Single Crystal Terfenol-D Development
Final Report

28 July 1994

Submitted To:
Office of Naval Research
Ballston Tower One
800 North Quincy Street
Arlington VA 22217-5660

Technical Points of Contact:
CDR John Dever

Submitted By:
EDO Corporation, Undersea Warfare Division
2645 South 300 West, Salt Lake City, Utah 84115
EDO Points of Contact:
Contractual: Gary Oksutcik (801) 486-7481 x466
Programmatic: James F. Smith (801) 461-9435
Technical: P. David Baird (801) 486-7481 x311
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Acknowledgement

EDO Undersea Warfare Division wishes to recognize the technical contributions of Art Clark and Joseph Tetter both of the Naval Surface Weapons Center, Silver Spring, Md. These individuals provided comments and testing which were instrumental in the execution of this program. There advice and experience was given freely in an environment of genuine cooperation between Government and Industry.
Table of Contents

1.0 Introduction ................................................................................................................. 1
2.0 Program Objective ........................................................................................................ 1
3.0 Fe Tb_xDy_(1-x) Compounding ................................................................................. 1
4.0 Fe Tb_xDy_(1-x) Casting ......................................................................................... 3
5.0 Float Zone Growth Method (FZGM) ......................................................................... 3
6.0 Traveling Heater Method (THM) .............................................................................. 5
7.0 THM Crystal Growth and Results ............................................................................. 7

List of Tables and Figures

Figure 2-1 Magnetostrictive Strain-Field Curve ......................................................... 2
Figure 5-1 Tb_xDy_(1-x)Fe Phase Diagram ................................................................. 4
Figure 6-1 Traveling Heater Method Illustration ......................................................... 6
Figure 7-1 THM Terfenol-D Crystal ............................................................................. 8
Figure 7-2 THM Terfenol-D Crystal Chemical Analysis, Sample A ......................... 9
Figure 7-3 THM Terfenol-D Crystal Chemical Analysis, Sample B ......................... 10

Appendix - Engineering Design, Analysis and Drawings

A.1 Vacuum System .......................................................................................................... A1
A.2 Traveling Heater Method Apparatus ........................................................................ A1
A.3 Dash and Czochralski Methods ............................................................................... A1
A.3.1 Dash Method Apparatus .................................................................................... A2
A.3.2 Czochralski Method Apparatus ........................................................................ A2
A.4 Compounding and Casting Apparatus ................................................................... A3
A.5 Strain-Field Testing Apparatus ............................................................................... A3
1.0 Introduction

This report will provide a review of both existing and newly attempted methods for processing Terfenol-D. This review will describe each process and highlight both benefits and drawbacks of each method. The commonly used method of manufacturing Terfenol-D today is referred to as the Float Zone Growth Method. EDO proposed to develop the following two alternate manufacturing methods the Traveling Heater Method and the Dash Method. The Traveling Heater Method appeared to provide the greatest probability of success and was therefore the focal point at the onset of the process development. Due to the short duration of the contract, approximately 3-4 months, little effort was initiated on the DASH Method.

2.0 Program Objective

The objective of this program has been to develop low cost processes that would produce single, non dendritic, and non-rotationally twinned crystals of the rare earth magnetostrictive material Terfenol-D (RFe₂).

The performance benefit of the development of the stated material would be a higher magnetostrictive strain-field constant, as illustrated in Figure 2-1, which in turn would result in lower DC bias fields and more compact bias coils/bias magnets. The saturation strain is expected to be similar to existing Terfenol-D materials.

A second benefit would be derived in cost. High raw material costs, labor intensive manufacturing techniques and low manufacturing yields results in very high end product costs. The use of low purity materials (ie lower cost) combined with automated processes would result in a substantial reduction of costs on the order of 5 to 1.

3.0 Fe Tbₓ Dy(1-x) Compounding

The raw materials (Fe platlets, Dy and Tb chunks) are compounded using an arc melter in a non-reactive argon environment. The uncompounded materials are set on a water cooled copper hearth. This prevents the materials from melting onto and reacting with the copper surface. The high current, low voltage arc melter provides the heat to melt and compound the materials. The slab of material is flipped over and repeatedly melted. Typically the Tb and Dy are compounded first.

The stoichiometry of this mixture can be affected during this compounding process. Loss of material can occur through material ejection (slab cracking) or through vaporization. In Float Zone Growth all of the materials remain with the final rod (ie. no transport of excess material or contaminants to an end). A change in stoichiometry can dramatically effect the performance of the final product.

An improved method of compounding larger volumes of material is detailed in Appendix A.4. but was not implemented during the program.
Figure 2-1, Magnetostrictive Strain-Field Curve
4.0 Fe Tb x Dy(1-x) Casting

The compounded material is placed in a quartz crucible and melted using an RF induction heater in an non-reactive argon atmosphere. The molten material is then either poured into or drawn up into a quartz tube.

The pouring technique utilizes a quartz crucible with a hole in its base. A thermocouple rod seals the hole in the base of the crucible until the desired pouring time. Many rods can be cast in a short period of time using this technique.

The second technique applies a partial vacuum to the end of the quartz tube. Pressurized argon on the surface of the molten compounded material forces it up into the tube.

The major problem with either technique is cracking of the quartz tube during casting. The tube must be preheated prior to filling. A resistance heater placed around a tube(s) will raise the temperature to approximately 800°C.

5.0 Float Zone Growth Method (FZGM)

This process requires the use of an off-stoichiometric compounded material, as illustrated in Figure 5-1. RFe₂ is the desired magnetostrictive end product. This process generates plate-like dendritic, edged defined, rotationally twinned crystals. Between the rotational twins is a backbone of rare earth rich material. The typical float zone growth process steps are as follows:

An RF induction heater, surrounding the rare earth-iron rod, creates a molten zone in the sample rod (compounded and cast material). As the heater or rod is translated along the molten zone moves with it. The rate of translation is dependent upon the induction heating effectiveness. Input power fluctuations (5% common) dramatically effect the temperature and therefore the rate of travel. If the molten zone is not wide enough, it results in a freeze out in the center of the rod. This results in a core of unoriented material and a useless rod. Unfortunately there is no means of automated temperature control of the rare earth rod. Visual control of temperature is difficult because the quartz tube fogs.

EAD has implemented power stabilization circuit for the RF induction heater. This has resulted in a reduction of process labor. This process still requires constant monitoring and subtle adjustments in position and temperature in order to yield high quality materials. Typical process rates are approximately 18 inches per hour.

Prior to contract award, EAD attempted to grow true single crystals by slowing down the baseline float zone process. The result was a rod that tried to grow single but in the wrong direction. The magnetostrictive strain field performance of these rods were much lower.
Figure 5-1, $\text{Tb}_x\text{Dy}_{(1-x)}\text{Fe}$ Phase Diagram
6.0 Traveling Heater Method (THM)

The traveling heater method is a zone refining process. This method has been used successfully to grow high quality Cadmium Telluride and Gallium Arsenide crystals. The process as it pertains to Terfenol is illustrated in Figure 6-1. There are three rare earth compounds associated with crystal growth process: (1) Terfenol-D seed, (2) eutectic solvent, and (3) a Terfenol-D feed rod. The furnace or the process sample may be translated in this process. The Terfenol-D seed provides crystal growth surface. This seed would eventually be refined during processing into a "single crystal seed". The eutectic solvent provides a means of lower temperature transport of raw materials to the seed as well as filters out impurities. The feed rod is provides the raw material for crystal growth.

Rare earth compounds have a great affinity for oxygen. Raw materials, compounding, casting and final processing steps all introduce oxides (or other impurities) into the material. These oxides would contaminate the material and one would expect an impact upon magnetostrictive performance. It is therefore desirable to purge the material of oxides. THM does just that. The problem of rare earth oxides contamination is eliminated in THM by virtue of the oxides lower density relative to the eutectic solvent. The traveling furnace moves upwardly carrying the solvent and oxides along with it. The eutectic solvent of choice is Tb$_{20.2}$Dy$_{48.3}$Fe$_{31.4}$ wt %.

The introduction of new oxides during the final THM processing is expected to be greatly reduced. Rare earth reaction with the quartz crucible are very low due to the lower zone refining temperature of approximately 900°C (ref. Figure 5-1). The reaction rate decreases by a factor of 10 for each 50°C drop in temperature. The THM reaction rate would be $10^{-5}$ of the FZGM.

This process requires very precise control over temperature and translation of the eutectic solvent. The lower process temperatures permit the use of a resistance heater furnace which can easily be automatically controlled to ±0.2°C. The furnace can be translated automatically as well resulting in elimination of costly labor.

The negative side of this process is its relatively slow speed. The melting of the feed rod and diffusion of the materials through the eutectic solvent are slow. EDO estimates a process speed of .1 to 2 mm per hour. When balancing the requirement for slower process speed against the cost benefits of (1) greatly reduced labor demands, (2) reduced energy consumption, and (3) reduced material costs, the speed becomes less of an issue.

The engineering design and sketches of the hardware associated with the THM process and alternate processes (Dash and Czochralski) undertaken in this contract are provided in the Appendix. Materials and equipment were purchased under contract to support primarily the THM process development.
Figure 6-1 Traveling Heater Method Illustration
7.0 THM Crystal Growth Experiment and Results

In advance of the procurement of the engineered crystal growing equipment, EDO attempted to grow single crystal Terfenol-D utilizing existing laboratory equipment. The composition of the feed and seed rods should be stoichiometrically balanced RFe₂. Crystal growth with off stoichiometric compositions would eventually change the eutectic melting temperature. Since the planned process length was short (~4-5 mm), float zone refined Terfenol-D material was substituted. The feed and seed rod compositions were Tb₁₆.₉Dy₄₃.₃Fe₃₉.₈ wt % while the eutectic was Tb₂₀.₂Dy₄₈.₃Fe₃₁.₄ wt %. The resistance heater was not available at the time of experiment and so an existing induction heater was utilized. Constant attention was required in order to attempt to maintain a uniform zone temperature. A slow and smooth motorized translation system was not available and therefore required the operator to periodically make large (3 mm) translational steps of the sample. The process test required approximately 12 hours to complete. The rate of movement was 0.5 mm per hour resulting in an net translation of 6 mm. When the zone refined region was removed from the feed rod and fractured, there appeared to be 3 large crystals and 5 small crystals. A photograph of the fractured THM sample is illustrated Figure 7-1. Analysis of the sample using X-ray florescence energy dispersion technique at two locations are provided in Figures 7-2 and 7-3. The measurements indicated that the composition was 39.48% Fe, 19.63% Tb, 40.89% Dy and 37.40% Fe, 17.27% Tb, 45.32% Dy for the respective samples. The Dy₅Tb₇(1-x) component of RFe₂ is expected to be 57% but is actually approximately 60-63% or rare earth rich.

Joseph Tetter of NSWC/Silver Spring requested use of crystal sample for further evaluation. The samples were to be prepared at NSWC prior to testing in England. The sample would be evaluated using two techniques: (1) differential interference contrast and (2) Berg-Barrett. The differential interference technique uses coherent visible light over a range of wavelengths. When activated with a magnetic field a rotationally twinned surface looks different than single crystal surface. The Berg-Barrett technique utilizes the scattering of low energy X-rays incident at a 90° angle re the normal to the crystal surface. Again, when activated with a magnetic field, a rotationally twinned surface scatters the X-rays differently than single crystal surfaces.

Joseph Tetter did identify 8 single crystals within the sample provided. The magnetic measurements using the stated techniques resulted in some odd results (no detailed results were disclosed to EDO). Tetter performed his own chemical analysis yield the following compound Tb₀.₉Dy₃₁.₆Fe₅₇.₅ wt % or what Tetter believed to be RFe₃. NSWC has retained the sample.

The rate of diffusion of Tb and Dy through the eutectic solvent would be different. Dy would diffuse more rapidly. If the zone was translated to quickly or erratically than it is conceivable that an imbalance in Tb and Dy diffusion could occur, resulting in primarily a DyFe product.

The discrepancies between the EDO and NSWC measurements of composition have remained unresolved.
Figure 7-1, THM Terfenol - D Crystal Sample
Figure 7-2 THM Terfenol-D Crystal Chemical Analysis, Sample Point A
Appendix

Engineering Design, Analysis and Drawings
A.1 Vacuum System

Because oxides are a difficult to control contaminant in the Terfenol crystal growing systems, many operations must be carried out under vacuum. Figure A-1 shows the layout of the planned vacuum system for the Terfenol laboratory. This system was designed to make use of a single rough pump and cryopump for all the laboratory’s needs. Tubing runs have been kept as short as possible, and there are numerous valves that are used to seal off portions of the system when they are unused, minimizing the volume to be evacuated. Figures A-2A and A-2B are a parts list with cost estimates for this vacuum system.

A.2 Traveling Heater Method

Figure A-3 is conceptual layout drawing for the traveling heater method apparatus. Once a Terfenol rod is cast inside a small diameter quartz tube, it is suspended from a pulley by a cable. The casting is slowly lowered down through the central diameter of a silicon carbide heating element. A small segment of the heating element, approximately 1 inch long, is surrounded by an aluminum silicate insulating ring. This causes a local area of higher temperature inside the heating element that becomes the melt zone of the cast Terfenol rod. Crystalline Terfenol forms in the base of the melt zone. The melt zone travels up the rod, until a large segment of the rod has formed the hopefully single crystal Terfenol.

The rod must be lowered through the melt zone slowly enough that the crystals have time to form. Experience with other growth apparati of this type suggests that the proper rate will be in the vicinity of 4 mils/hr to 40 mils/hr. Such slow, controlled motion requires a drive motor with a very large reduction gearing. Consistent crystal growth also requires very smooth motion. The allowable variation in velocity is unknown, but ±1% was used as a design goal.

A platinum-rhodium thermocouple is required to withstand the high temperatures in the heating zone (approximately 1350°C). It is positioned inside the heating element and used as a feedback sensor to the temperature controller, controller, an SCR.

Figure A-4 is an apparatus parts list for the Traveling Heater Method, with estimated costs and targeted acquisition dates.

A.3 DASH and Czochralski Methods

Because the DASH method of crystal growth is a variation of the well known Czochralski method, there can be much commonality to the apparati required for both methods. This was considered in our apparatus design. Both methods were to be carried out inside the same water cooled pressure/vacuum chamber. The heating elements and some associated apparati would be different for each, as described below.
A.3.1 DASH Method Apparatus

Figure A-5 is a conceptual layout drawing for the DASH Method. In this method the single crystal is pulled slowly upward out of the melted surface of a cast boule of raw Terfenol materials.

The boule's surface is heated by an induction heater with a concentrator coil. The purpose of the concentrator coil is to confine the induction heating to a small area at the center of the boule. Figure A-6A is a concept sketch of the concentrator coil, showing the coil in relation to the melted surface of the boule. Figures A-6B and A-6C show two experimental coil designs. The concentrator coil is cooled by water flowing through the conductor coils that would be brazed to its surface. Figures A-7A and A-7B are design calculations that were used to estimate the required water flow rates to adequately cool the concentrator coil. Figure A-8 is a feed-through design for transmitting power and cooling water to the concentrator coil.

Additional details can be noticed in the overall concept drawing, Figure A-5.

A platinum-rhodium thermocouple is positioned as closely as possible to the melted surface for temperature measurements (approximately 1350ºC).

Motor #1 drive the moving crosshead that slowly pulls the crystal upward out of the melt at a rate of .02 to .5 inches per hour. Motors #2 and #3 rotate the boule and sample in opposite directions at rates of somewhere between 25 and 40 RPM. The hand crank and roller screw are used to raise the boule to compensate for its loss of volume as material is pulled from the surface to form the crystal. The hand crank was low cost alternative to another motor drive system. It was planned to have the hand crank replaced by another motor drive after proof-of-concept experiments had been performed.

A.3.2 Czochralski Method Apparatus

The Czochralski method has some similarity to the DASH method, but instead of melting the surface of a boule by induction heating, a crucible of amorphous Terfenol is melted by a resistance heating furnace. Because of the similarities, the same water-cooled vacuum/pressure vessel would be used for both methods. Both methods take place inside a pressure vessel that has first been evacuated to about 10-7 Torr, then backfilled to a positive 20 psi with argon gas. These precautions are to prevent contamination of the raw material or crystal with oxides. Figures A-9A and A-9B are preliminary working drawings for the chamber details. The pressure vessel would be cooled by water flowing through channels in the walls, base, and cap. It was planned to use shrink-fit construction to form these water channels in the walls of the vessel. Figures A-10A through A-10C are design calculations for this type of construction. Figures A-11A through A-11D are computerized calculation results that were used in making design trade-offs.
Figures A-9A and A-9B show the Czochralski method, with a crucible inside the heating furnace. The furnace is surrounded by a heat shield made of three layers of 30 mil thick tantalum sheets. Figure A-12 is a pedestal to position the crucible.

In the initial concept for the Czochralski method, a ring a five silicon carbide heating elements surrounding the crucible was considered. Figures A-13A and A-13B were created during this effort. This approach was later abandoned in favor of the molybdenum wire required 1400°C and provided significant cost savings over the silicon carbide elements or molybdenum-disilicide wire elements.

Figures A-14A and A-14B are a combined parts list for the DASH and Czochralski methods with estimated costs and target acquisition dates.

A.4 Compounding and Casting Apparatus

Regardless of the method of crystal growth, it was considered important to control oxide contamination in the raw material as it was mixed and cast. A Vacuum chamber for mixing raw materials was planned. Figures A-15A and A-15B show a pressure cap for this chamber. During mixing, it was planned to thorough mix the molten Terfenol constituents by using an yttria stirring paddle. The handle of this paddle would protrude through the central hole of the pressure cap. Figure A-16 is a drawing of the stirring paddle, and Figures A-17A and A-17B depict modifications of a standard pressure fitting to allow passage of the paddle’s handle.

Figure A-18 is a fixture used to hold 6 quartz tubes inside the vacuum chamber (a larger diameter quartz tube) so that all six could be cast full of raw Terfenol during one casting session.

A.5 Strain-Field Testing Apparatus

Figures A-19 through A-26 are drawings and design calculations used in developing a test apparatus for low frequency testing of Terfenol rods.

Figure A-19 is an estimate of the lower limit of strain resolution achievable using strain gage techniques. The strain gage method was not used, however, due to concerns over how the strong magnetic fields surrounding the Terfenol rod would affect the strain gage signals.

Another test method that was tried, but later abandoned, was to use a long lever arm to amplify the strain of the rod under test. Efforts were made to produce the lightest, stiffest lever arm possible so the resonant frequency of the apparatus would be significantly higher than the frequencies used in testing. Figure A-20 is a calculation of the area moment of inertia of an lever arm having the cross section of an I-beam. Figure 21 is a calculation of the resonant frequency of the same beam, and the amount of static deflection to under its own weight. Figures A-22A and A-22B are computer aided
calculations used in making design trade-off studies, and a graphical representation of resonant frequency vs. length for a candidate design. Figure A-23 is a sketch of the I-beam, made of epoxy/graphite composite, that was built for use in the apparatus.

The strain capability of a Terfenol rod varies with the amount of longitudinal stress it is under. The test fixture had provisions for supplying a controlled prestress to the rod from a pneumatically driven piston. The load was applied to the rod ends through hemispherical load-button-and-socket joints that would transmit longitudinal force without transmitting bending moments to the rod. This concept is illustrated in Figure A-24. Stress calculations for this joint are shown in Figure A-25, and the load button and socket are shown as drawings 6784RD1 and 6784RD2.

Drawings 6784RD3 through 6784RD19 are the main portions of the test apparatus frame and miscellaneous fittings used in conjunction with it. Figure A-26 is an apparatus parts list.
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MDC = MDC High Vacuum Components, Hayward, Ca., (415)-887-6100  
SLV = Salt Lake Valve, SLC, Ut., 266-3560  
JMC = JMC instruments, SLC, Ut., 972-8920
TRAVELLING HEATER METHOD
Apparatus Concept

Figure A-3
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TOTAL=22,295.00
DASH METHOD
Apparatus Concept

FILE: DASH_CPT.FCD
R. Daley 12/3/92

Figure A-5
We have tested T-20-3-KC-TL and Model SCR-120.
PANCAKE COIL

MATERIAL: COPPER: C11000

FILE: PCOIL.FCD
CONE COIL
MATERIAL: COPPER: C10200, C10400, C10500, OR C10700

FILE: CCOIL.FCD
Fully Developed, Turbulent Internal Fluid: Constant Surface Temperature.

\[ \Delta T = T_s - T_m \]

\[ \Delta T_{em} = \frac{\Delta T_o - \Delta T_m}{\ln \left( \frac{\Delta T_o}{\Delta T_m} \right)} \]

Assume constant surface temp. \( T_m \) and max allowed \( T_o \) known \( \Rightarrow \Delta T_{em} \) known

All fluid properties evaluated at \( \frac{T_m}{2} \)

\[ \dot{m} = \dot{m} C_p (T_m - T_m) = \frac{A}{2} (D L) \Delta T_{em} \]

\[ f = \frac{N_u D}{K} \]

\[ \Rightarrow \dot{m} C_p (T_m - T_m) = \frac{N_u D}{K} \pi L \Delta T_{em} \]

\[ N_{ud} = 0.027 \sqrt{\frac{\gamma}{\gamma}} \left( \frac{M}{M_o} \right)^{1.4} \]

\[ \Rightarrow \dot{m} C_p (T_m - T_m) = 0.027 \pi \gamma \sqrt{\frac{M}{M_o}}^{1.4} K \pi L \Delta T_{em} \]

\[ \pi \gamma = \frac{D u_m}{\sqrt{2}} \]

\[ \dot{m} = \frac{m}{A} = \frac{m y}{D^2 D} \]

\[ \Rightarrow \pi = \frac{D \dot{m} y}{A^{1/2} D^{2/2}} = \frac{4 \dot{m} y}{\pi D m} \]

\[ \Rightarrow \dot{m} C_p (T_m - T_m) = (0.027 Y \sqrt{\pi}) \left( \frac{M_y}{M_o} \right)^{1.4} (K \pi L \Delta T_{em}) \left( \frac{4 \dot{m} y}{\pi D m} \right)^{1/4} \]

\[ \Rightarrow \dot{m}^2 = (0.027 Y \sqrt{\pi}) \left( \frac{M_y}{M_o} \right)^{1.4} (K \pi L \Delta T_{em}) \left( \frac{1}{D m} \right)^{1/4} \]

\[ \Rightarrow \dot{m} = (1.159)(10^{-5}) \left[ \frac{(\frac{M_y}{M_o})^{7/3} K^5 (\Delta T_{em})^5}{C_p (T_m - T_m)^5 D m Y} \right]^{1/5} \]

\[ \text{FIGURE 8.7} \]
**Assume**

\[ T_m = \text{room} = 29.5^\circ C \]
\[ T_m_0 = 90^\circ C = 363 \]

**Note**: 2D axial generator

\[ \dot{m} = \frac{Q}{C_p \Delta T} = \frac{2000 \times 2}{(4187 \times 68)} = \frac{10703}{25} \]

\[ T_m = 32^\circ C = 355 \]
\[ C_p = 4187 \]
\[ \mu = 0.089 \times 10^{-6} \]
\[ k = 0.65 \]
\[ Pr = 3.15 \]

\[ D = 7.25 - 0.030 = 4.826 \times 10^{-3} \]

\[ \frac{2.5}{39.37} = 0.063 \]

**Simpler Form:**

\[ N_p = 0.23 \times 10^{-6} \]

\[ \Rightarrow \dot{m} C_p (T_m - T_m) = 0.23 \times 10^{-6} \times L \times \Delta T_m \times Pr \times \left( \frac{4 \dot{m}}{D \mu} \right)^{0.4} \]

\[ = 0.8766 \times 10^{-6} \times L \times \Delta T_m \times Pr \times \left( \frac{4 \dot{m}}{D \mu} \right)^{0.4} \]

\[ = \frac{5.176 \times 10^{-6}}{D \mu} \left( \frac{L}{Pr} \right)^{0.4} \frac{1}{(C_p (T_m - T_m))^{0.4}} \]

\[ \dot{m} = \frac{5.176 \times 10^{-6}}{D \mu} \left( \frac{L}{Pr} \right)^{0.4} \frac{1}{(C_p (T_m - T_m))^{0.4}} \]

\[ \dot{m} = 5.176 \times 10^{-6} \times L^5 \times \left( \frac{C_p (T_m - T_m)}{D \mu} \right)^{0.4} \]

\[ 0.703 = 1.0306 \times 10^{-10} \times L^5 \times \Delta T_m^5 \]

\[ 6.821 \times 10^8 = L^5 \times \Delta T_m^5 \]

**Assume**

\[ L = \frac{39.37}{5} \Rightarrow \Delta T_m = 24.4 \]

**Assume**

\[ T_s = 94^\circ C \Rightarrow \Delta T_s = 94 - 92 = 2 \]
\[ \Delta T_0 = 94 - 90 = 4 \]

**Close.**

\[ \Delta T_m = 23.5 \]
Shrink Fit of Aluminum Tubing

\[ \Delta T = \frac{D_e - D_i}{x \cdot D_i} \]

Temp. required to assemble the outer component.

\[ \Delta T = \frac{
\begin{array}{c}
\Delta x
\end{array}
}{x \cdot D_i} \]

\[ \frac{P_i}{\Delta T} \cdot \frac{T_0}{273} \cdot \frac{1}{\alpha \cdot V_0} \]

\[ P \text{ causes } \Delta x \text{ in inner cylinder} \]
\[ P \text{ causes } \Delta x \text{ on outer cylinder} \]
\[ R_i + \Delta x = R_i + \Delta x \]
\[ (R_i - R_0) = \text{Initial interference} \]
\[ \text{that must be overcome by heating outer cylinder} \]
\[ \text{and } (R_i - R_0) = \Delta x - \Delta x \]

This is the "Shrinkage Allowance" \( \Delta \)

Start by determining the temperature difference allowable.

The temperature achievable \( \Delta T \) determines stresses.

Effect of internal pressure:

\[ P \text{ causes some expansion of } R_0 \]
\[ \text{and } \Delta x \text{. There two expansions must be equal.} \]

\[ \Delta T = \frac{D_e - D_i}{x \cdot D_i} = \frac{\Delta}{x \cdot V_0} \]

\[ \Delta = (\Delta T) \cdot x \cdot V_0 \]

Figure A-10A
\[ \Delta = \Delta y_0 \Delta T \]

\[ \Rightarrow P = \frac{\Delta (E) (R_0^2 - r_0^2) (r_0^2 - r_1^2)}{2 \cdot r_0^3 (R_0^2 - r_1^2)} \]

\[ R_1 = r_0 + \Delta \]

Shrink Fit Stresses:

\[ \sigma_{hi} = -\frac{P}{r_0} \frac{r_0^2}{(R_1^2 - r_1^2)} \]

both at inner radius

\[ \sigma_{ho} = \frac{P}{r_0} \frac{r_0^2}{(R_0^2 - r_0^2)} \left[ 1 + \frac{R_0^2}{r_0^2} \right] \]

With Internal Pressure, \( P \)

**Inner Cylinder**

\[ \sigma_i^* = \sigma_{hi} + \frac{P r_i^2}{(R_i^2 - r_i^2)} \left[ 1 + \left( \frac{R_0}{r_i} \right)^2 \right] \]

**Outer Cylinder**

\[ \sigma_o^* = \sigma_{ho} + \frac{P r_i^2}{(R_0^2 - r_0^2)} \left[ 1 + \left( \frac{R_0}{r_0} \right)^2 \right] \]
Shrink Fit: Practical Tolerances

Assume \( R_i = \bar{x} \pm 0.02 \)
\( R_o = \bar{y} \pm 0.02 \)

To insure at least 0.01 in. of interference:
\[ R_i - R_o = 0.01 = (\bar{x} - 0.02) - (\bar{y} + 0.02) \]
\[ = (\bar{x} - \bar{y}) - 0.04 \Rightarrow \bar{x} - \bar{y} = 0.05 \]

\( \Rightarrow \) Design for 5 mil nominal interference.

Then maximum interference would be
\[ \Delta_{\text{max}} = R_i - R_o = (\bar{x} + 0.02) - (\bar{y} - 0.02) \]
\[ = (\bar{x} - \bar{y}) + 0.04 \]
\[ = 0.05 + 0.04 = 0.09 \]

Analysis shows stresses in this case are acceptable \((< 96 ksi)\) and \(dT\) required would be 128°F \(\Rightarrow\) OK.

Note that if at least 0 mil of interference are acceptable

\( \Rightarrow \) Design for 4 mil interference
\[ \Delta_{\text{max}} = 0.008 \]

\( (dT)_{\text{req.}} = 114.5 \text{°F} \)
Max stress = 77.8 ksi \( (x+ 20 psi) \)
VARIABLE SHEET

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RULE SHEET

\[
\begin{align*}
\text{DELTA} &= \alpha^* r^* d^T \\
\text{Ri} &= \text{DELTA}^* E^* (R^* - r^*)^2 / (2* r^* 3^* (R^* - r^*)) \\
\text{SFhi} &= -P^* 2^* R^* 2^*/(R^* - r^* 2^*) \\
\text{SFho} &= P^* r^* 2^* (1^* (R^* / r)^* 2^*) / (R^* 2^* - r^* 2^*) \\
\text{SPhi} &= \text{SFhi} + P^* r^* 2^* (1^* (R^* / r)^* 2^*) / (R^* 2^* - r^* 2^*) \\
\text{SPho} &= \text{SFho} + P^* r^* 2^* (1^* (R^* / r)^* 2^*) / (R^* 2^* - r^* 2^*)
\end{align*}
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Figure A-11C
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| TOTAL = $61,210.00

* CZ METHOD ONLY

Figure A-14B
Hand Tight Engagement Depth, .550 from Surface - A -

\( \phi 0.35 \times 0.003 \)

\( \phi 0.534 \times 0.003 \)

\( \phi 0.280 \text{ THRU} \)

\( 45 \)°

\( \phi 0.20 \times 0.005 \)
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<th>CHECKED</th>
<th>STRESS</th>
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MODIFY BODY OF CAJON FITTING, PN SS-4-UT-1-4
ADD O-RING GROOVE AND BORE OUT CENTRAL HOLE
(O-RING 2-013)
MATERIAL: 6061-T6 ALUMINUM
FINISH: ALL SURFACES ARE 125
REMOVE SHARP EDGES; DEGREASE

FIGURE A-18
\[
V_{\text{out}} = \left[ \frac{R + \Delta R}{R + \Delta R + R} - \frac{R}{2R} \right] V_{\text{in}}
= \left[ \frac{R + \Delta R}{2R + \Delta R} - \frac{1}{2} \right] V_{\text{in}}
= \frac{2R + 2\Delta R - 2R - \Delta R}{2(2R + \Delta R)} = \frac{\Delta R}{2(2R + \Delta R)}
\Delta R \ll R \Rightarrow V_{\text{out}} \approx \frac{\Delta R}{4R} V_{\text{in}}.
\]

\[
\frac{\Delta R}{R} = (GE)^{1/2}
\Rightarrow V_{\text{out}} = \left( \frac{(GE)^{1/2} N}{4} \right) V_{\text{in}}
N = \# \text{ active gages.}
\]

**Johnson (Thermal) Noise:**

\[
V_{\text{rms}} = \left[ \frac{4kT R(\Delta f)}{3} \right]^{1/2}
\]

**Signal to Noise:**

\[
\frac{V'}{V} = \frac{\left[ \frac{4kT R(\Delta f)}{3} \right]^{1/2}}{\left[ (GE)^{1/2} N \right]^{1/2}}
T = 300 \quad R = 750 \quad N = 2 \quad G = 2 \quad \varepsilon = \frac{1}{2}
\]

\[\delta N = 1 \Rightarrow \varepsilon = 0.76 \left( 10^{-6} \right) \]
\[\Rightarrow \approx 1 \mu \varepsilon \text{ measurable.}\]
\[ I = \frac{1}{12} W \left( h - \frac{t}{2} \right)^3 + \frac{W t^3}{6} + 2 W t \left( h - \frac{t}{2} \right) \]

For \( t = \frac{h}{2} \):

\[ I = \frac{1}{12} W \left( h - \frac{h}{4} \right)^3 + \frac{W h^3}{6} + 2 W t \left( h - \frac{h}{4} \right) \]

\[ \frac{h}{w} = R \quad \Rightarrow \quad I = \frac{1}{12} W \left( Rh - \frac{h}{2} \right)^3 + \frac{W h^3}{6} + 2 W t \left( h - \frac{h}{2} \right) \]

\[ t = \frac{h}{2} \implies h = 2.5 \]

\[ W = 37.25 \]

\[ h = 5 \]

\[ \Rightarrow I = 1.8 \times 27(10^3) \]

\[ \Rightarrow f = \]
Natural Frequency of Fixed/Free Rectangular Beam

Harvio, Eq. 7-15

\[ f_2 = \frac{1}{2\pi} \left( \frac{1.875}{L^2} \right)^{\frac{3}{2}} \frac{E I}{A} \]

Rectangular: \[ \frac{I}{A} = \frac{bh^3}{12} \cdot \frac{h}{A} = \frac{b h^2}{12} \]

\[ \Rightarrow f_2 = \frac{1}{2\pi} \left( \frac{1.875}{L^2} \right)^{\frac{3}{2}} \sqrt{\frac{E I}{A}} \]

\[ g = 386 \text{ in/sec} \Rightarrow f_2 = 3.173 \frac{g}{L^2} \left( \frac{E h^2}{I} \right)^{\frac{3}{2}} \]

Example: Aluminum, \[ A = 3/2 \quad \rho = 0.098 \quad E = 10(10^6) \quad L = 18'' \]

\[ f_2 = 31 \text{ Hz.} \]

If \( h = 1.5 \), \[ f_2 = 49.5 \text{ Hz.} \]

\[ f_2 = 3.2 \times 10^9 \frac{h}{L^2} \quad L = 1000 \Rightarrow A = 10'' \]

Static Deflection: Own weight.

\[ x = \frac{W L^4}{8 E I} \quad W = \rho b h L = \rho b h \]

\[ x = \frac{\rho b h L^4}{8 E A h^2} = 12 \frac{\rho L^4}{8 E A h^2} \]

\[ x = 1.5 \frac{\rho L^4}{E I h^2} \]

\[ \begin{array}{c|c}
6AL 4V & 103 \\
6061 T6 & 102 \\
31655 & 96.5 \\
40542 & 139 \\
\end{array} \]

Figure A-21
St Input | Name | Output | Unit | Comment
---|---|---|---|---
| | | | | FUNDAMENTAL FREQUENCY OF FIXED-FREE Beam: HARRIS PG. 7-15 ALL IN IN-LBM SYSTEM
| | | | | THIS CASE: GRAPHITE EPOXY

- **f1**: 1078.0301
- **E**: 1.488
- **I**: .6
- **L**: .05094
- **A**: 15
- **h**: 2
- **tf**: .2
- **tw**: .125
- **w**: 1

**RULE SHEET**

S Rule

A = 2*tf*w + tw*(h-2*tf)
I = (h-2*tf)^3*tw/12 + tf^3*w/6 + 2*w*tf*(h-tf/2)^2
f1 = .55953*sqrt(E*I*g/(A*rho))/L^2

**Figure A-22A**
Drill Holes in Graphite I Beam.

'A' orientation mark on Beam.

R. Derry
5C 87-6767-78

ls. Typ.

.562 3.82 (ls. Typical)

∅
Drill Hole in Graphite Beam.

Orientation mark on Beam.

R. Daley

5C 67-6767-78

Typical
Purpose of Ball Joints

Theoretical Center Line

Rod & Endper. rotate until No net Torque.
Contact points and Force application are in line with C.L. of Rod.
Spherical Ball in Spherical Socket

Roark, E. 610

\[ \sigma_{\max} = 1.616 \left[ \frac{P E^2}{K^2} \right]^{\frac{1}{2}} \]

\[ K = \frac{P_1 D_2}{D_1 - D_2} \]

If \( D_1 - D_2 \) controlled by Tolerances, assume \( D_1 - D_2 = S \)

\[ D_1 \approx D_2 \Rightarrow D_1 = D_2 = D \]

\[ \Rightarrow K = \frac{D^2}{S} \quad K^2 = \frac{D^4}{S^2} \]

\[ \left( \frac{\sigma_{\max}}{1.616} \right)^3 \frac{D^4}{S^2} = P E^2 \]

\[ D_{\text{req}} = \left[ \frac{P E^2 S^2 (1.616)^3}{\sigma_{\max}^3} \right]^{2.5} \]

\[ D_{\text{req}} = (1.6953) \left[ \frac{P E^2 S^2}{\sigma_{\max}^3} \right]^{2.5} \]

Example: \( E = 280000 \) \( \delta = 0.010 \quad \sigma_{\max} = 40,000 \)

\[ P = 52812 \]

\[ \Rightarrow D_{\text{req}} = 1.6235 \]

---

**Figure A-25**
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<td>JAM NUT</td>
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19 Level Adjust LevelAdj.FCD

FIGURE A-26
Test Apparatus Drawings
\( \phi.190-32 \text{ UNF-2B} \)
\( \varphi.250 \text{ MIN FULL THREAD} \)
\( .320 \text{ MAX DRILL PT.} \)

\( \phi.112-40 \text{ UNC-2B} \)
\( \varphi.200 \text{ MIN FULL THREAD} \)

NOTES, UNLESS OTHERWISE SPECIFIED:

1. FINISH AS STOCK.
   REMOVE ALL BURRS & SHARP EDGES.
   ALL MACHINE SURFACES TO BE 125% UNLESS OTHERWISE NOTED.

2. IDENTIFY PART BY BAG OR TAG WITH
   PART NUMBER AND REVISION LETTER LEGIBLY
   PER MIL-STD-130 USING .12 INCH HIGH CHARACTERS.

3. FINISH: AUTOCATALYTIC NICKEL/PTFE COATING, SINTERED AT 750°F
   .0002 ± .0001 COATING THICKNESS. DIMENSIONS APPLY AFTER COATING.
   RECOMMENDED SOURCE OF COATING: LINCOLN PLATING
   LINCOLN, NEBRASKA. (402) 275-3671

Material:
STAINLESS STEEL
AISI TYPE
316 OR 316L

Approved
SC: 87-6784-78

EDO CORPORATION
ELECTRO ACOUTIC DIVISION

DRAWN: Rick Daley
CHECKED: Rick Daley
STRESS: Rick Daley
ENGRC: Rick Daley

Drawing Title:
BUTTON SOCKET

Release Date:

Size: 67B4RD2
Code: A 24338

Scale: NONE
Sheet: 1 OF 1
File: SOCKET.FCD
### Notes, Unless Otherwise Specified:

1. Finish as Stock. Remove all burrs & sharp edges. All machine surfaces to be 125.

2. Identify part by bag or tag with part number and revision letter legibly per MIL-STD-130 using .12 inch high characters.

3. Finish: Autocatalytic Nickel/PFA coating, sintered at 750°F. 0.002 ± 0.001 coating thickness. Dimensions apply after coating. Recommended source of coating: Lincoln Plating. Lincoln, Nebraska. (402) 275-3671

### Drawing Information:

- **Drawing Title:** JAM NUT
- **Material:** Stainless Steel AISI Type 316 or 316L
- **Size:** A24338
- **Code Ident. No.:** 6784RD3
- **Scale:** None
- **Sheet:** 1 of 1
- **File:** JAMNUT.FCD

---

### Dimensions:

- Hole: ∅0.875
- Hole: ∅0.500-13 UNC-2B Thru
- 45° x 0.060
- Medium Diamond Knurl
- 0.675
### Notes

1. **Finish as stock:**
   - Remove all burrs and sharp edges.
   - All machine surfaces to be 125 UNLESS OTHERWISE NOTED.

2. **Identify part by bag or tag with:**
   - Part number and revision letter legibly.
   - Per MIL-STD-130 using 1/2 inch high characters.

---

**Unless Otherwise Specified:**

- Dimensions are in inches.
- Tolerances are ±0.03.
- 2 place decimals: 0.00
- 3 place decimals: 0.000

**Drawing Title:**

LVDT BLOCK

**Material:**

- Stainless steel
- AISI Type 316 or 316L

**Drawing Data:**

- **Drawing Number:** 67B4RD4
- **Drawing Sequence:** 87-6784-78
- **Revision:** A
- **Sheet:** 1 of 1

---

**Dimensions:**

- Ø .190-32 UNF-2B THRU
- Ø .218 THRU
- Ø .760 +.010 - .000 THRU
- Ø .500 THRU
- .125
- 1.00
- 2.15
- 1.88
- .250
- .44
- .315
- .880
NOTES, UNLESS OTHERWISE SPECIFIED:
1. FINISH AS STOCK.
   REMOVE ALL BURRS AND SHARP EDGES.
   ALL MACHINED SURFACES TO BE DGS.

2. METAL STAMP PART NUMBER AND REVISION
   LETTER PERMANENTLY AND LEGIBLY PER
   MIL-STD-338 USING .02 INCH HIGH CHARACTERS.
   PART NUMBER IS SAME AS DRAWING NUMBER.

3. MATERIAL: ALUM. ALLOY 2001-T6, .020 INCH THICKNESS.

4. FINISH HARD ANODIZE. 002 THICKNESS, COLOR BLACK.

Dimensions and Tolerancing:

- Per ANSI Y14.5M-1994
- Unless otherwise specified dimensions are in inches
- Tolerances: 2 place decimal ± .03

Application:
- Interpreting drawing in accordance with DCC-O-1000

Engineer:
- R. Daley

Next Assy. Used On:
- B-243238

Interpret Drawing By:
- R. Daley

Drawn By:
- R. Daley

Date:
- [Blank]

Size Case DWG No.:
- B-243238

Scales:
- None

File:
- LSPLATE.FCD
NOTES UNLESS OTHERWISE SPECIFIED
1. FINISH AS STOCK.
   REMOVE ALL BURRS AND SHARP EDGES.
   ALL MANUFACTURED SURFACES TO BE 25.
2. METAL STAMP PART NUMBER AND REVISION
   LETTER PERMANENTLY AND LEGIBLY PER
   MIL-STD-250 USING .12 INCH HIGH CHARACTERS.
   PART NUMBER IS SAME AS DRAWING NUMBER.
3. MATERIAL ALUM ALLOY 6061-T6 .250 THICK PLATE
4. FINISH HARD ANODIZE .002 THICKNESS. COLOR BLACK

DIMENSIONING AND TOLERANCING
PER ANSI Y14.5M-1982
LESS THAN .002 TOLERANCES
TOLERANCES:
2 PLACE DECIMAL ±.03
3 PLACE DECIMAL ±.010

HELCOILS: .190-24 UNC-2B
X .285 NOMINAL LENGTH
40 PLACES ON MIDLINE OF PLATE
USE .100 NOMINAL LENGTH
WHERE INTERFERENCE MAY OCCUR
2 PLACES

6.218 THRU
.531 ± .250
6 PLACES

19.872
21.50
37.5

FILE: BACKPLATE.FCD
45° x 0.60
BOTH ENDS

Φ 0.500-13 UNC-2A

20.60

NOTES, UNLESS OTHERWISE SPECIFIED:
1. FINISH AS STOCK.
   REMOVE ALL BURRS & SHARP EDGES.
   ALL MACHINE SURFACES TO BE 125.
   UNLESS OTHERWISE NOTED.

2. IDENTIFY PART BY BAG OR TAG WITH
   PART NUMBER AND REVISION LETTER LEGIBLY
   PER MIL-STD-130 USING .12 INCH HIGH CHARACTERS.
NOTES, UNLESS OTHERWISE SPECIFIED
1. FINISH AS STOCK. REMOVE ALL BURRS AND SHARP EDGES. ALL MACHINED SURFACES TO BE #25 .
2. METAL STAMP PART NUMBER AND REVISION LETTER PERMANENTLY AND LEGIBLY PER MIL-STD-110C USING .52 INCH HIGH CHARACTERS. PART NUMBER IS SAME AS DRAWING NUMBER.
3. MATERIAL: ALUM. ALLOY 6061-T6 75B THICK PLATE
4. FINISH: HARD ANODIZE, .002 THICKNESS, COLOR BLACK

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<th>DIMENSIONING AND TOLERANCING</th>
<th>EDO ELECTRO ACUSTIC CORPORATION</th>
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<td>3 PLACE DECIMAL .0010</td>
<td>ENGINEER: R. Daley</td>
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APPLICATION ACCORDING TO DOD-D-1000
NOTES, UNLESS OTHERWISE SPECIFIED:

1. FINISH AS STOCK.
   REMOVE ALL BURRS AND SHARP EDGES.
   ALL MACHINED SURFACES TO BE 125 .

2. METAL STAMP PART NUMBER AND REVISION
   LETTER PERMANENTLY AND LEGIBLY PER
   MIL-STD-138 USING .12 INCH HIGH CHARACTERS.
   PART NUMBER IS SAME AS DRAWING NUMBER.

3. MATERIAL: ALUM. ALLOY 6061-T6, .750 THICK PLATE

4. FINISH: HARD ANODIZE, .002 THICKNESS, COLOR: BLACK

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### NOTES
1. Finish as stock.
2. Remove all burrs & sharp edges.
3. All machine surfaces to be 1/2 V.

### UNLESS OTHERWISE NOTED
- Stainless Steel: AISI Type 316 or 316L
- Carbon Steel: AISI Type 1006 or 1010

---

**Drawing Title:** ROD CHUCK

**Drawing Date:**
- Drawn: Rick Daley
- Checked: Rick Daley
- Stress: Rick Daley
- Enggr: Rick Daley
- Electro Acoustic Division: EDO Corporation

**Material:** AS DASH NUMBER TABLE

---

**Approval:**
- Code: 87-67B4-78
- Release Date: A
- Scale: None
- Revisions: A

**Drawing Number:** 67B4RD12-□

---

**File:** RODCHUCK.FCD
NOTES, UNLESS OTHERWISE SPECIFIED:
1. FINISH AS STOCK.
   REMOVE ALL BURRS & SHARP EDGES
   ALL MACHINE SURFACES TO BE 125
   UNLESS OTHERWISE NOTED

2. IDENTIFY PART BY BAG OR TAG WITH
   PART NUMBER AND REVISION LETTER LEGIBLY
   PER MIL-STD-130 USING .12 INCH HIGH CHARACTERS.

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
   ANGULAR ±
   2 PLACE DECIMALS ± .03
   3 PLACE DECIMALS ± .010

STAINLESS STEEL
316 OR 316L

DRAWN: Rick Daley
CHECKED: Rick Daley
STRESS: Rick Daley
ENGRC: Rick Daley

LEVER PIVOT

EDO CORPORATION
ACOUSTIC DIVISION

DRAWING TITLE:

MATERIAL:

SIZE: A
CODE IDENT NO.: 6784RD13
DWG NO.: 24338
SC: 87-6784-78
SCALE: NONE
SHEET: 1 OF 1
FILE: PIVOT.FCD
FULL RADIUS 2 PLCS

.156 THRU (BOTH SIDES)

.135 .010/-.000

32

.500

.800

.562

.405

225

360

.112-40 UNC-2B THRU 3 PLCS

NOTES, UNLESS OTHERWISE SPECIFIED:
1. FINISH AS STOCK. REMOVE ALL BURRS & SHARP EDGES. ALL MACHINE SURFACES TO BE 125.

2. IDENTIFY PART BY BAG OR TAG WITH PART NUMBER AND REVISION LETTER LEGIBLY PER MIL-STD-130 USING .12 INCH HIGH CHARACTERS.

3. AUTOCATALYTIC NICKEL/PFTE COATING, TREATED AT 750°F.

4. FINISH REQUIRED ON INDICATED SURFACE ONLY (.156 THRU HOLE).

OTHER SURFACES OPTIONAL.

RECOMMENDED SOURCE OF COATING: UNCOL PLATING

EDO CORPORATION

DRAWN: Rick Daley
CHECKED: Rick Daley
STRESS: Rick Daley
ENGRC: Rick Daley

DRAWING TITLE: BEARING BLOCK

MATERIAL:
STAINLESS STEEL
AISI TYPE
316 OR 316L

RELEASE DATE
APPROVED

SIZE CODE IDENT NO. DWG NO.
SC: 87-6784-78

SCALE: NONE

FILE: BEARINGB.FCD

UNLESS OTHERWISE SPECIFIED,
DIMENSIONS ARE IN INCHES
TOLERANCES:
2 PLACE DECIMALS: .03
3 PLACE DECIMALS: .010

DO NOT SCALE THIS DRAWING
O.125 +0.002/-0.002

0.112-40 UNC-2A
MIN THD RELIEF
BOTH ENDS

0.250

.188
.235
.188
.660

NOTES, UNLESS OTHERWISE SPECIFIED:
1. FINISH AS STOCK.
   REMOVE ALL BURRS & SHARP EDGES.
   ALL MACHINE SURFACES TO BE 125.

UNLESS OTHERWISE NOTED

2. IDENTIFY PART BY BAG OR TAG WITH
   PART NUMBER AND REVISION LETTER LEGIBLY.
   PER MIL-STD-130 USING .12 INCH HIGH CHARACTERS.

△FINISH AUTOCATALYTIC NICKEL/PTE COATING, SINTERED AT 750°F
   .0002“+.0001” COATING THICKNESS. DIMENSIONS APPLY AFTER COATING.
   FINISH REQUIRED ON INDICATED SURFACE ONLY (.156 THRU HOLE)
   OTHER SURFACES OPTIONAL.

RECOMMENDED SOURCE OF COATING: LINDON PLATING
LINCOLN, NEBRASKA (402) 275-3271

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES
ANGLAR±
2 PLACE DECIMALS± .03
3 PLACE DECIMALS± .010

STRESS
ENGRG
Rick Daley
Rick Daley

DO NOT SCALE THIS DRAWING

DRAWING TITLE:
AXLE

DRAWN
CHECKED
STRESS
ENGRG
Rick Daley
Rick Daley

MATERIAL:
STAINLESS STEEL
316 OR 316L

EDO CORPORATION
EDO ELECTRO
ACOUSTIC
DIVISION

DRAWING
RELEASE
APPROVED

SC: 87-6784-78

FILE: AXLE.FCD

SIZE
CODE IDENT NO.
DWG NO.

SC: 87-6784-78

SCALE: NONE

SHEET 1 OF 1

A 24338
6784RD16
Modify Threaded Studs
NOTES, UNLESS OTHERWISE SPECIFIED
1. FINISH AS STOCK
   REMOVE ALL BURRS AND SHARP EDGES.
   ALL MACHINED SURFACES TO BE 125.

2. METAL STAMP PART NUMBER AND REVISION
   LETTER PERMANENTLY AND LEGIBLY PER
   MIL-STD-138 USING .12 INCH HIGH CHARACTERS.
   PART NUMBER IS SAME AS DRAWING NUMBER.

3. MATERIAL: ALUM ALLOY 8861-T6. 7/8 THICK PLATE

4. FINISH HARD ANODIZE, .002 THICKNESS, COLOR BLACK

DIMENSIONS AND TOLERANCING
PER ANSI Y14.5M-1994
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES

TOLERANCES:
2 PLACE DECIMAL .02
3 PLACE DECIMAL .018

DRAWN BY R. Daley
DATE

INTERPRET DRAWING IN ACCORDANCE WITH DOD-D-1000
ENGINEER R. Daley

SCALE: NONE

FILE: tabletop.FCD
NOTES, UNLESS OTHERWISE SPECIFIED:

1. FINISH AS STOCK.
   REMOVE ALL BURRS AND SHARP EDGES.
   ALL MACHINED SURFACES TO BE 125 .

2. METAL STAMP PART NUMBER AND REVISION
   LETTER PERMANENTLY AND LEGIBLY PER
   MIL-STD-130 USING .12 INCH HIGH CHARACTERS.
   PART NUMBER IS SAME AS DRAWING NUMBER.

3. MATERIAL: ALUM ALLOY 6061-T6. .050 THICK PLATE

4. FINISH HARD ANODIZE, .002 THICKNESS, COLOR: BLACK.
NOTES, UNLESS OTHERWISE SPECIFIED:

1. FINISH AS STOCK.
   REMOVE ALL BURRS & SHARP EDGES.
   ALL MACHINE SURFACES TO BE 120°.

UNLESS OTHERWISE NOTED

2. IDENTIFY PART BY BAD OR TAG WITH
   PART NUMBER AND REVISION LETTER LEGIBLY
   PER MIL-STD-130 USING .12 INCH HIGH CHARACTERS.

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES:
   3 PLACE DECIMALS: ± .001
   3 PLACE DECIMALS: ± .010

DO NOT SCALE THIS DRAWING

MATERIAL:
STAINLESS STEEL
316 OR 316L

DRAWN: Rick Daley
CHECKED: Rick Daley
STRESS: Rick Daley
ENGRG: Rick Daley

EDO CORPORATION
ACOUSTIC DIVISION

DRAWING TITLE:
LEVEL ADJUSTER

SIZE CODE IDENT NO. DWG NO.
A 24338 67B4RD19

SC: 87-6784-78

SCALE: NONE

FILE: LEVELADJ.FCD