10^5 \text{ psi} = 236 \text{ in}^2$$

It consists of (10) 1.5" thick ribs spaced in two "end plates, approximate size of these ribs will be 60" in average length and 30" wide.

$$\text{Total Volume: } 10 \times 1.5 \times 60 \times 30 = 27000 \text{ in}^3$$

Sp. wt. 1.29 g/in^3

Total wt 7830 #

End plate is about 30" wide Average length: 70"

Two required

Total Vol. $2 \times 30 \times 70 \times 1 = 4200 \text{ in}^3$ Wt. $4200 \times 1.29 = 1218 \text{ #}$

Total wt. of rail with rail member is

$$\text{Wt} = 7830 + 1218 = 9048 \text{ #}$$

EACH MEMBER
 4 TOTAL

ENGINEERING NOTE

1225

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SUBJECT

MFE - MAGNET COST EST.

NAME ALTES

DATE 5/25/77

INTERCONNECTING MEMBERS

MATERIAL COST EST.

NITRONIC 40

WT EA. MEMBER (FINISH) 9048 LB.

SCRAP @ 30% = ~ $\frac{3000}{12,048}$

STK WT = 12,048

Cost @ \$1.41/LB =

\$17,000

SHIPPING, FABRICATOR TO L³

.05 x ~10,000 #

 $\frac{500}{\$17,500}$

USE \$18,000 EA. MEMBER

ENGINEERING NOTE

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SUBJECT

MFTF cert Estimation (intercon. members)

NAME

Y CHANG

DATE

5-22-77

Interconnecting members

QTY: 4 REQUIRED

MAT'L Nitronic 60 (21-6-9) stainless steel.

$$(10 \times 1.5 \times 60 \times 30 + 1 \times 70 \times 30) \cdot 29 \\ = 904 \text{ lb} \quad \times \quad \$ 1.35/\text{lb} \quad = \$ 12214.00$$

Labor: Assume this piece of structure is welded together.

Cutting 120 MH

Machining 120 MH

Welding 800 MH

1040 MH.

SUBJECT

MFTF - MAGNET SUPPORT STRUCTURE

NAME

A.M.D.

DATE

5.24.77

• ESTIMATE COLUMN SIZE

• VIEW OF STRUCTURE

• DEAD LOAD REQUIREMENTS

$$P_{TOTAL} = 430 \text{ k}$$

$$P/col = 430/4 \doteq 110 \text{ k/col}$$

• ASSUME A LATERAL LOAD OF $1/2 q$

• ASSUME COLUMNS ~~ARE~~ MOMENT RESISTANT CONNECTION AT MAGNET AND PINNED AT THE FOUNDATION.

SUBJECT

MFTF - MAGNET SUPPORT STRUCTURE

NAME AMD

DATE 5.24.77

- ESTIMATE CONT'D
- LOAD ON COL. "A"

$$\Sigma M_B = 0 = 2P(29) - R(17)$$

$$R = \frac{2(29)}{17} \cdot P = 3.41 P$$

ASSUME

- COLUMNS MADE WITH STAINLESS STEEL WITH $F_y = 36 \text{ ksi}$
- $F_b = 0.6 F_y = 21.6 \text{ ksi}$

FROM AISC CODE

$$\frac{f_a}{F_a} + \frac{C_m f_b}{(1 - \frac{f_a}{F_c}) F_b} \leq 1.0$$

TRY 48" ϕ PIPE W/ $\frac{1}{2}$ " THK WALL

$$A = \frac{\pi}{4} (d_o^2 - d_i^2) = 74.61 \text{ in}^2$$

$$I = \frac{\pi}{64} (d_o^4 - d_i^4) = 21045.5 \text{ in}^4$$

$$S = \frac{\pi}{32} \left[\frac{d_o^4 - d_i^4}{d_o} \right] = 876.9 \text{ in}^3$$

$$r = \sqrt{\frac{I}{A}} = 16.8$$

THEN

$$f_a = \frac{4.41(110)}{74.61} = 6.5 \text{ ksi}$$

$$f_b = \frac{M}{S} = \frac{9.5(110)(12)}{876.9} = 14.3 \text{ ksi}$$

$$\frac{K L}{r} = \frac{2(19)(12)}{16.8} = 27.1$$

$$F_a = 20.1 \text{ ksi}$$

$$F_c = 20.48 \text{ ksi}$$

$$\frac{f_a}{F_a} + \frac{C_m f_b}{(1 - \frac{f_a}{F_c}) F_b} = \frac{6.5}{20.1} + \frac{0.85(14.3)}{(1 - \frac{6.5}{20.48}) 21.6} = 0.323 + 0.581$$

$$= 0.904 \leq 1.0$$

OK

SUBJECT

MFTF - MAGNET SUPPORT STRUCTURE

NAME AMD

DATE 5.24.77

• ESTIMATE COLUMN SIZE

• DETERMINE PERIOD

FOR CANTILEVERED BEAM $\Delta = \frac{PL^3}{3EI}$

$$K = \frac{P}{\Delta} = \frac{3EI}{L^3} = \frac{3(30)(10^3)(21045.5)}{[(19)(12)]^3}$$

$$K = 159.8 \text{ K/IN}$$

$$\text{TOTAL STIFFNESS} = 4K = 639.2 \text{ K/IN}$$

$$\text{PERIOD } T = 2\pi \sqrt{\frac{M}{K}} \quad M = \frac{W}{g} = \frac{130}{386} = 1.114 \frac{\text{K-sec}^2}{\text{IN}}$$

$$T = 2\pi \sqrt{\frac{1.114}{639.2}} = 0.26$$

FROM RESPONSE SPECTRUM CURVE, $P \approx 4g$
SUPPLIED BY LLL.

$$S_{a_{max}} = 1.95g$$

$$\text{USING } \frac{1}{2} S_a = 0.975 \approx \underline{1.0g}$$

• DETERMINE NEW LOAD IN COLUMN "A"

$$\sum M_B = 0 = 4P(29) - R(17)$$

$$R = \frac{4(29)}{17} P = 6.82 P$$

TRY 48" ϕ w/ 1" WALL

$$A = 147.65 \text{ IN}^2$$

$$I = 40789.65 \text{ IN}^4$$

$$S = 1699.57 \text{ IN}^3$$

$$r = 16.62$$

$$\frac{KL}{r} = \frac{2(19)(12)}{16.62} = 27.43$$

$$F_a = 20.1 \text{ KSI}$$

$$F'_e = 198.66 \text{ KSI}$$

$$f_a = \frac{7.82(110)}{147.65} = 5.83 \text{ KSI}$$

$$f_b = \frac{M}{S} = \frac{19(110)(12)}{1699.57} = 14.76 \text{ KSI}$$

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Fig. 6. Response spectrum of maximum magnitude earthquake (~~SSS~~) on the Tesla fault.

Use 1/2 of Fig 6

ENGINEERING NOTE

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SUBJECT

MFTF - MAGNET SUPPORT STRUCTURE

NAME

AMD

DATE

5.24.77

ESTIMATE COLUMN SIZE

$$\frac{f_a}{F_a} + \frac{C_m f_b}{\left(1 - \frac{f_a}{F_c}\right) F_b} = \frac{5.83}{20.1} + \frac{0.85(14.76)}{\left(1 - \frac{5.83}{198.66}\right) 21.6}$$

$$= 0.29 + 0.598 = 0.89 \leq 1.0$$

OK

USE - 48" ϕ PIPE WITH 1" THK WALL

WEIGHT ESTIMATE OF SUPPORT STRUCTURE

$$CIRC = \pi d = \pi(47) = 147.65 \text{ IN}$$

$$VOL/lf = 147.65 \times 12 \times 1 = 1771.9 \text{ IN}^3/\text{IN}$$

$$WT/lf = 1771.9 \times 0.283 \frac{\#}{\text{IN}^3} = \underline{\underline{500 \#/\text{lf}}}$$

$$\text{TOTAL COL. WEIGHT} = 4(19)(500)$$

$$= \underline{\underline{38 \text{ KIPS}}}$$

9.5 KIPS/COLUMN

ENGINEERING NOTE

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SUBJECT

MFTF - COIL SUPPORT COST

NAME ALTES

DATE 5/25/77

MATERIAL

ENGINEERING NOTE

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SUBJECT

MFTF - COIL SUPPORT

NAME ALTES

DATE 5/25/77

MATERIAL. (PER COLUMN)

STEEL MTL WT.PIPE PER AMID EST. LEAVE 1 FT
TO ALLOW SPACE FOR INSULATOR

$$\approx 9500 - 500 =$$

9000 LB.

BOTTOM FLG. (4" THK.)

$$WT = \frac{\pi}{4} (46)^2 (4) (.283) =$$

1881 LB.

TOP FLG.

$$WT = \frac{\pi}{4} (58^2 - 46^2) (4) (.283) =$$

523 LB.

COLUMN ADAPTER BLK & FLG.

$$FLG: \frac{\pi}{4} (52)^2 (4) (.283) =$$

2404 LB.

BLOCK. (POSSIBLY A FORGING)

$$WT = \frac{\pi}{4} (50)^2 (48) (.283)$$

$$= 26,672 \text{ LB.}$$

LESS CONTOUR AREA

ASSUME ~ 15,000 LB.

FLG TO ADAPTER SECTION

12000 LB

300 LB

TOTAL STEEL FINISH WT $\approx$ 26,108 LB.

SCRAP 10%

2600

TOTAL STEEL WT.

 $\approx$

28,700 LB

SAY 29,000 LB.

ENGINEERING NOTE

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SUBJECT

MFTF - COIL SUPPORT

NAME

ALTES

DATE

5/25/77

MATERIAL COST.

STL. ASSUME NITRON 40

$$\text{COST} = 29,000 \text{ LB.} \times \$1.41/\text{LB} = \$40,890$$

SHIP PARTS TO L³ FROM
FAB.

$$26,100 \text{ LB.} \times \$0.05/\text{LB}$$

1305

~\$42,000

INSULATOR

ASSUME

\$ 2500

\$ 44,500SAY \$45,000 INCL. FASTENERS ETC
(PER COLUMN)

ENGINEERING NOTE

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SUBJECT

NETF - COIL SUPPORTS

NAME

ALTES

DATE

5/25/77

FAB LABOR.

ASSUME \$3/LB OF FINISH WT FOR METAL FAB

 $26,108 \times 3 = \$78324$ LESS METAL 42,000METAL FAB LABOR = \$36,324INSULATOR FAB = 7500TOTAL FAB LABOR = \$43824

IF LABOR RATE OF \$25/HR PREVAILED

FAB EFFORT PER COLUMN = $\frac{43824}{25} = 1753 \text{ MTRS.}$

PROJECT MEFE - MAGNET COIL WINDING LABOR

JOB NO. B-320-02 BY ALTES

CHECKED

DATE 5/25/77

SHEET 1 OF 1

[illegible]

SUBJECT

INSTALLATION OF COIL MOUNTING ADAPTER

NAME L. HUNT

DATE 5-23-77

ADAPTER SIZE

EST WEIGHT 20000 LB

THE ADAPTER IS A "C" SHAPED BOX BEAM WHICH MUST BE POSITIONED ON THE WINDER, ALIGNED AND BOLTED TO NINE MOUNTING PADS.

(REF SEC. 1730)

1. ROTATE WINDER SO ADAPTER / WINDER INTER FACE IS UP.
2. TRANSFER ADAPTER FROM SHIPPING CRATE (PALLET) TO WINDER — REQUIRES:
 - (1) CRANE OPERATOR
 - (2) MECH. TECHS (MILL RIGHTS)

TIME - 4 HRS = 12 MAN-HR

NOTE - USE BRIDGE CRANE BLDG 431

ENGINEERING NOTE

1300

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SUBJECT

INSTALL COIL MTG ADAPTER

NAME L. HUNT

DATE 5-23-77

3. AFTER INITIAL ALIGNMENT, MATCH
DRILL THRU ADAPTER AND MOUNTING PADS
ON WINDER SIX PLACES. INSTALL
MOUNTING HARDWARE. (4 MEN @ 8 HR = 32 MAN-HR)
4. ROTATE WINDER ABOUT HORIZONTAL AXIS
& CHECK ALIGNMENT OF ADAPTER (8 MAN-HR)
5. ADJUST ALIGNMENT & SHIM AS REQ'D.
(4 MEN @ 8 HR = 32 MAN-HR)
6. AFTER ALIGNMENT IS COMPLETE - MATCH
DRILL ADAPTER AND WINDER 14 ADDITIONAL
PLACES - SHIM & INSTALL MOUNTING HARDWARE -
CHECK ALIGNMENT. (4 MEN @ 12 HR = 48 MAN-HR)

NOTE: MOVING THE ADAPTER AFTER TRANSFER TO
WINDER CAN BE DONE WITH HYDRAULIC
JACKS OR "PORT-A-POWER" RATHER THAN
CRANE.

TOTAL LABOR — 132 MAN-HR
INSTALL ADAPTER

MAT'L 20 1 1/4 x 6" LONG
GRADE 5 BOLTS

SHIM MAT'L —

DOWEL PINS —

INSTALL ADAPTER

TOTAL LABOR
132 MAN-HR

AIM

Association for Information and Image Management

1100 Wayne Avenue, Suite 1100
Silver Spring, Maryland 20910
301/587-8202

Centimeter

Inches

MANUFACTURED TO AIM STANDARDS
BY APPLIED IMAGE, INC.

2 of 4

SUBJECT
INSTALL INNER HALF OF JACKET
NAME

L. HUNT

DATE

5-23-77

JACKET CONFIGURATION

EST WEIGHT 10000 LB.

THE INNER HALF OF JACKET IS A FOLDED STEEL RING WHICH MUST BE FASTENED TO THE COIL MOUNTING ADAPTER, ALIGNED CONCENTRIC TO BOTH AXES OF WINDER AND SECURED WITH CAPSCREWS.

1. POSITION WINDER WITH COUNTER-WEIGHT DOWN.
2. TRANSFER JACKET FROM SHIPPING CRATE TO WINDER - LOWER JACKET OVER ADAPTER. (USE BRIDGE CRANE)

(12 MAN-HR)

3. ROUGH ALIGN THE JACKET AND FASTEN IN 20 LOCATIONS (JACKET WILL FAB'ED WITH BOTTOM TAPPED HOLES)

(16 MAN-HR)

ENGINEERING NOTE

1300

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SUBJECT

INSTALL INNER HALF OF JACKET

NAME L. HUNT

DATE 5-23-77

4. ROTATE WINDER ABOUT BOTH AXES TO
CHECK ALIGNMENT - SHIM AS REQD.
TIGHTEN SCREWS TO SPECIFIED TORQUE.

(64 MAN-HR)

TOTAL LABOR

92 MAN-HR

INSTALL INNER JACKET

TOTAL LABOR

92 MAN-HR

SUBJECT

INSTALL CLAMP TABLES

NAME L. HUNT

DATE 5-23-77

CLAMP TABLES

EST WEIGHT -
 24 SEGMENTS @
 625 EA = 15000 LB.

THE CLAMP TABLES ARE BOX SHAPED WELDMENTS WHICH ARE BOLTED TO THE HORIZONTAL AXIS STRUCTURE OF WINDER, THESE TABLES PROVIDE A MOUNTING SURFACE FOR THE STEP CLAMPS, CLAMPS & MISC. TOOLING

(REF SEC. 1741)

1. POSITION WINDER WITH COUNTER WEIGHT DOWN. (STARTING POSITION)
2. INSTALL TABLE SECTIONS IN PAIRS (ONE ON EACH SIDE OF COIL JACKET), MATCH DRILL & TAP WINDER. SHIM & FASTEN TABLE TO WINDER. UPPER SURFACE OF TABLES MUST BE PARALLEL TO THE PLANE OF THE MEAN RADIUS OF THE COIL.

(6 MAN-HR PER TABLE x 24 = 144 MAN-HR)

144 MAN-HR

SUBJECT

INSTALL STEP CLAMPS

NAME

L. HUNT

DATE

5-23-77

STEP CLAMPS

THE STEP CLAMPS ARE 1 INCH THK ALUMINUM PLATES WHICH ARE FASTENED TO THE CLAMP TABLES AND TOGETHER TO FORM A "STAIR STEP" SURFACE TO SUPPORT THE TAPERED SECTION OF THE COIL. & PROVIDE LATERAL CLAMPING.

THE STEP CLAMPS ALONG THE COIL MAJOR RADIUS WILL BE TRUNCATED SECTOR SHAPED — THE STEP CLAMP ALONG THE MINOR RADIUS WILL BE SECTIONS OF CYLINDERS

SUBJECT

 NAME L. HUNT

 DATE 5-24-77

INSTALL STEP CLAMPS

STEP CLAMP
(MAJOR RADIUS)

STEP CLAMP
(MINOR RADIUS)

ASSUME THERE ARE 24 CLAMPS PER STEP AND ABOUT 6 BOLTS PER CLAMP.

AT BEGINNING STEP CLAMPS ARE REQUIRED FOR FIRST TWO LAYER ALONG MAJOR RADII. $\frac{1}{2}$ FIRST LAYER ALONG ^{MINOR} RADII —. THAT IS 44 CLAMPS @ 1 HR = 44 MAN HR

(44 MAN HR)

INSTALL STEP CLAMPS

44 MAN -HR

ENGINEERING NOTE

1300

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SUBJECT

INSTALL BARRIER INSULATION

NAME

X. Hunt

DATE

5-24-77

THIS TASK INVOLVES THE BONDING OF SHEETS OF PERFORATED FIBER GLASS LAMINATE & CUT TO FIT MYLAR FILM TO SIDES & BOTTOM OF INNER JACKET

STEPS

1. CUT MYLAR FILM (ABOUT 180 SQ FT)
2. APPLY ADHESIVE
3. FASTEN TO INNER CASE (MAY NEED CLAMPS)
4. CUT FIBER GLASS (ABOUT 180 SQ FT)
1/6 THK
5. APPLY ADHESIVE
6. FASTEN TO MYLAR FILM (MAY NEED CLAMPS)

NOTE - INSULATION ON SIDES WILL COVER NEARLY FULL DEPTH OF JACKET

1 -	8 man hr
2 -	4 man hr
3	8 man hr.
4.	16 man hr
5	4 man hr.
6	8 man hr

TOTAL

(48 man hr)

BARRIER INSULATION

48 MAN-HR

SUBJECT

INSTALL END CLAMPS & SIDE CLAMPS

NAME *L Hunt*

DATE 5-24-77

END CLAMP IS JACK SCREW ASSY
 FASTENED TO COIL MTG ADAPTER WITH
 ONE LARGE SCREW OR PIN.

assume 1 HR / CLAMP $\times 6 = 6$ HR

Self (8 man HR)

SIDE CLAMPS 6 @ 2 HR (12 man HR)

END & SIDE CLAMPS

20 man HR

SUBJECT

NAME

X. Hunt

DATE

5-24-77

MOUNT REEL ON REEL SUPPORT

1. MOVE REEL FROM STORAGE AREA STAGING AREA UNDER BRIDGE CRANE (FORK LIFT)
2. ATTACH LIFTING BEAM TO CRANE & SLINGS TO REEL
3. LIFT REEL & POSITION NEXT TO REEL SPINDLE
4. ROTATE REEL SPINDLE AND JOG CRANE TO ALIGN REEL WITH SPINDLE — SLIDE REEL ONTO

ENGINEERING NOTE

1303 +

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SUBJECT

MOUNT REEL

NAME

L. Hunt

DATE

5-24-77

REEL SPINDLE.

5. TIGHTEN REEL CLAMPS & REMOVE SLINGS.

1.	2 man hr.
2.	2 man hr.
3.	1 man hr.
4.	2 man hr.
5.	1 man hr.

(8 man hr.)

REMOVE EMPTY REEL (4 man hr.)

12 REELS REQ'D FOR ONE COIL

FOR 12 REEL & $12 \times 12 = (144)$

12 REEL CHANGES

144 MAN-HR

ENGINEERING NOTE

1304-1307

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SUBJECT

PULL CONDUCTOR FROM REEL & FORM BEND

NAME L. Hunt

DATE 5-24-77

1. DISCONNECT LEADER FROM REEL RIM, SWITCH REEL TENSION MOTOR TO "UNWIND" & PULL CONDUCTOR TO WINDER SERVICE PLATFORM.
2. FORM INTERLAYER TRANSITION BEND WITH BENDING TOOL. (SPECIAL TOOL)
3. FORM & BOND IN PLACE FILLERS FOR TRANSITION BEND. (HAND FIT)
4. PREFORM CONDUCTOR TO FIT MINOR RADIUS OF COIL FORM. (SPECIAL TOOL)
5. PLACE PREFORMED CONDUCTOR ON COIL FORM (INNER JACKET) WITH TRANSITION BEND AT FILLERS.
6. CLAMP THE CONDUCTOR WITH THE END CLAMPS, & TIE OFF "PIG TAIL" SO IT WILL NOT INTERFERE WITH WINDING.
7. ROTATE WINDER ABOUT VERTICAL AXIS (MINOR RADIUS) CLAMP CONDUCTOR AS WINDING PROCEEDS.

LABOR EST.

1.	2	MAN	HR
2.	1	MAN	HR
3.	1	MAN	HR
4.	2	MAN	HR
5.	1	MAN	HR
6.	1	"	"
7.	1	"	"

9 " "

9 MAN HRS

ENGINEERING NOTE

1308-13-14

PAGE

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SUBJECT

WINDING FIRST TURN

NAME *A. Hunt*

DATE 5-24-77

1. OVER BEND CONDUCTOR AT INTERSECTION OF MINOR AND MAJOR RADIUS USING OVER-BENDING SHOES.
2. STOP ROTATION OF WINDER ABOUT VERTICAL AXIS & START ROTATION ABOUT HORIZONTAL AXIS (MAJOR RADIUS) & CLAMP AS WINDING PROCEEDS.
3. AT INTERSECTION OF MAJOR & MINOR RADIUS ON OTHER END OF COIL STOP ROTATION ABOUT HORIZONTAL AXIS - OVER BEND CONDUCTOR.
4. STRAIGHTEN LENGTH OF CONDUCTOR TO BE WOUND AROUND MINOR RADIUS (SINCE CONDUCTOR WILL BE CURVED IN WRONG DIRECTION AS IT COMES OFF REEL) - USE SPECIAL TOOL.
5. ROTATE WINDER ABOUT VERTICAL AXIS (MINOR RADIUS) & CLAMP AS WINDING PROCEEDS. (THREE CLAMPS USED.)
6. AT INTERSECTION OF MINOR & MAJOR RADIUS AGAIN OVER BEND CONDUCTOR & WIND ALONG MAJOR RADIUS. & OVER BEND AT END OF MAJOR RADIUS.

LABOR EST.

1.	0.1 MAN/HR
2.	0.5 MAN/HR
3.	0.1 " "
4.	1.5 " "
5.	0.2 MAN HR
6.	0.6 " "
	<hr/>
	2.0

3 MAN HR

ENGINEERING NOTE

1314 - 1317

PAGE

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SUBJECT

WINDING SECOND TURN

NAME

L. Hunt

DATE

5-24-77

1. AS CONDUCTOR PASSES STARTING POINT
INSERT TAPERED FILLER BLOCK TO GUIDE
CONDUCTOR AROUND FIRST TURN.
2. BEGIN FEEDING INTER TURN INSULATION
(FIBER GLASS LAMINATE BUTTONS ON A TAPE).
3. REPEAT THE 7 STEPS PRECEDING THIS
PAGE.

1	-	0.5	MAN HR
2	-	1.5	MAN HR
3		4	MAN HR
		<u>5.5</u>	MAN HR

FIRST LAYER LABOR = $9 + 3 + 5.5 = 17.5$
say 18 man hr

FIRST LAYER

18 MAN-HR

SUBJECT

FINISHING FIRST LAYER

 NAME *A. Hunt*

DATE 5-24

1. AT THE END OF FIRST LAYER (APPROX 2 TURNS) CLAMP CONDUCTOR, RELAX CONDUCTOR TENSION & CUT CONDUCTOR WITH ENOUGH FREE LENGTH TO FEED TO JACKET OUT LET AREA. TIE OFF FREE END.

2. INSERT FILLER BLOCKS BETWEEN LAST TURN & NEXT LAYER STEP CLAMP — BOND & CLAMP IN PLACE.

EST LABOR

1. 2 MAN-HR

2. 14 MAN HR

FINISH FIRST LAYER

16 MAN-HR

ENGINEERING NOTE

1320-1324

PAGE

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SUBJECT

NAME J. Hunt

DATE 5-25-77

WINDING SECOND & THIRD LAYERS

1. INSTALL NEXT LAYER STEP CLAMPS — ABOUT 24 SECTIONS.
2. PREPARE "PIGTAIL" FROM FIRST LAYER AND CONDUCTOR FROM REEL FOR SPLICING & JOIN PER JOINING PROCEDURE — (SPECIAL JOINING MACHINE)
3. INSTALL INTERLAYER INSULATION — CUT SHEET GLASS LAMINATE AND BOND TO FIRST LAYER.
4. THE SECOND LAYER IS THEN WOUND IN SAME MANNER AS THE FIRST — BUT IN OPPOSITE DIRECTION.
5. REPEAT THE FORGOING PROCESS FOR THE THIRD LAYER. (THIRD LAYER HAS TWO MORE TURNS - 4 TOTAL)

LABOR EST

2 ND LAYER 2 TURNS	1.	24 MAN-HR (24 SECTIONS @ 1 HR)	
	2.	8 MAN-HR (2 MEN @ 4 HR)	
	3.	2 MAN HR.	
	4.	24 MAN-HR. (SUM STEPS 4, 5, 7 & 1-6 & 142)	PAGE 12 PAGE 13 PAGE 15
THIRD LAYER 4 TURNS	5.	66 MAN-HR	4 HR 3 16
		<u>124</u>	

WIND 2ND LAYER

124 MAN-HR

ENGINEERING NOTE

1325-

PAGE

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SUBJECT

JOINT BETWEEN LAYERS 2 & 3

NAME *S. Hunt*

DATE 5-25-77

1. PREPARE ENDS OF OUTER TURNS OF SECOND & THIRD LAYERS FOR JOINING & JOIN PER PROCEDURE — (SOFT SOLDER LAP JOINT)

2. INSERT FILLER BLOCK BETWEEN LAST TURN & NEXT LAYER STEP CLAMP — BOND AND CLAMP IN PLACE.

LABOR EST

1. 6 man-HR (2 men - 3HR)

2. 14 MAN HR

(20 MAN HR)

FIRST OUTSIDE JOINT

20 MAN-HR

ENGINEERING NOTE

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SUBJECT

WINDING TAPERED SECTION OF COIL

NAME

J. Hunt

DATE

5-25-77

1. THE FORGOING STEPS SHALL BE REPEATED
UP TO LAYER 32 WITH JOINTS ALTERNATING
FROM INSIDE TO OUTSIDE ON ALTERNATE LAYERS. &
ALTERNATE LAYER WOUND IN OPPOSITE DIRECTION

FROM LAYER #4 THRU #32 THERE ARE -

15 INSIDE JOINTS @ 8 MAN/HR	= 120
29 LAYERS INSULATION @ 4 HR	= 116
14 OUTSIDE JOINTS @ 6 MAN/HR	= 84
14 STEP CLAMPS @ 24 MAN HR	= 336
29 FILLER BLOCKS @ 16 MAN HR	= 464
260 TURNS @ 4 MAN HR	= 1040
	<hr/>
	2160

(SAY 2200 MAN HR)

WINDING REMINDER OF
TAPERED SECTION

2200 MAN-HR

ENGINEERING NOTE

1326

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SUBJECT

WINDING RECTANGULAR SECTION

NAME

L. Hunt

DATE

5-25-77

1. WINDING THE RECTANGULAR SECTION
IS SAME AS TAPERED SECTION EXCEPT
STEP CLAMPS ARE NO LONGER NEEDED.
FROM LAYER 33 THRU LAYER 61.

14 INSIDE JOINTS @ 8 MAN HR = 112
30 LAYER INSULATION @ 5 MAN HR = 150
15 OUTSIDE JOINTS @ 6 MAN-HR = 90
15 FILLER BLOCKS @ 16 MAN-HR = 240
936 TURNS @ 5 MAN-HR = 4680

5272

(Say 5300 MAN-HR)

WINDING RECTANGULAR SECTION

5300 MAN-HR

ENGINEERING NOTE

1327

PAGE

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SUBJECT

INSTALL FINAL FILLER & ROUTE LEADS

NAME

L. Hunt

DATE

5-25-77

1. FILL VOIDS WITH EPOXY & FILLER BLOCKS, ROUTE LEADS FROM FIRST & LAST TURNS & INSTRUMENTATION SENSORS (THERMO COUPLES & STRAIN GAGES ETC) TO OUTLET AREA. FILL FILL AROUND LEADS.

LABOR EST

(160 MAN HR)

FINAL FILLING & ROUTING
LEADS

160 MAN-HR

ENGINEERING NOTE

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PAGE

SUBJECT

JACKET INSTALLATION

NAME

J. Hunt

DATE

5-25-77

1. POSITION WINDER WITH COUNTER WEIGHT DOWN - REMOVE CLAMPS, STEP CLAMPS AND CLAMP TABLE FROM CENTER SECTOR OF COIL.
2. TRIM EXCESS MATERIAL FROM FILLER AND INSULATION - USE ROUTER TYPE TOOL WITH GUIDE TO ENSURE CLOSE FIT OF COIL WITH OUTER JACKET
3. INSTALL OUTER JACKET SECTION & TACK WELD IN PLACE.

LABOR EST

1. 1 side clamp @ 2 hr, 15 step clamps
@ 1 hr, 1 clamp table @ 4 man hr
= 21

2. 16 man hr.

3. 16 man hr.

53

(say 56 man hr)

ENGINEERING NOTE

1331-

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SUBJECT

INSTALL REMAINING JACKET SECTIONS

NAME

L. Hunt

DATE

5-25-77

1. THERE ARE 19 MORE SECTIONS ALONG
MAJOR RADIUS AND ONE LARGER
SECTION AROUND EACH MINOR RADIUS.
EACH LARGE SECTION $\approx$ 3 SIDE SECTIONS

$$19 @ 56 \text{ MAN HR} = 1064$$

$$2 @ 3 \times 56 \text{ " " } = 336$$

$$\text{PLUS } 8 \text{ " " } = 8$$

FOR FEEDING LEADS
THRU JACKET

1408

(say 1400 man hr)

JACKET INSTALLATION

1400 MAN-HR

ENGINEERING NOTE

1332

PAGE

22a

SUBJECT

TDRUS.

NAME

ALTES

DATE

6/27/77

COIL WINDING - SUMMARY

OPERATION	M-HRS	① ADJUSTED
INSTALL ADAPTER	132	② 44
INSTALL INNER JACKET	92	31
✓ CLAMP TABLES	144	
✓ STEP CLAMPS	44	
✓ BARRIER INSULATION	48	
✓ END & SIDE CLAMPS	20	
✓ REEL CHANGES	144	
PULL CONDUCTOR	9	
WIND FIRST TURN	3	
WIND FIRST LAYER	18	2700
FINISH FIRST LAYER	16	
WIND 2ND LAYER	124	
FIRST OUTSIDE JOINT	20	
WINDING REMAINDER OF TAPERED SEC.	2200	
WINDING RECTANGULAR SECTION	5300	
FILL VOIDS	160	53
JACKET INSTALLATION (TACK WELD ONLY)	1400	467
	<u>9874</u>	<u>3296</u>
	13,170 M-HRS	

① INCL. ENG'G & SUPERVISION = 3296 (REF P-23)

② ADJ = $3296 \times \frac{132}{9874} = 44$

ENGINEERING NOTE

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SUBJECT

SUMMARY OF WINDING

NAME

J. Hunt

DATE

5-25-77

TOTAL OF STEPS (PAGES 1 THRU 22)

9874 MAN-HREXCLUDING
FINISH WELDING
OF JACKET

ASSUMING 6 MEN PER SHIFT, 2 SHIFTS
PER DAY, 5 DAYS PER WEEK (480 MAN-HR
PER WEEK) THEN WINDING TIME IS:

$$\text{TIME} = \frac{9874}{480} = 20.6 \text{ WEEKS}$$

ADDING MANPOWER OF 1 ENGINEER
& 1 SUPERVISOR DURING COIL WINDING
THEN ADDITION MAN-HR ARE

$$\text{MAN-HR} = 2 \times 80 \times 20.6 = 3296$$

AND TOTAL IS $9874 + 3296 = 13170$
FOR ONE COIL

Say 13 200 MAN-HR

FOR TWO COILS — 26 400 MAN-HR

MAX MAGNET

WINDING DIMENSIONS

6-29-76

7-19-76 REV.

2.50 m

MAJOR RAD.

SEE WINDING DETAIL
FOR BUNDLE DIM.

80 m DISPLACEMENT

75 m MINOR RAD.

75 m

TOTAL NO. OF TURNS: 1200

DETAIL: A
SCALE: 1/1

50 LAYERS $\times$ 15 MM = 75.0 CM
(EQUIV. RECT. DIM.)

39 LAYERS $\times$ 15 MM = 58.5 CM

43.03°

264 TURNS $\rightarrow$ 936 TURNS

12 TURNS $\times$ 14 MM
= 16.8 CM

36 LAYERS $\times$ 15 MM = 54.0 CM

61 LAYERS $\times$ 15 MM = 91.5 CM

250 CM MAJOR RADIUS

"MX"
MAGNET WINDING CROSS-SECTION
SQUARE CONDUCTOR

DRN BY: CARL ORTEGA 7-22-76

SCALE: 1/2

AAATE-111030-00

PROJECT MFTF - MAGNET ASSEMBLY, INSTALLATION AND TESTJOB NO. B-320-01 BY ALTES

CHECKED _____

DATE 7/14/77SHEET 1 OF _____

ITEM	DESCRIPTION	QTY.	UNIT	MATERIAL		LABOR			TOTAL ITEM COST	
				UNIT COST	TOTAL \$	UNIT MAN HOURS	TOTAL MAN HOURS	\$		
1400	MAG ASSY, INSTL. & TEST.	1	EA.							
1405	MAGNET SUPPORT INSTALLATION	4	EA	—	① —	128	512			① SEC 1200
1410	COIL JACKET PREFAB	2	EA	\$890	\$1780	914	1828			
1420	COIL CASE PREFAB	2	EA	\$1350	\$2700	2155	4310			
1430	MAGNET ASSY.	2	EA	14080	28160	1851	3702			
1440	VACUUM LEAK TESTING.	2	EA	1000	2000	490	980			
1450	MAGNET INSTALLATION	1	ASSY	—	① 30,000	—	562			① DIGGING.
1460	INTEGRATION & ACCEPTANCE TESTS	1	LOT	—	10,000	—	3224			
1470	WELD MATERIAL	2	LOTS	59,400	118,800					
1480	WELDING ENGINEERING				(INCLUDED IN ENGINEERING)					SEC 1600
1490	WELDER QUALIFICATION	1	LOT		—		320			
	TOTAL				293,460		17438			1400

ENGINEERING NOTE

1400
AWW 77-36

PAGE

1/3

SUBJECT

MFTF SUPERCONDUCTING MAGNET COST ESTIMATE

NAME

A. W. Williams

DATE

May 25, 1977

WELD FABRICATION OF ARMCO NITRONIC 40

I. MATERIALS ANALYSIS

The choice of materials for the magnet jacket and case has been made by LLL. It is to be Nitronic 40, a high chrome high manganese stainless steel. Contact with Armco has indicated that they do not roll this plate. It must be procured from G. O. Carlson, Incorporated. The present price for large quantities of the steel, in the as-rolled annealed condition, is \$1.35/lb. Shipping charges must be added.

Armco Bulletin S54 presents some interesting data relative to the physical properties of this steel. The strength is good at 4°K as well as the toughness of the parent metal.

Armco is presently under contract with ERDA via the Tokamak Program to determine the weld physical properties of Nitronic 40. The data for the "simulated Heat Affected Zone (HAZ)" is not valid. This material was sensitized for a corrosion study and does not simulate the HAZ of a welded structure. Mr. Harry Espy of Armco has discussed the present state-of-the-art of Nitronic 40 in a telecon on 5/25/77. The major problem area is the weld metal. Nitronic 40 is a nitrogen-strengthened stainless steel. Two phenomena result from this constituent: The yield strength and ultimate strength go up as the temperature is reduced and the metal has low permeability at low temperature. Metals like 304 stainless, behave differently, i.e., the yield strength remains about the same while the ultimate strength goes up and they increase in permeability. Therefore in large welds such as will be required for this case, the joints will exhibit significantly lower yield strength and higher permeability than the parent plate. Toughness, however, will be increased.

In addition to the above, Mr. Espy discussed two other areas. First, none of the slag types of processes should be used if the toughness is to remain high. Inert gas processes, such as, spray, short or pulsed arc should be used. Secondly, E. B. Welding is not acceptable even if

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NAME

DATE

the equipment was available. The problem centers about the nitrogen, it boils out, and the weld nugget is not only lower in strength but is porous. E. B. Welding (in air) was considered because of the small weld nugget and HAZ, as well as shorter welding time.

It is apparent that careful consideration of joint location must be made so that the radial joints are made in low stress fields. A study to determine properties of the toughness of welded structures at 40°K should be made. As received, material should be checked against the accumulated data. Mr. Espy has indicated that NBS recommends against attempting Charpy tests at 4°K, as the specimen heats up too quickly. Testing at -320°F is used for screening with further testing at -423°F for those materials that show promise. Study of the data presented in the Armco S54 Bulletin show a significant change in toughness from -110°F to -310°F, but only slight changes from -310°F to -423°F. It is not apparent that 3-inch plate is available for such a study. Note should be made that a more appropriate material has not been located. Estimated cost of the above study is 4 man years.

II. WELDING

A. The development of welding specifications and procedures is dependent upon the above recommended study. However, due to the massive welds required for this structure, low heat input processes are appropriate. In addition, semi-automatic processes should be used wherever possible in order to provide maximum weld quality. The initial choice is the pulsed-arc Gas Metal Arc process. Because of the distortion aspects of stainless steel and due to the "one-sided" weld problem, block welding should be used. Appropriate welding engineering techniques will provide sound welds with minimal distortion.

B. Joint Design - It is assumed that all welds must be full penetration. However, due to the inaccessability of some welds, sound metal cannot be obtained throughout the nugget. The basic joint design must

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1400

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NAME

DATE

consider the problem of lamellar tearing which results from rolled plate having weak through thickness properties. This requires that corner joints be designed such that the weld nugget covers the thickness of the plate. Bevel cuts will be utilized where possible in order to allow "flame" cutting rather than milling edge preparation. However, it is also important that the nose of the weld prep be accessible to the arc so that maximum penetration is obtained. Modified J-Grove preparations and quarter J-Groves will be used on milled edges. The total mill time is estimated to be 310 hrs. for the case. No mill time is expected for the jacket as the lamellar problem is reduced because of plate size.

C. Capital Equipment - The above program will require the following equipment:

Four pulse-arc welding machines - Airco PA3 water cooled
or equivalent, for final fabrication at LLL \$16,000

One welding positioner - 15 ton

One plasma-arc cutting machine or
one propane powder cutting torch

One horizontal mill 5-inch spindle
min.

Assumed to be
on hand at fabri-
cators facility

D. Qualification and Certification - The welders and welding procedures would have to be qualified according to ANSI N45.2 - 1971. A minimum of 6 welders should be qualified. The welding procedure would serve to qualify all of the machines and one welder. Estimated time would be 8 man weeks.

Armco NITRONIC 40 Stainless Steel Bar and Wire

Armco NITRONIC 40 stainless steel is the new name for Armco 21-6-9 stainless steel. It is a member of Armco's growing family of nitrogen-strengthened stainless steels that have been designated NITRONIC stainless steels. Other members of this family are Armco NITRONIC 32 (formerly Armco 18-2 Mn), Armco NITRONIC 33 (formerly Armco 18-3 Mn) and Armco NITRONIC 50 (formerly Armco 22-13-5) stainless steels. They all share the outstanding characteristics of high strength levels, excellent corrosion resistance and extremely low magnetic permeability, even after severe cold working.

Armco NITRONIC 40 stainless steel is one of the most versatile stainless steels. It combines high yield strength with good corrosion resistance. Room temperature yield strength is about twice that of Types 304, 321 and 347 stainless steels. In addition, it has remarkably good elevated temperature properties. And, Armco NITRONIC 40 stainless steel retains high strength and toughness at sub-zero temperatures.

Although it has higher yield strength than conventional 18-8 stainless steel, the same fabricating equipment and techniques can be used successfully in forming Armco NITRONIC 40 stainless steel. It is readily forgeable and can be welded by conventional welding methods.

The values shown in this bulletin were established in U.S. customary units. The metric equivalents of U.S. customary units shown may be approximate. Conversion to the metric system, known as the International System of Units (SI), has been accomplished in accordance with ASTM Standard E380-72 "Metric Practice Guide."

The information and data set forth in this Product Data Bulletin are accurate to the best of our knowledge and belief, but are intended for general information only. General and specific applications suggested for the materials described herein are made solely to permit the reader to make his own evaluation and decision, and are not to be construed as either express or implied warranties of fitness for these or other applications. The data reported herein have been developed through tests conducted by or for Armco. They are not guarantees.

Armco, the Armco Triangle and 21-6-9® trademarks of Armco Steel Corporation, Middletown, Ohio
NITRONIC trademark of Armco Steel Corporation

AVAILABLE FORMS

Armco NITRONIC 40 stainless steel is available in bar, wire and forging billets. In addition it is available in standard finishes in annealed or high tensile temper sheet and strip and in plate form. It can be cast or extruded. (Data on flat rolled forms are published in an Armco Product Data Bulletin *Armco NITRONIC 40 Stainless Steel, Sheet and Strip*.)

APPLICATIONS

Because of its high strength and good fabricability, Armco NITRONIC 40 stainless steel is used extensively in a wide variety of aircraft applications. Substantial weight-savings have been made for parts such as ducting and bellows systems, clamps, fasteners and flanges.

The combination of high strength and toughness at temperatures down to -423 F (-254 C) also makes Armco NITRONIC 40 stainless steel ideal for cryogenic applications. In addition, it has good resistance to high temperature oxidation in air.

COMPOSITION

The following compositions are acceptable for specifications covering Armco NITRONIC 40 stainless steel:

	%	%
Carbon	0.08 max	0.040 max
Manganese	8.00-10.00	8.00-10.00
Phosphorus	0.060 max	0.060 max
Sulfur	0.030 max	0.030 max
Silicon	1.00 max	1.00 max
Chromium	19.00-21.50	19.00-21.50
Nickel	5.50-7.50	5.50-7.50
Nitrogen	0.15-0.40	0.15-0.40

The 0.040% maximum carbon composition must be specified when Armco NITRONIC 40 is required to meet the $\text{CuSO}_4\text{-H}_2\text{SO}_4$ test as defined in the requirements of Federal Test Methods Standards 151b, Method ASTM A 393 for stabilized or extra low carbon stainless steels.

METALLURGY

Armco NITRONIC 40 is a stable austenitic stainless steel. Even after 60% cold reduction, it is still essentially nonmagnetic.

SPECIFICATIONS

Armco NITRONIC 40 Stainless Steel Bar and Wire is covered by the following specifications:

AMS 5656—Bar, Wire, Forgings and Rings

ASTM A 276-72a—Stainless and Heat-Resisting Steel Bars and Shapes (Grades XM-10, XM-11)

ASTM A 580-71—Stainless and Heat-Resisting Steel Wire (Grades XM-10, XM-11)

MIL-T-9821 C

ELEVATED TEMPERATURE EXPOSURE

The effects of heating Armco NITRONIC 40 stainless steel at temperatures of 600 to 1600 F (316 to 871 C) for times up to 100 hours on the precipitation of grain boundary carbides are shown in the following table:

Carbide Formation

Temperature F (C)	Carbide Formation Rating*			
	Time, hrs.			
	1	9	25	100
600 (316)	None [1]	None [1]	None [1]	None [1]
800 (427)	None [1]	None [1]	None [1]	None [1]
900 (482)	None [1]	None [1]	None [1]	None [1]
1000 (538)	None [1]	None [1]	None [1]	None [1.4]
1100 (593)	None [1]	Trace [1.6]	Light [3.2]	Heavy [5]
1200 (649)	Trace [1.6]	Medium [3.6]	Heavy [4.8]	Very Heavy [5.6]
1400 (760)	Light [3]	Light [3]	Medium [3.8]	Medium [3.8]
1600 (871)	Trace [1.6]	Trace [2]	Trace [2]	Trace [2.5]

* Carbide Rating — Solar Aircraft Co., San Diego, California

None - (1 to 1.4)

Medium - (3.5 to 4.5)

Trace - (1.5 to 2.5)

Heavy - (4.6 to 5.4)

Light - (2.6 to 3.4)

Very Heavy - (5.5 to 6)

Numbers in [] are average Solar Carbide Ratings of 5 heats of NITRONIC 40 — 0.040% max carbon.

The effects of heating Armco NITRONIC 40 stainless steel in the annealed condition at temperatures of 600 to 1600 F (316 to 871 C) for times up to 100 hours on sigma formation are shown in the following table:

Sigma Formation

Temperature F (C)	Sigma Formation Rating*			
	Time, hrs.			
	1	9	25	100
600 (316)	None [1]	None [1]	None [1]	None [1]
800 (427)	None [1]	None [1]	None [1]	None [1]
900 (482)	None [1]	None [1]	None [1]	None [1]
1000 (538)	None [1]	None [1]	None [1]	None [1.2]
1100 (593)	None [1.2]	None [1.2]	None [1.2]	Trace [1.6]
1200 (649)	None [1.2]	None [1.2]	Trace [2]	Light [2.6]
1400 (760)	None [1.4]	Light [2.8]	Light [3.4]	Medium [3.6]
1600 (871)	Trace [1.6]	Trace [2.4]	Light [3]	Light [3.4]

* Sigma Rating

None - (1 to 1.4)

Medium - (3.5 to 4.5)

Trace - (1.5 to 2.5)

Heavy - (4.5 to 5)

Light - (2.6 to 3.4)

Numbers in [] are average rating of 5 heats of NITRONIC 40 — 0.040% max carbon.

MECHANICAL PROPERTIES

Properties Acceptable for Material Specification

Table I
Minimum Mechanical Properties*
Annealed

Condition	UTS ksi (MPa)	0.2% YS ksi (MPa)	Elong. % in 2" (50 mm)	Red. of Area %
Bar - Condition A	90 min (620)	50 min (345)	40 min	60 min

*Longitudinal direction through 12" (300 mm) section. On sizes over 12" (300 mm), please inquire.

Typical Properties

Table II
Room Temperature Properties
Annealed Bar

Section Size, in. * (mm)	Test Direction	UTS ksi (MPa)	0.2% YS ksi (MPa)	Elong % in 2" (50 mm)	Red. of Area %
6 x 6 (150 x 150)	Longitudinal	99 (683)	65 (448)	48	70
6 x 6 (150 x 150)	Transverse	97 (669)	54 (372)	32	47
4 x 4 (100 x 100)	Longitudinal	98 (676)	58 (400)	55	75
2-1/2 x 4-1/2 (73 x 113)	Longitudinal	100 (690)	68 (469)	48	70
1" Rd. (25)	Longitudinal	100 (690)	57 (393)	53	75

*Annealed in full section

Table III
Properties of
Cold Drawn Wire

Final Cold Reduction, %	Stress Relieving Heat Treatment	UTS ksi (MPa)	0.2% YS ksi (MPa)	Elong. % in 4xD	Red. of Area %	Hardness R _c	Relaxation* (% Loss in Load)
15	none	128 (882)	108 (745)	56	70	—	—
15	1000 F - 2 hr AC (538 C)	128 (882)	102 (703)	56	68	21	10.2
15	1150 F - 2 hr AC (621 C)	125 (862)	92 (634)	45	67	20	10.0
15	1300 F - 2 hr AC (704 C)	122 (841)	93 (641)	60	65	20	6.8
30	none	179 (1234)	162 (1117)	28	57	40	—
30	1000 F - 2 hr AC (538 C)	179 (1234)	162 (1117)	28	57	39	9.1
30	1150 F - 2 hr AC (621 C)	166 (1145)	149 (1027)	28	54	33	6.8
30	1300 F - 2 hr AC (704 C)	159 (1096)	140 (965)	40	57	30	7.3

*Compression springs stressed at 40,000 psi (276 MPa)
(room temp) exposed at 850 F (454 C) for 5 days

Table IV
Typical Properties at Cryogenic Temperatures*
4-3/4" (118 mm) Thick Slab—Annealed

Test Temp F (C)	UTS ksi (MPa)	0.2% YS ksi (MPa)	Elong. % in 1" (25 mm)	R/A %	Charpy Impact	
					V-Notch ft-lbs (J)	Keyhole ft-lbs (J)
75 (24)	103 (710)	58 (400)	50	70	205 (294)	—
-110 (-79)	134 (924)	87 (600)	59	71	146 (196)	60 (80)
-320 (-196)	203 (1400)	150 (1034)	—	24	65 (87)	37 (50)
-423 (-253)	245 (1689)	196 (1351)	15	20.5	53 (71)	34 (46)

*Tested in transverse direction

Table V
Typical Charpy Impact Strength
1" (25 mm) Round Bar
(.040 max carbon)

Test Temperature	Charpy V-Notch Impact—ft-lbs (J)	
	Annealed	Simulated HAZ*
Room Temperature	Over 240 (324)	Over 240 (324)
-100 F (-73 C)	Over 230 (310)	175-186 (236-251)
-320 F (-196 C)	112-118 (151-159)	20-21 (27-28)

*Heat treated at 1250 F (677 C) for 2 hours to simulate heat-affected zones of weldments. These data strongly support the use of Armco NITRONIC 40 in cryogenic applications, especially in view of the excellent toughness in the heat-affected zone of weldments.

Table VI
Stress-Rupture Strength
Annealed Bar

Temperature F (C)	Stress to Rupture, ksi (MPa)					
	100 hrs			1000 hrs		
	NITRONIC 40	Type 347*	19-9 DL**	NITRONIC 40	Type 347*	19-9 DL**
1200 (649)	33.5 (231)	25/37 (172/255)	32/42 (221/290)	27.5 (190)	20/25 (138/172)	35 (241)
1350 (732)	21.0 (145)	18 (124)	21 (145)	13.5 (93)	—	12 (83)
1500 (816)	10.2 (70)	8/10 (55/70)	7 (48)	6.1 (42)	3/5 (21/34)	—

*Reference: ASTM Special Technical Publication No. 124

**Reference: ASTM Special Technical Publication No. 160

FIG. 1- STRESS-STRAIN CURVE (LONGITUDINAL)

FIG. 2 STRESS-STRAIN CURVE (LONGITUDINAL)

FIG. 3- STRESS-STRAIN CURVE (TRANSVERSE)

FIG. 4 - STRESS-STRAIN CURVE (TRANSVERSE)

Table VII
Creep Strength
Annealed Bar

Temperature F (C)	Stress in ksi (MPa) for Creep Rate of					
	0.1% in 1000 hrs			0.01% in 1000 hrs		
	NITRONIC 40	Type 347*	19-9 DL**	NITRONIC 40	Type 347*	19-9 DL**
1200 (649)	14.4 (99)	12/22 (83/152)	—	10.2 (70)	6/10 (41/69)	12 (83)
1300 (704)	—	8/12 (55/83)	—	—	5/6 (34/41)	—
1350 (732)	6.3 (44)	—	—	4 (28)	—	—

*Reference: ASTM Special Technical Publication No. 124

**Reference: ASTM Special Technical Publication No. 160

Endurance Limit

The endurance limit of Armco NITRONIC 40 stainless steel annealed bar stock is approximately 49,000 psi (338 MPa) at 100,000,000 cycles. This information was developed using smooth specimens machined from 1" (25 mm) diameter bar stock and stressed as rotating beams on the R. R. Moore testing machine. The ratio of the endurance limit to tensile strength is approximately 0.49.

PHYSICAL PROPERTIES

Table VIII
Coefficient of Thermal Expansion
Annealed Condition

Temperature, F (C)	in/in/°F (mm/mm/°C)	Temperature, F (C)	in/in/°F (mm/mm/°C)
80-200 (27-93)	9.3x10 ⁻⁶ (16.7x10 ⁻⁶)	80-1400 (27-760)	11.1x10 ⁻⁶ (20x10 ⁻⁶)
80-400 (27-204)	9.6x10 ⁻⁶ (17.3x10 ⁻⁶)	80-1600 (27-899)	11.2x10 ⁻⁶ (20.2 x 10 ⁻⁶)
80-600 (27-316)	10.1x10 ⁻⁶ (18.2x10 ⁻⁶)	80-1800 (27-982)	11.4x10 ⁻⁶ (20.5x10 ⁻⁶)
80-1000 (27-538)	10.6x10 ⁻⁶ (18.6x10 ⁻⁶)		

Thermal Conductivity

Table IX
Thermal Conductivity
Annealed Condition

Temperature, F (C)	BTU/hr/ft ² /in/°F (W/m•K)
-290 (-179)	54 (7.8)
-100 (-73)	76 (10.9)
200 (93)	96 (13.8)
400 (204)	112 (16.1)
600 (316)	126 (18.2)
800 (427)	140 (20.2)
1000 (538)	156 (22.5)
1200 (649)	172 (24.8)
1400 (760)	186 (26.8)
1600 (871)	200 (28.8)

Young's Modulus of Elasticity

In the annealed condition, Young's modulus in tension is 28,500,000 psi (197,000 MPa).

Poisson's Ratio is 0.285.

Density

7.83 gm/cm³

0.283 lb/in³

Electrical Resistivity

Electrical Resistivity at room temperature is 73 microhm-cm.

Magnetic Permeability

Armco NITRONIC 40 stainless steel is useful in applications where low permeability is important because it remains nonmagnetic even after severe cold working or exposure to sub-zero temperatures. At a field strength of 500 oersteds, it has a permeability in the annealed condition of 1.002. After approximately 60% cold reduction, the permeability is still less than 1.02.

Table X
Magnetic Permeability

Condition	Field Strength (Oersteds)			
	50	100	200	500
Annealed	1.005	1.004	1.004	1.002
15% Cold Reduction	1.004	1.004	1.003	—
35% Cold Reduction	1.005	1.005	1.005	—
60% Cold Reduction	1.010	1.010	1.012	<1.02
H.R. & Pickled	1.008	1.007	1.006	—

Table XI
Effect of Sub-Zero Temperature on Magnetic Permeability
Annealed

Test Temperature* F (C)	Field Strength 500 (Oersteds)	
	NITRONIC 40	Type 310
75 (24)	1.002	1.002
-320 (-196)	1.005	1.007
75 (24)	1.002	1.003

*Specimens tested at 75 F (24 C), at -320 F (-196 C) and finally at 75 F (24 C). Last test measured effects of low temperature exposure on room temperature permeability.

OXIDATION RESISTANCE

Armco NITRONIC 40 stainless steel, because of its high chromium content, exhibits good resistance to high temperature oxidation in air.

Table XII
Oxidation Resistance*

Alloy	Temperature, F (C)	Time Hours	Oxidation Loss	
			Loss gms/sq in	Loss in/yr
NITRONIC 40	1600 (871)	1000	.06	.004
Type 304	1600 (871)	1000	.05	.003
NITRONIC 40	1800 (982)	400	.11	.018
Type 304	1800 (982)	400	.30	.049

*Tests run in electric muffle furnace with small amount of saturated air introduced to prevent stagnant atmosphere from occurring during exposure.

Armco NITRONIC 40 stainless steel has a high level of corrosion resistance. Normally in chemical media and in industrial and marine environments, its resistance to attack is between that of Type 304 and Type 316 stainless steels.

The 0.040% maximum carbon grade, due to its low carbon content, is resistant to intergranular attack, and usually can safely be used in the as-welded condition. However, like Type 304L, Armco NITRONIC 40 stainless steel can be corroded intergranularly after long exposure in the carbide precipitation temperature range of 1000-1600 F (583-871 C).

The resistance of Armco NITRONIC 40 stainless steel to stress corrosion cracking in hot chloride solutions is about like that of Types 304 and 304L stainless steels. Annealed, furnace sensitized and cold-rolled specimens of Armco NITRONIC 40 stainless steel have shown excellent resistance to stress corrosion cracking when exposed to marine atmospheres at ambient temperature for over 3½ years.

FABRICATION

Annealing and Stress Relieving

In-process annealing may be done between 1950-2050 F (1066-1121 C). The final annealing temperature is 1950 F (1066 C). Cooling practices are the same as those required for Type 304 with rapid air cooling for sheet thicknesses and water or oil quenching for heavier sections.

Welding

Armco NITRONIC 40 stainless steel is readily welded in all forms. Welded joints in the as-welded condition have strengths equivalent to the unwelded base metal. Data on welded joints made by both gas tungsten-arc (TIG) and shielded metal-arc (SMAW) with covered electrodes are shown in the following table.

Table XIII
Mechanical Properties of Armco NITRONIC 40 Welds

Welding Process	Thickness Inches (mm)	UTS ksi (MPa)	0.2% YS ksi (MPa)	Elong. % in 2" (50 mm)	Lateral Contraction %	Failed in
Gas Tungsten-Arc (TIG)	0.062 (1.5)	109 (752)	68 (469)	22	17	Weld Metal
Shielded Metal-Arc (SMAW)	2.0 (50)	106 (731)	65 (448)	39	—	Base Metal

For the gas tungsten-arc (TIG), gas metal-arc (MIG) and shielded metal-arc (SMAW) weld methods, NITRONIC 40W weld wire should be used. For most applications, use of the NITRONIC 40W (matching filler) will give as-welded corrosion and mechanical properties equivalent to those of the unwelded base metal. However, in cases where the matching filler may not be readily available, other more standard stainless steel electrode types may be substituted. Selection of a substitute electrode should be based on properties required.

For example, in heavy joints, a Type 312 electrode will give matching strength, but will not have the toughness needed for cryogenic applications. Types 308L and 309 will give matching 0.2% yield strengths, but will be low in ultimate tensile strengths. In lighter gage materials, (i.e. approximately 1/8" [3.17 mm]) where the Gas Tungsten Arc Process is frequently used, the weld filler comprises only a small part of the weld. Consequently, weld joint properties more nearly match that of the unwelded base metal regardless of the substitute used.

As an aid in considering substitute fillers for general applications, typical properties of several all-weld deposits along with those of the unwelded base metals are shown.

AWS Weld Filler Type	UTS ksi (MPa)	0.2% YS ksi (MPa)	Elong. % in 2" (50 mm)
308L	85 (586)	60 (414)	45
309	90 (620)	60 (414)	45
312	110 (759)	80 (550)	30
Unwelded base metal, heavy sections (4" [101.6 mm])	103 (710)	58 (400)	50
Unwelded base metal sheet-strip	112 (772)	68 (469)	44

For cryogenic applications, weldments of 1/4" (6 mm) or less in thickness made with the NITRONIC 40W exhibit good toughness. Where weldments greater than 1/4" (6 mm) in thickness are to be used at cryogenic temperatures, nickel-base fillers are generally suggested. Type 308 stainless steel fillers may be used for all thicknesses providing allowance is made for the lower ultimate tensile strength in heavy joints. More information on the selection of fillers for cryogenic applications will be supplied upon request.

When welding Armco NITRONIC 40 stainless steel using inert gas shielded processes (primarily TIG), the metal should be handled carefully to avoid contamination from other materials such as copper, brass or bronze. Defects resulting from such contamination usually occur as shallow surface cracks in the base metal immediately adjacent to the weld deposit.

Copper backup and hold-down fixtures commonly used in welding stainless steels are the principal source of this contamination. In addition to careful handling, the use of chromium-plated copper fixtures is suggested. However, chromium stainless steel, steel or aluminum fixtures are satisfactory.

Table XIV
Properties of Welded Joints at Elevated Temperatures*
Sheet and Strip

Test Temp. F (C)	UTS ksi (MPa)	0.2% YS ksi (MPa)	Elong. % in		Location of Fracture
			2" (50 mm)	1/2" (13 mm)	
75 (24)	115.2 (794)	66.6 (456)	37.0	36.0	BM [1], HAZ [2]
800 (427)	80.2 (553)	33.5 (231)	37.5	—	BM
900 (482)	77.8 (536)	32.9 (227)	33.0	—	BM [2], HAZ [1]
1000 (538)	73.5 (507)	31.4 (216)	28.5	—	BM
1100 (593)	66.8 (461)	28.9 (199)	24.5	25.0	BM [1], HAZ [2]
1200 (649)	59.2 (408)	27.9 (192)	20.0	20.0	HAZ
1300 (704)	48.2 (332)	26.5 (183)	11.0	12.5	HAZ

* Average of Triplicate Tests

HAZ = Heat-Affected Zone

BM = Base Metal Failure

Number in [] = Number of Specimens

Welding Conditions <i>GTA FOR SHEET + STRIP (TIG)</i>			
Current	90 amps	Shielding Gas	He (a) 40 cfh
Voltage	15-1/2	Wire Feed	16 ipm (400 mm/min)
Travel Speed	16 ipm (400 mm/min)	Wire Diameter	.062" (1.5 mm)

Armco NITRONIC 40 bar and wire is readily resistance welded (cross wire and butt welding) using conventional resistance welding equipment.

Machining

Machining tests indicate that cutting speeds for Armco NITRONIC 40 stainless steel will be somewhat lower than those for other austenitic stainless steels. This is due to the higher work-hardening rates and higher yield strength of Armco NITRONIC 40 stainless steel. The following table indicates comparable cutting rates of Armco NITRONIC 40, Type 304 and Type 316 stainless steels.

Cutting Rates in Surface Feet Per Minute (m/min)	Armon NITRONIC 40		
	Type 304	Type 316	
Machining Operation Single Point Turning	Carbide Tools	100-150 (30-45)	60-80 (12-18)
	Roughing	150-200 (45-60)	60-90 (18-24)
High Speed Steel Tools	Finishing	130-180 (39-54)	60-90 (18-27)
	Roughing	150-300 (45-90)	100-120 (30-36)
Finishing	Finishing		

Table XV

Forging

Armon NITRONIC 40 stainless steel is readily forgeable. It is recommended that products 4" (100 mm) and over in diameter or thickness be charged into furnaces operating at or below 1600 F (871 C). After charging, the material should be equalized at 2000 F (1093 C), followed by soaking for 20 minutes per inch of thickness at 2200 F (1204 C). Inherent good hot workability will allow the material to be forged to minimum forging temperature range of 1700-1800 F (927-982 C). Any reheating which is necessary should consist only of equalization at 2200 F (1204 C). On products under 4" (100 mm) in diameter or thickness, charging temperature is not critical and equalization at 2000 F (1093 C) may not be necessary. Depending upon the nature of the forging operation, it may be possible to use temperatures lower than 2200 F (1204 C) but the material does become stiff as the temperature drops during forging. Water quenching or air cooling after forging may be used.

Forming

Most fabricating techniques for Armco NITRONIC 40 stainless steel are similar to other austenitic stainless steels. It must be remembered, however, that Armco NITRONIC 40 stainless steel has approximately twice the yield strength of Type 304. This must be considered in choosing equipment for forming Armco NITRONIC 40 stainless steel.

The parts shown in the following photograph demonstrate the good fabricability of Armco NITRONIC 40 stainless steel. Most of them were made without in-process anneals or stress relieving.

ENGINEERING NOTE

1405

PAGE

1/1

SUBJECT

MFTF

NAME

ALTES

DATE

5/25/77

MAGNET SUPPORT COLUMN INSTALL.

QUAN: 4 EA.

ASSUME 32 HRS/COLUMN

4 MAN CREW.

$$\text{4 MEN} \times \frac{32 \text{ HRS}}{\text{COL}} = 128 \text{ WHRS/COLUMN.}$$

SHEET 1 OF

1410

SUBJECT

COIL, JACKET, CASE ASS'y

NAME

LDH

DATE

7-14-77

 CASE UPPER
SEGMENT

 COIL W/
JACKET

 CASE LOWER
SEGMENT

SEC. A-A

EXPLODED VIEW SEC A-A

SUBJECT

WELD LOCATIONS (APPROX) - CASE 2 JACKET

NAME

LDH

DATE

7-14-77

USE FOR CALC. SEAM LENGTHS

$$\textcircled{4} \text{ CUTS} \quad 4 \times 408 = 1632 \text{ in}$$

$$L_{\text{DOWN}} = (118-67) \times 8 = 408 \text{ in}$$

THERE ARE 8 RADIAL SEAMS (DOUBLE-V)

$$\overline{L_2} = 1220 \text{ in (PLASMA ARC)}$$

$$L_2 = \overline{L_1} + L_5 (\text{INSIDE OF CASE}) = 476 + 744 =$$

PLATE $\frac{1}{2}$ - 2 SQ CUT $\frac{1}{2}$ CASE 30° BEVEL

$$= 952 \text{ in (PLASMA ARC)}$$

$$L_1 = \text{same as } \frac{1}{2} \text{ OF CASE} = 2 \times 476$$

PLATE $\frac{1}{2}$ LENGTH OF CUTS - ONE SQ $\frac{1}{2}$ ONE 45°

WELD PREP

SEE THRU JACKET

JACKET PREPAR

SUBJECT

ENGINEERING NOTE

1410

1/6

PAGE

NAME A. Williams / LDH

DATE 7-15-77

SUBJECT
JACKET PREFAB
NAME
A. Williams / LDA
DATE
7-15-77

PLATE P₃

$$\underline{L_3} = \text{same as } L_2 \text{ of CASE} = \underline{1176 \text{ in}}$$

THERE ARE 26 RADIAL SEAMS $\frac{20}{\sin 45^\circ}$ long

$$L_{3\text{RAD.}} = 26 \times \frac{20}{.707} = 735 \text{ in.}$$

all these SEAMS are 2 CUTS (PLASMA ARC)

$$\therefore \text{TOTAL } \underline{L_{3\text{RAD.}}} = 735 \times 2 = \underline{1470 \text{ in}}$$

PLATE P₄

$$L_4 = \text{same as } L_3 \text{ of CASE} = \underline{1560 \text{ in}}$$

1 CUT (plasma arc)

THERE ARE 26 RADIAL SEAMS

$$L_{4\text{RAD}} = 26 \times (118 - 84) = 884 \text{ in.}$$

$$\text{at 2 CUTS PER SEAM } L_{4\text{RAD}} = 2 \times 884 = \underline{1768 \text{ in}}$$

(plasma arc)

PLATE P₅

$$L_5 = \text{same as } L_5 \text{ of CASE} = \underline{1613 \text{ in}}$$

THERE ARE 26 HORIZ. SEAMS @ 20"

$$L_{5\text{HORIZ.}} = 26 \times 20 = 520 \text{ in.}$$

$$\text{@ 2 CUTS} = 2 \times 520 = \underline{1040 \text{ in}}$$

SUBJECT

JACKET PREFAB

NAME

A. Williams / CDH

DATE

7-15-77

WELD W₁

$$A = \frac{bh}{2} = \frac{1^2}{2} = .5 \text{ in}^2$$

$$\text{Vol. of Weld} = .5 \times L_1$$

$$= .5 \times 476 = \underline{\underline{238 \text{ in}^3}}$$

THE RADIAL SEAMS

$$A = \left[\frac{.5 \times .5 \times .866}{2} \right] \times 2 =$$

$$= .22 \text{ in}^2$$

$$\text{Vol. of Weld} = .22 \times 408 = \underline{\underline{88 \text{ in}^3}}$$

WELD W₂

$$A = \frac{.5^2}{2} = .13 \text{ in}^2$$

$$\text{Volume} = .13 \times L_2 (\text{UPPER}) =$$

OF CASE

$$.13 \times 691 = \underline{\underline{86 \text{ in}^3}}$$

SUBJECT
JACKET PREFAB
NAME
A. Williams / LCH
DATE
7-15-77
WELD W₃

$$A = \frac{.75 \times .75 \times .866}{2} = .24 \text{ in}^2$$

$$\text{Vol.} = .24 \times L_3(\text{UPPER}) =$$

OF CASE

$$= .24 \times 869 = \underline{212 \text{ in}^3}$$

NOTE WELDS W₄, W₅ & THE RADIAL WELDS OF PLATES P₃, P₄ & P₅ WILL BE DONE AT FINAL ASS'Y. NOT AT PREFAB

WELD W₄

$$A = \text{same as } W_2 = .13 \text{ in}^2$$

$$\text{Volume} = .13 \times L_1 = .13 \times 476$$

$$= \underline{62 \text{ in}^3}$$

SUBJECT

JACKET PREFAB

NAME

A Williams / CDH

DATE

7-18-77

WELD W₅ 60° V SAME AS W₃

$$A = .24 \text{ in}^2$$

$$\text{Vol.} = .24 \times \underset{\text{OF CASE}}{L_5(\text{INSIDE})} = .24 - 744 = 179$$

$$= \underline{\underline{179 \text{ in}^3}}$$

RADIAL WELDS PLATES P₄ & P₅

$$A = \frac{1}{2}bh = \frac{.75^2 \times .866}{2} = .24 \text{ in}^2$$

$$\text{Volume} = .24 \times (L_{4\text{RAD.}} + L_{5\text{RAD.}}) =$$

$$= .24 \times (844 + 520) = 327$$

$$= \underline{\underline{327 \text{ in}^3}}$$

RADIAL WELDS PLATE P₃

$$A = \frac{.5^2 \times .866}{2} = .11 \text{ in}^2$$

$$\text{Vol.} = .11 \times L_{3\text{RAD.}} = .11 \times 735 =$$

$$= \underline{\underline{80 \text{ in}^3}}$$

SUBJECT
JACKET PREFAB
NAME
A. Williams / LDH
DATE
7-18-77

PLATES P_1, P_3 & P_5 MUST BE FORMED TO CYLINDRICAL OR CONIC SHAPE ABOUT THE MAJOR AXIS —

PLATES P_2, P_3 & P_4 MUST BE FORMED ABOUT THE MINOR AXIS.

TOTAL WT. OF PLATES TO BE FORMED

$$W_T = .281 [L_1 A_1 + L_3 A_3 + L_5 A_5 \dots]$$

$$= .281 \left[\overset{700}{350 \times 1 \times 2} + \overset{5587}{\frac{350 + 440}{2} \times \frac{20}{.707} \times .5} + \overset{9270}{618 \times 20 \times .75} + \right.$$

$$\left. \overset{6408}{2\pi \times 20 \times (118 - 67)} + \overset{1142}{\frac{251 + 126}{2} \times \frac{20}{.707} \times .5} + \overset{8545}{2\pi \times 40 \times (118 - 84)} \right]$$

$$\underline{W_T} = \underline{8894 \text{ lb.}} \quad \text{say } 8900 \text{ lb}$$

ENGINEERING NOTE

1411

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SUBJECT

JACKET PREPAR

Summary

NAME

A. Williams / CDH

DATE

7-19-77

WELD PREP

PLASMA ARC CUTS

TOTAL CUT LENGTH = 952 + 1220 + 1632 + 1176 + 1470
+ 1560 + 1768 + 1613 + 1020 =
 $L_{cut} = 12411$ in.

Assuming a cut rate of 60 in/min for
 $\frac{3}{4}$ " thick plate the cutting time is -

$$T = \frac{12411}{60} = 206 \text{ min or } 3.4 \text{ day } 4 \text{ hr}$$

$$T = 4 \text{ hr}$$

HANDLING (132 pieces @ 1.5 hr) = 198 day 20 hr
GRINDING (132 pieces @ 0.5 hr) = 66 day 70 hr
TOT 274 hr

ENGINEERING NOTE

1412

PAGE

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SUBJECT

JACKET PREFAB SUMMARY

NAME

A Williams / LDH

DATE

7-F-77

THERE ARE APPROX 50 PIECES THAT
MUST BE ROLLED TO VARIOUS RADII
ABOUT THE MAJOR & MINOR AXES

TOTAL WEIGHT THESE 50 PCS 8900 lb

ASSUME \$0.10/lb FOR ROLLING
EXCLUDING MAT'L COST

ROLLING COST = $8900 \times .10 = \$890.00$

SUBJECT

JACKET PREFAB

SUMMARY

NAME

A. Williams/CDH

DATE

7-19-77

WELDING

$$\text{Vol. of Weld} = 238 + 88 + 86 + 212 = \underline{624 \text{ in}^3}$$

ASSUME $17.2^* \text{ in}^3/\text{HR}$ DEPOSITION RATE —

$$T = \frac{624}{17.2} = 36.3 \text{ say } 40 \text{ HR.}$$

$$\text{Set-up (assume 132 PCs @ 2 HR)} = 264 \text{ HR}$$

ASSUME INSPECTION 30% WELD TIME

$$\underline{\underline{\text{TOTAL TIME}}} = (40 + 264) 1.3 = 395.2 \text{ say } \underline{\underline{400 \text{ HR}}}$$

* REF SEC 1423 P. 4/6

$$\text{Ref. Weld WIRE} = 624 \times .281 = 175.316 \text{ say } \underline{\underline{200 \text{ lb}}}$$

ENGINEERING NOTE

1414

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SUBJECT

JACKET PREFAB SUMMARY

NAME

LDH

DATE

7-19-77

MACHINING -

MACHINE HOLES FOR LHe LINES

FACE OFF, DR & TAP HOLES FOR
80 3/4 CAP SCREWS (FOR ATTACHMENT
TO COIL MOUNTING ADAPTER)

EST

MISC MACH.

160

80 HOLES @ 1 HR

80

240 HR

1420

SUBJECT

CASE PREFAB

NAME A WILLIAMS/LDH

DATE 7-14-77

CASE LOWER SEGMENT

SEC THRU SEG.

THIS SEGMENT IS MADE UP OF 8 SECTIONS -
 EA COMPOSED OF PLATES P_1 & P_2 & P_3 OR A TOTAL
 OF 24 PLATES.

WELD PREP

LENGTH OF CUT -

PLATE #1

$$\begin{aligned} \text{(ARC LENGTH EACH EDGE)} L_1 &= 2 \left(2\pi \times 67 \times \frac{150}{360} \right) + 2\pi \times 20 \\ &= 476 \text{ in} \end{aligned}$$

$$\text{TWO EDGES } 2L_1 = \underline{952 \text{ in.}} \quad (\text{PLASMA ARC})$$

PLATE #2

$$\begin{aligned} \text{ARC LENGTH } L_2 &= 2 \left(2\pi \times \frac{150}{360} \times 84 \right) + 2\pi \times 40 \\ \text{(UPPER EDGE)} \end{aligned}$$

$$L_2 = 691 \text{ in}$$

$$\begin{aligned} \text{LOWER EDGE} &= 476 \\ \text{SAME AS } P_1 & \end{aligned}$$

$$\text{TOTAL} = \underline{1167 \text{ in}}$$

(PLASMA ARC)

SUBJECT

CASE PREFAB

NAME A WILLIAM/LDH

DATE 7-14-77

PLATE #3

$$\text{UPPER ARC LENGTH } L_3 = 2 \left(2\pi \times 118 \times \frac{150}{360} \right) + 2\pi \times 40 =$$

$$= 869 \text{ in}$$

+ LOWER ARC LENGTH

$$\text{TOTAL} = \frac{869}{691} \text{ in.} \quad (\text{PLASMA ARC})$$

THERE ARE 8 RADIAL JOINTS IN CASE SEGMENT —

$$\text{JOINT LENGTH} = (118 - 84 + \frac{40 - 30}{\sin 45^\circ} + 7) = 64.5$$

$$L = 65 \text{ in.}$$

THE JOINT WILL BE DOUBLE BEVEL BOTH SIDES

THEREFORE 4 CUTS REQ'D

$$\text{TOTAL LENGTH} = 65 \times 4 \times 8 = \underline{2080 \text{ in.}}$$

for ENTIRE SEGMENT

(PLASMA ARC)

$$\text{TOTAL LENGTH ALL JOINTS} = 952 + 1167 + 1560 + 2080$$

$$= 5759$$

(PLATES P₁, P₂ & P₃)

$$\text{SAY } \underline{5800 \text{ in}}$$

SUBJECT
CASE PREFAB
NAME A WILLIAM/CDH

DATE 7-15-77

LENGTH OF WELD SEAM —

$$L_{\text{WELD}} = W_1 + W_2 = 476 + 691 = 1167$$

$$L_{\text{avg}} = \underline{\underline{1170}}$$

RADIAL JOINTS

$$\underline{\underline{L_{\text{WELD}}}} = 65 \times 2 \times 8 = \underline{\underline{1040 \text{ in}}}$$

ASSUME WELDS W_1 & W_2 HAVE CROSS SECTION OF

$$A = \frac{1}{2}bh = \frac{3 \times 3 \times .866}{2} = 3.89 \text{ in}^2$$

$$\text{VOLUME/FT } W_1 \text{ \& } W_2 = 3.89 \times 12 = 46.8 \text{ in}^3/\text{FT OF WELD}$$

$$\underline{\underline{\text{TOTAL Vol.}}} = 3.89 \times 1170 = \underline{\underline{4551 \text{ in}^3}}$$

RADIAL JOINTS —
ASSUME

$$A = \frac{1}{2} \times 1.5^2 \times .866 = .97 \text{ in}^2$$

$$\text{Volume/FT} = .97 \times 12 = 11.64 \text{ in}^3/\text{FT}$$

SUBJECT

CASE PREFAB

NAME A WILLIAM/LDH

DATE 7-15-77

$$\text{TOTAL VOLUME (RADIAL SEAMS)} = .97 \times 1040 = \underline{1008 \text{ in}^3}$$

NOTE - (12 PCS) PLATES P_1 & P_2 ARE CURVED (FORMED) ALONG MAJOR RADIUS & (4 PCS) PLATES P_2 & P_3 ARE CURVED (FORMED) ALONG MINOR RADIUS.

WEIGHT OF PLATES TO BE FORMED -

$$\begin{aligned} W_{\text{MAJ}} &= [L_{\text{MAJ}} A_1 + L_{\text{MAJ}} A_2] \cdot 281 = \\ &= \left[350 \times 3 \times 7 + \frac{395}{2} \times 3 \times \frac{20-3}{.707} \right] \cdot 281 = \end{aligned}$$

$$W_{\text{MAJ}} = \underline{10072 \text{ lb}} \quad \text{ALONG MAJ. R}$$

ASSUME THESE 12
PIECES ARE
ROLLED.

$$W_{\text{MIN}} = L_{\text{MIN}} A_2 + L_{\text{MIN}} A_3 =$$

$$= \left[\frac{251 + 126}{2} \times 3 \times \frac{17}{.707} + 251 \times 3 \times (118 - 84) \right] \times .281$$

$$W_{\text{MIN}} = \underline{11015 \text{ lb}} \quad \text{ALONG MINOR R.}$$

ASSUME THESE 4
PIECES ARE
RING ROLLED
FORGINGS.

SUBJECT

CASE PREFAB

NAME A WILLIAM/LDH

DATE 7-15-77

CASE UPPER SEGMENT

SEC THRU SEG.

THIS SEGMENT IS MADE UP OF APPROX 50 PCS.

WELD PREP —

PLATE P_4 LENGTH OF EDGES TO BE CUT

$$L_4 = \underbrace{2 \left(67 \times 2\pi \times \frac{350}{360} \right) + 2\pi \times 20}_{\text{LOWER EDGE}} + \underbrace{2 \left(120 \times 2\pi \times \frac{754}{360} \right) + 2\pi \times 20}_{\text{UPPER EDGE}} =$$

$$L_4 = \underline{\underline{1356 \text{ in}}}$$

NOTE THESE WILL BE MILLED CUTS (J-GROOVE)

THERE ARE 20 RADIAL JOINTS

$$L_{4R} = \left(\frac{\text{AVE LENGTH } 79"}{2} \times (120 + 40 - 67 + 65) \right) \times 20 = 1580 \text{ in}$$

HOWEVER THERE 4 CUTS PER JOINT (DOUBLE VEE GROOVE)

$$\underline{\text{TOTAL}} = 1580 \times 4 = \underline{\underline{6320 \text{ in.}}} \text{ (PLASMA ARC CUT)}$$

SUBJECT
CASE PREFAB
NAME
A WILLIAMS/LDH
DATE
7-15-77

PLATE P5

$$L_5(\text{INSIDE}) = 2 \left(118 \times 2\pi \times \frac{150}{360} \right) + 2\pi \times 20 = 744 \text{ in}$$

$$L_5(\text{OUTSIDE}) = 2 \left(118 \times 2\pi \times \frac{150}{360} \right) + 2\pi \times 40 = 869 \text{ in}$$

$$L_5 = 1613 \text{ in.}$$

@ 2 CUTS/EDGE $L_5 = 1613 \times 2 = 3226 \text{ in.}$ (MILLED CUTS)

THERE ARE 12 HORIZONTAL JOINTS (DOUBLE V)
 @ 4 CUTS/JOINT

$$L_{5 \text{ HORIZ.}} = 12 (40 - 20) \times 4 = 12 \times 20 \times 4 = 960 \text{ in}$$

(PLASMA ARC)

PLATE P6

$$L_6(\text{lower}) = \text{Same as } L_5(\text{OUTSIDE}) = 869 \text{ in (PLASMA ARC)} \\ \text{1 CUT}$$

$$L_6(\text{upper}) = 2 \left(120 \times 2\pi \times \frac{180}{360} \right) + 2\pi \times 40 = 1005 \text{ in} \\ \text{(MILLED CUT)} \\ \text{1 CUT}$$

THERE ARE 12 VERTICAL (RADIAL) JOINTS

$$L_{6R} = \left(\overset{\text{AVE LENGTH}}{79 - 50} \right) \times 12 = 348 \text{ in.}$$

$$@ 4 \text{ CUTS/JOINT} = 4 \times 348 = 1392 \\ \text{(DOUBLE V)}$$

$$\text{SAY } 1400 \text{ in} \\ \text{(PLASMA ARC)} \\ \text{CUT}$$

SUBJECT

CASE PREFAB

NAME

A. WILLIAMS / L.D.H.

DATE

7-15-77

 PLATE P₁

$$L_7 \text{ (INNER)} = \text{SAME AS } L_4 \text{ UPPER} = 754 + 126 = 880$$

$$L_7 \text{ (OUTER)} = \text{SAME AS } L_6 \text{ UPPER} = 754 + 251 = 1005$$

$$L_7 = \underline{\underline{1885 \text{ in}}}$$

 1 CUT
 (PLASMA ARC)

 THERE ARE 12 HORIZ JOINTS
 SAME AS R₅ @ 4 CUTS / JOINT

$$L_{7 \text{ HORIZ}} = 12 \times 20 \times 4 = \underline{\underline{960 \text{ in}}} \text{ (PLAS ARC)}$$

 ASSUME WELD W₃ IS DOUBLE J

$$\text{AREA} \approx \frac{1}{2}bh = \frac{1.5 \times 1.5 \times .866}{2} = .98 \text{ in}^2$$

$$\text{for TWO } A \approx 2 \times .98 = 1.96 \text{ in}^2$$

$$\underline{\underline{W_3}} = 1.96 \times 12 = \underline{\underline{23.5 \text{ in}^3/\text{FT}}}$$

$$\begin{aligned} \text{TOTAL VOLUME} &= 1.96 \times L_5 \text{ (INSIDE)} = 1.96 \times 744 = 1458 \\ &= \underline{\underline{1458 \text{ in}^3}} \end{aligned}$$

SUBJECT

CASE PREFAB

NAME

A. Williams / CDH

DATE

7-15-77

ASSUME W₄ 60° V

$$AREA \approx \frac{1}{2} \times 3 \times 3 \times .866 = 3.9$$

$$VOLUME = 3.9 \times 12 = 47 \text{ in}^3/\text{FT}$$

$$TOTAL VOL = 3.9 \times L_5 \text{ (OUTSIDE)}$$

$$\underline{W_4} = 3.9 \times 869 = \underline{\underline{3389 \text{ in}^3}}$$

Weld W₅

ASSUME

$$AREA \approx \frac{1}{2} \cdot 2.8^2 + 2.8 \times 1 = 6.72$$

$$= 6.72 \text{ in}^2$$

$$Vol. = 6.72 \times 12 = 80.6 \text{ in}^3/\text{FT}$$

$$Vol W_5 = 6.72 \times L_4 \text{ (UPPER)} =$$

$$= 6.72 \times (754 + 126) = 5914$$

$$\underline{\underline{W_5 = 5914 \text{ in}^3}}$$

SUBJECT

CASE PREFAB

NAME A. Williams/LD.H

DATE 7-15-77

WELD W_6 SAME AS W_5

$$A = 6.72 \text{ in}^2$$

$$W_6 = 6.72 \times L_6 (\text{UPPER}) =$$

$$6.72 \times 1005 = 6754$$

$$\underline{W_6} = \underline{6754 \text{ in}^3}$$

VERTICAL, RADIAL & HORIZONTAL JOINTS

$$A = \frac{1}{2} 1.5 \times 1.5 \times .866 =$$

$$= .97 \text{ in}^2$$

$$2 \text{ weld/joint } A = 2 \times .97 = 1.95$$

$$\text{Vol} = 1.95 \left(L_{4R} + \frac{L_{5HB12}}{4} + L_{6R} + \frac{L_{7HB12}}{4} \right) =$$

$$= 1.95 \left(1580 + \frac{960}{4} + 348 + \frac{960}{4} \right) = 2408$$

$$\underline{\text{Vol}} = \underline{2408 \text{ in}^3}$$

SUBJECT

CASE PREFAB SUMMARY

NAME

A. Williams / LCH

DATE

7-18-77

WELD PREP-

PLASMA ARC CUTS

$$\text{(length)} L = 952 + 1167 + 1560 + 2080 + 6320 + 960 + 1400 + 1885 + 960 =$$

$$L = 17284 \text{ in}$$

Assume 10 in/min cutting rate for 3" PLATE
 (REF P 2/10 - 4/10)
 CUTTING TIME-

$$T = \frac{17284}{10} = 1728 \text{ min or } 28.8 \text{ HR say } \underline{30 \text{ HR}}$$

$$\text{HANDLING (74 PIECES @ 2 HR)} = 148 \text{ say } \underline{150 \text{ HR}}$$

$$\text{GRINDING (74 PCS @ 1 HR)} = \underline{74 \text{ HR}}$$

MACHINE CUTS

$$\text{length } L = 1356 + 3226 + 1005 = 5587 \text{ in.}$$

APPROX CROSS SECTION AREA OF CUT - 2.5 in²

$$\text{Vol. of CUTS} = 5587 \times 2.5 = 13968 \text{ in}^3$$

ASSUMING A METAL-REMOVAL RATE OF 1.6^{*} cu.in./min

THE CUTTING TIME IS-

* (REF P 7/10 & 10/10 SEC 1421)

$$T = \frac{13968}{1.6} = 8730 \text{ min or } 145.5 \text{ HR say } \underline{150 \text{ HR}}$$

$$\text{HANDLING (40 PIECES @ 4 HR)} \quad \underline{160 \text{ HR.}}$$

TOTAL THIS PAGE 564

ENGINEERING NOTE

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SUBJECT

MFTF

NAME

ALTES

DATE

7/19/77

PLASMA ARC CUTTING.

METALS HANDBOOK SHOWS TYPICAL CUTTING SPEEDS FOR STAINLESS STEEL IN

TABLE 4 P 303

FIGURE 4 P 304

} SEE FOLLOWING PAGES

BASED ON DATA FOLLOWING, CUTTING SPEEDS WILL BE USED FOR ESTIMATING PURPOSES.

PLATE
THICKNESS
IN.

CUTTING
SPEED
IN/MIN.

3

10

2

20

1

40

 $\frac{3}{4}$

60

 $\frac{1}{2}$

70

1461 3/10

METALS HANDBOOK

8th Edition

VOL. 4

Forming

*prepared under the direction of the
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ENGINEERING NOTE

1421

PAGE

4/10

SUBJECT

MFTF -

NAME

ALTES

DATE

7/15/27

Plasma-Arc Cutting

Plasma-arc cutting is done with a high-velocity jet of high-temperature ionized gas. The relatively narrow plasma jet melts and displaces the work-piece material in its path. Because plasma-arc cutting does not depend on a chemical reaction between the gas and the work metal, and because temperatures are extremely high, it can be used on almost any material that conducts electricity, including those that are resistant to oxy-fuel gas cutting. This process is used extensively for profile cutting of stainless steel plate and, to a lesser extent, on aluminum.

Principles. At temperatures above about 10,000 F (as in a welding arc), gases are partially ionized, and exist as a plasma, or mixture of free electrons, positively charged ions, and neutral atoms. The plasma torch confines the plasma-forming gas in an arc chamber, while the arc supplies a large input of electrical energy. The central zone of the plasma reaches a temperature of

50,000 F, and is completely

3 shows the essential components and mechanics of a plasma-arc torch. It is similar to a -inert gas welding torch with the tungsten electrode recessed into a small opening, but it is pulsed. A high-frequency pulsing is used to initiate a pilot arc between the tungsten electrode (cathode) and the copper nozzle (anode), both of which are cooled. The pilot or internal arc is an external or "transferred" arc between the torch electrode and the workpiece, which is connected as an anode. The pilot arc is then transferred to the workpiece and the external arc supplies the cutting energy. Some nonconductive materials can be cut with the plasma jet by the internal arc alone, but cutting energy is available.

Design of plasma-arc torches among different manufacturers. The torch illustrated in Fig. 3, the electrode is introduced around the electrode orifice. Passage through the lower part of the electrode chamber causes the gas to swirl around the walls of the electrode chamber and the conical arc. The layer of cooler gas at the nozzle acts as a thermal insulator and prevents the plasma jet from heating the nozzle.

The plasma jet heats the workpiece and the tungsten electrode (anode) and by transfer of energy the high-temperature, high-energy plasma-arc-constricting or the torch nozzle focuses the arc on a small area of the workpiece and heats the area to melting temperature. The molten products are continuously removed by the jet.

Flow of Gas. Any gas or gas mixture does not adversely affect the plasma arc or the workpiece can be used in the plasma-arc torch. The frequently used gases are compressed air, argon, nitrogen, hydrogen, or mixtures of these gases. Carbon steels, alloy steels, and aluminum and other nonferrous metals, are cut with hydrogen or nitrogen-hydrogen mixtures. Carbon steels, alloy steels, and iron are cut with a nitrogen-hydrogen mixture, compressed air, or hydrogen-oxygen mixture. Torches are used by one manufacturer use oxygen as an outer sheath with nitrogen as an inner sheath to protect the electrode.

Flow rates of the gases and setting of current are regulated according to metal, thickness of cut, and gas, to produce the maximum rate consistent with an acceptability of cut.

Total gas flow rates are 70 and 400 cu ft per hour. Arcs range between 150 and 1000 typical cutting rates of 10 to 70 in. min. The diameter of the orifice (1/16 to 1/4 in.) depends on the current and gas flow required. Tables recommended rates of flow mixtures and for air, based on metal thickness, cutting speed, current, and nozzle size, for steel and cast iron.

Mixtures of argon and hydrogen, or argon and hydrogen, are generally

Fig. 3 Essential components and mechanics of a typical plasma-arc cutting torch

Table 4. Typical Current Levels Used for Plasma-Arc Cutting of Steel, Stainless Steel, and Aluminum at Various Thicknesses

Cutting speed, ipm	Current, amp		
	Steel	Stainless	Aluminum
1/4-In. Thickness			
20	200	250	200
40	250	260	200
70	275	270	200
100	275	275	250
150	275	300	250
1/2-In. Thickness			
20	250	250	250
40	275	300	250
70	275	350	250
100, 150	...	...	275
1-In. Thickness			
10	250	300	300
20	275	300	325
40	275	350	350
70	...	...	350
100	...	...	375
2-In. Thickness			
5, 10	500	400	350
20	550	475	375
3-In. Thickness			
5	...	...	400
10	...	500	425
4-In. Thickness			
5	...	475	400
10	...	500	450
5-In. Thickness			
5	...	550	450
10	...	...	475

used for cutting stainless steel, and aluminum and other nonferrous metals. Table 3 gives recommended rates of gas flow for cutting stainless steel and aluminum, based on work-metal thickness, cutting speed, amount of current, and nozzle size.

Nozzle Construction. Special nozzle construction is needed when an outer sheath of oxygen is employed. Multiport nozzles with a ring of smaller orifices around the central orifice are used with compressed air, or when it is desired to reduce the taper of the cut.

Power Supply. Direct-current power sources rated at about 400 volts (open-circuit) or 200 volts (under load) are necessary. The circuit is basically the same as that used for tungsten-arc welding, except that a lead is taken from the ground through a resistor to the nozzle of the torch for the high-

frequency pulse used to initiate the pilot arc.

Current demand depends on type and thickness of the work metal, and on cutting speed. Current levels based on these variables are given in Tables 2, 3 and 4. Other variables, such as equipment, can influence current demand.

Work Metals. Plasma-arc cutting is used mainly on stainless steel and aluminum alloys; in these metals, it produces comparatively smooth cuts, free from contaminants. Oxy-fuel gas cutting of stainless steel requires the addition of iron powder or chemical flux. Aluminum alloys cannot be cut by the oxy-fuel gas method. Heavy-duty plasma torches can cut stainless steel up to 6 in. thick and aluminum alloys up to about 8 in. thick.

Other metals that are resistant to oxy-fuel gas cutting are also cut by the plasma method, including magnesium, copper, nickel, and copper-nickel alloys.

Titanium can be cut by either method, but is cut more rapidly by the oxy-fuel method. This is because titanium has a great affinity for oxygen, and therefore reacts with the gas cutting stream at a rate faster than the rate of melting by the high-intensity plasma arc. Although gas cutting is faster, plasma-arc cutting with inert gas mixtures is less likely to contaminate the titanium next to the surface.

Because of its rapid cutting rate, a plasma arc is economical for cutting of carbon steels 1/2 to 3 in. thick.

Cutting Speed. Figure 4 compares cutting speeds of a plasma arc at five different power levels with conventional gas cutting of carbon steel. The speeds shown for cutting of work metal 1 in. thick or less can be as much as five or more times as great for plasma arc as for conventional gas cutting. For metal 3 in. thick, speeds for both processes are about equal; for metal more than 3 in. thick, gas cutting is faster.

Workpiece Size and Shape. The reduction in cutting time (and saving in labor cost) compared with gas cutting is more likely to be realized on long continuous cuts such as are required in bridge construction, shipbuilding and tank fabrication. The relative economy of shorter cuts, which require frequent starts, will depend on the number of

that is practical, since gas cut-small pieces is usually done multiple-torch setups.

icient use of equipment, and the comparative costs of plas-oxy-fuel cutting vary widely rent applications, multitorch machines equipped with both cutting torches are sometimes warehouse cutting and in plate ng. Cutting speeds of 2 to 240 in have been used on a large with a cutting area of 44 by Various automated guidance es are used for profile cutting, n. radii can be cut at the max-eed of the machine.

sections of work metal are limited to single-torch opera-ause of the size of the available machine—an important con-in justifying the use of the arc process. Although there is retical limitation to multitorch n, it is usually practical to limit arc installations to a maximum torches, because (a) power de-or plasma-arc cutting are high, tallations using more than two usually develop prohibitive equirements; (b) limited visibil-posed on the operator by the r darker eye shields, which pre-ificulty in monitoring multiple ; and (c) greater damage to ent can result from delayed de-of malfunction. Therefore, for small sections of carbon steel, requires a large number of , gas cutting is generally more h than plasma-arc cutting.

nique. With a mechanically op-plasma-arc torch, the standoff e from the work metal is be- $\frac{1}{4}$ and $\frac{3}{8}$ in. Current and rate flow are set in accordance with ons shown in Tables 2 to 4.

anual operation, the current and gas flow are set according to conditions. The arc is struck by g a button on the torch, which ed manually over the work met-he end of the cut, the arc auto-ally extinguishes, and the control the contactor and closes the gas The operator can extinguish the any time by moving the torch rom the work metal.

void damage to the torch, the nozzle of the torch must never be d to touch the work metal. For l cutting, the nozzle is insulated vent accidental contact between rk metal and the torch metal. lity of Cut. Surfaces of plasma-ts are usually smoother than obtained by gas cutting, but the ges may be rounded. Also, the of the cut often have a V-shaped ed angle, which may be 5° to ultipoint nozzles, properly operat-duce this bevel to 1° to 2° .

angle must be acceptable in cutting or other applications in the torch must be kept vertical. er, when only one side of the s critical, the V-angle can be nsated for by keeping the torch angle while cutting.

en cutting stainless steel, the a arc produces smooth, clean Only light grinding to remove oration is required before welding.

Unwelded, unstabilized austenitic steels require removal of the heat-affected zone to maintain corrosion resistance.

The quality of cut produced by plasma-arc cutting of nonferrous metals varies considerably. For these metals, no comparison with gas cutting is possible. Cut surfaces will generally be rougher than all but the roughest surfaces produced by machining. For mechanical assemblies, it is often necessary to machine to final dimensions. For weld preparation, access openings, and clearances, parts are usually acceptable as cut.

In all plasma-arc cutting, the quality of the cut improves as speed is reduced, but reducing the speed defeats the main purpose of plasma-arc cutting; therefore, it is important to define the quality required.

Dimensional variation is ordinarily $\pm \frac{3}{32}$ to $\pm \frac{1}{8}$ in., and with close control can be held to $\pm \frac{1}{16}$ in. The depth of the heat-affected zone depends on the type of work metal, its thickness, and the cutting speed; maximum depth on stock up to 1 in. thick is about $\frac{3}{16}$ in., and is much less at high cutting speeds.

Width of kerf is greater than that produced by conventional gas cutting. Although work-metal thickness, nozzle size and cutting speed influence the width of a plasma-arc kerf, the range is usually $\frac{3}{16}$ to $\frac{3}{8}$ in. For thick work metal, width of kerf may exceed $\frac{1}{2}$ in. The minimum inside radius that can be formed depends on kerf width. Under optimum conditions—using thin work metal, small nozzle size, and slow speed—the minimum inside radius for plasma-arc cutting is $\frac{3}{16}$ in.

Bevel cutting for weld preparation is an important application of plasma-arc cutting. The intense heat makes it suitable for all types of beveling at a higher efficiency than gas cutting. The plasma-arc process produces surfaces of acceptable quality, and, because of the natural V-shaped cut, it is sometimes considered more efficient for bevel cutting than for perpendicular cutting. Torch equipment and settings are the same for both types.

Safety Precautions. The plasma arc is a much brighter source of radiation than the gas cutting flame, and is more closely related to the arcs of gas tungsten-arc and gas metal-arc cutting. Helmets and eye protection used for the latter processes must also be employed when plasma-arc cutting. Gen-

erally, shades 11 and 12 of protective lens are recommended. Similarly, because of the intensity of ultraviolet radiation of the plasma arc, all skin areas of the body should be protected by dark, substantial clothing to prevent ultraviolet burns. Otherwise, the precautions for plasma-arc and gas cutting are similar. Good maintenance and proper operation of the plasma equipment are essential, not only to avoid gas leaks, but also to guard against electrical hazards.

Natural ventilation is usually adequate in high-roofed, industrial structures. However, plasma fumes are generated rapidly at the high cutting speed that can be attained, and forced ventilation may be required if the fume concentration reaches dangerous levels, as in confined areas with poor natural ventilation.

During some plasma-arc cutting, noise levels may be high enough to warrant the use of ear protectors, such as earmuffs and earplugs, by the operator and by other personnel in the immediate vicinity who might be affected by such noise level. If the normal speaking voice must be raised to be understood, ear protection is recommended unless a noise survey by a qualified analyst indicates otherwise.

Seldom-Used Electric-Arc Cutting Processes

The four electric-arc cutting processes described in this section either are almost obsolete or have never been used extensively. However, these processes are sometimes used for highly specialized applications or when equipment for more suitable methods is not available.

Carbon-arc cutting is one of the oldest electric-arc cutting methods. This process uses the heat generated by the carbon arc to melt metal progressively to produce a kerf. The melted metal is removed from the cut by gravity or by the force of the arc, or by both.

The use of carbon-arc cutting is limited to cutting up of scrap and dismantling of structural steel assemblies.

Shielded Metal-Arc Cutting. Metal can be cut by a shielded metal arc, using flux-covered stick electrodes. The molten metal is removed from the cut by gravity or by the force of the arc, or both.

Shielded metal-arc cutting is most commonly used for removing gates and risers from castings and for cutting up scrap. The process can also be used for underwater cutting with specially processed (waterproof) electrodes.

Gas Metal-Arc Cutting (MIG). In this process, heat is obtained from an electric arc formed between a continuously fed wire and the work metal. The molten metal is continuously blown from the kerf by the shielding gas. The process is used mainly on stainless steel and aluminum, although other metals can be cut by this method.

Gas metal-arc cutting is most often used in fabricating shops where gas metal-arc welding is done, as the same equipment can be used for both cutting and welding. Gas metal-arc cutting is limited in application, because the rate of wire consumption is high, and the thickness of sections that can be cut is limited to about $1\frac{1}{2}$ in. for stainless steel, and about 3 in. for aluminum.

Gas tungsten-arc cutting (TIG) is similar to gas tungsten-arc welding, except that higher amperages and voltages are used. The same basic circuit and similar shielding gases are used for both processes.

Although gas tungsten-arc cutting can be used for cutting most ferrous and nonferrous metals, it is largely confined to the cutting of stainless steel and aluminum $\frac{1}{2}$ in. or less in thickness. The quality of the cut is usually good enough to permit welding without machining the cut surfaces.

Fig. 4. Effect of work-metal thickness on cutting speed for plasma-arc cutting at five different power levels, compared with conventional gas cutting

ENGINEERING NOTE

1421

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SUBJECT

MFTF.

NAME

ALTES

DATE

7/19/77

MILLING - METAL REMOVAL RATE.

ESTIMATES OF RATES RANGE FROM

 $.6 \frac{\text{IN}^3}{\text{MIN}}^*$ (EGG LAS VEGAS) TO $1.6 \frac{\text{IN}^3}{\text{MIN}}^*$ (ALTES/HUNT EGG) EST.

THE LAS VEGAS ESTIMATE IS FOR EQUIPMENT AVAILABLE IN EGG SHOP. A TYPICAL STEEL FABRICATOR WOULD PROBABLY USE LARGE PLANNER AND BORING MILLS WITH METAL REMOVAL RATES HIGHER THAN CAN BE ATTAINED IN EGG SHOP.

FOR ESTIMATING PURPOSES USE $1.6 \frac{\text{IN}^3}{\text{MIN}}$ REMOVAL RATE.

* REF. FOLLOWING PAGES.

SUBJECT

METE

NAME

A. WILLIAMS

DATE

5/25/77

TELLON

TO: BILL CAMP

SHOP SUPERVISOR

EG&G NORTH LAS VEGAS FACILITY

FROM: ART WILLIAMS

 RE: MACHINING J GROOVE WELD PREP.

- ESTIMATE TO MILL ONE SIDE OF DOUBLE JOINT

 IS $1.5 \frac{\text{HR}}{\text{FT.}}$ (INCLUDES 3 PASSES,

2 ROUGH CUTS & ONE FINISH PASS.)

- TIME WOULD BE LESS FOR STRAIGHT CUTS ON PLANE MILL, $0.5 \frac{\text{HR}}{\text{FT.}}$

$$19 \frac{\text{IN}^3}{\text{FT}} \times 30 \frac{\text{FT}}{\text{MIN}} = .6 \frac{\text{IN}^3}{\text{MIN.}}$$

THESE RATES ARE FOR EQUIPMENT AVAILABLE AT EG&G LAS VEGAS.

SUBJECT

MFTF

NAME ALTES

DATE 7/19/77

MILLING - METAL REMOVAL RATES

SOME COIL CASE PLATES WILL REQUIRE MILLED EDGE PREPARATION PRIOR TO WELD ASSEMBLY

FOLLOWING IS AN ESTIMATE OF METAL REMOVAL RATES.

ASSUME : CUTTER DIA. : 3"
 NO. TEETH : 8
 FEED RATE .005 IN./TOOTH
 CUTTING SPEED : 300 SURFACE FT./MIN.
 DEPTH OF CUT : .25 IN.
 WIDTH OF CUT : 3 IN.

TABLE FEED RATE

$$f_m = f_t n_t N \quad \text{WHERE:}$$

f_m = TABLE FEED RATE IN/MIN.

f_t = FEED RATE IN/TOOTH

n_t = NUMBER OF TEETH IN MILLING CUTTER.

N = SPINDLE SPEED (RPM)

$$= \frac{12V}{\pi D} \quad \text{WHERE}$$

V = CUTTING SPD FT./MIN.

D = CUTTER DIA.

$$N = \frac{12V}{\pi D} = \frac{12(300)}{\pi \times 3} = 382 \text{ RPM.}$$

$$f_m = .005 \times 8 \times 382 = 15.3 \frac{\text{IN}}{\text{MIN}}$$

SUBJECT

MFTF

NAME

ALTES

DATE

7/19/77

MILLING - METAL REMOVAL RATES.

TO FIND ACTUAL MACHINING TIME FOR A GIVEN PART AN ESTIMATE WILL BE MADE FOR A HYPOTHETICAL "J" GROOVE 60 IN. LONG.

$$\text{"J" GROOVE VOLUME/FT} = 1.587 \text{ IN}^3 \times 12 \text{ IN} = 19 \frac{\text{IN}^3}{\text{FT}}$$

ASSUME : SINGLE "J"

60 IN LENGTH

$$\text{NO. OF PASSES} = \frac{.75 \text{ IN}}{.25 \text{ IN/PASS}} = 3$$

<u>OPERATION</u>	<u>TIME, MIN.</u>
SET UP	(INCLUDED WITH HANDLING)
MILL 60 IN X $\frac{1 \text{ IN}}{15 \text{ MIN}}$	4
RETURN	2
RESET MACHINE	2
MILL & RETURN	6
INSPECT	10
RESET MACHINE FOR FINAL CUT	5
MILL & RETURN	6
INSPECT	10
REMOVE PIECE.	(INCLUDED WITH HANDLING)
TOTAL	45 MIN

ASSUMING 80% EFFECTIVITY TIME IS 56.3 MIN.

SAY 60 MIN.

RATES :

$$\frac{60 \text{ MIN}}{5 \text{ FT}} = 12 \frac{\text{MIN}}{\text{FT}}$$

$$\frac{19 \text{ IN}^3}{\text{FT}} \times \frac{\text{FT}}{12 \text{ MIN}} = 1.58 \frac{\text{IN}^3}{\text{MIN}} \quad \text{USE } 1.6 \frac{\text{IN}^3}{\text{MIN}}$$

* REF : WELD DEPOSITION RATE CALCULATION.

SUBJECT

CASE PREFAB

NAME

A. Williams / LDH

DATE

7-15-77

PLATES $P_4 \neq P_2$ MUST CURVED (CYLINDRICAL)
 ABOUT THE MINOR AXIS $\neq$ PLATES $P_5 \neq P_7$
 MUST CURVED ABOUT THE MAJOR AXIS.

I.E.

$$Wt P_4 = .281 (40^2 - 34^2) \frac{\pi}{4} \times 65 = 6369 \text{ lb}$$

$$Wt P_6 = .281 (86^2 - 80^2) \frac{\pi}{4} \times (65 - 50) = 3297 \text{ lb}$$

$$Wt P_5 = .281 (618 \times 20 \times 3) = 10419 \text{ lb}$$

$$Wt P_7 = .281 (754 \times 20 \times 3) = 12712 \text{ lb}$$

32797

Say 33000 lb

OR ABOUT 33000 lb OF PLATE MUST FORMED
 INTO CYLINDRICAL SECTIONS

SUBJECT

CASE PREFAB SUMMARY

NAME
A. Williams / CDH
DATE
7-18-77

PLATE FORMING

THERE ARE APPROX 28 PIECES THAT MUST BE FORMED TO A RADIUS ABOUT THE MAJOR AXIS - ASSUME THESE ARE ROLLED TO SHAPE. (3" THK PLATE)

$$\text{TOTAL WT} = 10072 + 10419 + 12712 = 33199 \quad \text{Say } 33200$$

$$\text{WT} = \underline{33,200 \text{ lb}} \quad \text{ROLLED}$$

$$\text{@ } \$0.30/\text{lb} \text{ for Rolling 3" PLATE} \quad \text{COST} = 33200 \times .3 = \underline{\$9960}$$

(P. 3/7)

THERE ARE 8 PIECES THAT MUST BE FORMED TO A RADIUS ABOUT THE MINOR AXIS - ASSUME THESE ARE RING ROLLED FORGINGS

$$\text{TOTAL WT} = 11015 + 6369 + 3297 = 20681 \quad \text{Say } 20700$$

$$\text{WT} = 20700 \text{ lb} \quad \text{RING ROLLED FORGINGS}$$

$$\text{@ } \$2.00 \text{ for forging} \quad \text{(P. 3/7)}$$

$$\text{COST} = 20700 \times 2.00 = \underline{\$41,400.00}$$

$$\text{TOTAL THIS PG} = \$51,360.00$$

ENGINEERING NOTE

1422

PAGE
3/7

SUBJECT

TK-TR.

NAME

ALTES

DATE

7/19/77

PLATE ROLLING.

FOLLOWING ARE \$/LB FOR ROLLING 3" THICK
PLATES TO RADII INDICATED.

THE COSTS ARE FOR ROLLING ONLY,
MATERIAL COST IS W SEC. 1200

RADIUS
IN.

COST *
\$/LB

72" - 108"
(ROLLED IR)

\$.30 / LB.

17"
(RING ROLLED FORMING)

\$ 2 / LB.

* REF FOLLOWING PAGES

ENGINEERING NOTE

1422

PAGE

4/7

SUBJECT

NAME

ALTES

DATE

7/19/77

M.R.T.P.

PLATE ROLLING

TELON

DATE 7/25/77

TO: NEAL BRIAN

KAISER STEEL PRODUCT FABRICATIONS

NAPA, CA

PH. 707-224-5421

FROM: BOB ALTES

RE: ROLLING COST FOR 3" THICK NITRONIC 40 PLATE.

AN INQUIRY WAS MADE FOR COST OF ROLLING PLATES FOR THE COIL CASE. PLATE SIZE USED FOR THIS INQUIRY WAS 2' X 10' X 3" THICK.

KAISER HAS A ROLLING MILL WITH FOLLOWING CAPABILITIES:

MAX PL THICKNESS : $5\frac{1}{2}$ IN. THK

WIDTH : 10 FT.

CAPACITY : SUFFICIENT TO COLD ROLL THE 2' X 10' NITRONIC 40 PL

PLATES SUPPLIED TO KAISER FOR ROLLING WOULD HAVE TO BE:

- CUT TO SIZE, KAISER WOULD HAVE TO CUT WITH POWDER CUTTING, MESSY.
- PLATES SUPPLIED LONG BY 2 FULL PLATE THICKNESSES. (E.G. 10' + 2(3')).

ROLLS WOULD BE CLEANED (SANDED) PRIOR TO ROLLING. FINISH ROLLED PLATE MAY HAVE SOME SURFACE IMPURITIES. IMPURITIES COULD PROBABLY BE REMOVED BY BEAD OR SAND BLAST. (CARBON STEEL ROLLS.)

COSTS ON NEXT PAGE.

SUBJECT

MFTF

NAME ALTES

DATE 7/19/77

PLATE ROLLING

TELLON - CONT'D
 BRIAN/ALTES.

COST FOR 2' x 10' x 3" THK PLATES
 ROLLED TO "r" AS INDICATED.
 (LABOR ONLY - MATERIAL COST ELSEWHERE - SEE 1200)

① RADIUS, r	COST ②	COST/LB
72 IN	\$ 500	~ \$.20 / LB
108 IN	\$ 750	~ \$.30 / LB.

① PREFORM & ROLL.

② INCLUDING HANDLING, ROLL LOADING & REMOVAL.

ROLL UNIT COST

2 MAN OPERATION

COST : $2 \times \$23.50/\text{HR} = \$47/\text{HR}$ (INCLUDING
 COST OF ROLLS)

IN GENERAL - FOR PLATES OF SAME SIZE
 AND SLIGHTLY DIFFERENT RADIUS, r, COST
 WOULD BE NEARLY CONSTANT.

FORMAL INQUIRIES SHOULD BE DIRECTED
 TO :

BILL DALEY
 KAISER STEEL
 300 LAKESIDE DR.
 OAKLAND CA.
 271-2994

ENGINEERING NOTE

1422

PAGE

6/7

SUBJECT

MRTF

NAME ALTES

DATE 7/19/77

PLATE ROLLING.

TELLOON:

TO: WALLY WOLF
STEEL MANOR
SOUTHGATE, CA.
213-869-2518

FROM: R. ALTES

RE: ROLLING 2' x 10' x 3/4" THK NITRONIC 40 P

- WALLY CANNON ROLL THIS PLATE
- CAN MAKE RADIUS BY USING PRESS BREAK.
- PLATE WOULD HAVE TO BE ANNEALED.
- TEMPLATE WOULD HAVE TO BE SUPPLIED BY CUSTOMER.

COST EA; FOR 72 - 108 BEND RADIUS

\$140 EA + \$.05/LB ANNEAL COST.

COST (ROLL LABOR ONLY) = \$ 140

+ .05(2506) = \$ 125

\$ 265

TEMPLATE

EST. 4 HR @ \$25/HR

100

\$ 365 EA P.

COST/LB $\frac{\$365}{2506} = \$.15/\text{LB.}$

ENGINEERING NOTE

1422

PAGE 7/7

SUBJECT

MT-F

NAME

ALTES

DATE

7/15/77

COIL CASE.

TELCON

TO : CAELTON FORGE WORKS.

7743 ADAMS,

PARAMOUNT

633 - 1131

MR. GILLIS.

FROM : ALTES

RE : 1214 ROLLED FORGINGS FOR COIL CASE
INNER WALL MINOR RADII.

- Roll Ring As Shown
- Cut in 2 Pcs.
- For one coil case
- 2 Rings Req'd.

$$STK.WT. = \frac{\pi}{4} (40^2 - 34^2) 60 \times .29 = 6068 \text{ LB. (ENTIRE RING)}$$

COST FOR FORGINGS

\$ 3/LB MTL. INCLUDED ASSUMING 304 ST. STL.
LESS MTL \$ 1/LB
\$ 2/LB FOR END ROLLING

SAN RAMON OPERATIONS

ENGINEERING NOTE

1423

PAGE 1/4

SUBJECT

CASE REFERS

SUMMARY

NAME A. Williams / LDH
DATE 7-19-77

WELDING -

$$\text{Vol of Weld} = \text{Sum W}_1 \text{ thru W}_6 + \text{Radial welds} =$$

$$= 4551 + 1458 + 3389 + 5914 + 6754 + 1008 + 2408 =$$

$$\text{Weld} = 25482 \text{ in}^3$$

ASSUME 17.2 cu-in/hr DEPOSITION RATE

THE WELDING TIME IS -

$$\bar{T} = \frac{25482}{17.2} = 1482 \text{ HR}$$

SET UP (assume 74 pieces @ 4hr) = 296 HR

INSPECTION EST 30% WELD TIME

$$\text{TOTAL TIME} = (1482 + 296) 1.3 = 2311 \text{ HR}$$

(* REF P 4/6 SEC 1423)

$$\text{Ref - Weld wire} = 25482 \times .281 = 7160 \text{ lb.}$$

$$36 \frac{\text{in}^3}{\text{ft}} \times 1.5 \frac{\text{hrs}}{\text{ft}} = 24 \frac{\text{in}^3}{\text{hr}}$$

(6 HRS OUT OF 8 IS GOOD PRODUCTION)

1.5 HRS (no down)

PRODUCTION RATE:

(HIGHER PRODUCTION RATE THAN WITH .062 ϕ)

WIRE SIZE : .045 in DIA.

VOLUME : 36 in³/ft

DOUBLE J WELD.

RE : WELD METAL DEPOSITION RATES

FROM: ART WILLIAMS.

EG&G NORTH LAS VEGAS FACILITY

SHOP SUPERVISOR

TO : BILL CAMP

TELON

MFTF -

SUBJECT

ENGINEERING NOTE

1423

2/6

PAGE

DATE 5/25/77

NAME A. WILLIAMS

SUBJECT

MATE

NAME ALTES

DATE 7/15/77

WELDING DEPOSITION RATES.

ANALYSIS OF CAMP INFO

WELD CROSSSECTION AREA, A

$$A \approx \frac{(.32)(2.5625)}{2} + (.43)(2.5625) + \frac{1}{8}(-.313)^2\left(\frac{1}{4}\right)$$

$$\approx .41 + 1.1 + .077$$

$$A = 1.587 \text{ in}^2$$

FOR DOUBLE J $A = 2(1.587) = 3.174 \text{ in}^2$

VOL/FT OF DOUBLE J = 38. in^3

$$38. \frac{\text{in}^3}{\text{ft}} \times 1.5 \frac{\text{ft}}{\text{lb}} = 25.33 \frac{\text{in}^3}{\text{hr}}$$

WELD DEPOSITION RATE =

$$25.33 \frac{\text{in}^3}{\text{hr}} \times .29 \frac{\text{lb}}{\text{in}^3} = 7.35 \frac{\text{lb}}{\text{hr}}$$

NOTE

A. WILLIAMS FEELS THIS RATE MAY BE TOO HIGH IN VIEW OF TECHNIQUES THAT SHOULD BE EMPLOYED TO MINIMIZE DISTORTION, I.E. BLOCK WELDING. ART THINKS 3-4 LB/HR MAY BE REASONABLE RATE.

SUBJECT

MITE

NAME

ALTES

DATE

7/15/77

WELDING DEPOSITION RATES.

PER AIRCO WELDING MANUAL TABLE 2
 (ALSO REF SEC 1790)

PRODUCTION RATES FOR .045 IN. DIA WIRE @
 VARIOUS ELECTRODE SPEEDS IS AS FOLLOWS.

ELECTRODE IPM	CURRENT AMPS.	$\frac{1}{IN^3}$ HR	$\frac{LB}{HR}$
100	85	9.54	2.77
140	110	13.36	3.87
180	140	17.18	4.98
220	180	20.99	6.09
260	220	24.80	7.19
300	260	28.62	8.30

$$A, .045 \text{ WIRE} = \frac{\pi}{4} (.045)^2 = .00159 \text{ IN}^2$$

WHILE $7.35 \frac{LB}{HR}$ DEPOSITION RATE MAY SEEM
 HIGH, A REVIEW OF AIRCO DATA TABLES 2 & 13
 SHOWS THAT $3-4 \frac{LB}{HR}$ IS A FAIRLY LOW
 PRODUCTIVITY FOR THIS PA-3 MACHINE

FOR ESTIMATING PURPOSES A DEPOSITION
 RATE OF $5 \frac{LB}{HR}$ WILL BE USED.

$$\underline{5 \frac{LB}{HR}} \quad , \quad 17.24 \frac{IN^3}{HR}$$

1423
5/6

Although relatively low average currents can be achieved in its background mode, still lower average current levels can be achieved by switching to the extra low mode. The minimum average currents that can be achieved for both modes are shown in Table 4 where they are compared to the minimum average currents that can be achieved with the PA-2 power source.

When the background selector switch is in the extra low mode, the level of background current is selected by one or more of the three current switches on the machine. As soon as one or more of these switches are placed ON, the brushes on the background transformer will move to its highest position (47 volts).

Once the level of background current has been selected by one of the current switches, the variables left to adjust are the pulse width and the electrode speed. The electrode speed determines the average current as in the normal mode of operation, BUT THE PULSE WIDTH BECOMES THE DEVICE FOR SETTING THE ARC LENGTH. At any given background current, a combination of electrode speed and pulse width are selected to produce spray transfer of metal. For a particular background current and electrode

diameter, the usable range of average current is narrow as shown in Fig. 15. Table 5 should be used to determine where the current switches are to be set.

Figure 14. Effect of Change in Pulse Width On Pulse - Peak Voltage

TABLE 2. Average Current In Amperes Vs. Electrode Speed In Inches Per Minute

Electrode Speed, IPM	Mild and Low-Alloy Steel Electrode Diameter, In.			Austenitic Stainless Steel Electrode Diameter, In.			4043 Aluminum Alloy Electrode Diameter, In.	
	0.035	0.045	1/16	0.035	0.045	1/16	3/64	1/16
40			65					
50		55	85			70		45
60		65	105		50	90		55
70		75	120		55	100		60
80		85	135	40	65	115		70
100	50	100	175	50	85	140	50	90
120	60	115	200	60	95	180	60	110
140	70	130	225	65	110	220	70	130
160	80	145	250	75	120	240	80	150
180	90	160	275	80	140	260	90	170
200	100	180	290	90	160	280	100	180
220	110	200	320	95	180	310	105	200
240	120	220		105	200		120	220
260	135	240		100	220		130	240
280	140	260		125	240		135	260
300	155	280		135	260		140	280
350	180			150	280		170	300
450	220			200	320		200	

14 23
6/6

TABLE 13. Model PA-3-Optimum Conditions For Welding Austenitic Stainless Steel In A Shield Of A + 1% O₂ Or A + 2% O₂

Metal Thickness, In.		Elect. Dia, In.	Average Current, Amp	Electrode Speed, IPM	Pulse-Peak Voltage, Volts*	Back-ground Voltage, Volts	Pulse Rate, PPS	Mode Of Operation	Background Current Amp			Elect. Melting Rate, Lb/Hr
Flat & Horiz. Position	Position Other Than Flat & Horiz.								8.5	8.5	17.0	
0.040	0.050	.035	40	80	65	—	60	Ex Low	On	On	Off	1.3
0.050	1/16	.035	50	110	66	—	60	Ex Low	On	On	Off	1.7
1/16	3/32	.045	60	75	69	—	60	Ex Low	On	On	Off	2.3
3/32	1/8	.035	80	180	68	—	120	Ex Low	On	On	Off	2.8
3/32	1/8	.045	80	100	65	—	60	Ex Low	On	On	On	2.7
1/8	3/16 Up	.045	100	130	72	—	120	Ex Low	On	On	Off	3.6
1/8	3/16 Up	1/16	100	65	67	—	60	Ex Low	On	On	On	3.4
3/16	3/8 Up	.045	140	185	66	22	120	Normal	Off	Off	Off	5.0
3/16	3/8 Up	1/16	140	100	67	23	120	Normal	Off	Off	Off	5.0
1/4		.045	160	215	66	24	120	Normal	Off	Off	Off	6.0
1/4		1/16	160	115	67	25	120	Normal	Off	Off	Off	5.8
3/8 Up		.045	200	260	66	26	120	Normal	Off	Off	Off	7.2
3/8 Up		1/16	200	130	67	27	120	Normal	Off	Off	Off	6.8

*Pulse Peak voltage settings are only a guide and practical experience indicates they may be as much as 10% high.

TABLE 14. Model PA-2-Optimum Conditions For Welding Austenitic Steel In A Shield Of A + 1% O₂ Or A + 2% O₂.

Metal Thickness, In.		Elect. Dia., In	Average Current, Amp	Electrode Speed, IPM	Pulse-Peak Voltage, Volts	Background Voltage, Volts
Flat & Horiz. Position	Positions Other Than Flat & Horiz.					
1/16	3/32	.035	60	120	34	17
3/32	1/8	.035	80	180	34	19
3/32	3/16	.045	100	125	36	19
1/8	1/4	.045	110	140	36	20
3/16	3/8 Up	.045	130	170	36	23
3/16	3/8 Up	1/16	130	90	39	23
1/4		1/16	180	120	39	27
3/8 Up		1/16	220	140	39	29

REF : PULSED SPRAY WELDING PROCESS
MANUAL - AIRLO WELDING PRODUCTS.

STAINLESS STEEL

ENGINEERING NOTE

1424

PAGE

1/1

SUBJECT

CASE PREFAB

Summary

NAME

L.D.H.

DATE

7-19-77

MACHINING CASE FOR INTER CONNECTING MEMBERS -

REQUIRES FACING OFF CASE IN FOUR LOCATIONS & DRILLING A TAPPING HOLES FOR 1 1/2" BOLTS IN 80 PLACES. DONE ON CASE UPPER SEGMENT AFTER WELDING.

EST

FACING OFF 160 HR
DR & TAPPING 80 HR

MISC. MACHINING FOR LHE LIVES ETC 40 HR

280 HR.

ITEM	DESCRIPTION	QTY. *	UNIT	UNIT COST	MATERIAL TOTAL \$	UNIT MAN HOURS	LABOR TOTAL MAN HOURS	TOTAL ITEM COST
1430	MAGNET ASSEMBLY	1	EA					
1431	ASSEMBLE COIL JACKET	1	EA				658	
1432	INSTALL CASE LOWER SEGMENT INTO WELDING FIXTURE.	1	EA				25	
1433	INSTALL JACKETED COIL IN COIL CASE	1	EA				143	
1434	INSTALL CASE UPPER SEGMENT	1	EA				49	
1435	WELD UP OUTER CASING.	1	EA				832	
1436	INSTALL INTERCONNECTING MEMBERS	1	EA				144	
1440	JACKET - CASE SHIMS	1	LOT.		14,030			
	TOTAL				14,080		1851	
	1: ONE MAGNET

ENGINEERING NOTE

1430

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SUBJECT

MFTF

NAME

ALTES

DATE

7/19/77

MAGNET ASSY

ASSUMPTIONS.:

- COIL MOUNTING ADAPTER ON COIL WINDER
- COIL INNER JACKET INSTALLED & COIL WINDING ON INNER JACKET COMPLETED.
- OUTER JACKET SEGMENTS HAVE BEEN FABRICATED AND ARE READY FOR ASSEMBLY.
- INNER AND OUTER CASING, HAVE BEEN FABRICATED AND ARE READY FOR ASSEMBLY.

ASSEMBLY OPERATIONS :

(AS LISTED SEC 1430 TABULATION SHEET)

REF SKETCHES SEC 1410

ENGINEERING NOTE

PAGE

1431

1/2

SUBJECT

NAME BEVERIS / ALTES

DATE 5/19/77

MP TF

ASSEMBLE COIL JACKET

ASSEMBLE OUTER JACKET TO INNER JACKET.
(24 PIECES):

<u>DESCRIPTION</u>	<u>MAN-HRS</u>
TRANSPORT JACKET SEGMENTS TO ASSEMBLY AREA	32
INSTALL LIFTING FIXTURE (SEC 1763)	10
Hoist JACKET SECTIONS TO WINDER	24
REMOVE CLAMPS. 1M @ $\frac{1}{2}$ HR (24)	48
FIT UP SEGMENTS. 1M @ 2 HR (24)	192
TACK SEGMENTS IN PLACE 1 HR EA (24)	24
INSTALL TIGS & WELDERS 8 HR (24)	192
WELD. (SEE P.2)	40
INSPECT & REPAIR 1 HR / SECTION (24)	24
POSITION WINDER 1 HR / SEC. (24)	24
REMOVE TIGS & WELDERS.	48
TOTAL	658 M-HRS.

AIM

Association for Information and Image Management

1100 Wayne Avenue, Suite 1100
Silver Spring, Maryland 20910
301/587-8202

Centimeter

Inches

MANUFACTURED TO AIM STANDARDS
BY APPLIED IMAGE, INC.

3 of 4

SUBJECT

COIL JACKET ASSY

NAME

L DH

DATE

7-19-77

WELDING

$$\begin{aligned}\text{Vol of Weld} &= 62 + 179 + 327 + 80^* = \\ &= 648 \text{ in}^3\end{aligned}$$

* Vol from SEC 1410
Pg 4 & 5

ASSUME DEPOSITION RATE OF 17.2 in³/HR

$$\text{Time} = \frac{648}{17.2} = 37.6 \text{ SAY } \underline{40 \text{ HR}}$$

$$\text{WELD WIRE WT: } 648 \text{ in}^3 \times .29 \frac{\text{LB}}{\text{in}^3} = 188 \text{ LB.}$$

ENGINEERING NOTE

1432

PAGE

X

SUBJECT

TFTR

NAME

DS

DATE

5/24

INSTALL CASE LOWER SEGMENT INTO WELDING FIXTURE.
(FIXTURE: REF SEC 1755)

RECEIVE & INSPECT PREFAB CASE LOWER
SEGMENT.

11-HRS.

4

INSTL. LIFT FIXTR. 1766

NEW HRS

3@2

6

INSTL. OUTER-CASING INTO WELD FIXTR. 3@2

6

SECURE PART TO FIXTR.

3@3

9

TOTAL MHRS.

25

ENGINEERING NOTE

1433

PAGE

SUBJECT

MAGNET ASSY.

NAME

WIS / ALTES

DATE

5/24

INSTALL JACKETED COIL IN COIL CASE

11 @ HES.

MHS.

POSITION COIL WINDER FOR PROPER LIFT

2

INST. LIFT FIXTR. 1767

1

3 @ 3

9

DETACH COIL, COIL MTR. ADAPTER FROM

4 @ 8.

32

WINDING FIXTURE

LIFT & MOVE JACKETED COIL TO CASING

3 @ 2

6

INST. JACKETED COIL IN CASING

3 @ 2

6

(1768) CLAMP JACKET & REMOVE FIXTR.

4 @ 2

8

SHIM FOR FINAL FITUP

80

TOTAL MHS = 143

ENGINEERING NOTE

PAGE

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SUBJECT

MAGNET ASSY.

NAME

2/3

DATE

5/24

	<u>M</u>	<u>HR</u>	<u>M-HRS</u>
INSTALL CASE UPPER SEGMENT			
RECEIVE & WSP. PRE FABBED CASING	2 @	2	4
INSTL. LIFT FIXTR. (1769)	3 @	2	6
LIFT & MOVE CASING TO WELD, FIXTR.	3 @	2	6
INSTL. CASING ONTO WELD FIXTR.	3 @	2	6
REMOVE CLAMPS & FITUP	6 @	4	24
REMOVE LIFT FIXTR AND LUGS	3 @	1	3
			<hr/>
	TOTAL	MHRS.	49

ENGINEERING NOTE

1435

PAGE

1/2

SUBJECT

MAGNET ASSY.

NAME

TJB

DATE

5/24

WELD UP OUTER CASING

INSTL. WELDING JIGS 1770 4m@16H 64

FINE ADJUST WELD JOINT CLEARANCE. 4m@8 32

INSTL. WELDING HEAD TRACKS 4m@8 32

PA 8 SYSTEM TEST 2m@8 16

INSTL. WELDING EQUIPMENT 4m@16 64

POSITION WELDER 3

WELD SETUPS 60

WELD (SEE P.2) 382

INSPECT @ 30% OF WELD TIME 115

REMOVE EQUIP. & JIGS 4m@16 64

TOTAL MHRS 832
PER MAG.

SUBJECT

CASE PREFAB

NAME

A. Williams /LDH

DATE

7-18-77

FINAL WELDS

THESE ARE DONE AFTER
COIL IS PLACED IN THE
CASE.

Weld W7

$$A = \text{Same as } W_5^* = 6.72 \text{ in}^2$$

$$\begin{aligned} \text{Vol} &= .672 \times L_1^* = 6.72 \times 476 = 3199 \\ &= \underline{\underline{3200 \text{ in}^3}} \end{aligned}$$

* SEE SEC 1420
Pg 1 & B

Weld W8

$$A = \text{Same as } W_4^* = 3.9 \text{ in}^2$$

$$\text{Volume} = \text{Same as } W_4^* = \underline{\underline{3389 \text{ in}^3}}$$

* SEE SECTION
1420 Pg B

$$\text{TOTAL WELD VOL, 2 WELDS,} = 6589 \text{ in}^3$$

$$\begin{aligned} \text{WELD TIME} &= \frac{6589 \text{ in}^3}{17.24 \frac{\text{in}^3}{\text{HR}}} = 382 \text{ HRS} \\ &\text{① } 17.24 \frac{\text{in}^3}{\text{HR}} \end{aligned}$$

① REF SEC 1423 - WELD DEPOSITION RATE.

$$\text{FILLER METAL WT} = 6589 \text{ in}^3 \times .29 \text{ lb/in}^3 = 1910.8 \text{ LB.}$$

ENGINEERING NOTE

1436

PAGE

1/1

SUBJECT

MFTF

NAME

JPS/ALTES

DATE

5/24 / 7/19/77

INSTALL INTERCONNECTING (ICON) MEMBERS

	M@ HRS	M-HRS
TRANSPORT I-CON MEMBERS TO ASSY. AREA.	2@2	4 ①
INSTL. LIFT FIXTR. 1771	3@2	6 ①
LIFT & MOVE TO WELD FIXTR'		2 ①
ROTATE WELD FIXTR. TO HORZ.		2
INSTL. I-CONN MEM. ON CASING	3@4	12 ①
FIT-UP	3@8	24 ①
INSTALL FASTENERS & TORQUE 1 1/2" 20 @ .5 HR EA		10 ①
INSTALL DOWEL PINS		8 ①
ROTATE COIL 180°		2
INSTALL SECOND I-CON MEMBER. ②		66 ②
INSPECT		8

TOTAL M-HRS.

144

② = Σ ①

SUBJECT

SHIMS JACKET / CASE

NAME

LDH

DATE

7-19-77

SHIMS BETWEEN JACKET & CASE

THERE IS APPROX $\frac{1}{2}$ " CLEARANCE
 BETWEEN JACKET & CASE - THIS SPACE
 MUST BE SHIMMED AT ASSY

ASSUME 6" WIDE SHIMS ON 12" CENTERS

$$\text{NO. STATIONS} = \frac{\text{PERIPHERY OF JACKET}^*}{12"}$$

$$N = \frac{869}{12} = 72.4$$

$$N = 72$$

$$@ 5 / \text{STATION} = 360 \text{ PIECES}$$

MAT'L — ASSUME SHIM .5" THK SST

$$\text{WEIGHT} = (2 + 24 + 25 + 20 + 45) \times 6 \times .5 \times .281 \times 72 =$$

$$= 7040 \text{ LB} / \text{MAGNET}$$

FABRICATION & MTLs @ \$2/LB.

$$\text{COST} = \$14,080 / \text{MAGNET}$$

* APPROX = TO LENGTH OF WELD W₃ OF
 JACKET - SEE SEC 1410 Pg 4.

5/23/77

1449

1/2

VERIFYING VACUUM INTEGRITY OF MFTF MAGNET SYSTEM

The leak detecting technique to be utilized in assuming the vacuum integrity of the MFTF Magnet System will consist of two phases. This will be true for both the superconductor jacket and the structural jacket. To reduce the amount of weld joints which must be checked after final assembly, a method of localized evacuation will be used prior to final assembly. All weld joints of the individual components will be checked by this method. Once the entire assembly is completed a leak check will be performed on only those welds incurred during final assembly.

The localized method of leak detection will consist of a flexible rubber sealed component similar to the rug attachment of a vacuum cleaner. This component must be designed and fabricated. It will be placed over a length of weld (approximately two or three feet) and attached to a leak detector. The component will be evacuated and helium introduced to the weld seam from the opposite side. This will allow verifying the vacuum integrity of welded joints prior to being in the final configuration.

During the final assembly of the magnet system several welded joints around the entire inner and outer perimeter of the magnet structure must be made. To detect any leaks in these welds and any other incurred during final assembly, the completed vessel will be evacuated. There are existing vacuum systems at NLVF which can perform this task.

It seems advisable to conduct another system's check after liquid helium has been circulated through the superconductors. This would insure that no damage has been caused by the cryogenic fluid.

Following is my estimate of manhours required to accomplish the tasks described above: (COST FOR 1 MAGNET ASSEMBLY)

<u>Task</u>	<u>Manhours</u>			<u>Technician</u>
	<u>Engr.</u>	<u>Drafting</u>	<u>Fab.</u>	
Design	60	50		
Fabrication			30	
Leak Detection				
1. Before assembly (inner jacket)	20			50
2. After assembly (inner jacket)	30			70
3. Before assembly (structural shell)	30			60
4. After assembly (structural shell)	30			80
5. After liquid helium	<u>30</u>	<u> </u>	<u> </u>	<u>60</u>
TOTALS	200	50	30	320
LESS DESIGN	<u>60</u>	<u>50</u>	<u>0</u>	<u>0</u>
TOTAL FAB MAN-HRS	140	0	30	320

490/MAG.

MTL EST \$ 1000 / MAG.

It is impossible to predict the number of leaks which will be detected, however, it should be pointed out that each time a leak is encountered and must be located, the leak detection process slows down.

2/2

1444

SUBJECT

MFTR

NAME

T. BEVERIS/RA

DATE

5/23/77 7/19

1450 MAGNET INSTALLATION.

ASSUMPTIONS:

- FIRST MAGNET ASSEMBLED IN JACKET AND CASING. INTERCONNECTING MEMBERS ARE ATTACHED.
- FIRST MAGNET IS IN POSITION ON WELD FIXTR. READY FOR TRANSPORT AND REMOVAL.
- FIRST STEP IN SECTION 1450 IS REMOVAL OF MAGNET FROM WELD FIXTR.
- COST BASIS UNLESS OTHERWISE STATED WILL BE BASED ON MAN-HRS PER TASK.
- WELD FIXTR. (1755) HAS (2) DEG. OF FREEDOM. CAN MOVE COIL ASSYS. 360°.
- FINISH ASSEMBLY OF SECOND MAGNET TO PROCEED ON WELDING FIXTURE AFTER FIRST MAGNET REMOVED.

ENGINEERING NOTE

1450

PAGE

2/7

SUBJECT

NAME

ALTES

DATE

7/15/77

MFTF

MAGNET INSTALLATION.

HEAVIEST ITEM TO HANDLE DURING MAGNET
ASSEMBLY & INSTALLATION IS ASSEMBLY
CONSISTING OF :

COIL		72,000 LB
COIL JACKET	1	13,202
COIL CASE		127,000
INTERCONNECTING MEMBERS	2 x 9048	18,096
		<hr/> 230,298

SAY 230,000 LB.

115 TONS.

ENGINEERING NOTE

1450

PAGE

3/7

SUBJECT

MFTF

NAME

ALTES

DATE

7/19/77

MAGNET INSTALLATION

TELEX

DATE: 7/19/77

TO: HERSHAL HALL

RIGGING SUPERVISOR

BIGGE CRANE & RIGGING

10700 BIGGE ST.

SAN LEANDRO, CA. 94577

PH. 415-638-8100

FROM: BOB ALTES

RE: CRANE AND RIGGING FOR MFTF MAGNET
INSTALLATION.

HERSHAL FEELS THE BEST METHOD FOR
MAGNET AND VESSEL INSTALLATION AND
ASSEMBLY IS AS FOLLOWS.

- SHIELDING BLOCKS REMOVED FOR ACCESS
TO INTERIOR OF SHIELDED CELL
SHOULD BE USED TO FILL THE PIT TO
SLIGHTLY BELOW FLOOR LEVEL, ~14 IN.
- INSTALL CRANE MATTS (LAMINATED OAK)
ON SHIELD BLOCKS FLUSH WITH FLOOR
TO ALLOW MOBILE CRANE TO ROLL WITHIN
WORKING DISTANCE OF VESSEL LOCATION.
- LIFT MAGNET COMPONENTS WITH 140 TON
CRANE AND 60 TON HOUSE CRANE. A
SPREADER BAR WILL BE REQUIRED FOR
THIS LIFT.

HERSHAL ENVISIONS 3-4 RIG-IN & RIG OUTS, E.G.,
INSTALLING & REMOVING CRANE & EQUIPMENT DURING
PERIOD OF VESSEL & MAGNET INSTALLATION

COSTS FOR CRANE & RIGGING ON NEXT PAGE

ENGINEERING NOTE

1450

PAGE

4/7

SUBJECT

MFTF

NAME

ALTFES

DATE

7/19/77

MAGNET INSTALLATION

TELLON : HALL/ALTES - CONT'D.

CRANE & RIGGING COSTS.

ITEM	RATE
140 TON CRANE (INCLUDING OPERATOR & OILER) ①	\$135.00/HR. ①
CRANE "RIG IN" i.e.: MOVE CRANE TO SITE & SET UP INCLUDES 2 EA. TRUCK LOADS OF AUXILIARY EQUIP.	\$1100.00
CRANE "RIG OUT"	\$1100.00
SPREADER BAR	N.C.
BRIDGE CRANE OPERATOR	\$30/HR.
RIGGING CREW.	
(1) FOREMAN	\$33.50/HR
(2-3) RIGGERS	\$32.00/HR
(1) 3/4 TON P.U. FOR EQUIP.	\$3/HR
BLOCK REMOVAL (SHIELDING)	BY OTHERS
CRANE MATT RENTAL 4 EA @ \$125/MO (5' x 30' x 14" LAMINATED WOOD)	\$500/MO.

① COST WILL PROBABLY BE \$137/HR. UNDER NEW CONTRACT
TO BE NEGOTIATED (UNION) FOR '78.

SUBJECT

MFTF.

NAME

ALTES

DATE

7/19/77

MAGNET INSTALLATION

MAGNET INSTALLATION STEPS AND ESTIMATED MAN HOUR REQUIREMENTS ARE AS FOLLOWS.

DESCRIPTION	M@HRS =	MAN HRS
<u>MAGNET NO. 1</u>		
• INSTALL LIFTING FIXTURE ON MAGNET (REF SEC 17B2)	3@3	9
• DISENGAGE WELD FIXTURE 1	3@2	6
• INSTALL SCAFFOLDING IN WORK AREA AROUND MAGNET SUPPORTS	6@16	96
• MOVE WELD FIXTURE INTO POSITION NEAR VAL. VESSEL.	3@2	8
• LIFT MAGNET #1 AND PLACE ON MAGNET SUPPORTS	①	①
• FASTEN INTERCONNECTING MEMBERS TO SUPPORT	6@8	48
• INSTALL PRELOAD FIXTURE ON MAGNET NO. 1 (REF SEC 17B1)	6@5	30
• INSPECT & PREPARE FOR MAGNET #2	2@8	16
<u>MAGNET NO. 2.</u>		
• INSTALL LIFTING FIXTURE ON COIL NO. 2 (REF SEC 17B3)	3@3	9
• DISENGAGE WELD FIXTURE.	3@2	6
• INSTALL SECOND LEVEL WORK AREA (SCAFFOLDS AROUND MAGNET ASSY LOCATION IN VESSEL)	6@16	96
• MOVE WELD FIXTURE INTO POSITION NEAR VAL VESSEL		8

CONT'D.

① RIGGING ESTIMATE FOLLOWS.

ENGINEERING NOTE

1450

PAGE 6/7

SUBJECT

MTF

NAME

ALTES

DATE

7/19/77

MAGNET INSTALLATION.

MAGNET No. 2 CONT'D.

- INSTALL PRELOAD FIXTURE ON MAGNET No. 2. 60 @ 5 30
- PRELOAD MAGNETS 1 & 2 6 @ 4 24
- LIFT MAGNET # 2 AND LOWER INTO POSITION ON MAGNET # 1 ① ①
- FASTEN INTERCONNECTING MEMBERS (BOLT 1/2" & TORQUE) 80 RL @ .5 HR/RL 40
- INSTALL DOWELS 24
- REMOVE PRELOAD FIXTURES. 2 (4 @ 4) 32
- INSPECT, MEASURE 16
- REMOVE SCAFFOLDING & CLEAN UP 1 @ 16 64

TOTAL LESS RIGGING, M-HRS. 562

(TOTAL FOR BOTH MAGNETS)

(Rigging NEXT PAGE)

① RIGGING ESTIMATE FOLLOWS.

SUBJECT

MRF

NAME

ALTES

DATE

7/19/77

MAGNET INSTALLATION - RIGGING

INSTALLATION OF MAGNET NO. 2 WILL PROBABLY BEGIN SOME MONTHS AFTER INSTALLATION OF MAGNET NO. 1. THEREFORE 140 TON CRANE WILL PROBABLY BE "RIGGED-IN" & "RIGGED-OUT" FOR EACH MAGNET INSTALLATION.

ASSUME FOR EACH MAGNET INSTALLATION CRANE & RIGGING CREW IS ON THE SCENE FOR 40 HOURS.

RIGGING COSTS FOR INSTALLING EACH MAGNET FOLLOWS:

"Rig-IN"

\$1100

CRANE RENTAL

40 HRS @ \$135/HR.

5400

BRIDGE CRANE OPERATOR

40 @ \$30/HR

1200

RIGGING CREW

(1) FOREMAN 40 x \$33.50/HR

1340

(3) RIGGERS 3(40 x 32.00/HR)

3840

P.U. TRUCK 40 x \$3 /HR

120

CRANE MATTS (ASSUME 1 MD MIN.)

500

"Rig - OUT"

1100

\$14,600 / MAGNET

USE \$15,000 / MAGNET

FOR RIG-IN & RIG-OUT CYCLE FOR
INSTALLING BOTH MAGNETS, COST IS

2 (15,000) = \$30,000

SUBJECT

INTEGRATION (LHE PIPING)

NAME

L. HUNT

DATE

7-12-77

INLET PORTS
LIQUID HELIUM MUST CONNECTED TO DEWAR
LOCATED OUTSIDE CONTAINMENT VESSEL. THE
OUT LET PORTS MUST CONNECTED TO CRYO PLANT
EXTERNAL TO CONTAINMENT VESSEL.

THERE ARE TWO (2) INLET LINES AND TWO
(2) RETURN LINES PER MAGNET AND EACH
LINE WILL HAVE AT LEAST ONE FLEX
SECTION. ASSUME EACH LINE WILL
HAVE 5 BOLTED JOINTS, AND LINE
TERMINATES AT BULKHEAD CONNECTION
ON CONTAINMENT VESSEL.

TOTAL JOINTS (2 MAGNETS)

$$4 \times 5 \times 2 = \underline{40 \text{ JOINTS}}$$

EST 4 HR EQ TO MAKE $\frac{1}{2}$ TEST

$$\underline{\underline{\text{TOTAL} = 4 \times 40 = 160 \text{ MAN HR}}}$$

MAG. ELEC. & INSTR LEADS MUST FEED
THRU PORTION OF LHE LINES

EST 8 HR / LINE TO GUIDE ELE
& INSTR. LEADS THRU LINES.

$$8 \text{ Lines @ 8 HR} =$$

ALL MTLS BY OTHERS.

2 WK

TOTAL
THIS PAGE

SUBJECT

INTEGRATION (ELEC & INTR. CONNECTIONS)

NAME

L. HUNT

DATE

7-12-77

MAGNET TO POWER SUPPLY

THERE ARE 2 LINES FROM EA. MAGNET. EACH LINE WILL PASS THRU AT LEAST 2 FEED THRU'S (2 CONNECTIONS EA). - EST FIVE CONNECTIONS PER LINE.

$$2 \text{ MAG.} \times 2 \text{ LINES} \times 5 \text{ CONNECTIONS/LINE} = 20$$

EST. 4 HR TO MAKE & TEST CONNECTION

$$20 \times 4 = \underline{80 \text{ MAN-HR}}$$

MAGNET INSTRUMENTATION LEADS

60 PR. (SUPER CONDUCTOR JOINT)
MONITORING

40 PR MISC. INSTR. (STRAIN GAGES
THERMO COUPLES, ETC.)

TOTAL 100 PR OR 200 LEADS

EACH LEAD PASSES THRU TWO FEED THRU'S - EST 6 CONNECTIONS PER LEAD

ASSUME 0.25 HR TO MAKE & TEST EACH CONNECTION -

$$200 \times 6 \times .25 = 300 \text{ MAN-HR PER MAGNET}$$

$$\underline{\underline{\text{FOR TWO MAGNET } 2 \times 300 = 600 \text{ MAN-HR}}}$$

2 MONTH

TOTAL THIS PAGE 680 M-HR

SUBJECT

INTEGRATION & ACCEPTANCE TESTING.

NAME

ALTES

DATE

7/12/77

FIELD MAPPING.ASSUMPTIONS.

- FIELD MAPPING MEASUREMENTS MADE BEFORE FINAL FINISH ASSEMBLY OF THE VACUUM VESSEL.
- MEASUREMENTS MADE WITH A PROBE WHILE MAGNET COILS ARE ENERGIZED WITH LOW CURRENT.
- MAPPING PERFORMED AT AMBIENT TEMPERATURE.

LABOR

ESTIMATE 2 WEEKS TO PERFORM MAPPING
CREW CONSISTS OF

4 TECHNICIANS

1 ENGR.

$$\text{TOTAL MAN-HOURS} = 80 \times 5 = 400 \text{ MAN HRS.}$$
MATERIALS

ASSUME PROBES WILL BE FABRICATED OR
PRODUCED.

$$\text{NO. REQ'D} : 1 + 1 \text{ SPARE} = 2$$
$$\text{COST EA.} : \text{EST } \$5,000$$
$$\text{TOTAL COST} = 2(\$5,000) = \$10,000.$$

CALENDAR TIME 2 WKS.

SUBJECT

INTEGRATION & ACCEPTANCE TESTING.

NAME

ALTES

DATE

7/12/77

CRYO TESTING. *

THE MAGNET SYSTEM WILL BE COOLED TO NORMAL OPERATING TEMPERATURE, 4°K. DURING THIS PERIOD STRESS IN JAWLETS, CASES, INTERCONNECTING MEMBERS, AND MISL COMPONENTS WILL BE MONITORED.

COOL DOWN TIME (PER DICK BYLNER, 7/12/77)

- OPTIMISTIC : 4.7 DAYS
- PESSIMISTIC : 10 DAYS
- ASSUME 10 DAYS INCLUDING TIME FOR STABILIZATION.

LABOR.

CREW : 4 TECHS
1 ENGR

TOTAL MAN HRS = 10 X 8 X 5 = 400 M.HRS.

MATLS

COST OF LHC NOT INCLUDED.

* ASSUMES VAL VESSEL EVALUATED.

CALENDAR TIME ~ 1.5 WKS.

SUBJECT

VACUUM LEAK CHECK (AFTER ASS'Y)

NAME C. HUNT

DATE 7-12-77

A GROSS VACUUM LEAK CHECK AFTER ASSEMBLY CAN BE MADE BY EVACUATING THE MAGNET CASE (STRUCTURAL SHELL) AND PRESSURIZING THE COIL JACKET WITH HELIUM. USE LEAK DETECTOR IN CASE VACUUM SYSTEM TO DETERMINE LEAKAGE THRU JACKET.

LEAKAGE BETWEEN VESSEL AND CASE CAN DETERMINED BY INTRODUCING HELIUM TO CONTAINMENT VESSEL AND AGAIN USING LEAK DETECTOR IN CASE VACUUM SYSTEM TO DETERMINE LEAKAGE THRU CASE.

EST - A CREW OF 4 MEN FOR 8 HR
EA CHECK

2 CHECK/MAGNET AL

$2 \times 2 \times 8 \times 4 = 128$ MAN HR

CHECKS SHOULD BE REPEATED AFTER LIQUID HELIUM IS CIRCULATED THRU SUPER CONDUCTORS - AND AFTER INITIAL ELECTRICAL TESTS.

THREE SERIES OF CHECKS @ 128 MAN-HR = 384

1 WEEK/SERIES

SAY 400 MAN HR

NOTE - VAC. LEAK CHECK IS AN ONGOING CHECK DURING ASS'Y OF MAGNET JACKET & STRUCTURAL CASE BEFORE INSTALLATION IN CONTAINMENT VESSEL.

ENGINEERING NOTE

1466

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SUBJECT

INTEGRATION & ACCEPTANCE TESTING

NAME

BOB ALTES

DATE

7/12/77

ELECTRICAL ACCEPTANCE TEST.

ASSUMPTIONS.

- VAC VESSEL ASSEMBLED
- CRYO TEST COMPLETED
- MAGNETS @ 4°K. & STABILIZED.
- MAGNET CHARGING WILL BE ACCOMPLISHED IN STEPS. OPERATING CHARACTERISTICS OF THE MAGNET WILL BE MEASURED & RECORDED AT EACH STEP.

ESTIMATED TIME FOR TOTAL TEST IS 1 MONTH.

CREW :

5 TECHNICIANS
2 ENGRS.} PER DICK BULMER
7/12/77LABOR HRS.

$$160 \frac{\text{HRS}}{\text{MAN}} \times 1 \text{ MO} \times 7 \text{ MAN.} = \underline{\underline{1120 \text{ MAN HRS.}}}$$

CALENDAR TIME 4 WKS.

1470

ENGINEERING NOTE

1470

PAGE

1/1

SUBJECT

MF-TF

NAME

A. WILLIAMS

DATE

5/19/77

TELCON

TO: AIRCO

FROM: A. WILLIAMS

RE: WELDING PRODUCTS COST.GAS -

ARGON - 2% OXYGEN.

80,000 - 100,000 FT³ QUAN.

LIQUID CYLINDERS.

COST : \$ 7.50 / 100 FT³WELD WIRE.308L

DIA : .045

25 LB SPOOLS

COST : \$ 3.89 / LB.

INCO 625

COST \$ 4.50 - 5.00 / LB.

GAS CONSUMPTION

100 FT³

25 LB SPOOL.

SUBJECT

MFTF

NAME

ALTES

DATE

7/19/72

WELDING WIRE.

TOTAL WIRE REQUIRED FOR EACH MAGNET IS.
AS SUMMARIZED BELOW.

<u>WELD ASSY</u>	<u>REF SECTION</u>	<u>WIRE REQ'D, LB.</u>
COIL JACKET PREFAB	1413	400
COIL CASE PREFAB	1423	7200
ASSEMBLE COIL JACKET	1431	188
WELD UP OUTER CASE	1435	1911

TOTAL LB. / MAGNET 9699 LB.

WASTE @ 15% 1455 LB.

TOTAL / MAGNET 11,154 LB.

USE 11,200 LB. / MAGNET.

COST @ \$5 / LB = \$56,000 / MAGNET.

ENGINEERING NOTE

1472

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SUBJECT

MFTF

NAME

ALTES

DATE

7/19/27

WELDING GAS.

GAS USED @ $\frac{100 \text{ FT}^3}{25 \text{ LB WIRE}}$

$$11,200 \text{ LB WIRE} \times \frac{100 \text{ FT}^3}{25 \text{ LB WIRE}} = 44,800 \text{ FT}^3$$

COST @ \$7.50/100 FT³

$$44,800 \times \frac{7.50}{100} = \$3360/\text{MAGNET.}$$

USE \$3400

ENGINEERING NOTE

PAGE

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SUBJECT

MFTF

NAME

ALTES

DATE

7/19/77

WELDER QUALIFICATION

PER ART WILLIAMS (REF SEC 1400 -
"WELD FABRICATION OF ARMCO NITRONK 40")

$$8 \text{ MAN WKS} \times \frac{40 \text{ HRS}}{\text{M-WK.}} = 320 \text{ M-HRS.}$$

SUBJECT

MFTF

NAME ALTES

DATE 5/26/77

ENGINEERING

25% OF TOTAL ITEMS 1000 → 1800

$$.25(5874 \text{ K\$}) = 1469 \text{ K\$}$$

EFFORT FOR

- ENGINEERING RELATED TO MACHINE DES.
- DRAWING PREPARATION
- SPEC. WRITING
- ASSEMBLY & OPERATION DOCUMENT PREPARATION.

PROJECT MFTF - TOOLING

 JOB NO. B-350-01 BY ALTES

CHECKED _____

 DATE 5/25/77

 SHEET 1 OF 1

ITEM	DESCRIPTION	QTY.	UNIT	MATERIAL		LABOR			TOTAL ITEM COST	
				UNIT COST	TOTAL \$	UNIT MAN HOURS	TOTAL MAN HOURS	\$		
1700	TOOLING									
1720	INSULATION FABRICATION								①	
1721	CONTOUR TEMPLATES	1	LOT		6000					
1730	COIL MOUNTING ADAPTER	2	EA	25,560	51,120	592	1184			
1740	COIL WINDING	1	LOT		148,970					
1755	WELDING FIXTURE	1	EA		132,000					
1760	COIL FAB. & MAGNET ASSEMBLY	1	LOT		589,300					
1780	MAGNET INSTL. TOOLS	1	LOT		140,000					
1790	WELDING EQUIPMENT	1	LOT		22,000					
					1,089,390		1184			
① INCLUDED IN MTL PURCHASE PRICE, SEE SER 1100

ENGINEERING NOTE

1720

PAGE

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SUBJECT

MFTF - TOOLING

NAME

OLSON

DATE

5/23/77

ITEM 1700 - TOOLING ESTIMATES

1720 INSULATION FABRICATION

AT THIS POINT IT IS ASSUMED THAT ALL INSULATION MATERIALS ARE PURCHASED READY TO USE EXCEPT FOR CUTTING TO FIT.

1721 CASE INSULATION / ROUTING

TEMPLATES TO CONTOUR EPOXY COVERING & ROUTING.

ENGINEERING DESIGN

160 HRS

DRAFTING

3 EA G ZONES

210 HRS

4 " D SIZE

50

3 EA E SIZE

120

TOTAL

380 HRS

FABRICATION

ENGINEERING

10 HRS

PURCHASE

(240 HRS @ \$25-/HR)

\$6K

INSPECTION

20 HRS

SUBJECT

MTF (Coil Mounting Adapter)

NAME

Y CHANG

DATE

5-23-77

COIL MOUNTING ADAPTER

Provides support for
coil jacket during coil winding
and be used as handling
attachment for wound coil.

Four side plates

$$2(38 \times 40) \times 1" \times .515 \times .29$$

$$= 23 \times 10^3 \text{ #}$$

Center gusset. ($\frac{1}{2}"$ plate with
hole cut at center) $40 \times 38 - 36 \times 32$

11 pieces PER.

$$11 \times \frac{1}{2} (40 \times 38 - 36 \times 32) \times .29$$

$$= 586 \text{ # total}$$

Lifting Lug : 500#

Total wt. of coil M't adapter

$$24 \times 10^3 \text{ #}$$

2 REQ. MAT'L : CARBON STEEL-

Adapter may be
bolted to
jacket, then
the support
may be
eliminated.

ENGINEERING NOTE

1730

PAGE

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SUBJECT

NAFTE COST Estimation

NAME

Y CHANG

DATE

5-20-77

COIL MOUNTING ADAPTER.

QTY: 2 REQUIRED (one for each coil, if welding and handling fixture is available, one coil mounting adapter could be used for both coils).

unit:

MATERIAL:

unit cost:	structural steel plates (A36)	8.80%	COST
	$\frac{1}{2}$ " PL 100 ft ² (2000")		1600
	1" PL 600 ft ² (24000")		19000
	$\frac{1}{2}$ " PL 20 ft ² (1200")		960
	MIS. (27,200 LB)		\$ 21,560

LABOR: unit cost

WELDING	360 MAN-HR \$29 $\frac{1}{2}$ /hr (2000 inch weld)
MAT'L CUTTING	80 MAN-HR
MACHINIST	120 MAN-HR
SAND BLAST.	16 MAN-HR
PAINTING	16 MAN-HR
ENG.	160 MAN-HR
DRAFTING	480 MAN-HR

SHIPPING

(12 drawings, E size) \$ 4000

FAB COST

$$M.T.L. = \$21,560 + 4000 = \$25,560 \text{ EA.}$$

$$FAB LABOR = 592 \text{ MAN-HR. EA.}$$

} ~\$1.50/LB.

PROJECT MF-TF - TOOLING

MFTF - Tooling

JOB NO. B-320-02 BY ALTES

CHECKED.

DATE 5/28/77

SECRET

OF

[illegible]

SUBJECT

MFTF - TOOLING

NAME

OLSON

DATE

5/24/77

1741 CLAMPING TABLE ESTIMATE

THE CLAMPING TABLE IS ASSUMED TO BE A BOX BEAM WITH THE APPROXIMATE DIMENSIONS SHOWN BELOW:

3/4" THK STL PL TYP.

WEIGHT:

$$W = \text{CIRCUMFERENCE} \times \text{PL THK.} \times 12' \times .283 \text{ #/in}^3$$

$$= 108 \times .75 \times 12 \times .283 = 275 \text{ #/ft}$$

ADDING IN WELD AND GUSSETS, $W \approx 300 \text{ #/ft}$

FOR 50' OF CLAMPING TABLE THE TOTAL WEIGHT IS $50' \times 300 \text{ #/ft} = \underline{15000 \text{ lbs.}}$

FOR A LARGE CURVED STL WELDMENT WITH MANY DRILLED AND TAPPED HOLES THE FABRICATION COST IS ESTIMATED AT \$ 200/lb.

$$\therefore \text{TOTAL FAB. COST} = 15000 \text{ #} (\$ 2/\text{lb}) = \$ 30 \text{ K}$$

TWO SOURCES WERE CONSULTED; ONE @ \$1.50/# & ONE @ \$2.00/#

ENGINEERING DESIGN TIME	200 HRS
DRAFTING 15 1/2 SIZE DWGS. @ 70 HRS	1050 HRS.
ENGINEERING COORDINATION	20 HRS.
INSPECTION	20 HRS.

ENGINEERING NOTE

1740

PAGE

2/7

SUBJECT

MFTF - TOOLING ESTIMATES

NAME

OLSON

DATE

5/23/77

1742 STEP CLAMP

SINCE THE STEP CLAMP ISN'T DESIGNED, THE CONCEPTUAL DRAWING STARTED BY DICK HINKLE WILL BE USED TO ESTIMATE THE AVERAGE COST.

AVERAGE CLAMP LENGTH IS APPROX. 60 FT
FABRICATION TIME ESTIMATES PER LINEAR FOOT ARE AS FOLLOWS.

	HRS/FT.
BASE PL (RADIUS)	1
GUSSET	1/2
VERTICAL PL (BREAK)	1/2
BREAK	1
WELD	1 1/2
FINISH & HOLES	1 1/2
SUB TOTAL	6
ADD ON PLATES (2EA)	5
TOTAL HRS/FT	11

∴ TOTAL HOURS FOR SIDE CLAMPS IS

$$(5 \text{ ASSY'S REQ'D}) \times 11 \text{ HRS/FT} \times 60 \text{ FT} = \underline{3300 \text{ HRS}}$$
$$@ \$25/\text{HR} = \underline{\underline{\$82.5 \text{ K}}}$$

VOLUME OF MATERIAL (ALUMINUM) IS

$$(5 \text{ ASSY'S REQ'D}) \times 20" \times .75" \times 60' \times 12 \frac{1}{4}" = 5.4 \times 10^4 \text{ in}^3$$

OR 5400 lbs ALUM.

COST OF 3/4" THK 6061-T651 PL ;

ASSUME 25% SCRAP & 4' x 12' PL SIZE

$$\frac{5400 \text{ lbs}}{508 \text{ lbs/pl}} \times 1.25 \approx 14 \text{ PL OR } 7112 \text{ lbs}$$

$$@ \$1.03/\text{# (PER REYNOLDS ALUM.)} \approx \underline{\underline{\$7.4 \text{ K}}}$$

ENGINEERING DESIGN

160 HRS

DRAFTING 10 EA "E" & D SIZE DWGS.

525 HRS

ENGINEERING COORDINATION

20 HRS

INSPECTION

30 HRS

ENGINEERING NOTE

1740

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SUBJECT

MFTF - TOOLING ESTIMATES

NAME OLSON

DATE 5/24/77

1743 SIDE CLAMPS

ASSUMING THREE CLAMPS PER SIDE FOR A TOTAL OF 6.

R. HINKLE OF LLL HAS DESIGNED A TELESOPING SCREW CLAMP FOR USE IN THIS APPLICATION. DWG. AAA 77-100545-00 SHEETS 1 & 2. THIS DWG & DESIGN IS USED TO MAKE THE FOLLOWING ESTIMATES.

ITEM #	FAB. HRS	QTY	TOTAL HRS
1 ASSY	$3\frac{1}{2}$	x6	21
2	$1\frac{1}{2}$		
3	$1\frac{1}{2}$		
WELD	$\frac{1}{2}$		
6 ASSY	$6\frac{1}{2}$	x6	39
7	1		
8	$4\frac{1}{2}$		
WELD	1		
12 ASSY	$3\frac{1}{4}$	x6	20
13	$2\frac{1}{2}$		
14	$\frac{1}{4}$		
WELD	$\frac{1}{2}$		
15	4	x6	24
16	3	x6	18
17	3	x6	18
19	$2\frac{1}{2}$	x6	15
21 ASSY	3	x3x6	54
22	1		
23	$1\frac{1}{2}$		
WELD	$\frac{1}{2}$		
24 ASSY (DITTO 21)	3	x6	18
27 ASSY (DITTO 21)	3	x6	18
31	$1\frac{1}{2}$	x6	9
TOTAL FAB HOURS			<u>254 HRS</u>

COST @ \$25/HR = \$6350

MISC. HARDWARE @ \$20/ASSY x6 = \$120

ENGINEERING DESIGN TIME

DRAFTING
INSPECTION

ENGINEERING COORDINATION

MTR. INCLUDED

80 HRS

160 HRS
20 HRS
20 HRS

ENGINEERING NOTE

1740

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SUBJECT

MFTF - TOOLING ESTIMATES

NAME

OLSON

DATE

5/24/77

1744 END CLAMP

ASSUMING 3 CLAMPS PER END OR 6 CLAMPS
R. HINKLE OF LLL HAS DESIGNED A CLAMP FOR
THIS APPLICATION. DWG AAA 77-102850-00 SHEET 1 & 2.
THIS DWG & DESIGN IS USED TO MAKE THE
FOLLOWING ESTIMATES.

<u>ITEM #</u>	<u>FAB HRS</u>	<u>QTY</u>	<u>TOTAL HRS</u>
<u>1 OR 2 ASSY</u>	<u>7</u>	<u>x 6</u>	<u>42</u>
3	1 1/2		
4	1		
5	1		
6	1/4		
7	3		
WELD	1 1/2		
9	1/2	2 x 6	12
10	1/2	x 6	3
12	4	3 x 6	72
13	1	x 6	6
15	1 1/2	x 6	9
16	2 1/2	"	15
17	3 1/2	"	21
18	2 1/2	"	15
19 + WELD	1	"	6
21 ASSY	<u>6</u>	<u>x 6</u>	<u>36</u>
22	1		
23	1/2 x 2		
24	2		
25	1/2		
WELD	1		
GLUE	1/2		
27 ASSY	<u>4 1/2</u>	<u>x 6</u>	<u>27</u>
28	1/2		
29	1/2 x 2		
30	1/2 x 2		
WELD	1 1/2		
GLUE	1/2		
TOTAL FAB HOURS			<u>264 HRS</u>

ENGINEERING NOTE

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SUBJECT

MFTF - TOOLING, ESTIMATES

NAME

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1744 END CLAMP (CONT'D)

COST OF FAB. @ \$25/HR IS

264 HRS x \$25/HR = \$6.6K

MISC. HARDWARE (MTL. INCLUDED)

.2K

TOTAL COST

\$6.8K

ENGINEERING DESIGN TIME

60 HRS

DRAFTING

120 HRS

ENGINEERING COORDINATION

20 HRS

INSPECTION

15 HRS

ENGINEERING NOTE

1740

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SUBJECT

MFTF - TOOLING ESTIMATES

NAME

OLSON

DATE

5/24/77

1745 OVERBENDING SHOES

ASSUME 2 REQ'D, ONE FOR EACH COIL RADIUS.

ENGINEERING DESIGN

40 HRS

DRAFTING 2 "E" SIZE

80 HRS

FAB.

ENGINEERING

2 HRS

ITEM COST @ \$250 EA (MTL. INCLUDED)

\$.5K

INSPECTION

4 HRS

1746 CONDUCTOR STRAIGHTENING/RADIUS PREFORMING ROLLERS

TWO THREE-ROLLER FIXTURES WILL BE NEEDED
FOR a) CONDUCTOR STRAIGHTENING
b) RADIUS PREFORMING.

THE CENTER ROLLER WILL BE ADJUSTABLE TO
PROVIDE PRESSURE FOR STRAIGHTENING OR BENDING.

ROLLERS (6) @ \$15 EA

\$ 90

FRAME WELDMENT @ \$700 EA

1400

TENSIONING SCREW ASSY @ \$250 EA

500

TOTAL COST (MTL. INCLUDED)

\$2K

ENGINEERING DESIGN

160 HRS

DRAFTING 4 EA "E" SIZE DWGS

160 HRS

ENGINEERING COORDINATION

10 HRS

INSPECTION

10 HRS

ENGINEERING NOTE

1740

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SUBJECT

MFTF - TOOLING ESTIMATES

NAME OLSON

DATE 5/24/77

1747 TRANSITION BENDING TOOL

DIE BLOCKS TO BEND CONDUCTOR IN ZIG-ZAG PATTERN IN EITHER OF TWO DIRECTIONS.

COST IS ESTIMATED AT (MTL INCLUDED) \$1K

ENGINEERING DESIGN TIME	160 HRS
DRAFTING 4-"E" SIZE DWGS.	160 HRS
ENGR COORDINATION	10 HRS
INSPECTION	10 HRS

1748 CONDUCTOR STRAIGHTENING TOOL

STRAIGHTENING TOOL USED TO TAKE TWIST OUT OF CONDUCTOR.

THIS IS A SIMPLE MANUAL TOOL WITH A SLOT TO FIT THE CONDUCTOR.

COST (MTL. INCLUDED) \$.2 K

ENGR DESIGN	40 HRS
DRAFTING "E" SIZE	40 HRS
ENGR COORDINATION	4 HRS.
INSPECTION	2 HRS

ENGINEERING NOTE

1749

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SUBJECT

MFTF - TOOLING ESTIMATES

NAME OLSON

DATE 5/24/77

1749 SPLICE FORMING

SINCE THE TYPE OF SPLICE HAS YET TO BE RESOLVED, ESTIMATES WILL COVER THE WORST CASE. THAT IS:

- a) COLD FORMED JOINT
- b) ONLY CONDUCTOR CORE COLD FORMED
- c) COPPER JACKET STRIPPED OFF BEFORE COLD FORMING.
- d) NEW JACKET SOLDERED ON AFTER JOINING.
- e) MODIFIED COLD FORMING MACHINE WILL BE ABLE TO MAKE BOTH INSIDE AND OUTSIDE JOINTS.

TOOLING REQUIREMENTS TO ACCOMPLISH THE ABOVE ARE:
SEE ITEM BREAKDOWN ON FOLLOWING PAGES.

1749.1) MODIFY EXISTING COLD FORMING MACH.	\$2 K
1749.2) 1-TON A-FRAME GANTRY WITH 40 FT SPAN
MOUNTED ON RAILS ON WINDER SCAFFOLDING.	5 K
1749.3) COPPER JACKET CUTTING TOOL	1.1 K
1749.4) JACKET INSTALLING CLAMP	1.5 K
1749.5) JACKET SOLDERING TOOL (USED TO
REMOVE JACKET ALSO)	1.5 K

TOTAL PURCHASE COST

\$11.1 K

ENGINEERING SUMMARY (BREAKDOWN ON FOLLOWING PAGES)

DESIGN

ENGR.

360 HRS

DRAFTING

480 "

FABRICATION

ENGR. COORDINATION

80 "

INSPECTION

40 "

ENGINEERING NOTE

1749

PAGE

2 1/2

SUBJECT

MFTF - TOOLING ESTIMATES

NAME

OLSON

DATE

5/25/77

1749 (CONT'D)
1749.1

ESTIMATED STRUCTURE TO PIVOT CLAMP JAWS
ABOUT CG. & HAND FROM CRANE DURING USE

& 2K

DESIGN

ENGR

DRAFTING

FAB.

ENGR, COORD.

INSPECTION

10 HRS

20 HRS

160 HRS

120 HRS

ENGINEERING NOTE

1749

PAGE

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SUBJECT

MFTE - TOOLING ESTIMATES

NAME

OLSON

DATE

5/25/77

1749 (CONT'D)

1749.2

1-TON A-FRAME GANTRY

\$5K

DESIGN

ENGR

40 HRS

DRAFTING - INCORPORATE RAILS ON
EXISTING SCAFFOLD DWGS.

40 HRS.

FAB.

ENGR. COORD.

10 HRS

ENGINEERING NOTE

1749

PAGE

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SUBJECT

MFTF - TOOLING ESTIMATES

NAME

OLSON

DATE

5/25/77

1749 SPLICE FORMING (CONT'D)

1749.3 FROM PREVIOUS PAGE

JACKET CUTTING TOOL, DWG. AAA77-102890-00, DESIGNED BY R. HINKLE OF LLL WILL BE USED FOR ESTIMATING WITH SOME MODIFICATION FOR BLADE CUTTING DEPTH ADJUSTMENT.

ITEM	HRS	QTY	TOTAL HRS
1	8	1	8
2	5	1	5
3	3	1	3
4	3	1	3
5	4	1	4
6	1	2	2
7	1	1	1
8	2	1	2
9	3	1	3
BLADE ADJ. DEVICE	5	1	5
TOTAL HRS			36 HRS

COST @ \$25/HR

\$900

MISC HARDWARE

20

AIR GRINDER - METAL REMOVAL CO. MOD.-W1

150

TOTAL COST

\$1070

DESIGN

ENGR

40 HRS

DRAFTING

2" E" SIZE DWGS.

80 HRS

FAB.

ENGR. COORD.

20 HRS

INSPECTION

10 HRS

ENGINEERING NOTE

1749

PAGE

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SUBJECT

MFTF - TOOLING ESTIMATES

NAME

OLSON

DATE

5/25/77

1749 (CONT'D)

1749.4

JACKET INSTALLING CLAMP WILL WRAP COPPER
JACKET AROUND CORE SUPER CONDUCTOR AND CLAMP
IN PLACE DURING SOLDERING.

ESTIMATED COST

\$1.5K

DESIGN

ENGR

80 HRS

DRAFTING

3 - "E" DWGS

120 HRS

FAB

ENGR. COORD.

10 HRS

INSPECTION

10 HRS

ENGINEERING NOTE

1749

PAGE

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SUBJECT

MFTF - TOOLING ESTIMATES

NAME

OLSON

DATE

5/25/77

1749 (CONT'D)1749.5

JACKET SOLDERING CAN BE DONE BY INDUCTION
HEATING.

ESTIMATED COST

\$1.5K

DESIGN

ENGR

80 HRS

DRAFTING

2 - "E" DWGS

80 HRS.

FAB

ENGR. COORD.

20 HRS

INSPECTION

10 HRS.

ENGINEERING NOTE

1750

PAGE

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SUBJECT

MFTF - TOOLING ESTIMATES

NAME

OLSON

DATE

5/25/77

1750 INTER-TURN INSULATION DISPENSER

DISPENSER TO UNWIND MYLAR TAPE WITH INSULATING BUTTONS AT SAME FEED RATE AS CONDUCTOR. ROLLERS WILL RIDE ON CONDUCTOR AND GUIDE TAPE WITH BUTTONS.

ESTIMATED FAB COST

\$1K

DESIGN

ENGR

60 HRS

DRAFTING

80 HRS

FAB

ENGR

20 HRS

INSPECTION

5 HRS

SUBJECT

METF, WELDING & HANDLING FIXTURE

NAME

Y CHANG

DATE

5-20-77

1. Introduction : In order to provide the coil bundle a temporary storage ^{place} after it is completed winding and before it is assembled to the magnetic system, a fixture is required to serve as storage, transport, maneuver & welding fixture. This fixture is called welding & handling fixture, or, to simplify, called general purpose fixture.
2. Performance Requirement :
 - a. It should be able to take the load of one coil bundle with jacket, plus coil case and all necessary tools and attachment. Load capability shall be around 300,000 #.
 - b. It should be designed to fit the coil case as well as to fit the coil jacket.
 - c. It should provide ^{motion like} rolling, turning to allow convenient welding positions for coil bundle and turn-over of coil case.
 - d. It shall be able to move on rails from working area to assembly area.
 - e. It can be partially disassembled and be used as handling fixture ^{which} can be lift, transported by a CRANE or Gin post.

SUBJECT

MFTF WELDING & HANDLING FIXTURE

NAME

Y CHANG

DATE

5-24-77

3. Conceptual Design

Descriptions:

1. COIL OR COIL WITH CASE IS SUPPORTED BY A SERIES OF "I" BEAMS Laying parallelly. "I" BEAMS are connected to a pair of MAIN GEARS
2. MAIN GEARS ARE PLACED ON TWO SETS OF DRIVE GEARS (OR CHAIN DRIVE, OR WITH IDLERS)
3. THE ENTIRE ASSEMBLY IS MOUNTED ON A PLATFORM WITH ROLLERS (WHEELS)
4. BOTH DRIVE GEARS AND WHEELS HAVE THEIR OWN POWER UNITS EQUIPPED.

ENGINEERING NOTE

1755

PAGE

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SUBJECT

METF WELDING & HANDLING FIXTURE

NAME

Y CHANG

DATE

5-24-77

4. Weight Estimation.

Beam shaft : $5 \times 40 (26 \times 12) \times \frac{1}{2} \times .3 = 9360^*$
Gusset : approx. 2340^*
MAIN Gear : 5000^* each 10000^*
DRIVE Gear : 2000^* each 8000^*
platform : 10000^*
wheels : 2400^*
power units. Brakes 2000^*
Misc. 3000^*
Total 47100^*

5. Cost Estimation :

MAT'L (structural, Motor, Gear, Brake etc.) \$ 40,000^*
Fab. \$ 60,000^*
Engineering 800 MH
DRAFT'G 2400 MH.
INSTALLATION 20,000^*
TEST & DEBUG 10,000^*
SHIP & HANDLE 2,000^*

* TOTAL HARDWARE COST. = 132,000

ENGINEERING NOTE

1760

PAGE

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SUBJECT

COIL ASSY. TOOLING

NAME

RBS

DATE

5/25

1760 COIL ASSY. TOOLING

COST SUMMARY

K\$

1761	TOOLING FOR INNER JACKET PRE-FAB	10.3K
1762	TOOLING FOR OUTER JACKET PREFAB	16K
1763	TOOLING FOR COIL JACKET ASSY	3K
1764	WELD FIXTR TOOLING	—
1765	WELD FIXTR.	200K
1766	LIFT FIXTR - LOWER CASE SEGMENT W/CERTS L J STRUCT	17K
1767	LIFT FIXTR - JACKETED COIL GOT STRUCT + BAR + CERTS	20K
1768	FIXTR. - HOLD COIL IN CASE GOT	4K
1769	LIFT + HANDL. INNER CASE SOT STRUCT + BAR + CERTS	20K
1770	WELD'G JIG FINE ADJ. SECT 1435 (HOLD CASE IN POSITION)	5K
1771	LIFT & HANDL - I/CONN MEM. STRUCT + BAR + CERTS + TRACK	5K
1773	WELD TRACK + SUPPORT - CASING	10K

ENGINEERING NOTE

1760

PAGE

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SUBJECT

COIL ASSY TOOLING

NAME

J.P.

DATE

5/26

1760 COIL ASSY. TOOLING

COST SUMMARY (CON'D.)

K.\$

1774 TOOLING - INNER CASE PREFAB

165K

FIXTR + SHIPG + FRT. + S/R

(ALSO USED @ ASSY. SITE)

1775 TOOLING - OUTER CASE PREFAB

112K

FIXTR + SHIPG. + FRT + S/R

(ALSO USED @ ASSY. SITE)

1776 SHIPG FIXTR - I/CONN. MEM.

2K

1760 TOTAL COST

\$ 589.3K

ENGINEERING NOTE

1780

PAGE

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SUBJECT

MAGNET INSTALLATION TOOLING

NAME

H3

DATE

5/26

1780 TOOLING FOR MAGNET INSTL.

COST SUMMARY

K\$1781 COIL PRE LOAD FIXTR., 2@30K
STRUCT + LIFT + CERTS + TESTS

60K

1782 LIFT FIXTR. - COIL #1 120T
STRUCT + LIFT + CERTS

30K

1783 LIFT FIXTR. - COIL #2 120T
STRU + LIFT + CERTS

35K

1784 SCAFFOLD @ SITE

15K

1780 TOTAL

\$ 140K

ENGINEERING NOTE

1790

PAGE

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SUBJECT

MFTF

NAME

ALTES

DATE

5/26/77

WELDING EQUIPMENT

4 PA-3 MACHINES @ \$4,000 \$16,000

GAS SUPPLY SYSTEM \$4,000

INSTALL, SETUP, TEST 2,000

\$22,000

AUGUST 1972

1790

PULSED SPRAY WELDING

PROCESS MANUAL

AIRCO Welding Products

III. METAL TRANSFER IN GAS METAL-ARC WELDING WITH NONPULSING DIRECT CURRENT

Gas Metal-Arc Welding, drops of molten metal are transferred from a continuously fed filler-metal electrode to a work. For a given diameter of electrode within a shield of substantially inert gas, the magnitude of the welding current determines the size of the drops, the number of drops that are detached from the electrode per unit of time, and the direction in which they travel from the electrode in welding positions other than flat. For current in the range from the lowest value at which a stable arc can be maintained up to a value that is designated the transition current, the drops grow to a diameter that is several times the diameter of the electrode before they are detached at a rate of several drops per second. As they grow, they wobble around and disturb the arc plasma so that it moves around the work. The heated zone in the work is shallow, the weld

metal deposit is irregular, and the drops may grow large enough to cause a short circuit with attendant blasts of liquid metal.

At the transition current, the size of the detached drop abruptly decreases to one that is equal to or less than the diameter of the electrode and the rate of drop detachment increases to several hundred per second.

Above the transition current, the rate of drop detachment continues to increase as the current increases but at a very slow rate compared to that at the transition current. The plasma-cone size and the penetration of heat into the work also increase due to the increased current density in the electrode. The drops are small enough to pass through the plasma without disturbing its shape or position.

Figure 1. Effect of Current Level on Metal Transfer

The transfer below the transition current is called globular; that above the transition current, spray. The word, spray, was adopted to designate the above-transition transfer because the shape of the arc emanating from the electrode tip appears to the unaided eye to be similar to a spray of water from a nozzle. Early experimenters did not become aware of the nature of the transfer until the arc was studied by ultraslow motion pictures using a camera with film speeds of several thousand frames per second. Further understanding of what happens as current increases can be gained by referring to Fig. 1 which shows, for a particular set of welding conditions, how metal transfer changes with increasing current.

The direction in which the drops move relative to the electrode axis changes when the transfer changes from globular to spray for any position of welding other than flat. In globular transfer, the detachment of the drop occurs when its weight exceeds the surface tension that tends to hold the drop on the electrode tip. The electromagnetic force which would act in a direction to detach the drop is small relative to the force of gravity when the current is in the range of globular transfer. Consequently, drops in globular transfer fall downward regardless of the direction in which the electrode is pointed. In spray transfer, the electromagnetic force is strong enough to eject the drop from the electrode tip in line with the electrode axis regardless of the direction in which the electrode is pointed. The effect of current level on the direction of metal transfer from the electrode tip is illustrated in Fig. 2.

A transition current exists for all electrodes. Its magnitude depends on several factors. For a given diameter of electrode with a bare metal surface, these factors are the chemical composition of the electrode, the electrode polarity (whether it is electrically positive or negative), the composition of the shielding gas, and the length of electrode between the arc and the contact tube (popularly known as electrode stick-out). Several examples of the effect of these factors on the transition current of a bare electrode are given in the following paragraphs

Example 1 — Chemical Composition of Electrode

A 1/16-in.-dia. aluminum electrode exhibits a transition current of 175 amperes when operated with a 1/2-in. stick-out in an argon shield. Under the same operating conditions, a carbon steel electrode exhibits a transition current of 270 amperes.

Example 2 — Electrode Polarity

In a shielding gas of 99% A — 1% O₂, there is a transition current when the electrode is positive, but none exists when the electrode is negative.

Example 3 — Composition of Shielding Gas

With a positive electrode, if carbon dioxide is substituted for the gas composition of Example 2, the transition current disappears.

Example 4 — Electrode Stick-Out

As the stick-out of a 1/16-in.-dia. carbon steel electrode is increased from the lowest value that is possible without melting the contact tube to a length of three inches, the transition current changes from 280 to 200 amperes.

When the combination of conditions is adjusted so that spray transfer is produced, the following advantages are gained. Weld spatter is minimized and a deposition efficiency as high as 98% can be achieved. Operator control of the molten weld metal is enhanced since the operator knows that the transferring metal will travel to the work in the direction in which the electrode is pointed. Since spray transfer can be achieved in a shield of pure inert gas, any deleterious effect of a reactive gas on the metal being welded can be avoided; for example, a heavy oxide film is not formed on the weld surface and thus cleaning of welds between passes is generally not required.

As a result of these advantages, there is wide use of Gas Metal-Arc Welding with spray-type transfer. There is, however a limit of metal thickness below which the process could not be used. Also, welding could not be performed in the vertical or overhead positions, except for aluminum alloys in thicknesses greater than 1/8 inch. In these greater thicknesses, the weld-metal cooling rate was high enough to

Figure 2. Mode of Metal Transfer for Horizontal Electrode

the rapid freezing of the relatively large pool of weld metal that is obtained with spray transfer and nonpulsing current. The limits of application of spray transfer of metal have been extended by the development of Pulsed Spray welding. The characteristics of this method are described in the following section.

IV. PULSED SPRAY WELDING

Pulsed Spray Welding, the welding current switches from one level to another. The power source is adjusted so that

Figure 3. Sequence of Metal Transfer and Current Pulses in Pulsed Spray Welding

the lower level of current (known as background current) is below the nonpulsing transition current (defined in the previous section). If an attempt were made to use this low level without pulsing to the high level, the metal transfer would be globular. The higher level of current (known as pulse-peak current) is above the nonpulsing transition current and would produce spray transfer if maintained continuously without pulsing. The pulsing current is produced by AIRCO'S PULSED-ARC® power sources.

When a PULSED-ARC power source is correctly adjusted, spray transfer of metal takes place at an average value of pulsing current that is less than the nonpulsing transition current for the electrode that is being used. The detachment of the drop occurs during the current pulse. A typical sequence of events for metal transfer with a pulsing current is shown in Fig. 3. An actual oscillogram trace of current and voltage is shown in Fig. 4.

Most of the energy for melting the work and electrode, and then transferring the drop of metal, is supplied during the pulse; some of it is supplied during the background part of the cycle. The pulse energy is proportional to i^2t where i is the rms current of the pulse and t is the time of pulse duration. A consequence of this relationship among i , t , and pulse energy is the fact that a drop is transferred by a narrow high pulse as well as a wide low pulse. The pulse-peak current is generally adjusted to a value above the nonpulsing transition current so that one drop of metal transfers per pulse. With one drop per pulse, the pulse rate does not make a difference in the energy needed to cause the transfer of a drop. The background current, depending

Figure 4. Oscillogram of Current and Voltage in Pulsed Spray Welding

on its level, can have an effect on the pulse-peak current that is required for metal transfer because it contributes somewhat to the melting of the electrode.

The level of pulse current necessary to cause metal transfer is affected by the same factors which affect the nonpulsing transition current. For example, a change in the composition of the shielding gas will have the same effect on the minimum pulse-peak current that is needed for spray transfer in Pulsed Spray Welding as it would have on the nonpulsing transition current. The necessary pulse-peak current also will vary with the electrode composition and diameter.

In adjusting welding conditions, the average values of the pulsing current and voltage of Pulsed Spray Welding can be considered by the welder to be equivalent to the current and voltage of Gas Metal-Arc Welding with nonpulsing power; therefore, the knowledge and experience of that type of Gas Metal-Arc Welding, insofar as the effect of voltage and current on other factors is concerned, can be translated readily to Pulsed Spray Welding. The relation between the average current and the speed of electrode feed in Pulsed Spray Welding is the same as the relation between current and the speed of electrode feed in Gas Metal-Arc Welding with nonpulsing power.

Pulsed Spray Welding can be understood most easily by viewing it as a method of producing spray transfer at lower currents than those required in Gas Metal-Arc Welding with nonpulsing direct current. Electrodes and shielding gases which are usable with nonpulsing current are usable with Pulsed Spray Welding. Some of the usable gas shields are argon, 98% argon-2% oxygen, and 90% argon-10% carbon dioxide; carbon dioxide by itself is not usable in the sense that spray transfer will not take place. Since Gas Metal-Arc Welding with nonpulsing current can be used to deposit electrodes of almost any composition, the same facility can be expected in Pulsed Spray Welding. A possible exception is a triple-deoxidized, carbon steel electrode which does not wet well when deposited by Pulsed Spray Welding.

As stated in the Foreword, Pulsed Spray Welding is a variation of Gas Metal-Arc Welding. It is a "new tool" in the GMAW family and complements the methods of spray transfer with nonpulsing direct current and of short circuiting transfer. Pulsed Spray Welding enables the weld fabricator to gain the advantages of GMAW with a shield of substantially inert gas in the low current area where, for reasons of position or metal thickness, lower average currents must be used.

V. WHEN TO USE PULSED SPRAY WELDING

5.1 GENERAL

Pulsed Spray Welding is an extension of Gas Metal-Arc Welding as originally conceived and complements both this original concept and Short Circuiting Arc Welding. In the low current area, both Pulsed Spray Welding and Short Circuiting Arc Welding must be considered.

Any fabricator who wants to use semiautomatic GMAW is faced with the problem of selecting one of three variations of the process. In the remainder of this section, comparisons of these variations will be made, and then the situations in which Pulsed Spray Welding should be selected in preference to the other two types of GMAW will be summarized. First, Pulsed Spray Welding will be compared to Short Circuiting Arc Welding in two categories: by type of metal and by type of application. Second, Pulsed Spray Welding will be compared to welding with spray metal transfer and nonpulsing direct current.

5.2 COMPARISON TO SHORT CIRCUITING * ARC WELDING

MILD STEEL PLATE

Prior to the introduction of Pulsed Spray Welding, the only GMAW method available with low heat input on mild steel was Short Circuiting Arc Welding. While this method is generally satisfactory, the welder must carefully control his technique to prevent lack-of-fusion defects, commonly called cold shuts. Considerable research has been done to determine the causes for this lack of fusion. The two principal causes are: (1) changes in the distance of the contact tip from the work and (2) improper adjustment of both the voltage and dynamic characteristics of the welding machine.

When Short Circuiting Arc Welding is used on sheet metal, the welder can reduce the heat input to the weld by

*A method of gas metal arc welding in which the consumable electrode is deposited during repeated short circuits

creasing the distance between the contact tube and the workpiece and this is a highly desirable feature for sheet metal. However, if this technique is employed to fabricate heavy weldments in position other than flat, cold shuts are likely to result. When welding in the vertical and overhead positions, the contact tube-to-work distance must be kept constant once a satisfactory set of conditions is established. This places a considerable burden on the welder. When the contact tube-to-work distance increases, the fusion of the weld pool to the workpiece decreases and the height-to-width ratio of the weld bead increases. In Pulsed Spray Welding, the effect of the change in distance is much less pronounced, and in this respect, it has an advantage over Short Circuiting Arc Welding.

When a welder sets conditions for short-circuiting metal transfer on sheet metal, those conditions which give satisfactory weld appearance are usually those which provide complete fusion. This is not the case in the vertical and overhead welding of heavy weldments; the most attractive bead appearance is likely to give poor fusion. In order to minimize lack-of-fusion defects, the dynamic characteristics of the welding machine (chiefly controlled by slope, inductance or both) and the arc voltage must be carefully tuned to the job. The general recommendation to minimize poor fusion is to set both the voltage and the inductance of the welding machine to as high a value as possible. The wide range of adjustments over which a welder must seek the correct settings increases the probability of a less-than-optimum setting being used, and thus the likelihood of lack of fusion increases.

Since the dynamic response of the machine is not a variable in Pulsed Spray Welding, there is no need to tune an inductor. Setting arc voltage is simple since the only effect of arc voltage is to vary arc length, and an improper arc length is readily apparent. Pulsed Spray Welding therefore offers relative freedom from lack-of-fusion defects in the welding of mild steel plate in comparison to Short Circuiting Arc Welding.

MILD STEEL SHEET

Pulsed-Arc machines also may be used for sheet-metal welding since currents as low as 30 amperes can be attained. However, because it is not possible to affect the heat input significantly by varying electrode extension, wide variations in fit-up cannot be tolerated. Thus, Short Circuiting Arc Welding is usually preferable for thin-gauge work; however, Pulsed Spray Welding may be used to decrease spatter, improve weld shape, and attain better control of penetration.

LOW-ALLOY STEEL

The preceding comments about mild steel apply equally to low-alloy steels; however, since welds in this class of metal are expected to withstand tougher service conditions than mild-steel welds, the presence of lack-of-fusion defects is more serious and Pulsed Spray Welding can therefore be used to even greater advantage in joining low alloy steel plate than it can in joining mild steel plate. A high quality Pulsed-Spray weld in a low alloy steel plate with a yield strength above 80,000 psi is shown in Fig. 5 after it has been subjected to six explosions. An etched side-bend test specimen of this weld is shown in Fig. 6.

AUSTENITIC STAINLESS STEEL

Pulsed Spray Welding can be applied effectively to the welding of austenitic stainless steel in argon-oxygen shielding gas. The ability to use an argon-oxygen mixture that contains less than 2% oxygen eliminates the danger of carbon pickup, which is present when using Short Circuiting Arc Welding with a gas shield that contains a large amount of carbon dioxide. With a small amount of CO₂ as in Airco's AG-90 (90 He - 7.5 Argon - 2.5 CO₂) shielding gas which can be used for short-circuiting metal transfer, the same comparison applies as made previously for mild steel.

Stainless steel to mild steel welds also can be made with PULSED-ARC power sources. A typical example would be the welding of thin-gauge stainless steel bellows to mild steel pipe.

9% NICKEL STEEL

This metal usually is used in plate form and welded with an Inconel electrode. Pulsed Spray Welding will exhibit the same advantages over Short Circuiting Arc Welding for this metal as it does in the previously discussed joining of mild steel plate. In addition, weld spatter is somewhat reduced, there is less oxidation of the base metal, and a better shaped weld bead is produced.

The last two advantages are related and can be explained in this way. Welds with an acceptably contoured upper surface which fairs into the base metal can be made with pulsed direct current in either plain inert gas or with up to 0.4% oxygen in the shield for better arc stability. Welds also can be made in an inert gas with short circuiting transfer, but the weld shape is generally unacceptable, being highly crowned. If oxygen is added in sufficient amount to

prove the shape, the deposit has a highly scaled surface, and difficulty can be encountered in obtaining good fitting of the base metal.

MAGNESIUM & ALUMINUM ALLOYS

In this group of metals, Pulsed Spray Welding can be used to great advantage whereas Short Circuiting Arc Welding is difficult. In the welding of these metals, active shielding gases are considered detrimental except in extremely small amounts because of deterioration of weld appearance that is caused by a heavy scale and the entrapment of slag. Trapped slag can lead to lack of fusion. Inert gases can be used in Pulsed Spray Welding to avoid these difficulties, but the use of such gases in Short Circuiting Arc Welding is not satisfactory. Although welds in pure inert gas can be made with Short Circuiting Arc Welding, they have high crowns and do not fair well into the base metal; furthermore, adjustment of welding conditions to obtain good fusion is difficult.

OTHER METALS

A number of other metals are similar to aluminum and its alloys in respect to (1) the adverse effect that reactive gases in the shield have on weld quality and (2) the difficulty in achieving acceptable welds in them with inert-gas-shielded short-circuiting transfer. Included in this group are nickel and its alloys, copper and its alloys, magnesium and its alloys, and titanium and its alloys.

PIPE WELDING (Fig. 7)

Short Circuiting Arc Welding is being used successfully for industrial pipe welding; however, the frequent occurrence of lack-of-fusion defects has prevented general widespread acceptance of this process. Pulsed Spray Welding offers potential advantage in minimizing these defects with one exception.

Pulsed Spray Welding has not been used successfully for root pass welding in the 5G position with an open root joint. (In this position, the longitudinal axis of the pipe is horizontal and the pipe is not rotated.) If the gap from 4 to 8 o'clock is too large, a keyhole is formed in the weld pool and metal drops pass straight through the hole. If wall thickness is above approximately 3/4 inch, weave techniques will prevent the formation of a keyhole, but the majority of pipe is not this heavy.

Full fusion requirements dictate a minimum gap of approximately 0.020 inch. The maximum gap that can be tolerated when pulsing is approximately 0.040 inch; thus, on piping in the 5G position, fit-up tolerance is far too small for most practical applications. The combination of Short Circuiting Arc Welding or Gas Tungsten-Arc Welding for the root pass and Pulsed Spray Welding for subsequent passes can produce sound welds with the minimum possibility of defects. If a backing strip can be used, the root pass can be deposited with Pulsed Spray Welding. Fig. 7 shows such a weld and lists the conditions under which it was made. For all pipe positions other than 5G, Pulsed Spray Welding can be used for the root pass.

comparing the two figures, the effect of electrode position on the current that is required for a given meter of electrode can be seen readily. As shown in Fig. 10, for example, with a 1/16-in.-dia Airco A308 stainless steel electrode and a shielding gas of 98% Ar - 2% O₂, the minimum pulse-peak current that is required to transfer one drop of metal per pulse of energy is 320 amp. The average current for this condition is 110 amp. As shown in Fig. 11, for a 110-amp average current, the minimum pulse-peak current that is required with a 1/16-in.-dia AIRCO A675 mild steel electrode is 420 amp. The reason for the difference in minimum pulse-peak currents between the two metals is that the nonpulsing transition currents for these metals differs as follows: (a) for AIRCO A308 stainless steel, it is 210 amps, (b) for AIRCO A675 mild steel it is 280 amps.

A requirement for metal transfer to occur on every pulse sets a lower limit on the average current. The average current, however, can be reduced if this requirement is relaxed. If the pulse-peak current is reduced, transfer can be made to take place on every second, third or fourth current pulse. This is not generally recommended, however, because great decay of arc forces accompanies this condition. If the pulse-peak current is increased sufficiently, several drops can be transferred with each pulse. This condition is generally considered undesirable because it can produce undercutting and spatter. If the pulse-peak current is set high enough, arc instability also becomes a problem and a stable arc is difficult to maintain. The effect of pulse peak current on the transfer rate is shown in Fig. 12.

Figure 12. Effect of Pulse - Peak Current On Rate Of Drop Transfer

The PA-2 power source is adjusted for welding with the following sequence of steps. With the arc off, the pulse-peak-voltage handwheel is rotated while depressing a switch which converts the average-voltage meter to a peak voltage-meter. As previously stated, the peak voltage can be obtained from Table 1. The electrode speed is set at the value which will produce the required average current and this value can be determined from Table 2 for the type and diameter of electrode in use. The arc is then initiated and the background-voltage handwheel is rotated to produce the proper arc length. So long as the type and diameter of electrode remain the same, all further power source adjustments are made by means of the background-voltage handwheel. The meters on the power source read the average voltage and current which are the values familiar to every welder.

6.3 THE MODEL PA-3

Although the PA-2 provided for a broad coverage of applications of Pulsed Spray Welding, a second generation machine was needed to supplement the equipment line. Such a machine was developed and is called PA-3; it is shown in Fig. 13.

The PA-3 is a more versatile power source than the PA-2. It is designed for either half- or full-wave rectification. Either 60 or 120 pulses per second are available by simply throwing a switch. For most applications 120 pps are preferred. The pulses are provided by a fixed-voltage, single-phase transformer.

The pulse width can be adjusted by varying the firing angle of silicon controlled rectifiers. As the pulse width is decreased, the pulse-peak voltage is reduced as shown in Fig. 14. With this type of control of pulse-peak voltage, much lower average currents can be achieved than with the PA-2 because more time is available for the background current.

The control also is used to minimize the effect of line voltage variations. If the line voltage changes $\pm 10\%$, the arc voltage will change by only ± 0.1 volt, an insignificant amount.

The background current is supplied from a power supply which can be operated either as a constant-potential, adjustable-voltage unit as in the PA-2 or as a drooping-potential unit in which three preset levels of background current (8.5, 17.0, and 34.0 amp) can be selected by switches. Operation as a c-p unit is designated the "normal mode"; operation as a d-p unit is designated the "extra low mode".

Figure 13. The Model PA-3 PULSED-ARC Power Source

To operate in the normal mode, the pulse-peak voltage is selected from Table 3 and set by depressing the peak-meter switch while adjusting the pulse-width control until the required voltage is obtained on the voltmeter. Once this setting has been made, it is not necessary to change it unless a different electrode diameter or composition is used. Although a given pulse-peak voltage can be maintained over the entire current range of any given electrode diameter and composition it may be decreased as the average current

increases if a reduction in arc force is desired.

Two other variables are then selected,--they are the electrode speed, which will govern the average current level, and the background voltage which is used to adjust the arc length. To adjust the background voltage with the raise-lower switch, three switches, which are marked 8.5, 8.5 and 17, must be in the "off" position.

ough relatively low average currents can be achieved in background mode, still lower average current levels can be achieved by switching to the extra low mode. The minimum average currents that can be achieved for both modes are shown in Table 4 where they are compared to minimum average currents that can be achieved with PA-2 power source.

When the background selector switch is in the extra low mode, the level of background current is selected by one or more of the three current switches on the machine. As soon as one or more of these switches are placed ON, the brushes on the background transformer will move to its highest position (47 volts).

Once the level of background current has been selected by one of the current switches, the variables left to adjust are pulse width and the electrode speed. The electrode speed determines the average current as in the normal mode operation, BUT THE PULSE WIDTH BECOMES THE PRINCIPAL FACTOR FOR SETTING THE ARC LENGTH. At any given background current, a combination of electrode speed and pulse width are selected to produce spray transfer of metal. For a particular background current and electrode

diameter, the usable range of average current is narrow as shown in Fig. 15. Table 5 should be used to determine where the current switches are to be set.

Figure 14. Effect of Change in Pulse Width On Pulse - Peak Voltage

TABLE 2. Average Current In Amperes Vs. Electrode Speed In Inches Per Minute

Electrode Speed, IPM	Mild and Low-Alloy Steel Electrode Diameter, In.			Austenitic Stainless Steel Electrode Diameter, In.			4043 Aluminum Alloy Electrode Diameter, In.	
	0.035	0.045	1/16	0.035	0.045	1/16	3/64	1/16
40			65					
50		55	85			70		45
60		65	105		50	90		55
70		75	120		55	100		60
80		85	135	40	65	115		70
100	50	100	175	50	85	140	50	90
120	60	115	200	60	95	180	60	110
140	70	130	225	65	110	220	70	130
160	80	145	250	75	120	240	80	150
180	90	160	275	80	140	260	90	170
200	100	180	290	90	160	280	100	180
220	110	200	320	95	180	310	105	200
240	120	220		105	200		120	220
260	135	240		100	220		130	240
280	140	260		125	240		135	260
300	155	280		135	260		140	280
350	180			150	280		170	300
450	220			200	320		200	

TABLE 3. Data For Model PA-3 In The Normal Mode Of Operation

Electrode Composition	Gas Composition	Elect. Dia., In.	Pulse Rate of 60 PPS		Pulse Rate of 120 PPS	
			Pulse-Peak Volts	Avg. Current Range, Amp	Pulse-Peak Volts	Avg. Current Range, Amp
Mild And Low Alloy Steel	98% A + 2% O ₂	0.035	58	85-200	60	110-200
		0.045	61	105-300	71	120-300
		1/16	67	130-300	74	165-300
Austenitic Stainless Steel	98% A + 2% O ₂	0.035	57	75-200	59	85-200
		0.045	59	85-300	66	105-300
		1/16	62	110-300	67	125-300
4043 Aluminum Alloy	Argon	0.030	60	55-150	65	65-150
		3/64	62	62-200	67	75-200
		1/16	65	65-300	70	90-300

TABLE 4. Minimum Average Currents Available With Pulsed-Arc Power Sources

Electrode Composition	Electrode Diameter, Inch	Shielding-Gas Composition	Minimum Average Current For PA-2, Amp	Minimum Average Current For PA-3, Amp			
				Extra Low Mode		Normal Mode	
				60 PPS	120 PPS	60 PPS	120 PPS
Mild and Low Alloy Steel	0.035	98% A + 2% O ₂	55	45	85	85	110
	0.045		90	55	100	105	120
	1/16		110	60	130	130	165
Austenitic Stainless Steel	0.035	98% A + 2% O ₂	55	40	65	75	85
	0.045		90	50	85	85	105
	1/16		110	70	100	110	125
4043 Aluminum Alloy	0.030	Argon	45	30	45	50	60
	3/64		75	40	60	60	75
	1/16		90	50	75	65	90

The setting will depend on the required average current for a particular diameter and composition of electrode. Also seen in Table 5 are the corresponding minimum pulse-peak voltages for each setting of the current switches. The pulse-width control is used to set the arc length over the listed current range. For example, if an 0.045-in.-dia A675 electrode were to be used at 55 amp, one 8.5 switch would

be "up". The electrode feed speed would be set to provide an average current of 55 amp and the pulse-peak voltage would be set at 72 volts. If an increase in the average current to 70 amp is desired, the electrode speed and the pulse-width control are increased. If a further increase in the average current is required, the current switches must be changed and the minimum pulse-peak voltage must be

TABLE 5. Data For Model PA-3 In The Extra Low Mode Of Operation

Electrode Composition And Diameter, In.		Background Current, Amperes					
		Pulse Rate of 60 PPS			Pulse Rate of 120 PPS		
		8.5	17.0	34.0	8.5	17.0	34.0
Mild Steel 0.035	Avg. Current Range, Amp		45-65	60-85	85-95	90-105	100-115
	Min. Pulse-Peak Voltage, Volts		66	59	73	71	64
Mild Steel 0.045	Avg. Current Range, Amp	55-70	65-85	80-100	100-115	110-130	125-145
	Min. Pulse-Peak Voltage, Volts	72	70	65	74	72	68
Mild Steel 1/16	Avg. Current Range, Amp	60-85	80-110	105-135	130-155	150-170	160-175
	Min. Pulse-Peak Voltage, Volts	76	73	70	76	75	72
Austenitic Stainless Steel 0.035	Avg. Current Range, Amp	U N S T A B L E	40-60	60-80	65-80	75-90	80-95
	Min. Pulse-Peak Voltage, Volts		65	60	72	68	61
Austenitic Stainless Steel 0.045	Avg. Current Range, Amp		50-70	65-90	85-100	90-110	100-120
	Min. Pulse-Peak Voltage, Volts		68	62	73	71	65
Austenitic Stainless Steel 1/16	Avg. Current Range, Amp		70-90	85-110	100-115	110-130	120-135
	Min. Pulse-Peak Voltage, Volts		71	66	75	73	68
4043 Aluminum Alloy 3/64	Avg. Current Range, Amp		42-60	55-70	60-75	65-80	75-90
	Min. Pulse-Peak Voltage, Volts		66	59	71	67	60
4043 Aluminum Alloy 1/16	Avg. Current Range, Amp		45-60	50-70	65-80	75-85	80-95
	Min. Pulse-Peak Voltage, Volts		72	68	64	74	72

set to a lower value. The reason for having to reset the pulse-peak voltage is that an excessively high setting reduces severe arc instability. Figs. 16 and 17 show the relationship graphically between the pulse-peak voltage and the operating current ranges for both 60 and 120 pulses per second.

The pulse-peak voltage must vary to obtain the peak currents that are required for spray transfer of metal. Although measurement and control of the peak CURRENT would seem to be a more desirable way of obtaining the desired transfer, the equipment to do this would be too

complex and expensive to be feasible commercially. For this reason, the pulse-peak VOLTAGE of the PA-3 machine is adjusted as in the PA-2 machine.

The PA-3 has a second pulse-width control called program control which, with a special electrode feeder or with a modification of some electrode feeders, can produce two different sets of welding conditions. These welding conditions can be selected at any time and for any duration by the welder while welding. This feature has been found beneficial in use as a hot start, in going over tacks, and for getting into tight corners.

Pulsed Spray Welding

7.2 Application Data

Stainless Steel

That these are only guides must be emphasized since there are factors other than those which are covered in the guides that are under the control of the fabricator and affect the weld quality; some of these are welder skill, the existence of drafts, and conditions of the base-metal surface prior to welding.

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INDEX TO ABBREVIATIONS

GAS FLOWS — Cubic feet per hour

TRAVEL SPEEDS — Inches per minute

VOLTAGE — Volts

CURRENT — Amperes

WIRE FEED — Inches per minute

ELECTRODE FEED — Inches per minute

WORK AND ELECTRODE DIMENSIONS — Inches

TABLE 11. Electrode Speed And Settings For A Model PA-3 Power Source Over The Operating Current Range For A 0.045-In.-Dia Austenitic Stainless Steel Electrode In A Shield Of A + 2% O₂

Average Current, Amp	Electrode Speed, IPM	Pulse-Peak Voltage, Volts *	Background Voltage, Volts	Pulse Rate, PPS	Mode of Operation	Background Current, Amp		
						8.5	8.5	17.0
50	60	68	—	60	Ex Low	On	On	Off
70	90	71	—	60	Ex Low	On	On	Off
65	80	62	—	60	Ex Low	On	On	On
90	115	65	—	60	Ex Low	On	On	On
85	100	59	22	60	Normal	Off	Off	Off
85	100	73	—	120	Ex Low	On	Off	Off
100	130	76	—	120	Ex Low	On	Off	Off
90	115	71	—	120	Ex Low	On	On	Off
110	140	74	—	120	Ex Low	On	On	Off
105	135	66	22	120	Normal	Off	Off	Off
100	130	65	—	120	Ex Low	On	On	On
120	160	68	—	120	Ex Low	On	On	On
140	185	59	24	60	Normal	Off	Off	Off
140	185	66	24	120	Normal	Off	Off	Off
200	240	59	28	60	Normal	Off	Off	Off
200	240	66	28	120	Normal	Off	Off	Off
300	425	59	30	60	Normal	Off	Off	Off
300	425	66	30	120	Normal	Off	Off	Off

*Pulse Peak voltage settings are only a guide and practical experience indicates they may be as much as 10% high.

STAINLESS STEEL

TABLE 13. Model PA-3-Optimum Conditions For Welding Austenitic Stainless Steel In A Shield Of A + 1% O₂ Or A + 2% O₂

Metal Thickness, In.		Elect. Dia, In.	Average Current, Amp	Electrode Speed, IPM	Pulse- Peak Voltage, Volts*	Back- ground Voltage, Volts	Pulse Rate, PPS	Mode Of Operation	Background Current Amp			Elect. Melting Rate, Lb/Hr
Flat & Horiz. Position	Position Other Than Flat & Horiz.								8.5	8.5	17.0	
0.040	0.050	.035	40	80	65	—	60	Ex Low	On	On	Off	1.3
0.050	1/16	.035	50	110	66	—	60	Ex Low	On	On	Off	1.7
1/16	3/32	.045	60	75	69	—	60	Ex Low	On	On	Off	2.3
3/32	1/8	.035	80	180	68	—	120	Ex Low	On	On	Off	2.8
3/32	1/8	.045	80	100	65	—	60	Ex Low	On	On	On	2.7
1/8	3/16 Up	.045	100	130	72	—	120	Ex Low	On	On	Off	3.6
1/8	3/16 Up	1/16	100	65	67	—	60	Ex Low	On	On	On	3.4
3/16	3/8 Up	.045	140	185	66	22	120	Normal	Off	Off	Off	5.0
3/16	3/8 Up	1/16	140	100	67	23	120	Normal	Off	Off	Off	5.0
1/4		.045	160	215	66	24	120	Normal	Off	Off	Off	6.0
1/4		1/16	160	115	67	25	120	Normal	Off	Off	Off	5.8
3/8 Up		.045	200	260	66	26	120	Normal	Off	Off	Off	7.2
3/8 Up		1/16	200	130	67	27	120	Normal	Off	Off	Off	6.8

*Pulse Peak voltage settings are only a guide and practical experience indicates they may be as much as 10% high.

TABLE 14. Model PA-2-Optimum Conditions For Welding Austenitic Steel In A Shield Of A + 1% O₂ Or A + 2% O₂

Metal Thickness, In.		Elect. Dia., In	Average Current, Amp	Electrode Speed, IPM	Pulse-Peak Voltage, Volts	Background Voltage, Volts
Flat & Horiz. Position	Positions Other Than Flat & Horiz.					
1/16	3/32	.035	60	120	34	17
3/32	1/8	.035	80	180	34	19
3/32	3/16	.045	100	125	36	19
1/8	1/4	.045	110	140	36	20
3/16	3/8 Up	.045	130	170	38	23
3/16	3/8 Up	1/16	130	90	39	23
1/4		1/16	180	120	39	27
3/8 Up		1/16	220	140	39	29

STAINLESS STEEL

APPENDIX A

TASK FORCE

In response to LLL's request EG&G assembled the special task force of nine mechanical engineers and a senior technical writer required to produce this document in less than ten working days. The task force was selected and organized as follows:

Jon Garcia, B.S.M.E.

Mechanical Engineering Section supervisor with 16 years project management experience.

Responsibilities: Task force leader, organization, planning, customer liaison, reporting and scheduling.

Bob Altes, B.S.M.E.

Experienced in cost estimating of superconducting magnets for Brookhaven National Laboratory while employed at Brobeck and Associates in Berkeley.

Responsibilities: Report integration, system flow chart, overall manpower plan, and cost estimate.

Lee Hunt, B.S.M.E.

Registered Professional Engineer, State of Nevada. Design Engineer for MFTF Superconducting Yin-Yang Magnet System.

Responsibilities: Generation of the baseline engineering design criteria, task definition, and sequence of task performance.

Yun Chang, M.S.M.E.

Registered Professional Engineer, State of California. Co-Design Engineer with Lee Hunt in the development of the superconducting magnet coil winding machine.

Responsibilities: Verify LLL weight analysis and identify engineering development areas.

Art Williams, B.S.M.E., M.S.E.D.

Registered Professional Engineer - Mechanical Engineering
and Nuclear Engineering, State of California.

Responsibilities: Material analysis, welding specifications and procedures, joint design, capital equipment, qualification and certification.

Terry Bevers, B.S.M.E.

Experienced in large steel vessel and structural fabrication.

Responsibilities: Fabrication engineering, handling, assembly procedure appraisal, ground support equipment, rigging requirements, fixtures, and safety analysis.

Bill Ruvalcaba, B.S.M.E.

Section Head, Vacuum Systems Engineering.

Responsibilities: Vacuum leak testing, plans, procedures, equipment and manpower estimates.

Bill Olson, B.S.M.E.

Responsible Design Engineer for MFTF tooling requirements.

Responsibilities: Special tooling, superconductor joining, insulation, etc..

Tony Davito, M.S.C.E.

Registered Civil Engineer, State of California, experience in structural computer analysis and earthquake safety analysis.

Responsibilities: Review coil structural mounting requirements and earthquake protection.

Dick Ingraham, B.A. (English)

Senior Technical Writer with 18 years experience.

Responsibilities: Report coordination, art work, editing, and publication.

APPENDIX B

200-TON TROLLEY HOIST

The information supplied in this Appendix is not direct supporting data for the cost analysis. The intent was to provide cost information relative to a recent procurement of a 200-ton trolley hoist for use in the ATLAS tower at the EG&G North Las Vegas Facility (NLVF). This procurement dealt with LLL's fracture safe criteria.

EG&G INC.

PURCHASE ORDER

No. 816679

PAGE 1 OF 3

SELLER

HECO PACIFIC MANUFACTURING, INC.
383 BEACH ROAD
BURLINGAME, CALIFORNIA 94010

SHIP
TO

☐
☐
☐
☐
☒

ATT: M. ALARAB
(415)342-9741 \$138,123.00/TOTAL

SEE BELOW

1

SLEE	EXT. AA	F.O.B. LAS VEGAS, NEV.	TERMS SEE ATTACHMENT 0	SHIP VIA MOTOR FREIGHT	DATE OF ORDER 4/28/76
CT NO. 29-1) 1183	TYPE CPAF	PRIORITY	DO-E-2	CERTIFIED FOR NATIONAL DEFENSE USE UNDER DMS REG.	SELLER PROMISES SHIPMENT(S) FEBRUARY 28, 1977
				10 MONTHS AFTER RECEIPT OF ORDER	

QUANTITY	E. G. & G. STOCK NO.	DESCRIPTION	ACCOUNT OR JOB NO.	DEPT.	UNIT COST
ILL TO:	EG&G, INCORPORATED	FOR U.S. ENERGY RESEARCH & DEVELOPMENT ADMINISTRATION (ADDRESS AS INDICATED ABOVE)			
SHIP TO:	EG&G, INCORPORATED	FOR U.S. ENERGY RESEARCH & DEVELOPMENT ADMINISTRATION NORTH LAS VEGAS FACILITY 316 ATLAS CIRCLE NORTH LAS VEGAS, NEVADA 89030			
1	P/N 231441	200-TON TROLLEY HOIST PER EG&G SPECIFICATION "200-TON TROLLEY HOIST."	C-57-02-0 1530		138,123.00

- NOTES:
- EG&G SPECIFICATION DIA-031, REV. 3 WILL APPLY TO THIS REQUIREMENT.
 - EG&G SOURCE INSPECTION WILL BE ACCOMPLISHED AT SELLER'S FACILITY.
 - REPRESENTATION: UNLESS THE SELLER EXPRESSLY STATED OTHERWISE IN ITS PROPOSAL, WHERE FUNCTIONAL REQUIREMENTS ARE EXPRESSLY STATED AS PART OF THE REQUIREMENTS OF THIS ORDER, THE SELLER REPRESENTS THAT IN ITS OPINION THE SYSTEM PROPOSED IS CAPABLE OF MEETING

CERTIFICATION REQUIRED, THAT MATERIAL AND PROCESSES COMPLY WITH APPLICABLE SPECIFICATIONS AND DIRECTIVES			PROPERTY CODE 2A	INSPECTION	☐ GOVT SOURCE ☒ E.G.&G. SOURCE
ATIONER GANASSIN/DAVIS	REQ'N. NO. 05151	REQUIRED DATE	IN-PLANT DESTINATION MAIL STOP TO HERRY/GANASSIN		☐ INCOMING ☐ NONE ☐ OTHER

4/28/76

CONFIRMATION TRANSACTION CODE FOLLOW-UP CODE

BY PURCHASING MANAGER
E G & G INC.

EG&G INC.

PURCHASE ORDER

No. 016679

PAGE 2 OF 3

SELLER

**HECO PACIFIC MANUFACTURING, INC.
393 BEACH ROAD
BURLINGAME, CALIFORNIA 94010**SHIP
TO

ATT:

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SEE PAGE 1

ISLEE	EXT. AA	F.O.B.	TERMS	SHIP VIA	DATE OF ORDER 4/29/78
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ACT NO. (29-1) 1183	TYPE CPAF	PRIORITY DC-E-2	CERTIFIED FOR NATIONAL DEFENSE USE UNDER DMS REG. 1	SELLER PROMISES SHIPMENT(S) FEBRUARY 28, 1977
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QUANTITY	E. G. & G. STOCK NO.	DESCRIPTION	ACCOUNT OR JOB NO.	DEPT.	UNIT COST
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NOTE 3 (CONT.)

THOSE REQUIREMENTS.. HOWEVER, ONCE THE FUNCTIONS HAVE BEEN DEMONSTRATED OR PUT TO USE ON THE DELIVERED SYSTEM, THE SELLER'S RESPONSIBILITY UNDER THIS CLAUSE CEASES. IN THE EVENT OF ANY INCONSISTENCY BETWEEN THE DETAILED SPECIFICATIONS AND THE FUNCTIONAL SPECIFICATION CONTAINED IN THE ORDER, THE FORMER WILL CONTROL.

- WHEREVER THE WORD(S) "ATOMIC ENERGY COMMISSION," "AEC," "COMMISSION," OR "COMMISSIONER" APPEAR IN THIS PURCHASE ORDER, PLEASE SUBSTITUTE THE APPROPRIATE TERM(S), "ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION," "ERDA," "ADMINISTRATION" OR "ADMINISTRATOR.")
- EG&G WILL SUPPLY MATERIAL LISTED ON PAGE 2 OF SPECIFICATION 200-TON TROLLEY HOIST. CERTIFICATION OF THIS MATERIAL WILL BE BY EG&G.
- UPON RETURN RECEIPT OF THE ATTACHED ACKNOWLEDGMENT COPY, THIS PURCHASE ORDER CONSTITUTES A BINDING CONTRACT BETWEEN HECO PACIFIC MANUFACTURING, INCORPORATED AND EG&G, INCORPORATED. ANY CHANGES TO THIS PURCHASE ORDER, WITHOUT THE EXPRESS PERMISSION OF EG&G'S PURCHASING MANAGER OR DESIGNEE AND A WRITTEN CHANGE ORDER, IS SOLELY THE RESPONSIBILITY OF HECO PACIFIC MANUFACTURING, INC. COST BREAKDOWN WILL BE REQUIRED PRIOR TO MAKING ANY CHANGE.

CERTIFICATION REQUIRED, THAT MATERIAL AND PROCESSES COMPLY WITH APPLICABLE SPECIFICATIONS AND DIRECTIVES		PROPERTY CODE 2A	INSPECTION	☐ GOV'T SOURCE ☒ E. G. & G. SOURCE
ISSUING OFFICER GANASSIN/DAVIS	REQ'N. NO. 05151	REQUIRED DATE	IN-PLANT DESTINATION MAIL STOP TO HERRY/GANASSIN	☐ INCOMING ☐ NONE ☐ OTHER

4/29/78

CONFIRMATION TRANSACTION CODE FOLLOW-UP CODE

BY _____
PURCHASING MANAGER
EG & G INC.

EG&G INC.

PURCHASE ORDER

No. 016679

PAGE 3 OF 3

NECO PACIFIC MANUFACTURING, INC.
383 BEACH ROAD
BURLINGAME, CALIFORNIA 94010

SHIP
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SEE PAGE 1

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ATT:

SLEE	EXT. AA	F.O.B.	TERMS	SHIP VIA	DATE OF ORDER 4/29/78		
ICT NO. 29-1) 1183	TYPE CPAF	PRIORITY	DD-E-2 CERTIFIED FOR NATIONAL DEFENSE USE UNDER DMS REG. 1	SELLER PROMISES SHIPMENT(S) FEBRUARY 28, 1977			
QUANTITY	E. G. & G. STOCK NO.	DESCRIPTION			ACCOUNT OR JOB NO.	DEPT.	UNIT COST

THE FOLLOWING ARE ATTACHED HERETO AND MADE A PART HEREOF:

1. EG&G TERMS AND CONDITIONS FORM 511 (NOV.73)
2. ATTACHMENT "A" WARRANTY
3. ATTACHMENT "B" COST OR PRICING DATA
4. ATTACHMENT "C" NONSEGREGATED FACILITIES CLAUSE
5. ATTACHMENT "D" PROGRESS PAYMENTS "TERMS & CONDITIONS" AND SCHEDULE
6. ATTACHMENT "E" EMPLOYMENT OF THE HANDICAPPED CLAUSE
7. ATTACHMENT "F" CLEAN AIR AND WATER CLAUSE
8. ATTACHMENT "G" MINORITY BUSINESS ENTERPRISE CERTIFICATION
9. ATTACHMENT "H" HANDICAPPED CERTIFICATION

CERTIFICATION REQUIRED, THAT MATERIAL AND PROCESSES COMPLY WITH APPLICABLE SPECIFICATIONS AND DIRECTIVES				PROPERTY CODE 2A	INSPECTION	☐ GOVT SOURCE ☒ E. G. & G. SOURCE
POSITIONER GANASSIN/ DAVIS	REQ'N. NO. 05151	REQUIRED DATE	IN-PLANT DESTINATION MAIL STOP TO HERRY/GANASSIN		☐ INCOMING ☐ NONE ☐ OTHER	

CONFIRMATION 4/29/78 TRANSACTION CODE FOLLOW-UP CODE

BY
PURCHASING MANAGER
EG & G INC.

SPECIFICATIONS

200-Ton Trolley Hoist Revision A 5/24/77

System Description

The following specification covers the design and manufacture of one (1) 200-ton capacity hoist for outdoor service under roof. The hoist is to be mounted on the roof of a 100-foot self-supporting tower. The tower consists of eight (8) working levels 12-1/2 feet in height. The tower has a continuous vertical shaft 13 ft. x 15 ft. in cross-section. The 200-ton hoist will be used to lift heavy welded structures through this shaft.

Performance Criteria

The trolley hoist assembly will conform to the following performance criteria:

Capacity	200-ton
Hoist travel	93-ft. minimum*
Hoist speed (no load)	3 fpm
Trolley speed (no load)	5-7 fpm
Trolley travel	5-ft. minimum*
Runway length	15-ft. maximum*
Power requirement	480-3-60 AC

*For clarity, consult sketches 1 & 2.

Materials

Choice of materials for parts and components to be used within the hoist assembly are at the discretion of the contractor. However, certain components within the assembly have been deemed "critical components" and must conform to the materials specified in section one (1) page three (3) of Appendix A. The six (6) critical components shown and numbered on the following sketches are:

1. Lifting pin
2. Trunnion
3. Hanger plates (2 each)
4. Sheave pin
5. Drum trunnions (2 each)
6. Box beam lower flange and safety stops

EG&G has presently available in stock some of those materials that qualify under section one (1) of Appendix A. Those materials suitable for use on the hoist assembly will be furnished to the contractor upon request. EG&G will also assist the contractor in locating qualified materials available at outside vendors.

EG&G Material Stock List

<u>Material</u>	<u>Size (inches)</u>	<u>Quantity</u>
A-537 Plate	3/4 x 60 x 60	1 each
A-537 Plate	1 x 60 x 60	1 each
A-537 Plate	1-1/2 x 60 x 60	1 each
A-537 Plate	2 x 60 x 60	1 each

<u>Material</u>	<u>Size (inches)</u>	<u>Quantity</u>
A-537 Plate	2-1/2 x 60 x 60	1 each
HY-80 Plate	3 x 96 x 144	1 each
4330 Forging	15-1/2 dia. x 72 long	2 each

The latest revision of C.M.A.A. Specification No. 70 will be used wherever applicable. All codes and association practices listed therein will be adhered to.

Acceptance

1. Vendors Facilities

The vendor will, prior to shipment and in the presence of an authorized Buyer representative, conduct a systems test designed to show that all mechanical systems are free and operable. Calculations will be made available in order to determine that the lift travel will be fulfilled. The vendor will provide an instruction sheet for reaving the bottom block. All components will be complete and ready for crating.

2. Erection Site

After erection at the ATLAS Facility a systems performance will be run according to Appendix B of this specification. EG&G will be responsible for erection, including electrical wiring into the facility power and control cable. In addition, EG&G will be responsible for reaving the bottom block according to the instructions supplied. EG&G will perform the tests described in Appendix B, including the load test to 500 kips. The vendor may witness all tests included in this specification and upon receipt of the test will issue an appropriate certification and warranty.

SUBJECT

SPECIFICATION - 200-TON TROLLEY HOIST ASSY.

NAME TEMPLE

DATE 1/6/76

SKETCH NO. 1

NOTES:

1. HOOK CENTER TO HAVE A MINIMUM OF 5'-0" LATERAL MOVEMENT. 2'-6" IN EACH DIRECTION FROM DATUM -A-.
2. DRUM ORIENTATION TO BE PERPENDICULAR TO TROLLEY RAILS AS SHOWN. DRUM TO BE DOUBLE REEVED.

SUBJECT

SPECIFICATION - 200-TON TROLLEY HOIST ASSY.

NAME TEMPLE

DATE 1/6/76

SKETCH NO. 2

Runway stops shall be provided by the purchaser and shall be located at the limits of the trolley travel. Size and type to be specified by vendor.

Trolley rails shall be furnished by purchaser. Size and type to be specified by vendor.

A floor-operated pushbutton pendant will be provided by the vendor. The "floor" is considered to be at elevation "0".

Before shipment, the trolley-hoist assembly will be thoroughly cleaned and primed with Rust-o-leum #678 red primer and painted with Rust-o-leum #2766 high-gloss white paint.

APPENDIX B

200-TON HOIST TEST PROCEDURE

1 SCOPE

This procedure defines the tests to be conducted in the Tower at the ATLAS Facility, North Las Vegas, Nevada. These tests will serve as the final acceptance testing and certification of this feature of the ATLAS Facility. The tests will be conducted at the direction of an EG&G engineer. Heco Pacific Manufacturing is to be notified one week in advance of such testing and at their option may have a representative present to witness all tests. The representation of Heco Pacific shall be done at the expense of Heco Pacific Manufacturing.

2 TEST PROCEDURE

2.1 Trolley Load Tests

The hoist will undergo the following no-load test:

- (1) The trolley will be moved at maximum speed, as determined by full depression of the control button, from the east stop for 4 feet. The elapsed time will be recorded.
- (2) The trolley will be moved at maximum speed, as determined by full depression of the control button, from the west stop for 4 feet. The elapsed time will be recorded.
- (3) The average travel speed will be computed in each direction and the values will be recorded.

2.2 Bottom Block No-Load Tests

- (1) The bottom block will be checked for full extension of 93 feet by determining that the lower sheave pin is 95 ft. 1½ in. min. from the trolley rails.
- (2) From this position the bottom block will be raised 5 feet at maximum speed, as determined by full depression of the control button. The elapsed time will be recorded.
- (3) The bottom block will be raised approximately 39 feet.
- (4) The bottom block will be raised 5 feet from the 49.0 foot position at maximum speed, as determined by full depression of the control button. The elapsed time will be recorded.
- (5) The bottom block will be raised approximately 36 feet.
- (6) The bottom block will be raised 5 feet from the 8.0-foot position at maximum speed, as determined by full depression of the control button. The elapsed time will be recorded.

- (7) The bottom block will be raised to the zero position.
- (8) The bottom block will be lowered 5 feet from the zero position at maximum speed, as determined by full depression of the control button. The elapsed time will be recorded.
- (9) The bottom block will be lowered to the 44-foot position.
- (10) The bottom block will be lowered 5 feet at maximum speed, as determined by full depression of the control button. The elapsed time will be recorded.
- (11) The bottom block will be lowered to the 85-foot level.
- (12) The bottom block will be lowered 5 feet at maximum speed, as determined by full depression of the control button. The elapsed time will be recorded.
- (13) The bottom block will be lowered to the 93-foot position.
- (14) The bottom block will be raised to the 3-foot level at maximum speed, as determined by full depression of the control button. The elapsed time will be recorded.
- (15) The bottom block will be raised to the zero position.
- (16) The bottom block will be lowered to the 90-foot position at maximum speed, as determined by the full depression of the control button. The elapsed time will be recorded.
- (17) Average velocities will be calculated for Steps (2), (4), (6), (8), (10), (12), (14), and (16) and recorded.

2.3 Hoist and Structure Load Test

- (1) The 1.5 m load cell from the HLTM will be threaded onto the load pin.
- (2) The spanner beam will be placed over the Rat Hole.
- (3) Secure the load cell to the beam. Torque all bolts to 600 ft-lb.
- (4) Secure the beam to the Rat Hole casing as shown on the load test assembly drawing.
- (5) Set deflection instrumentation (if required) to zero.
- (6) At low speed, impose a 50-kip load on the hoist as determined by the load-cell readout.
- (7) Check all pin connections and the beam attitude.
- (8) Clear the area. The operator and supervising engineer or his representative will be located behind an appropriate barrier. This barrier is to be located so that visual contact is maintained with the hoist and spanner beam but at full control box extension (93 feet).

- (9) Load the hoist and structure to 200 kips. Examine all rigging for misalignment.
- (10) Load the hoist and structure to 500 kips. Hold load for 5 minutes.
- (11) Set safety stops to engage rails.
- (12) Slowly reduce load to zero.
- (13) Record deflection data (if taken).
- (14) Secure data sheet and disassemble equipment.
- (15) Examine hoist and surface conductor for visual changes in the load-carrying members. Record results of that examination.

SPEC. NO. DIA-031

REVISION

DATE Sept. 11, 1975

APPROVED W. J. L.

SPECIFICATION

APPENDIX "A"

FRACTURE TOUGH STEEL
PERFORMANCE SPECIFICATION
FOR
CRITICAL LOAD HANDLING EQUIPMENT

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1 SCOPE--This document specifies material requirements, test and inspection procedures, and Seller-Purchaser responsibilities for production of critical components from fracture tough steels. The approved fracture tough steels are AISI 304 A 517, Grade F, and ASTM A 352.

1.1 Conflicts between or interpretation of specifications, drawings, and reference specifications shall be resolved by Purchaser and Seller.

1.2 Critical Components: A component shall be judged critical and requiring fracture tough steels when the following criteria are met.

a. The component is loaded in tension or bending.

b. There exists no redundant load path bypassing the component to prevent the load from falling.

All load carrying components shall be investigated to the above criteria, and a list of the items deemed critical shall be submitted to the Purchaser, along with an overall drawing outlining the supporting load paths.

2 REFERENCE DOCUMENTS--These reference documents shall constitute, to the extent specified, an integral part of this specification.

2.1 EG&G, Inc., Specifications:

DIA-024, Rev. "A"

Welding Spec. for Fracture Tough Weldments

2.2 American Society for Testing and Materials (ASTM) Standards:

ASTM A 20-72a

General Requirements for Delivery of Steel Plates for Pressure Vessels

ASTM A 352-72

Standard Specification for Ferritic Steel Castings for Pressure-Containing Parts Suitable for Low-Temperature Service

ASTM A 370-72

Standard Methods and Definitions for Mechanical Testing of Steel Products

ASTM A 517-70a

Standard Specification for High-Strength Alloy Steel Plates, Quenched and Tempered, for Pressure Vessels

ASTM A 537-70

Standard Specification for Carbon-Manganese-Silicon Steel Plates, Heat Treated, for Pressure Vessels

ASTM E 10-66

Standard Method of Test for Brinell Hardness of Metallic Materials

ASTM E 18-67

Standard Methods of Test for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials

ASTM E 94-68

Recommended Practice for Radiographic Testing.

ASTM E 109-63

Standard Method for Dry Powder Magnetic Particle Inspection

ASTM E 138-63

Standard Method for Wet Magnetic Particle Inspection

ASTM E 142-68

Standard Method for Controlling Quality of Radiographic Testing

ASTM E 165-65

Standard Methods for Liquid Penetrant Inspection

ASTM E 208-69

Standard Method for Conducting Drop-Weight Tests to Determine Nil-Ductility Transition Temperature of Ferritic Steels

2.3 American Iron and Steel Institute (AISI) Standards:

AISI 304

AISI Type 304 and Type 304L Austenitic Stainless Steels

3 REQUIREMENTS--All requirements specified for each fracture tough steel shall be met prior to final acceptance of the finished product.

3.1 AISI 304 Stainless Steel--Prior to initiation of production of components from AISI 304 stainless steel, Seller shall submit mill material certifications to Purchaser and receive approval that the material meets the requirements of AISI 304.

3.2 4330 Vanadium Modified Steel--The following requirements shall be met for all parts produced from 4330 V. Mod. ingot, forged, or bar material.

3.2.1 Material Certification--Prior to initiation of production, Seller shall submit to Purchaser and receive approval of mill material certifications for each heat of steel to document the manufacturing process, chemical composition, austenitic grain size, and Jominy end-quench hardenability. Material certifications shall be required for all 4330 V. Mod. steel from which parts are produced. Seller may submit mill material certifications for all 4330V. Mod. bar material from which parts will be produced for Purchaser approval that the bar material meets the requirements of Table 2 as specified in 3.2.5.

3.2.1.1 Manufacturing Process--The material shall be fine grain practice fully killed and vacuum degassed electric furnace quality steel.

3.2.1.2 Chemical Composition--The chemical composition shall meet the requirements specified in Table 1.

Element	Analysis %
Carbon	0.28 - 0.34
Manganese	0.60 - 1.00
Phosphorus	0.025 Max.
Sulfur	0.025 Max.
Silicon	0.17 - 0.35
Nickel	1.65 - 2.40
Chromium	0.75 - 1.02
Molybdenum	0.35 - 0.57
Vanadium	0.05 - 0.12
Copper	0.35 Max.
Iron	Balance

CHEMICAL COMPOSITION

Table 1

3.2.1.3 Austenitic Grain Size--The austenitic grain size shall be predominantly No. 5 or finer with occasional grain sizes as large as No. 3 permissible.

3.2.1.4 Jominy End-Quench Hardenability--The minimum Jominy Hardenability values shall be Rockwell C 48 at 14/16 inch and C 44 at 24/16 inch.

- 3.2.2. Forging Production**--Seller shall be responsible for determination of a manufacturing method which will produce forgings that meet the specified requirements. Seller shall be responsible for production of test forgings to provide material for specimens for the required mechanical property tests. The test forgings shall be designed to produce the number and orientation of tensile and impact test specimens specified in 3.2.5. Thickness T of the test forgings shall be equal to the diameter of the largest circle that can be inscribed in any cross-section of the product forgings prior to heat treatment. Seller may select the test blank (Section 4.2.1), forged prolongation (Section 4.2.2), or some other method of material sampling for mechanical property tests which will meet the requirements of this specification. Prior to production of the test forgings, Seller shall submit the proposed material sampling method to Purchaser for review and comment. One test forging shall be produced to be heat treated with each group of rough machined forgings that are the same configuration, produced from the same heat, and heat treated in the same heat treatment charge. Excess test forgings shall also be required to provide material for mechanical test specimens, as specified in 4.4, in the event that the results of mechanical property tests do not meet the specification requirements and reheat treatment is approved by Purchaser.
- 3.2.3. Welding**--Welding is prohibited without specific Purchaser approval.
- 3.2.4. Heat Treatment**--Seller shall be responsible for determination of a heat treatment procedure which will produce forgings that meet the specified requirements. Prior to heat treatment, Seller shall submit the proposed heat treatment procedure to Purchaser for review and comment. For Purchaser information, Seller shall submit the heat treatment certifications and time-temperature records. One test forging shall be heat treated with each group of rough machined forgings that are the same configuration, produced from the same heat, and heat treated in the same heat treatment charge. Forgings shall be machined to within 1/4 inch of finished dimensions prior to heat treatment. Adequate pyrometric equipment shall record all heat treatment temperatures.
- 3.2.4.1. Identification Marking**--Seller shall be responsible for positive identification and complete documentation of each forging produced. Each test forging shall be assigned a heat treatment number 1 to X or any other designation Seller may prefer. Each rough machined forging in a group of forgings that are the same configuration, produced from the same heat, and heat treated in the same heat treatment charge shall be marked with the same identification designation as the test forging which represents the rough machined forgings. Seller shall positively identify each rough machined forging and test forging by a marking method which will be retained through heat treatment.

3.2.5

Mechanical Properties--The heat treated forged material shall meet the specified tensile, impact, and hardness test requirements. Tensile test results are required for pins, shafts, or axles which are produced from 4330 V. Mod. bar stock. Mill material certification of tensile properties of 4330 V. Mod. bar stock are acceptable. All test results shall be tabulated, when applicable, with the respective heat treatment number assigned, to the test forging as specified in 3.2.4.1 and submitted to Purchaser. Seller shall receive Purchaser approval of test results prior to continuation of production. If the mechanical property test results do not meet the specified requirements, reheat treatment and/or retests may be performed only with Purchaser approval. Mechanical property tests shall require 2 longitudinal and 2 transverse tensile specimens and 3 longitudinal impact specimens. The configuration of the test forging shall determine the location of the tensile and impact test specimens. If the test forging is basically a hollow cylindrical shape, the tensile and impact specimens shall be cut from the test forging so that the center of the gauge length of each tensile specimen and the notch area of each impact specimen are a distance of $T/2$ from the outside (or inside) cylindrical surface and at least a distance of T from all other quenched surfaces. If the test forging is a solid cylindrical shape, the tensile and impact test specimens shall be cut from the test forging so that the center of the gauge length of each tensile specimen and the notch area of each impact specimen are a distance of $T/4$ from the cylindrical surface and at least a distance of T from all other quenched surfaces. For rectangular test forging configurations, the tensile and impact specimens shall be cut from the test forging so that the center of the gauge length of each tensile specimen and the notch area of each impact specimen are a distance of $T/4$ from one quenched surface and at least a distance of T from all other quenched surfaces. The dimension T shall be as defined in Section 3.2.2.

3.2.5.1

Tensile Properties--The average tensile test results shall meet the requirements specified in Table 2.

Tensile Property	Requirement
Ultimate Strength ¹	_____
Yield Strength (0.2% Offset)	120,000-150,000 psi
Elongation (2 inches)	_____
--Longitudinal	16% Min.
--Transverse	16% Min.
Reduction of Area	_____
--Longitudinal	40% Min.
--Transverse	40% Min.

TENSILE PROPERTIES

Table 2

¹Record for information only.

- 3.2.5.2 Impact Properties--The Charpy V-notch impact test results shall meet the requirements specified in Table 3. Unless otherwise specified, only longitudinal test specimens with the root of the notch perpendicular to the test forging surface shall be required. Test temperature shall be (minus) $-20 \pm 5^{\circ}\text{F}$.

Section Thickness T	Impact Strength, Minimum
Less than 1"	35 ft-lb
1" - 2", Incl.	40 ft-lb
2" - 3"	45 ft-lb
Greater than 3"	50 ft-lb

IMPACT PROPERTIES

Table 3

¹Specified impact strengths are the average of three tests. No single test shall be below the minimum average by more than 5 foot-pounds (ft-lb).

- 3.2.5.3 Hardness Tests--A minimum of 3 Rockwell or Brinell hardness tests shall be performed on the flat ends or other flat areas of each heat treated forging and test forging. The average of these hardness values shall be the criterion for acceptance or rejection of forgings as specified in 3.7 and 3.7.1. The test areas shall be properly cleaned and, if necessary, ground to remove oxidized surface material. Hardness tests shall also be performed on one end of each impact test specimen and the results shall be recorded with the respective impact test values. Based upon the required yield strength range of 120-150 ksi, the hardness values should range between Brinell 275-361 or Rockwell C 28.5-38.9.

- 3.2.6 Quality of Forgings--Forgings shall be of uniform quality and condition and free of defects such as tears, flakes, cracks, porosity, nonmetallic inclusions, shrinkage cavities, and laps. Defects shall be identified by visual examination, nondestructive testing (NDT), and, when specified, macroetched sections of forgings.

- 3.2.6.1 Surface Soundness--Each finished part, produced from 4330 V. Mod. bar stock, shall be magnetic particle inspected in accordance with 4.5.1 and 4.5.2. Repair welding is prohibited without specific Purchaser approval. Threaded areas shall be dye penetrant inspected in accordance with 4.5.2.

3.2.6.2 Internal Soundness--The finish machined 4330 V. Mod. forged steel shackles shall, in addition to magnetic particle inspection, be radiographically inspected in accordance with 4.5.3. The hook shall, in addition to magnetic particle inspection, be ultrasonically inspected in accordance with 4.5.3.

3.3 ASTM A 537 Grade A Steel Plate--Prior to initiation of production, Seller shall submit all specified test results and/or mill material certifications and receive Purchaser approval that the material meets the requirements of ASTM A537 Grade A and, where applicable, ASTM A 20 with the additional Purchaser requirements specified in 3.3.1 and 3.3.2.

3.3.1 Purchaser Requirements: ASTM A 537 Specification--

- A. Section 3.1.4: The steel shall be ASTM A. 537 Grade A--normalized.
- B. Section 3.1.5: Heat treatment shall be performed by the manufacturer in accordance with ASTM A 537 Section 5.1.1.
- C. Section 3.1.7: Test specimens which represent the plates shall not be thermally treated subsequent to normalization to simulate post-welding or stress-relieving operations which will be part of the fabrication process.
- D. Section 3.1.8: Supplementary Requirements: The supplementary requirements of ASTM A 20 described as follows in 3.3.2 shall also be performed.

3.3.2 Purchaser Requirements: ASTM A 20 Specification--

- A. Sections 7.2, 7.3.2, 7.3.3, and 8: Repair welding is prohibited without specific Purchaser approval.
- B. Sections 13.1 and 13.2: Certified copies of all mill test and supplementary test reports must be submitted for Purchaser approval.
- C. The following supplementary test requirements of ASTM A 20 shall be performed for approval of the plate material.
 - S4 Additional Tension Test: In accordance with S4.1.
 - S5 Charpy V-Notch Impact Test: Impact tests shall be performed in accordance with S5.1 with the following two requirements. Three Charpy V-notch impact test specimens shall be removed from each thickness of plate material 7/16 to 5/8 inch thick for each heat of steel from which parts are produced.

1. One set of three specimens shall be tested at room temperature ($70 \pm 5^\circ\text{F}$). The specimens shall be removed from the plate transverse to the direction of rolling. The minimum average impact strength for the 3 specimens shall be 35 ft-lb with no single specimen value less than 30 ft-lb.
2. One additional set of three transverse impact specimens shall be tested. The test temperature shall be (minus) $-75 \pm 5^\circ\text{F}$. The minimum average impact strength shall be 15 ft-lb with no single specimen value less than 12 ft-lb.

S6 Drop-Weight Test (for Plates 0.625 inches and Over in Thickness): Drop-weight tests shall be performed in accordance with S6. The maximum acceptable Nil-Ductility Temperature (NDT) shall be (minus) -60°F . A no-break temperature of (minus) -50°F will be accepted as evidence that the NDT is (minus) -60°F or less.

3.3.3 Nondestructive Final Inspection--Each finished part shall be magnetic particle inspected in accordance with 4.5.1 and 4.5.2.

3.4 ASTM A 517 Grade F Steel Plate--Prior to initiation of production, Seller shall submit all specified test results and/or mill material certifications and receive Purchaser approval that the material meet the requirements of ASTM A 517 Grade F and, where applicable, ASTM A 20 with the additional Purchaser requirements specified in 3.4.1 and 3.4.2. In addition only material 1" or less in thickness may be used.

3.4.1 Purchaser Requirements: ASTM A 517 Specification--

- A. Section 8.3: The impact tests shall be performed at a temperature of (minus) $-50 \pm 5^\circ\text{F}$.
- B. Section 8.7: The minimum average impact strength for the 3 specimens shall be 15 ft-lb with no single specimen value less than 12 ft-lb.
- C. Section 10.1: Three Charpy V-notch impact test specimens shall be removed from each thickness of plate material 7/16 inch or thicker for each heat of steel from which parts are produced.

3.4.2 Purchaser Requirements: ASTM A 20 Specification--

- A. Sections 7.2, Repair welding is prohibited without specific 7.3.2, 7.3.3, Purchaser approval. and 8:
- B. Sections 13.1 Certified copies of all mill test and supplementary test reports must be submitted for Purchaser approval. and 13.2:

3.4.3 Nondestructive Final Inspection--Each finished part shall be magnetic particle inspected in accordance with 4.5.1 and 4.5.2.

3.5 ASTM A 352, Class LC 3 Steel Castings--Seller shall submit all specified test results and/or mill material certifications and receive Purchaser approval that the material conforms to ASTM A 352, Class LC 3, minimum impact strength of 15 ft-lb at a test temperature of (minus) -150°F. with the additional Purchaser requirements specified in 3.5.1.

3.5.1 Purchaser Requirements: ASTM A 352 Specification--

- A. Section 7: Hydrostatic tests not required.
- B. Section 10: Weld repaired castings shall be stress relieved. Repaired castings that are stress relieved shall be tested to assure that the tensile and impact properties conform to the LC 3 requirements specified in ASTM A 352 Sections 6.1 and 6.2. The test specimens shall be removed from material which has received the same stress relief treatment as the casting material. Purchaser approval of the post stress relief material sampling method and test results shall be required prior to final acceptance.

3.5.2 Nondestructive Final Inspection--Each casting shall be magnetic particle inspected prior to final acceptance. Inspection shall be in accordance with 4.5.1 and 4.5.2.

3.6 Acceptance Criteria--Each finished product shall meet the requirements of this specification and the purchase order. Seller shall submit all required certifications, documentation, and test results and receive Purchase approval prior to continuation of each phase of production. All information that is specified to be submitted to Purchaser shall be received prior to final acceptance of the finished product.

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Material whose mill certifications fail to meet the requirements of this specification shall be subject to rejection. If an individual part fails to meet visual, dimensional, or non-destructive inspection requirements, the part shall be subject to rejection. If test specimens from test material fail to meet the mechanical property requirements, all parts represented by the test material shall be subject to rejection.

3.6.1 Required Documents--For each type of steel, Seller shall submit to Purchaser and receive approval of the following documentation, as applicable, prior to continuation of each phase of production.

- Material Certifications
- Mechanical Property Test Reports
 - Tensile Test Results
 - Impact Test Results
 - Hardness Test Results
- NDT Inspection Reports

Seller shall submit the following information to Purchaser, as applicable, for review and comment prior to continuation of each phase of production:

- Proposed Heat Treatment Procedure for 4330 V. Mod. Steel
- Proposed Material Sampling Method
- Proposed Number and Location of Mechanical Test Specimens

Seller shall submit the following information, as applicable, for Purchaser information:

- Heat Treatment Certifications
- 4330 V. Mod. Heat Treatment Temperature-Time Records

4 QUALITY ASSURANCE--Acceptance and rejection of parts shall be based upon the criteria specified in 3.7 and 3.7.1.

4.1 Inspection and Test Responsibility--Unless otherwise specified in the contract or purchase order, the Seller is responsible for performance of all testing and inspection required by this specification. Unless otherwise specified, tests may be performed with Purchaser-approved Seller or commercial laboratory facilities. Purchaser reserves the right to perform any inspection where such inspection is deemed necessary to assure conformance to specified requirements.

4.1.1 In-Plant Inspection--Purchaser reserves the right to have an inspector present to monitor selected manufacturing processes, tests, or inspection performed by Seller and Subcontractors. Presence of the inspector shall be at the discretion of Purchaser and will depend upon the production schedule. Seller shall provide, at no additional cost to Purchaser, all measuring and testing instruments necessary to perform a complete inspection. Calibration of these instruments shall be subject to Purchaser approval.

- 4.2 Sampling Methods for Mechanical Property Tests--Mechanical test specimens must be cut from material representative of the heat treated material. Seller shall be responsible for determination of a material sampling method which will produce the required number and orientation of tensile and impact test specimens. The proposed material sampling method shall be submitted to Purchaser prior to heat treatment for review and comment. Two material sampling methods which may be applicable are described in 4.2.1 and 4.2.2.
- 4.2.1 Test Blank Method--A sufficient number of test blanks shall be produced to provide material for mechanical test specimens. One test blank shall be produced to represent each group of parts of the same configuration, produced from the same heat, and heat treated together in the same heat treatment charge. In order to produce the same heat treated tensile and impact properties in the product forgings and test forgings, the dimensions of the test blanks shall be either equivalent to the dimensions of the product forgings (an additional product forging is produced to function as a test forging) or equal in one dimension, usually the thickness, to the cross-sectional thickness (as defined in 3.2.2) of the product forgings with the other dimensions of the test forging large enough to allow production of the specified number and orientation of tensile and impact test specimens.
- 4.2.1.1 Heat Treatment--Except for stress relief operations, one test blank shall be heat treated simultaneously with each part or group of parts that it represents. Each test blank and part, which it represents shall be assigned duplicate heat treatment numbers, as specified in 3.2.4.1, or some other system which will provide positive identification of the test specimens and the parts which they represent.
- 4.2.2 Prolongation Method--The manufacturing process shall be designed to produce on each part a prolongation of excess material for mechanical test specimens. The cross-sectional thickness of the prolongation shall be equal to the thickness T of the product forging with T as defined in 3.2.2. The prolongation shall be large enough to provide material for reheat treatment if necessary.
- 4.2.2.1 Heat Treatment--The prolongation shall not be cut from the part until after completion of all heat treatment.
- 4.3 Mechanical Property Tests--Mechanical property tests shall be conducted in accordance with the specified standards and procedures.

- 4.3.1 Tensile and Impact Tests--Tensile and impact tests shall be performed in accordance with ASTM A 370. Tensile specimens shall, as applicable, conform to Figure 4 of ASTM A 370 for plate materials and to specimen 3, Figure 6, of ASTM A 370 for cast and wrought materials. Impact specimens shall conform to Charpy V-Notch Type A, Figure 11, ASTM A 370.
- 4.3.1.1 Number and Location of Tensile and Impact Test Specimens--The required number and location of tensile and impact test specimens shall be specified either by this specification or the ASTM steel reference specification. For the SC-7 cast material, Seller shall determine the number and location of tensile and impact specimens, which shall be subject to Purchaser approval. Reduced size impact test specimens are not acceptable.
- 4.3.2 Hardness Tests--Hardness tests shall be performed in accordance with either ASTM E-10 or E-18.
- 4.4 Reheat Treatment and/or Retest--In the event that mechanical property tests fail to meet the specified requirements, reheat treatment and/or retests may be performed with Purchaser approval. For reheat treatment, material representative of the heat treated condition of the part must be available for reheat treatment and subsequent material sampling.
- 4.5 Nondestructive Inspection--Nondestructive inspection shall be required on all finished parts as specified in either this specification or the applicable ASTM reference specification prior to final acceptance.
- 4.5.1 NDT Inspection Requirements--Unless otherwise specified, Seller shall submit certified magnetic particle, liquid penetrant, ultrasonic, or radiographic inspection reports to document inspection of each finished product. The inspection report shall conform to the specification requirements when NDT inspection is specified by the ASTM steel reference specifications. Otherwise, the inspection report shall state the inspection results and document the inspection method, techniques, and test equipment. The report shall also contain documentary proof that the test operator was qualified to perform the nondestructive inspection and be signed by the operator and approved or notarized. In the event that discontinuities are located by inspection, the inspection report shall also contain the following information:
- A sketch of the finish machined part and its serial number, part number, or other identification designation.
 - Number and location of all acceptable and unacceptable internal and surface discontinuities.
- 4.5.2 Magnetic Particle and Liquid Penetrant Inspection--Inspection shall be with either the dry powder or, preferably, wet magnetic particle inspection method in accordance with ASTM E 109 or ASTM E 138. When magnetic particle testing may

damage a machined surface, liquid penetrant testing per ASTM E 165 shall, with Purchaser approval, be substituted. The choice of magnetic particle inspection methods, means to induce the magnetizing currents, and selection of visible or fluorescent magnetic particles shall be subject to Purchaser approval.

- 4.5.2.1 Acceptance Standards--All indications of linear discontinuities 1/8 inch or longer shall be investigated. The depth of the cracks shall be determined by grinding. Cracks deeper than 0.030 inch or longer than 0.500 inch shall be cause for rejection of the part. Parts ground out of dimensional tolerance shall be subject to rejection. Ground areas shall have a minimum radius of 0.250 inch and be blended into the surrounding surfaces. Discontinuities may be removed by chipping, grinding, or other mechanical means. The application of heat to remove discontinuities is prohibited on quenched and tempered steels.
- 4.5.3 Ultrasonic and Radiographic Inspection--Ultrasonic inspection shall be in accordance with EG&G Spec. DIA-030. Radiographic inspection in accordance with EG&G Spec. DIA-024, Rev. "A".

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