California AHMCT Program
University of California at Davis
California Department of Transportation

DEVELOPMENT OF TETHERED MOBILE ROUTING ROBOT (TMRR)*

Daehie Hong
James M. Stiles
Keith J. Mueller
Steven A. Velinsky

AHMCT Research Report
UCD-ARR-97-2-24-01

Final Report of Contract
IA 65X875 T.O. 95-10

February 24, 1997

* This work was supported by California Department of Transportation (Caltrans) Contract Number IA 65X875 T.O. 95-10 through the Advanced Highway Maintenance and Construction Technology Research Center at the University of California at Davis.

ABSTRACT

This report describes the development of a new wheeled mobile robot aimed at automating the crack preparation and sealing process. This robot is a differentially steered wheeled mobile robot with centrally located router and articulated sealant head. Additionally, a laser range sensor is installed from the front of the robot to allow for automated crack following. The sensor is slide mounted to provide the necessary field of view. A support vehicle provides all power and materials through the use of a tether, and also contains a vision based sensing system for crack identification. The robot position relative to the support vehicle is thus necessary, and it is accurately measured through a cable extension transducer based system. This mobile robot is referred to as the Tethered Mobile Routing Robot (TMRR). This report includes the descriptions of this unique mobile robot system and also operational instructions.

EXECUTIVE SUMMARY

A large number of highway maintenance activities involve the sealing of cracks and joints, the purpose of which is to prevent the intrusion of water and incompressible. When properly performed, this operation can help retain the structural integrity of the roadway and considerably extend the time between major rehabilitation. The operation is time consuming, tedious, and dangerous to the personnel involved, and accordingly, it is probably the worker's least favorite job.

Automation of this task would be extremely valuable, and thus a unique Automated Crack Sealing Machine (ACSM) was developed by the University of California, Davis through the Strategic Highway Research Program's H-107A project; see Velinsky, 1993. From this research, we concluded the following regarding the robot positioning system; it is desirable to operate on a full lane width ≈4 m (13 ft) and to have the ability to adequately prepare the pavement which included the use of a pavement router to enlarge the existing crack to promote better sealant adhesion and penetration. However, the router's weight and the forces that occur during the operation exceed the capacity of conventional manipulator type robots. Also, commercially available manipulator robots are costly, have relatively small workspaces compared to that necessary, and the mechanical advantage of the robot is dependent upon its joint positions.

Accordingly, unique concepts have been developed to overcome the inherent disadvantages of the use of conventional robots for highway maintenance operations (Velinsky et. al, 1994). This unique mobile robot was termed the Tethered Mobile Robot (TMR). In this project, the TMR concept is applied to develop the Tethered Mobile Routing Robot (TMRR) targeting a specific application, the crack sealing operation. This document reports on the development of the TMRR at the Advanced Highway Maintenance and Construction Technology (AHMCT) Research Center at the University of California at Davis. The TMRR is a differentially steered wheeled mobile robot with centrally located router and articulated sealant head. A laser range sensor is installed from the front of the robot to allow for automated crack following. The sensor is slide mounted to provide the necessary field of view. A support vehicle provides all power and materials through the use of a tether, and also contains a vision based sensing system for crack identification. The robot position relative to the support vehicle utilizes a cable extension transducer based system.

This document reviews some of the important aspects of the TMRR system development. The mechanical configuration is first presented. Next, the control system is discussed in detail, including hardware and software. The sensing systems including the robot localization system and crack sensing system are then reviewed in the next chapters. The operational instructions are included in detail in Chapter 6.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

DISCLAIMER/DISCLOSURE

"The research reported herein was performed as part of the Advanced Highway Maintenance and Construction Technology Program (AHMCT), within the Department of Mechanical and Aeronautical Engineering at the University of California, Davis and the Division of New Technology and Research of the California Department of Transportation. It is evolutionary and voluntary. It is a cooperative venture of local, state and federal governments and universities."

"The contents of this report reflect the views of the author(s) who is (are) responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the STATE OF CALIFORNIA or the FEDERAL HIGHWAY ADMINISTRATION and the UNIVERSITY OF CALIFORNIA. This report does not constitute a standard, specifications or regulation."

CHAPTER 1

INTRODUCTION

A large number of highway maintenance activities involve the sealing of cracks and joints, the purpose of which is to prevent the intrusion of water and incompressible. When properly performed, this operation can help retain the structural integrity of the roadway and considerably extend the time between major rehabilitation. The operation is time consuming, tedious, and dangerous to the personnel involved, and accordingly, it is probably the worker's least favorite job.

Automation of this task would be extremely valuable, and thus a unique Automated Crack Sealing Machine (ACSM) was developed by the University of California, Davis through the Strategic Highway Research Program's H-107A project; see Velinsky, 1993. In this concept, a conventional SCARA (Selectively Compliant Assembly Robot Arm) manipulator was inverted and mounted on a linear slide to provide a redundant degree of freedom allowing the manipulator to avoid singular positions in its motion and move through any prescribed path in its dexterous workspace. The SCARA manipulator was used to guide a secondary arm over the pavement along specific paths (following cracks). Such an approach provided accurate and consistent relative positioning between the maintenance device and the pavement, and additionally relieved the manipulator of the burden of carrying the weight of the sealant head. The tool's location was determined through the robot's joint positioning. Problems with this configuration include: the fact that the mechanical advantage of the robot is dependent upon its joint positions, the manipulator system is costly, and commercially available robots have relatively small workspaces compared to that necessary; it is desirable to operate on a full lane width ≈4 m (13 ft). Furthermore, this system did not provide for the ability to adequately prepare the pavement which included the use of a pavement router to enlarge the existing crack to promote better sealant adhesion and penetration. Specifically, the router's weight and the forces that occur during the operation exceed the relatively low load carrying capacity of the robot.

This report presents a new Wheeled Mobile Robot (WMR) aimed at automating the crack preparation and sealing process. This robot is differentially steered with centrally located router and articulated sealant head. The motors provide a large tractive force and the router is located on the center of the wheel base in order for better tracking control performance. The design provides a very small turning radius. Additionally, a laser range sensor is installed from the front of the robot to allow for automated crack following. The sensor is mounted to a linear slide for an extended field of view. The robot position relative to the support vehicle is accurately measured through Cable Extension Transducers (CETs), and all power and materials are supplied through the use of a boom/tether. This robot is termed the Tethered Mobile Routing Robot (TMRR).

This document concisely reviews some of the important aspects of the TMRR and includes its detailed operational instructions. The interested reader is referred to Boyden and Velinsky (1993), Hong (1994), Kochekali and Velinsky (1994), Winters and Velinsky (1992), Zang and Velinsky (1994b), Matsumoto (1996), and Chung (1996) which are detailed interim reports and theses of this and related projects, and provide significant detail on all of the areas covered.

CHAPTER 2

MECHANICAL CONFIGURATION

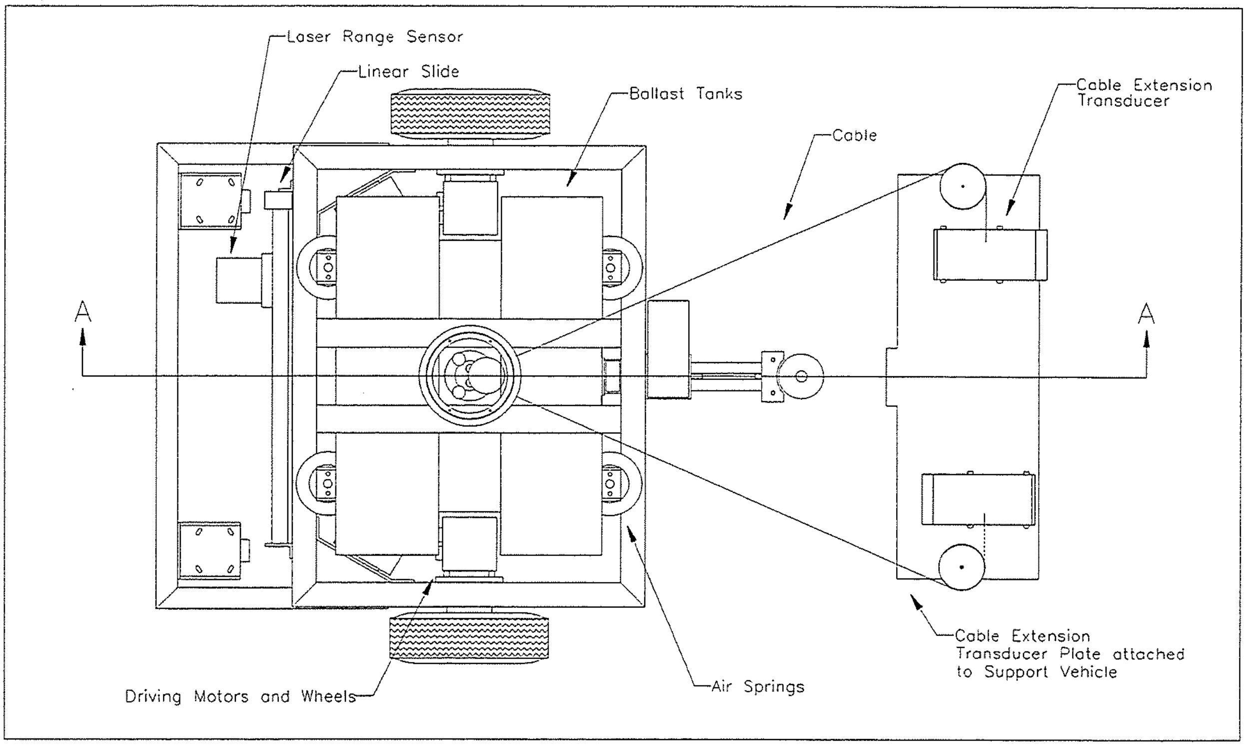
Figure 2-1 is a schematic of the TMRR. Mobility is the key feature in its design. Cracks on roadway surfaces can be very irregular and attempting to follow one through 360° is paramount in a successful sensing/routing/sealing operation. Computing the relative position of the TMRR to the support vehicle is also an added complexity. Our solution for this problem of position estimation is triangulation by two CETs mounted to large diameter radial bearings on the TMRR. Power and material lines drop through the center of the bearings and are either mounted to rotary unions or simply twist with robot orientation. Since the cables' point of attachment is along the center of the drive wheel base, the TMRR can conceivably perform a 360° rotation "in place".

The laser range sensor mounted in front of the router unit finds cracks via triangulation and stores three dimensional surface profiles. The limited view of a stationary laser sensor would limit the TMRR's practical turning radius. To overcome this, the sensor is mounted to a linear slide thereby increasing the possible field of view. Feedback control is provided and the position of the TMRR can be updated in real time using the offset position corrections of the laser sensor.

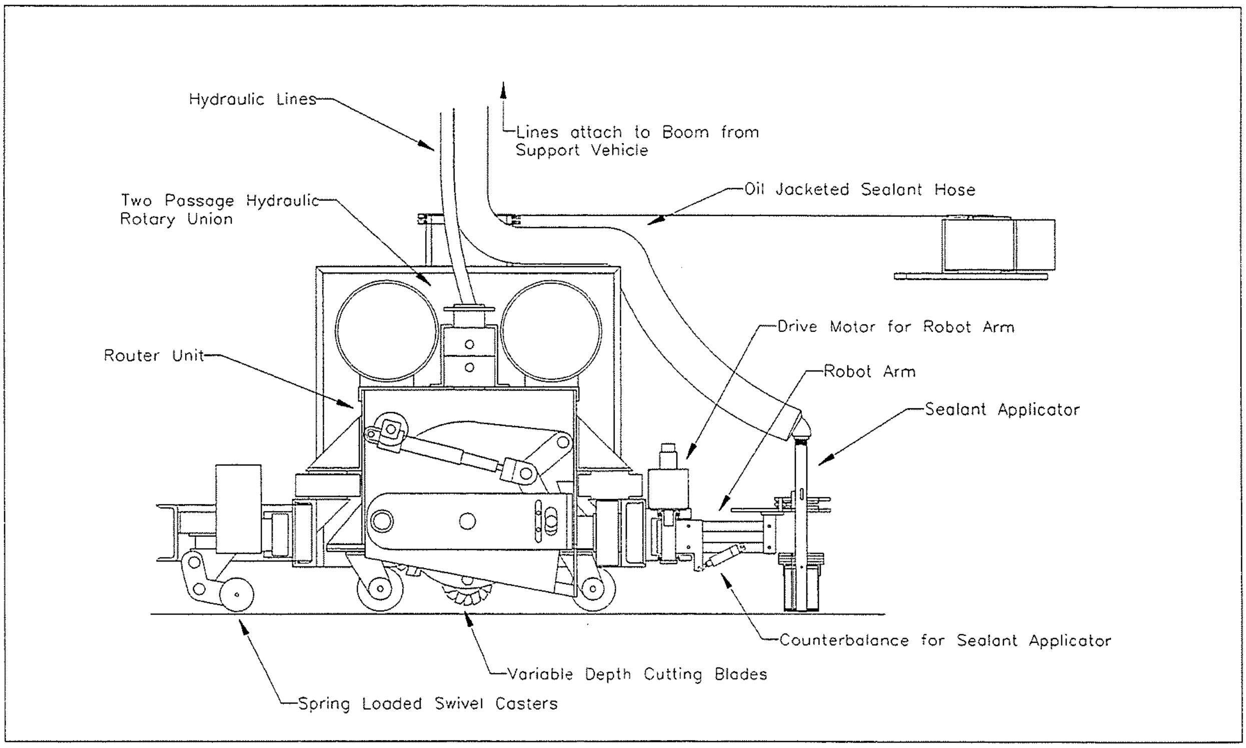
The router unit prepares cracks by cutting a channel which allows for increased penetration and adhesion of sealant. The design uses an existing impact router cutting wheel hydraulically powered with a remote power supply on the support truck. The driving motors provide the end effector forces necessary to move the router through the pavement. The router "up-mills" in order to both provide a high quality cut and to avoid the problem where the router can pull itself out of the roadway. Air springs are the only points of connection between the router unit and the complete TMRR. They provide support and dampen vibrations of the routing process with respect to other TMRR components.

The sealant applicator delivers hot thermoplastic sealant over the roadway. A part of its unique design is a pressurized reservoir that forces the sealant into the routed crack. The path generated by the laser sensor following a crack will be used for not only the router, but also the drive motor attached to the sealant applicator robot arm. Finally, to achieve proper down force of the sealant applicator, an air cylinder counterbalances the weight of the rotating robot arm and sealant applicator.

Figure 2-2 shows the front view of the fabricated TMRR. Figure 2-3 also shows the rear view of the TMRR including the rear arm assembly. A commercial liftgate is modified and attached to the back of truck as a transporting device of the TMRR. The TMRR is lifted up and held on the lifting platform while the truck is moving without sealing. Figure 2-4 shows the TMRR and the liftgate assembly at the back of truck.



(a) Top view



(b) Cutaway view (A-A)

Figure 2-1. Drawings of Tethered Mobile Routing Robot

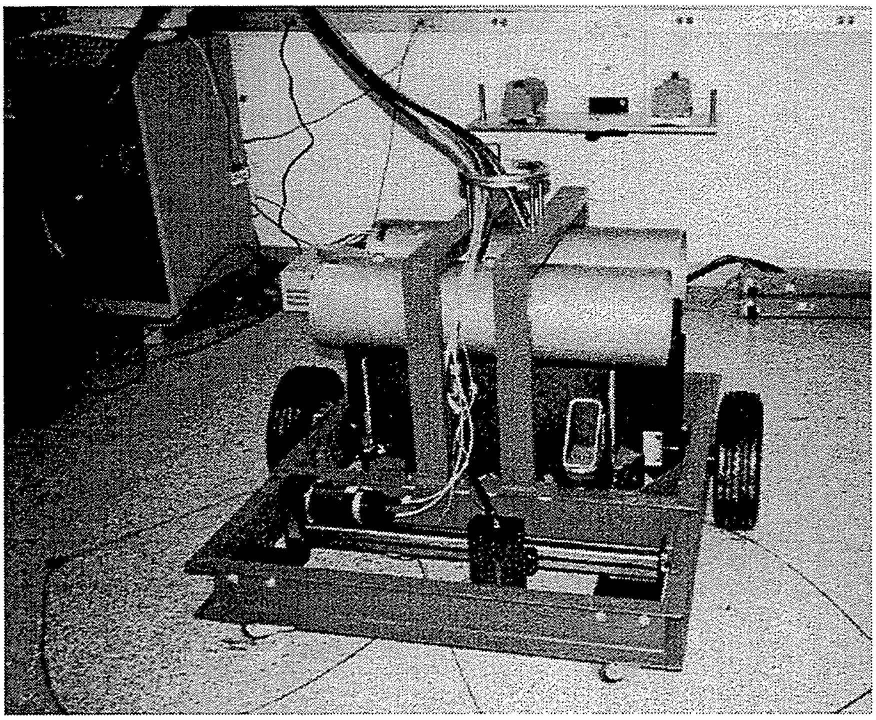


Figure 2-2. Front view of Tethered Mobile Routing Robot

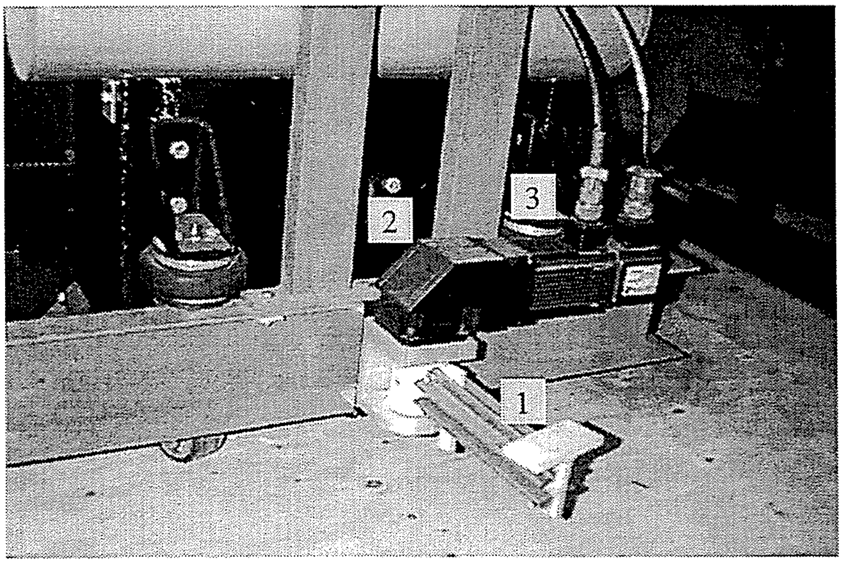


Figure 2-3. Rear arm assembly, *1: arm, 2: gear head, 3: BLDC motor*

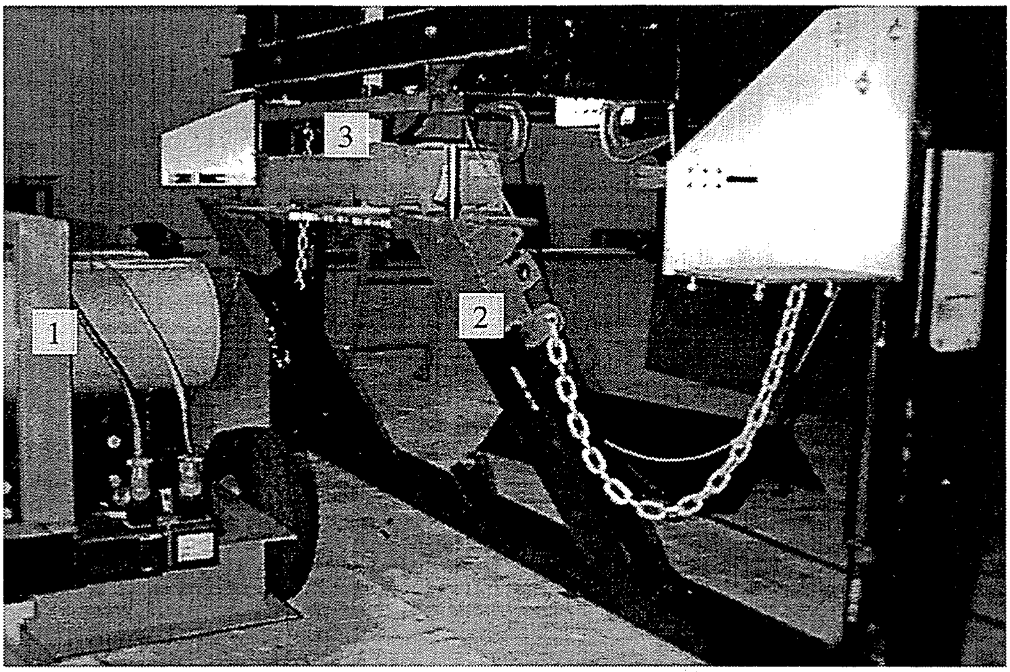


Figure 2-4. TMRR and lifter at the back of truck, *1: TMRR, 2: lifter, 3: CETs*

CHAPTER 3

CONTROL OF TMRR

3.1 Control Algorithms

The TMRR control system consists of three control modes, *Reference Path Tracking Control*, *Joystick Control*, and *Tracking Control with Laser Sensor*. One of these control modes can be selected depending on a required maintenance task. Figure 3-1 shows the block diagram of the control algorithm. Each of these control modes generates reference commands for mobile robot control and sealant arm control. Since the inertia of the sealant arm is much less than the one of the mobile robot platform, the dynamic coupling can be ignored. Therefore, the mobile robot platform and the sealant arm can be controlled independently. We have already developed several control algorithms for wheeled mobile robots using feedback linearization, sliding mode, and robust control techniques (Hong, et al., 1994; Hong, et al., 1997, b; Zhang, et al., 1997). Also, the sealant arm can be easily controlled with a Proportional and Integral control algorithm.

This report includes the kinematic model of the TMRR and the derivation of its trajectory tracking control algorithm. The TMRR consists of two components, the router blade on the robot platform and the sealant applicator at the end effector of the arm, which should be controlled to move along the crack path. The robot platform is driven by two driving wheels and the robot arm is separately actuated by an electric motor. There is dynamic interaction between the platform and the arm. However, the robot platform is designed to have a much heavier weight than the arm, so that the dynamic effect of the arm motion to the robot platform can be neglected; at the present design stage, the platform weight is expected to be over 200 kg and the arm weight is about 10% of it. The robot platform can therefore be controlled without considering the arm dynamics. The derivation of the tracking control is based on the work of Hong et al., 1997.

In order to describe the motion of the robot, two reference coordinate systems are introduced as shown in Figure 3-2. The *X-Y* coordinate system is attached to the support vehicle. The equations of motion are described based on the assumption that this coordinate system is stationary, so that it becomes a *global coordinate system* fixed with respect to the ground. The effect of the supporting vehicle's motion can be easily compensated later since it is primarily

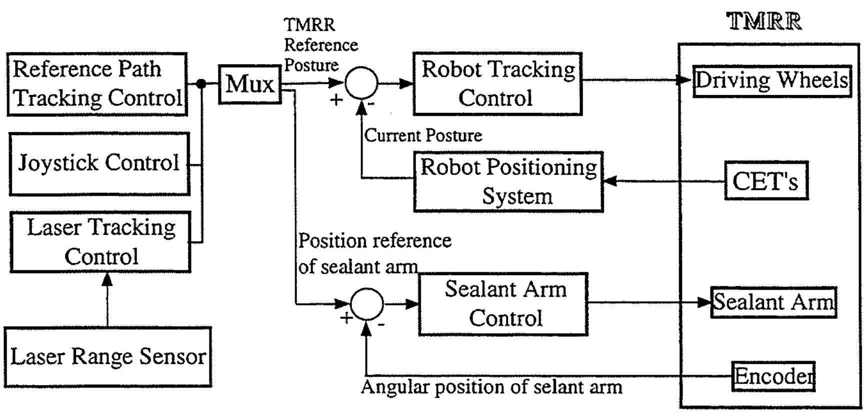


Figure 3-1. Block diagram of control software

translational in nature. The second coordinate system is the *body fixed system* attached to the TMRR with the x and y components representing the forward and lateral directions of the robot, respectively. The origin of the body centered coordinate system coincides with the control point C whose position is controlled to track the detected crack path; e.g., point C describes the router blade location. The control point C is placed on the center line, that is, on the x axis and on the center of the wheel baseline.

The elements of the posture vector include the translations in the x and y directions and the angular position ψ. After imposing the no slip condition, which forces the lateral velocity v_C to be equal to er_C, then the first derivative of the posture vector of the TMRR at point C in the global coordinate frame is written as

$$\begin{bmatrix} \dot{X}_C \\ \dot{Y}_C \\ \dot{\psi}_C \end{bmatrix} = \begin{bmatrix} \cos\psi_C & 0 \\ \sin\psi_C & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} u_C \\ r_C \end{bmatrix}, \tag{3-1}$$

where u_C represents the forward velocity of the TMRR and r_C represents the yaw rate of the robot. The posture $\mathbf{X}_C \equiv \left(X_C, Y_C, \psi_C\right)^T$ of the robot at C in the global coordinate system is obtained after integrating Eqn. (3-1) given the linear and the angular velocities

of the robot. Point D denotes the desired control point location, and we denote the posture vector for the point D as $\mathbf{X}_D$. Also, let us denote the error posture in the body coordinates as $\mathbf{x}_e$. Then the error posture can be expressed as:

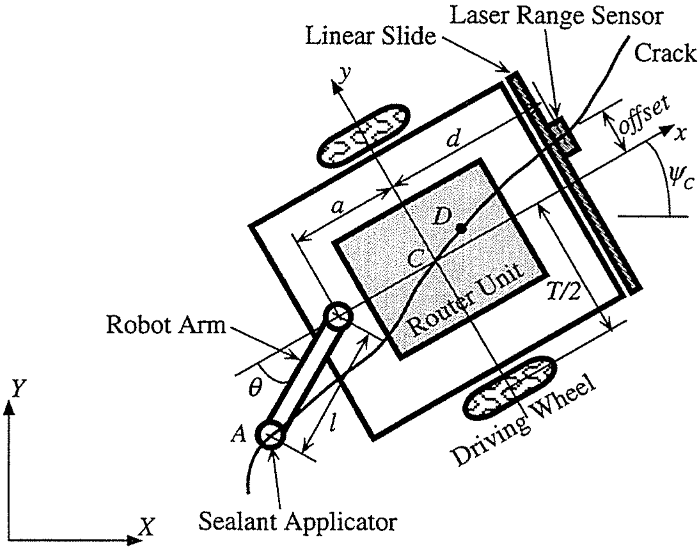


Figure 3-2. *Schematic of WMR and Coordinate Systems*

$$\mathbf{x}_e = \begin{bmatrix} \cos\psi_C & \sin\psi_C & 0 \\ -\sin\psi_C & \cos\psi_C & 0 \\ 0 & 0 & 1 \end{bmatrix} (\mathbf{X}_D - \mathbf{X}_C). \tag{3-2}$$

By differentiating the Eqn. (3-2) and substituting in Eqn. (3-1), we can obtain the following system equation:

$$\begin{bmatrix} \dot{x}_e \\ \dot{y}_e \\ \dot{\psi}_e \end{bmatrix} = \begin{bmatrix} u_D \cos\psi_e \\ u_D \sin\psi_e \\ r_D \end{bmatrix} + \begin{bmatrix} -1 & y_e \\ 0 & -x_e \\ 0 & -1 \end{bmatrix} \begin{bmatrix} u_C \\ r_C \end{bmatrix} \tag{3-3}$$

where u_D, r_D are the desired forward velocity and yaw rate of the robot at the point D. Our control problem is defined as finding a control law $(u_C, r_C)^T$ such that, starting from an arbitrary location in a region Ω, the state $(x_e, y_e, \psi_e)^T$ tends to 0 as $t \to \infty$, given the nonlinear system described by Eqn. (3-3).

The system has three outputs and two control inputs; thus it is not square. Therefore, the coefficient matrix of the control input $(u_C, r_C)^T$ is not invertable, which complicates the problem. Here, let us introduce a new variable, z_e, and positive constant c. The new variable can be used as a new state variable provided that the lemma is true: *for* $z_e = y_e + c\psi_e$ *and* $c>0$, *both* y_e *and* ψ_e *go to zero, as* z_e *goes to zero.* Proof has been shown in Hong et al., 1997. Consequently, by using the new state variable z_e, the equation of motion (3-3) becomes square as follows:

$$\dot{\mathbf{x}} = \mathbf{f}(\mathbf{x};t) + \mathbf{E}(\mathbf{x};t)\mathbf{u} \tag{3-4}$$

where

$$\mathbf{x} = \begin{bmatrix} x_e \\ z_e \end{bmatrix},\ \mathbf{f}(\mathbf{x};t) = \begin{bmatrix} u_D \cos\psi_e \\ u_D \sin\psi_e + cr_D \end{bmatrix},\ \mathbf{E}(\mathbf{x};t) = \begin{bmatrix} -1 & y_e \\ 0 & -(x_e + c) \end{bmatrix},\ \mathbf{u} = \begin{bmatrix} u_C \\ r_C \end{bmatrix}. \tag{3-5}$$

Finding a control law is fairly straight forward using the feedback linearization method which is commonly referred to as the computed torque method in robotics literature; see Fu et al. (1988). By selecting the control law as follows

$$\mathbf{u} = \mathbf{E}^{-1}(-\mathbf{f} - \mathbf{K}\mathbf{x}), \tag{3-6}$$

then Eqn. (3-4) is transformed to

$$\dot{\mathbf{x}} + \mathbf{K}\mathbf{x} = \mathbf{0}. \tag{3-7}$$

Thus, the control is locally exponentially stable provided that the gain matrix **K** is chosen suchthat the eigenvalues of the characteristic equations lie in the left-half plane.

The position $\mathbf{X}_A$ of the end-effector of the arm in the global frame is expressed with the robot posture and the angular position of the arm itself, such that:

$$\mathbf{X}_A = \begin{bmatrix} X_C \\ Y_C \end{bmatrix} + \begin{bmatrix} \cos\psi_C & -\sin\psi_C \\ \sin\psi_C & \cos\psi_C \end{bmatrix} \begin{bmatrix} -(d + l\cos\theta) \\ -l\sin\theta \end{bmatrix}. \tag{3-8}$$

Since the dynamic interaction between the arm and the robot platform is negligibly small, the arm angular position is independently controlled with a Proportional & Integral (PI) control algorithm, such that the motor torque τ is expressed as

$$\tau = K_P\theta_e + K_I\int\theta_e dt \tag{3-9}$$

where θ_e is the angular position error of the arm and K_P, K_I are proportional and integral control gains respectively.

3.2 Controller Architecture

The TMRR controller hardware is optimally designed in order to implement the developed control algorithms. The controller structure is shown in Figure 3-3. The main CPU of the controller is Pentium micro-processor based on PCI and ISA buses. The basic PC components, such as video card and hard disk controller, are housed in the PCI bus. Other peripheral boards necessary for control implementation are plugged into the ISA bus. The ISA is currently the most popular bus structure. Accordingly, commercially available hardware is available. The TMRR consists of two driving wheels and one sealant arm which are driven by Brushless DC motors. Accordingly, the TMRR controller should have motor controllers with as many node axes as the number of the total driving units. The motor controllers take ±10 VDC analog signals as control commands, so that a multi-channel D/A converter board is used in order to interface them to the host computer. For the Joystick Control mode, an industrial type joystick is interfaced through an A/D converter. The ISA based encoder interface boards are used for the cable extension transducers and the joint encoder of the sealant arm. Also, the laser sensor system consists of ISA bus based boards which are an image-processing board and a digital signal processing (DSP) board. In addition, the controller is equipped with 15 ISA slots that can be used to expand controller capability for various control purposes.

Figure 3-4 illustrates signal wiring between each unit. The back panel of the control computer is shown in Figure 3-5, which identifies each signal cable. Figure 3-6 shows the motor drives, the first drives, DM30's, are for the driving wheels, the third drive, DM20, is for the rear arm, and the last drive is for the linear slide of the laser sensor system. Also, Figure 3-7 shows power wiring on the back panel of the controller cabinet. The labels on the power circuit components shown in Figure 3-8 are used to identify the circuit components in the Figure 3-9. The numbers on the switches shown in Figure 3-8 correspond to the picture of the controller front panel shown in Figure 6-3.

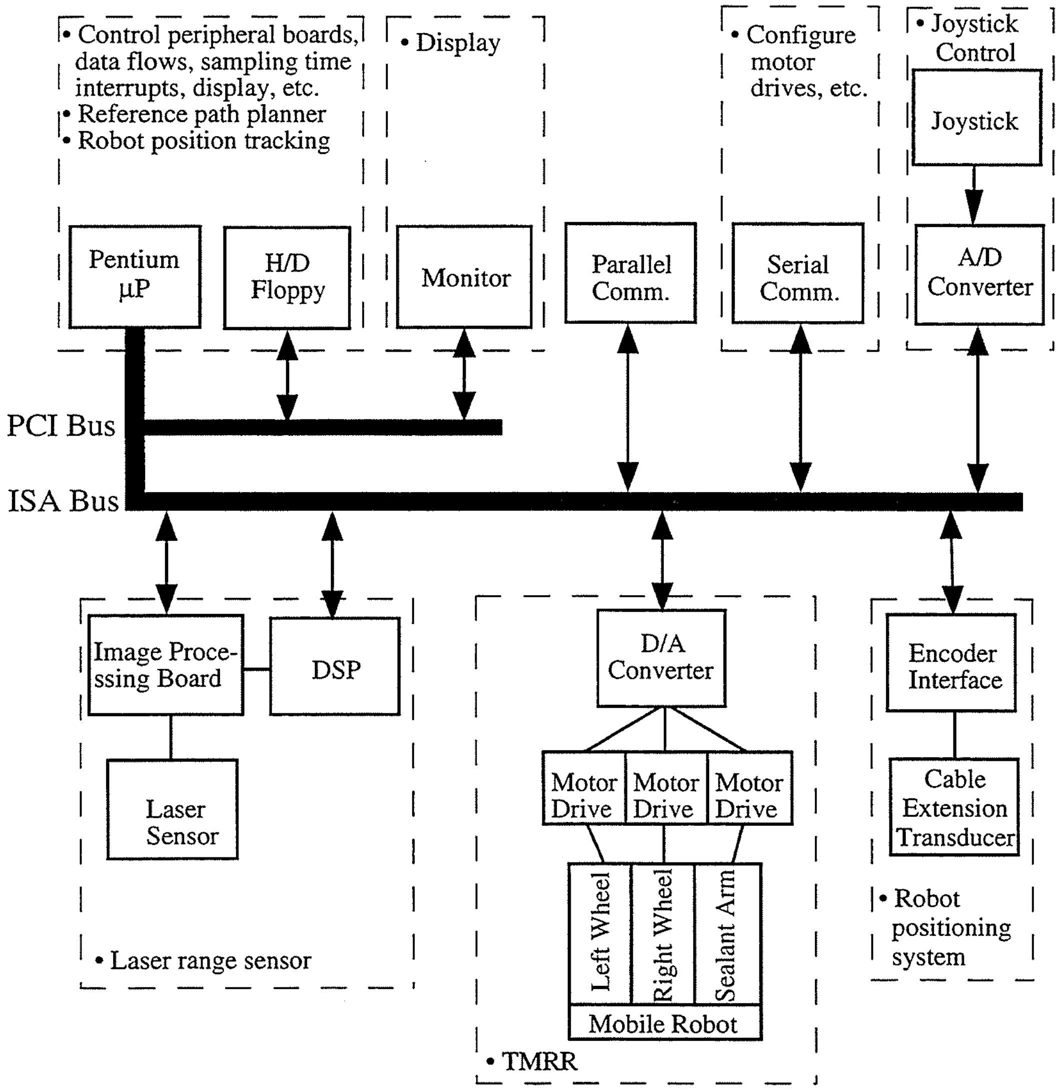


Figure 3-3. Block diagram of control hardware

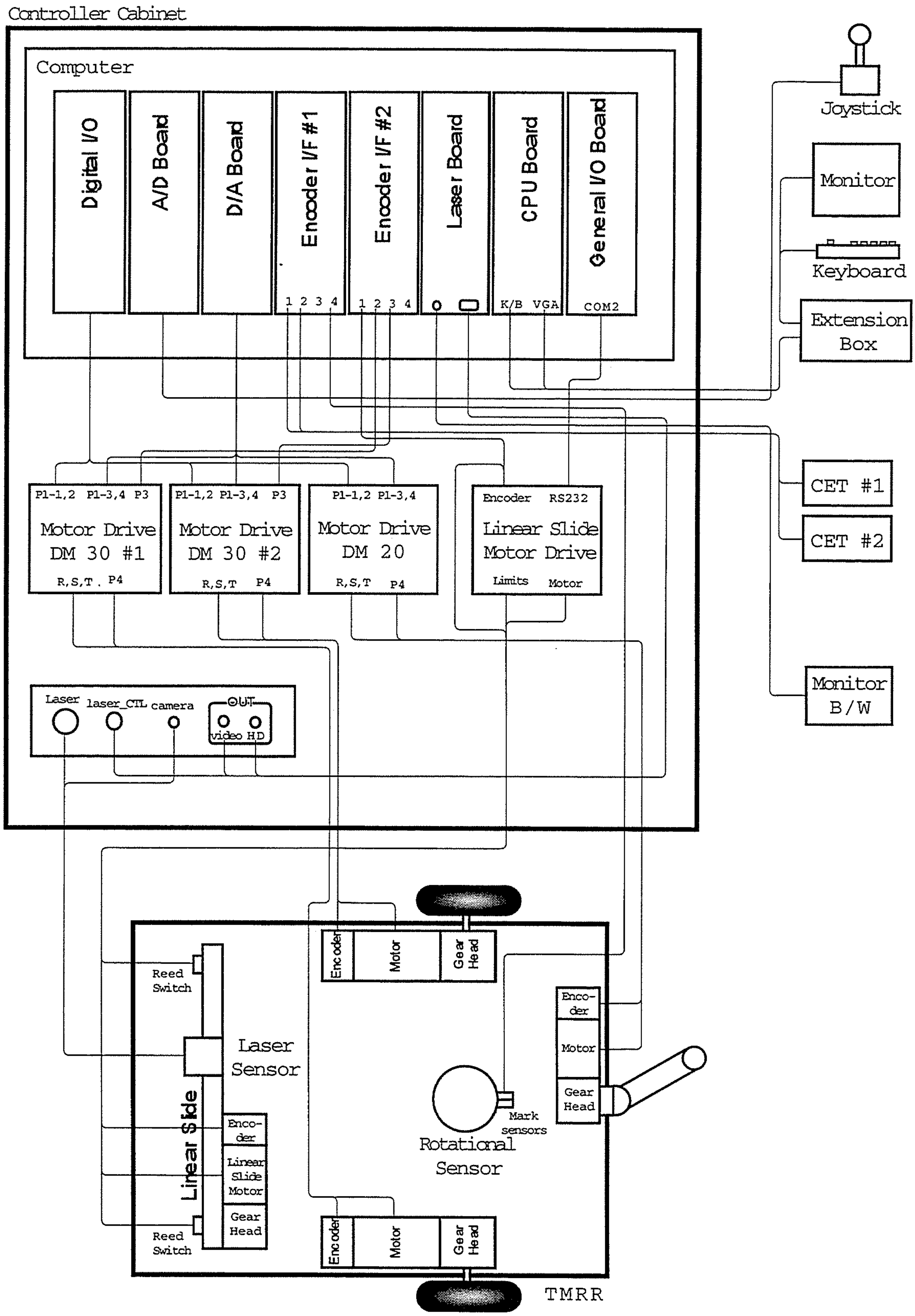


Figure 3-4. Overall wiring diagram of TMRR controller

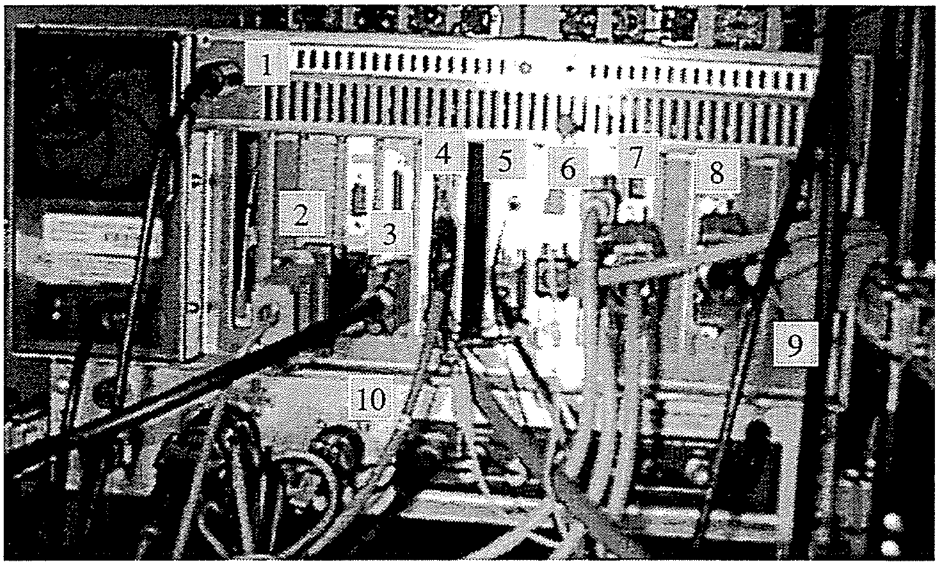


Figure 3-5. Back of computer, *1: keyboard connector, 2: COM1, 3: monitor cable, 4: encoder interface board #2, 5: laser processing board, 6: encoder interface board #1, 7: A/D converter board, 8: D/A converter board, 9: digital I/O board, 10: laser controller*

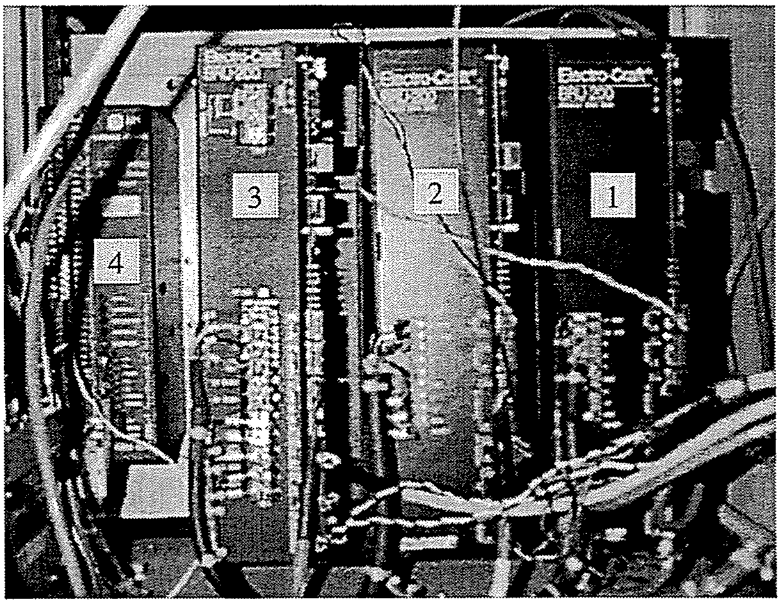


Figure 3-6. Motor drives, 1*: DM30 #1, 2: DM30 #2, 3: DM20, 4: linear slide motor drive*

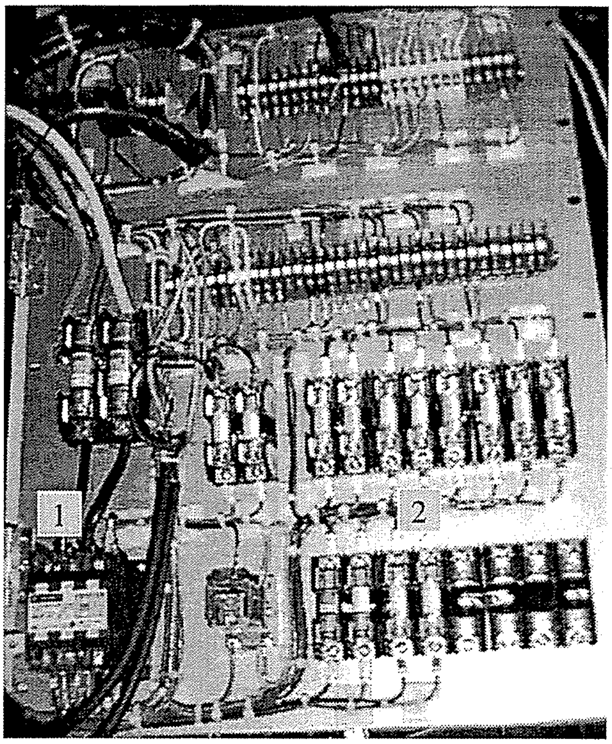


Figure 3-7. Power wiring on cabinet back panel, *1: magnetic contacter, 2: fuse blocks*

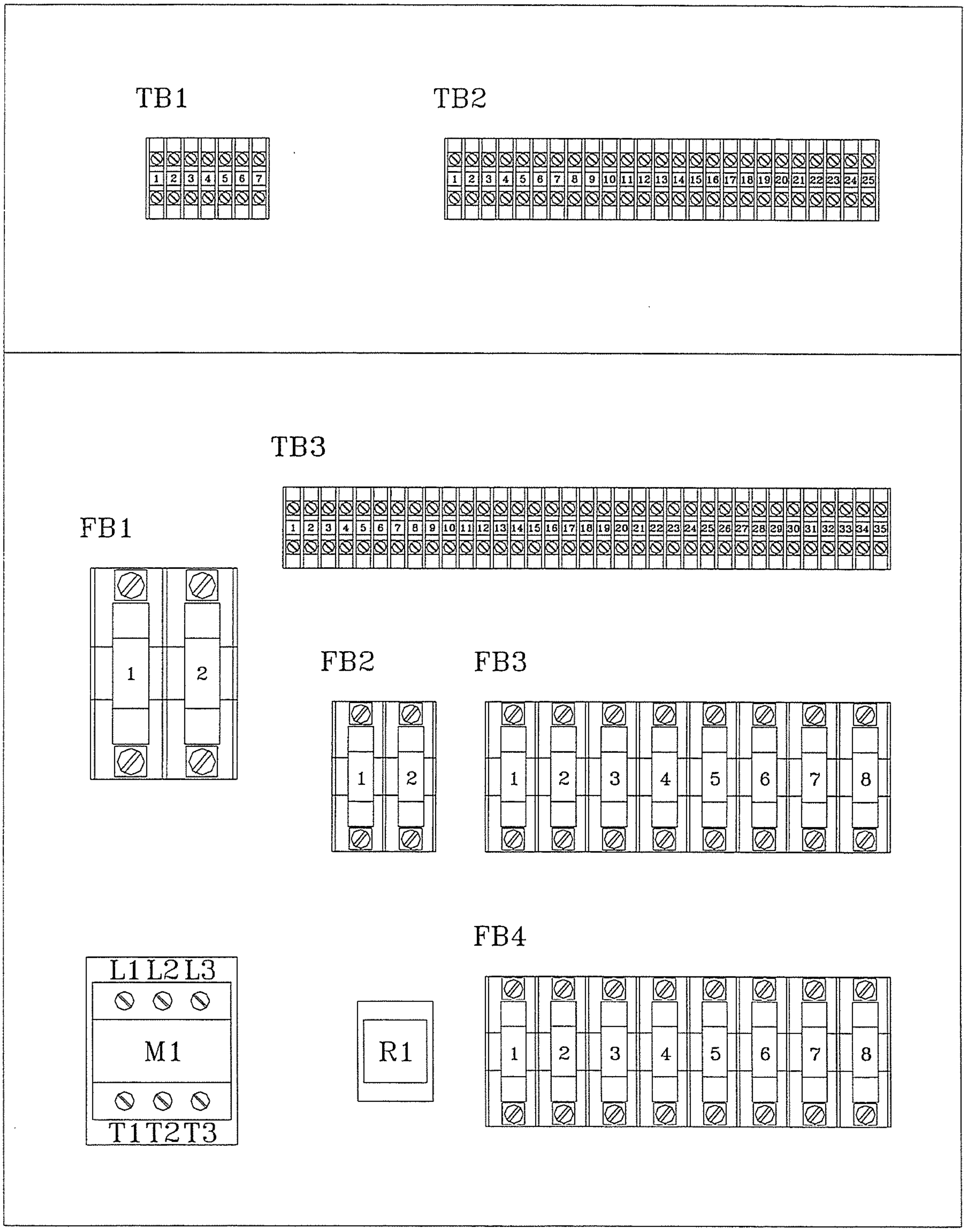


Figure 3-8. Power wiring components on cabinet back panel

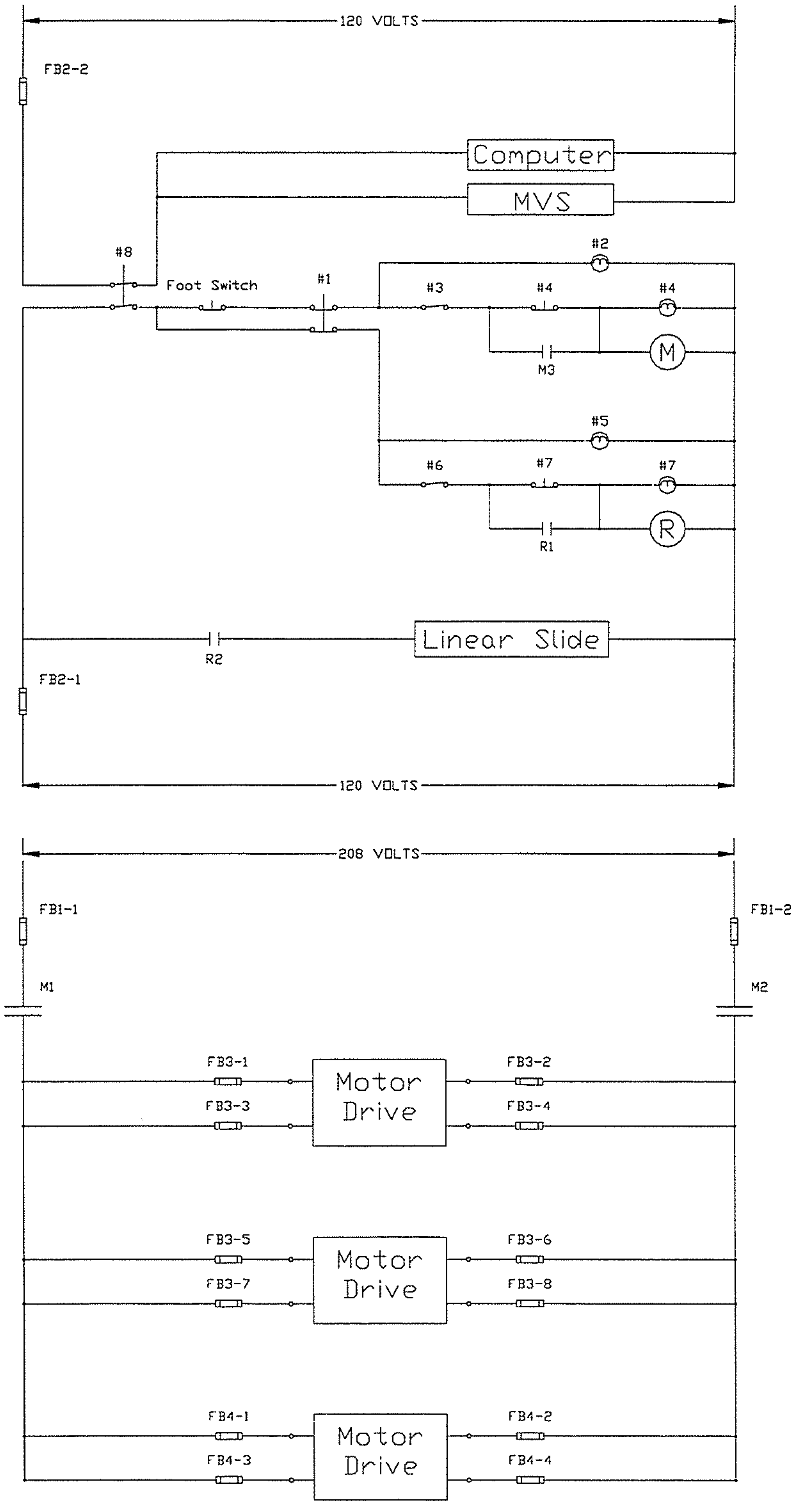


Figure 3-9. Power circuit of TMRR

CHAPTER 4

ROBOT LOCALIZATION SYSTEM

The motion of the robot is controlled relative to the support vehicle, so that a relative position tracking system is essential. Based on the intended applications of the robot system and the corresponding tracking system requirements, a new approach for robot localization has been developed (Hong, et al., 1995).

The developed sensor approach is novel in that it uses new technology in the form of cable-extension transducers (CETs) to determine robot position. CETs are linear-displacement sensors which produce electrical signals proportional to the travel of their extension cables. CETs achieve a 0.01% accuracy for up to approximately a 40 meter range, and they are relatively robust, inexpensive, and easy to use compared to other approaches. CETs do require a physical connection between the support vehicle and the mobile robot, but the support vehicle must provide power and materials, and thus a physical connection already exists.

The configuration of the sensor system is shown in Figure 4-1. The cables from both cable-extension transducers are passed around the pulleys and are attached to the robot. The pulleys are required to allow the cable to exit from the transducer with the same orientation, which is a necessity, yet locate an arbitrary position in the workspace. Also, the picture of the assembled sensor system is shown in the Figure 2-4.

The position equations are derived based on the parameters shown in the schematic diagram of the sensor system, Figure 4-1. The cables from both cable-extension transducers are passed around the pulleys A and B and are attached to point P on the robot. The pulleys are required to allow the cable to exit from the transducer with the same orientation, which is a

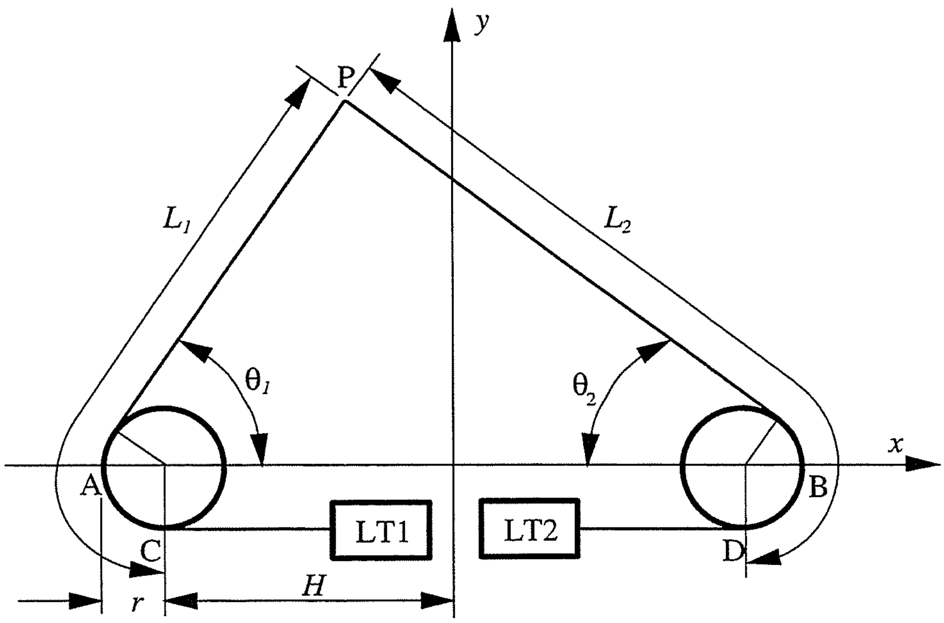


Figure 4-1. Schematic diagram of CET sensor system

necessity, yet locate an arbitrary position P in the workspace. The size of the pulleys in the figure are exaggerated for illustrative purposes.

The pulleys' diameters should be determined based on space constraints and the system's expected life. While this is a slow speed application, the cable's bending stresses will still dictate the life of the cable; i.e., cable fatigue due to the cyclic bending stresses will ultimately cause the cable to fail. In general, a relatively large pulley diameter compared to the cable diameter is necessary. In this application, there is no need to use a pulley diameter significantly larger than the diameter of the CET's spool.

The coordinate system is assigned as follows: x passes through the centers of both pulleys and its origin is midway between the two pulleys. The cable length is defined as the distance of P from the point C or D on the pulley circumference as shown in Fig. 4-1. This augmented cable length can be easily obtained by appropriately resetting the counter of the CETs or adding an offset value. Due to the pulley effect, it is impossible to find an explicit form for the position equation of point P. Thus, parametric variables, θ_1 and θ_2, which are the inner angles formed by the x-axis and the cables, are used. With these parameters, the following relationships are obtained:

$$L_1 - r(\pi - \theta_1) - (y_P - r\cos\theta_1)/\sin\theta_1 = 0 \qquad (4\text{-}1)$$

$$y_P \cot\theta_1 - H - x_P - r/\sin\theta_1 = 0 \qquad (4\text{-}2)$$

$$L_2 - r(\pi - \theta_2) - (y_P - r\cos\theta_2)/\sin\theta_2 = 0 \qquad (4\text{-}3)$$

$$y_P \cot\theta_2 - H + x_P - r/\sin\theta_2 = 0\,. \qquad (4\text{-}4)$$

In these equations, x_p and y_p are the dependent variables that need to be determined. The input variables are the lengths of each cable, L_1 and L_2. However, we cannot reduce the equations and get explicit equation forms for x_p and y_p in terms of L_1 and L_2 due to the nonlinearities with respect to the parametric variables θ_1 and θ_2. Consequently, the problem at hand is to numerically solve the nonlinear simultaneous equations (4-1) through (4-4) to obtain the four unknowns x_p, y_p, θ_1, and θ_2 given L_1 and L_2. The detailed schemes to solve these equations in real-time fashion are discussed in Hong, et al., 1995.

The general plane motion of a rigid body is described with three variables; x, y position and θ orientation. The position of the robot was determined by solving the above equations. In order to obtain the orientation of the robot, the rotational sensor system shown in the Figure 4-2 is installed on the robot center. The rotational sensor system has two rings mounted on ball bearings. The CET cables are attached on the rings, so that the rings freely turn due to cable tension as the robot moves around. The orientation of the robot is therefore determined by reading the rotation of one ring. In the Figure 4-2, the mark and mark sensors are provided to read the angular rotation of the ring. Since any frictional force hinders free rotation of the ring, the non-contact mark sensors are utilized. In order to detect rotational direction, two sensors and two rows of marks are placed in the way that 90° phase difference exists between each other. This also makes it possible to treat the sensor signals as quadrature inputs. The sensor signals are boosted up with differential line driver circuit in order to remove electric noise.

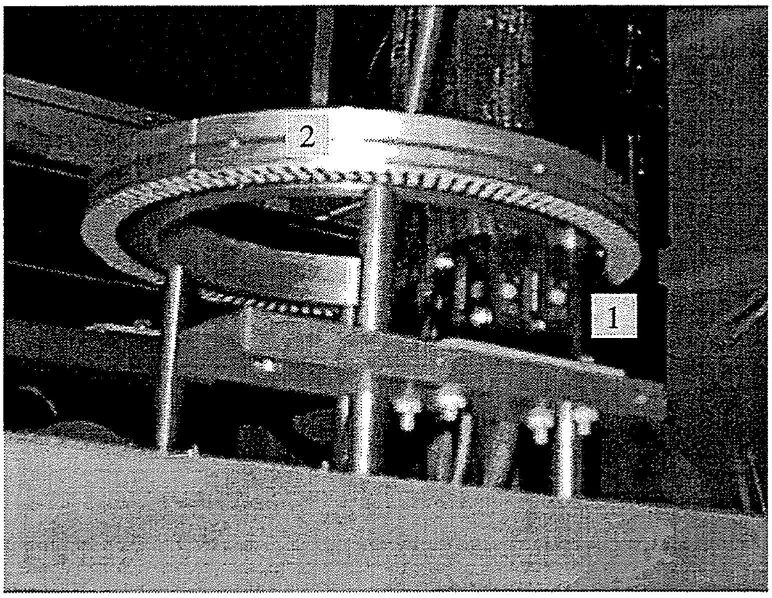


Figure 4-2. Rotational sensor assembly, *1: mark sensor, 2: mark*

CHAPTER 5

CRACK FINDING SENSOR

Based on the study of a variety of sensor technologies, Krulewich and Velinsky (1992) selected a laser range finder based sensor for their crack detecting device and showed its ability to identify cracks in both Asphalt Concrete (AC) and Portland Cement Concrete (PCC) pavements. The same laser range finder sensor is attached at the front of the TMRR platform in this work as shown in Figure 5-1. The laser range finder sensor scans the road surface with a narrow line of structured light produced through a cylindrical lens. It provides a line scan of the profile of the road surface. The field of view of the laser range sensor is about 5-8 cm. Also, the laser range sensor cannot be installed close to the control point due to the physical dimension of the router unit and also due to the debris produced by the router blade. In order to cope with this limitation on the small field of view, a linear slide is provided on which the laser range sensor is attached. The laser range sensor travels back and forth on the slide in a wide range, ≈50 cm. The laser range sensor is controlled to always lie on the crack position detected at the previous sampling time, so that the sensor can detect the current crack with the small field of view. The sensor system and crack detection algorithms are detailed in Matsumoto, 1996.

The y component of the detected crack position in the body fixed coordinate frame is the *offset* value, the distance between the sensor center (which aligns with the centerline of the mobile robot) and the crack reservoir center. The global coordinates of the detected crack position are then obtained by coordinate transformation. The distance d of the laser range sensor from the origin of the body coordinates in the x direction is fixed. The following equation expresses the crack position in the global coordinate system based on the robot position, the sensor position, and the sensed offset value:

$$\begin{bmatrix} X_i \\ Y_i \end{bmatrix} = \begin{bmatrix} X_{C_i} \\ Y_{C_i} \end{bmatrix} + \begin{bmatrix} \cos\psi_{C_i} & -\sin\psi_{C_i} \\ \sin\psi_{C_i} & \cos\psi_{C_i} \end{bmatrix} \begin{bmatrix} d \\ offset \end{bmatrix} \tag{5-1}$$

where the subscript i denotes the i-th sampling instance and $(X_{C_i}, Y_{C_i})^T$ is the position vector of the TMR. With the time function of X_i and Y_i in discrete form, the tangent angle of the crack path is obtained as

$$\psi_i = \operatorname{atan}\left(\frac{Y_i - Y_{i-1}}{X_i - X_{i-1}}\right). \tag{5-2}$$

The posture vector of the crack, $(X_i, Y_i, \psi_i)^T$ is formed from Eqns. (5-1) and (5-2). This posture vector is stored in buffer memory at each sampling time and utilized to determine the reference posture for the robot tracking control.

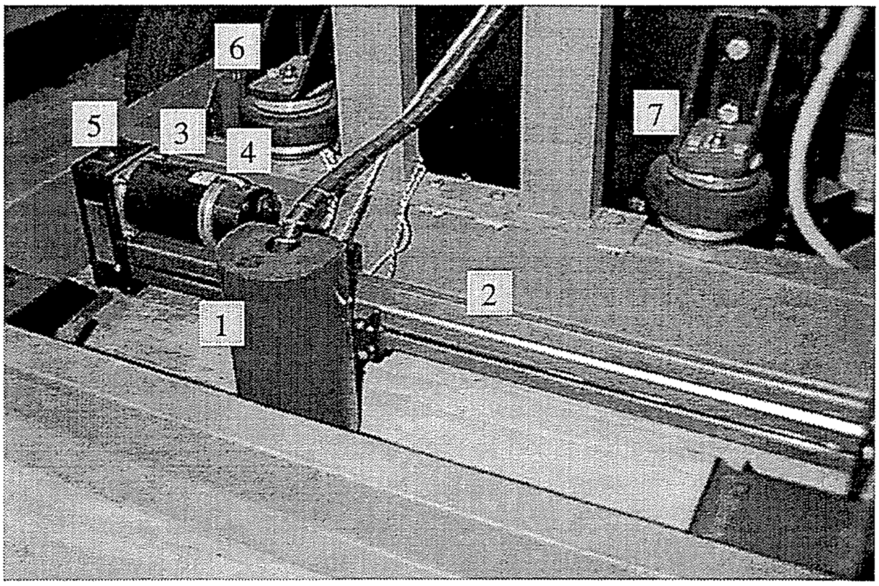


Figure 5-1. Laser sensor assembly, *1: laser sensor, 2: linear slide, 3: stepper motor, 4: encoder, 5: gear head, 6,7: air springs*

CHAPTER 6

OPERATIONAL INSTRUCTIONS

6-1. Liftgate Operation

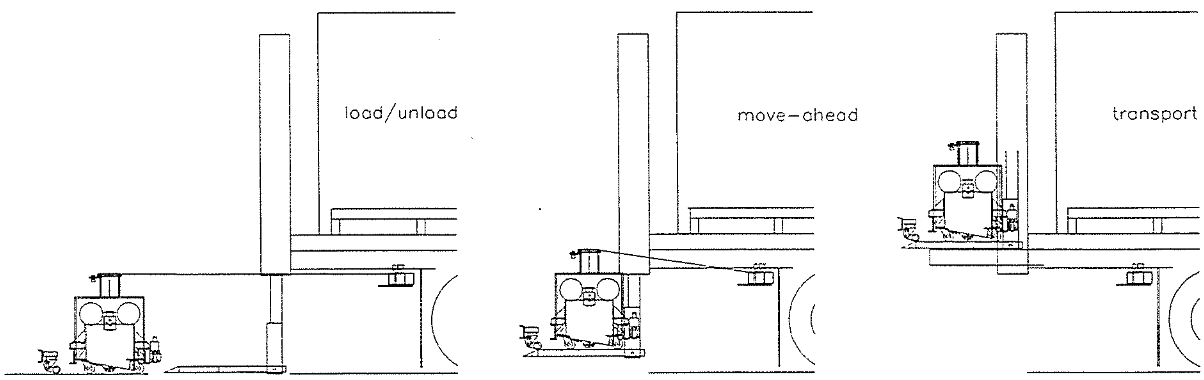
The liftgate operation consists of four different basic modes, Crack sealing/routing mode, Load/unload mode, Move-ahead mode, and Transport mode. The TMRR should be held on the lifting platform at 1.4 m (4.5 ft) up-position from the ground while it is being transported over long distances as shown in Figure 6-1 (c). In this transport mode, the CET cables should be disconnected from the TMRR. Also, the secondary support frame should be slid out and tied to the TMRR. The Move-ahead mode is used for short distance travel. In this mode, the TMRR is lifted up about 30 cm (1 ft) from the ground without disconnecting the CET cables and without tying the TMRR to the lifting platform. The Load/unload mode is used to load/unload the TMRR from the liftgate. In this mode, the lifting platform should make contact on the ground. In the Crack sealing/routing mode, the lifting platform should be folded (that is, up-right position), since the platform may be inside of the TMRR's workspace.

Figure 6-2 shows the liftgate control pendent. The first switch from the top is used to lift the liftgate up and down, the second switch is used to lock/unlock the liftgate, and the third switch is used to tilt up and down the lifting platform.

6-2. Descriptions of Switches on Controller Cabinet

Figure 6-3 shows the front panel of the controller cabinet. This section describes the functions of each switch on the controller cabinet as follows.

1. Emergency shutoff switch: It is a mushroom switch to shutoff motor power in the event of an emergency. It does not turn off the computer power.



(a) Load/unload mode (b) Move-ahead mode (c) Transport mode

Figure 6-1. Illustration of TMRR liftgate operating modes

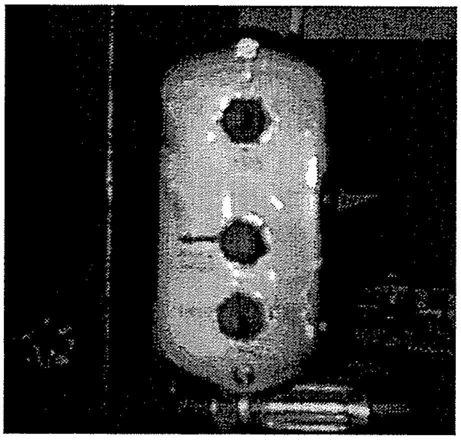


Figure 6-2. Liftgate control pendent

2. Motor controller power indicator light: It indicates that the motor controller power is ready to be turned on. It does not necessarily mean that the motors are already turned on.
3. Motor controller off/enable switch: Only when this switch is on, the motors can be turned on (with the motor controller on indicator light/push button (#4 in the Figure 6-2)). It should be switched to the right position to turn on.
4. Motor controller on indicator light/push button: It is a push button to turn on the motor power. It also indicates whether the motor power is on or not.
5. Linear slide power indicator light: It indicates that linear slide power is ready to be turned on. It does not necessarily mean that the linear slide is already turned on.
6. Linear slide off/enable switch: Only when this switch is on, the linear slide can be turned on (with the linear slide on indicator light/push button (#7 in the Figure 6-2)). It should be switched to the right position to turn on.
7. Linear slide on indicator light/push button: It is a push button to turn on the motor power. It also indicates whether the motor power is on or not.
8. Master power switch: It is a keyed switch to turn on all power. Anything in the controller cabinet cannot be turned on when this is off (left position).
9. Computer power switch: Computer power switch.
10. Laser controller power push button: It turns on the laser controller power.
11. Laser controller test push button: It is used to test the laser controller.
12. Laser controller master switch: It is a keyed master switch for the laser controller.
13. Laser indicator light: It indicates that the power is going through the laser.
14. Laser current control knob: It controls the amount of current going through laser.

6-3. TMRR Operation

This section describes how to operate the TMRR with the basic knowledge described in the previous section. Before TMRR operation, the liftgate should be in the Crack sealing/routing mode (that is, the TMRR is on the ground and the lifting platform is in the up-right position) and all power cables should be properly connected. The operation procedures will be described step

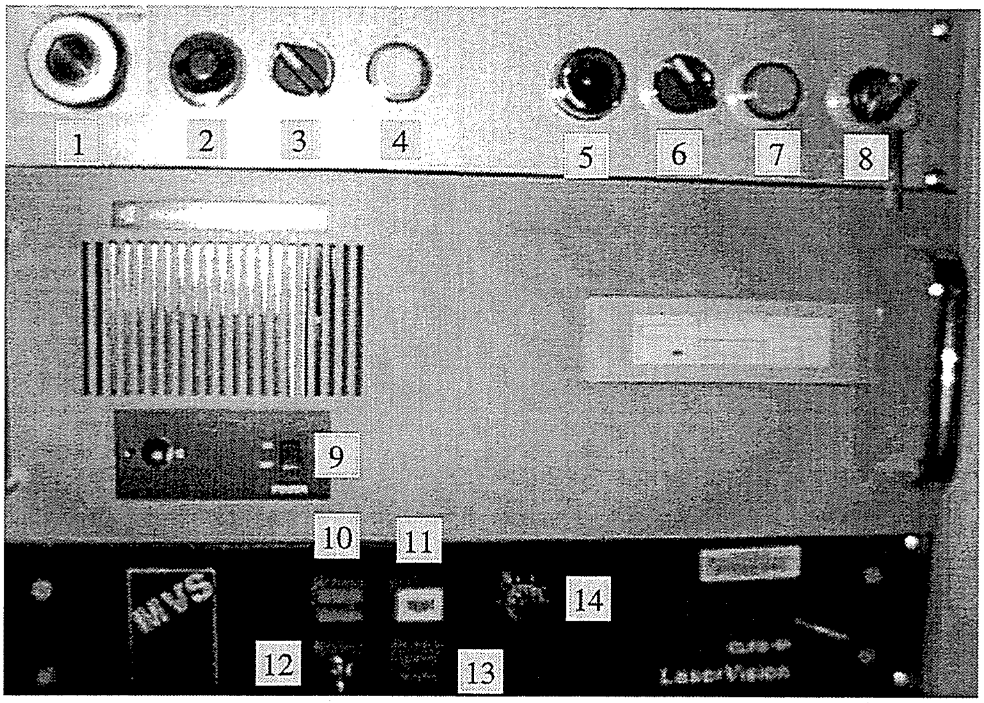


Figure 6-3. Front panel of controller cabinet, *1: emergency shutoff switch, 2: motor controller power indicator light, 3: motor controller off/enable switch, 4: motor controller on indicator light/push button, 5: linear slide power indicator light, 6: linear slide off/enable switch, 7: linear slide on indicator light/push button, 8: master power switch, 9: computer power switch, 10: laser controller power push button, 11: laser controller test push button, 12: laser controller master switch, 13: laser indicator light, 14: laser current control knob*

by step in the following sub-sections. First, power-up procedures will be explained. Then, control program initialization and three different control modes will follow.

A. <u>Power-Up</u>

1. Turn on the UPS which is placed in front of the controller cabinet. The computer power is supplied through the UPS.
2. Turn on the master power switch (#8 in the Figure 6-3). Make sure that the emergency shutoff switch (#1 in the Figure 6-3) and the emergency foot switch (Figure 6-4) are in pull position. Then, the indicator lights #2 and #5 in the Figure 6-3 should be lit.
3. Make sure that the motor controller off/enable switch should be at off position. This is because the command signal for the motor controller should be initialized before the motor power is supplied and this is done by the computer boot-up routine. Then, Turn on the computer power switch (#9 in the Figure 6-3) and the computer monitor.

B. <u>TMRR Control Program Initialization</u>

1. The control program is in the directory 'C:\TMRR'. Go into that directory and run 'TMRR'.
2. You will get the message, "Place the robot at the initial position and type y when ready". Then, place the TMRR at the index position and press 'y'.
3. Then, you will get the prompt, "TMR>>". Now, you are ready to run the following commands.

? : Help screen
a : Joystick control including rear arm
b : Clear rear arm control flag
c : Read CET
f : Turn off relay
h : Halt all motors
j : Joystick control (not include rear arm)
k : Swing rear arm with joystick
l : Laser tracking control
o : Turn on relay
p : Preprogrammed path
q : Quit!
r : Set rear arm position command (0-120000 = 0-180degree)
s : Send speed commands to motor drives
v : Return to default video mode

4. Turn the motor controller off/enable switch to the right and push the motor controller on indicator light/push button. Then, the push the motor controller on indicator light/push button will be lit, which means the motor controller is powered up.

C. *Joystick Control*
1. Type 'j' right after the prompt to run the joystick control mode.
2. Type 'o' to enable the motor drives.
3. Figure 6-5 shows the joystick control device.
4. Type any key to return the main prompt "TMR>>".

D. *Pre-programmed Path Following*
1. Place the robot around (-40, 70) with approximately 70° using the joystick control mode.
2. Type 'o' to enable the motor controllers.
3. Type 'b' to run the tracking control mode, then, the robot will start to follow the path.
4. Type any key to stop the robot. Then, you will get the main prompt "TMR>>".

E. *Laser Tracking Control*
1. You have to turn on the laser controller first. To do that, turn on the laser controller master switch (#12 in the Figure 6-3) and push the laser controller power push button (#10 in the Figure 6-3).
2. Place the robot on the starting position of a crack using the joystick control mode.
3. Type 'm' to run laser control mode and wait for a while until the laser sensor is initialized and stop on the crack.
4. You can stop the robot by hitting any key while operation.

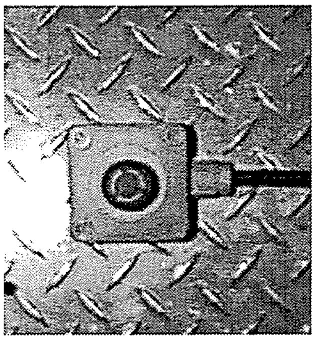


Figure 6-4. Emergency foot switch

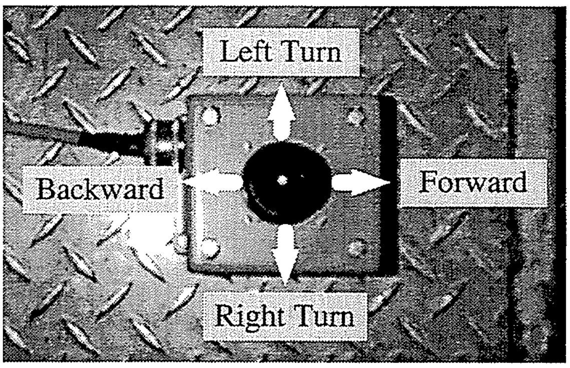


Figure 6-5. Joystick

CHAPTER 7

CONCLUSION

The Tethered Mobile Routing Robot (TMRR) has been developed at the Advanced Highway Maintenance and Construction Technology (AHMCT) Research Center at the University of California at Davis in order to automate the highway crack sealing operation. The TMRR is a differentially steered wheeled mobile robot with a centrally located router and articulated sealant head. A laser range sensor is installed from the front of the robot to allow for automated crack following. The sensor is slide mounted to provide the necessary field of view. A support vehicle provides all power and materials through the use of a tether, and also contains a vision based sensing system for crack identification. The robot position relative to the support vehicle utilizes a cable extension transducer based system.

The development effort has involved development of system design concept evolved from the TMR concept, improvement of sensor systems including robot localization system using CETs and crack sensing system, design and construction of a prototype TMRR attached to the Automated Crack Sealing Machine (ACSM). Also, the controller hardware was appropriately constructed and the control algorithm developed in the previous stage was successfully implemented on the robot.

This document has concisely reviewed some of the important aspects of the TMRR system development. The interested reader is referred to the noted technical reports and documents for additional detail.

CHAPTER 8

REFERENCES

Boyden, D. and Velinsky, S.A. (1993) "Dynamic Modeling of Wheeled Mobile Robots," *AHMCT Research Report UCD-ARR-93-10-5-01*, University of California at Davis.

Chung, J.H. (1996) "Modeling and Control of Mobile Manipulators," *Ph.D. Dissertation*, University of California at Davis.

Hong, D. (1994) "Control System Development for Tethered Mobile Robot for Automating Highway Maintenance Operations," *AHMCT Research Report UCD-ARR-94-09-12-01*, University of California at Davis.

Hong, D., Mueller, K.J., and Velinsky, S.A. (1995) "Mobile Robot Localization by Cable-Extension Transducers," Computational Kinematics '95, J.-P. Merlet and B. Ravani eds, Kluwer Academic Publishers, Netherlands, pp.19-30.

Hong, D., Velinsky, S.A., and Yamazaki, K. (1997) "Tethered Mobile Robot for Automating Highway Maintenance Operations," *Robotics and Computer Integrated Manufacturing*, in press.

Kochekali, H. and Velinsky S.A. (1994) "Adaptation of wheeled mobile robots to highway maintenance operations," *AHMCT Research Report UCD-ARR-94-1-5-01*, University of California at Davis.

Krulewich, D.A. and Velinsky, S.A. (1992) "Development of a High Resolution Sensing System for Automated Crack Sealing Machinery," *Interim Report of SHRP H-107A*, National Research Council Strategic Highway Research Program, Washington D.C.

Matsumoto, L.S. (1996) "Development and Testing of a Crack Sensing System for a Tethered Mobile Routing Robot," *MS Thesis*, University of California at Davis.

Mueller, K.A., Hong, D., and Velinsky, S.A., 1996, "A Wheeled Mobile Robot for Automated Pavement Crack Sealing," *Proceedings of Robotics for Challenging Environments,* 178-184.

Velinsky, S.A. (1993) "Fabrication and Testing of Maintenance Equipment Used for Pavement Surface Repairs," *Final Report of SHRP H-107A*, National Research Council Strategic Highway Research Program, Washington D.C.

Velinsky, S.A., Hong, D., and Mueller, K.A. (1994) "Development of a Tethered Mobile Robot for Highway Maintenance," *AHMCT Research Report UCD-ARR-94-10-31-01*, University of California at Davis.

Zhang, Y.L., Velinsky, S.A. (1994) "Tracking Control Algorithms for the Tethered Mobile Robot," *AHMCT Research Report UCD-ARR-94-06-30-01*, University of California at Davis.

Winters, S.E. and Velinsky, S.A. (1992) "Development of a tethered mobile robot (TMR) for highway maintenance," *AHMCT Research Report UCD-ARR-92-11-25-01*, University of California at Davis.

Zhang, Y.L., Velinsky, S.A. and Feng, X. (1997) "On the Tracking Control of Differentially Steered Wheeled Mobile Robots," *ASME Journal of Dynamic Systems Measurement & Control*, in press.

APPENDIX A

COMPONENT LIST

Table 1. Component list

Name	Model	Manufacturer	E.t.c
Pentium CPU Board	SB586P	Industrial Computer Source	Pentium single board computer
A/D Converter Board	CYDAS 8JR-AO	CyberResearch, Inc.	
D/A Converter Board	CYRDDA 06	CyberResearch	
Encoder Interface Board	M5312B	Industrial Computer Source	4 channel encoder interface card
PC to Incremental Encoder Interface Card	PC7166	U.S. Digital Co.	4 channel encoder interface card
Digital I/O Board	CYRDIO 32	CyberResearch	
Laser Sensor	Laser Vision Sensor MVS-30	MVS Modular Vision Systems Inc.	
BLDC Motor	S-3016	Electro-Craft	Brushless DC motor
BLDC Motor	S-4050	Electro-Craft	Brushless DC motor
BLDC Motor Drive	DM-20	Electro-Craft	Motor drive for S-3016
BLDC Motor Drive	DM-30	Electro-Craft	Motor drive for S-4050
Linear Slide Assembly	Linear Positioner	JASTA	
Gear Head	RA90-100	Bayside	100:1 ratio
Cable Extension Transducer (CET)	PT9150	Celesco	
Joystick	Induction Type Joystick Control	Maurey	Allied Electronics, Co.
Industrial PC Enclosure	7500	Industrial Computer Source	15 slots enclosure
Subminiature Mark Sensor	MQ-VD2AR-DC12-24V	Aromat	

APPENDIX B

TMRR CONTROL PROGRAM

```
////////////////////////////////////////////////////////////////////////////////////////////
//                                                                                        //
// TMRR CONTROL PROGRAM                                                                   //
//                                                                                        //
// AUTHOR: DAEHIE HONG                                                                    //
//                                                                                        //
// REVISION:                                                                              //
//      timer interrupt & CET real-time calculation                                       //
//      joystick control including rear arm, sampling rate for the joystick               //
//      control is 25Hz (=40ms).                                                          //
//      pre-programmed path.                                                              //
//      timer interrput routine is replaced with new one (no assembly parts).             //
////////////////////////////////////////////////////////////////////////////////////////////

#include <process.h>
#include <stdio.h>
#include <bios.h>
#include <conio.h>
#include <string.h>
#include <math.h>
#include <dos.h>
#include <graph.h>
#include <stdlib.h>

#include "m5312.c"
#include "ibm.h"


#define TMR_INTR


/*************************************************************************/
/* Define parameters                                                     */
/*************************************************************************/
#define S_limit 4000        // speed limit for driving wheels
#define Sr_limit 500        // speed limit for rear arm

#define rp    2.037         // CET pulley radius
#define HH    17            // CET base length
#define DD    38.074        // 2*(HH+rp)
#define DD2   19.037        // DD/2
#define Thr0  0.8142        // =46.65degree, initial angle for robot
                            // angular position measurement
#define IL1       31.633    // initial cable lengths
#define IL2       31.633
#define MaxEncoder    16777216    /* Maximum number of the 24 bit counter */
#define MaxEncoder2   8388608     /* and half of it */
#define Sensitivity   1004.804    /* 251.201 pulses per inch */


#define PI    3.141592654
```

```
#define cot(a)  (cos(a)/sin(a))
#define NTRIAL  5
#define TOLX    1.0e-6
#define N       4
#define TOLF    1.0e-6

#define RARM_LENGTH     12                    // rear arm length = 12"

/****************************************************************************/
/* Define parameters for A/D converter                                      */
/****************************************************************************/
#define BASE          0x200
#define ADC_LSB        BASE
#define ADC_MSB        BASE + 1
#define ADC_START      BASE + 1
#define ADC_CONTROL    BASE + 2
#define ADC_STATUS     BASE + 2
#define ADC_CH_0      0
#define ADC_CH_1      1

/****************************************************************************/
/* Define parameters for screen display                                     */
/****************************************************************************/
#define dashed 0xA0A0
#define solid 0xFFFF
#define red 4
#define cyan 3
#define green 2
#define yellow 14
#define white 7
#define lt_blue 9
#define brt_green 0
#define lt_magenta 13
#define black 0
#define blue 1

#define no_vert_lines 18
#define xconstant 35
#define no_horiz_lines 11
#define yconstant 35
#define pi 3.1415927
#define cga 2.0833333  /* distance from front of TMR to applicator in inches */
#define cgb 0.416667   /* distance from rear of TMR to applicator in inches */

/****************************************************************************/
/* Define parameters for sound (timer, speaker)                             */
/****************************************************************************/
#define TIMER_FREQ     1193180L
#define TIMER_COUNT    0x42
#define TIMER_MODE     0x43
#define TIMER_OSC      0xb6
#define OUT_8255       0x61
#define SPKRON         3

/****************************************************************************/
```

```
/* Define function prototypes                                    */
/***************************************************************************/
void   relay_on(int);
void   relay_off(int);
void   Send_Velocity_Commands(int, int);
void   Send_Velocity_RearArm(int);
float  AD_convert(int);
void   init_joystick(void);
void   joystick(int);
void   Stop_Motors(void);
long   Read_Rear_Encoder(void);
void   joystick_rear(int);
void   cet_rt(float *, float *, float *);
void   get_CET(float *, float *, float *);
void   usrfun(float, float);
void   mnewt(int,int,float,float, float,float);
void   lubksb(int,int *);
float  aatan(float, float, float, float);
int    Tracking_Control(void);
void   Help_Screen();
void   draw_tmr(float, float, float, int, int, int, int, int, int);
void   create_replace_grid(void);
void   mark_origin(int, int);
void   set_workspace(void);
void   draw_tmr_trajectory(void);
void   sound_on(unsigned);
void   sound_off(void);

#ifdef TMR_INTR
  void (interrupt far *OldTimerVect)();          /* save original vector */
  void interrupt far Timer_Intr_SR(void);
  void init_timer(void);
  void restore_timer(void);
  void settimer( long ms );
  long ReadClock();
#endif

#define ESC 27
extern void        sendline(unsigned char *s);
extern void rsout(unsigned char ch);

float Volt0_i,Volt1_i;       /* initial voltages of joystick */
int BaseAddr = 0x320;        /* Base Address for D/A borad */

// parameters for timer interrupt
long int no_ticks=0L;
long int ms=5L;

// parameters for rear arm position control
long int pos_c, pos_e;
long int pos_r=0;
long int pos_e_int=0;
int     RA_flag = 0;

// parameters for real-time calculation of CET system
```

```
float x[N+1], alpha[N+1][N+1], bet[N+1];

// buffer for robot posture
#define BL          2000
float Xcc[BL], Ycc[BL], Tcc[BL];
int bf=0, bp=0, nbf=0, nbp=0, bp1=0, bp2=0, bpo=0;
int movef_flag=0, outside_arm=0, inside_arm=0, bf_bp=0;

int x_pos, y_pos, x0, x1, x2, x3, x4, yy0, yy1, y2, y3, y4;
int tx1, tx2, tx3, tx4, tx5, tx6, tx7, tx8;
int ty1, ty2, ty3, ty4, ty5, ty6, ty7, ty8;


main()
{
   int rn,wl,wr,ra;
   char ch, cc1;
   long      d_cnt;  /* counter values          */
   long      tmp_pos_r;
   float     Xc,Yc,Tc;           // Robot Posture w.r.t. fixed frames
   float         xcr, ycr,xcr1,ycr1;  // Robot posture w.r.t. rear arm frames
   long int   begtime, no_sampling=0;
   float         cosT,sinT,radarm, arm_angle;
   int           loop_count, bpp;
   int       ik;

   relay_off(0);
   relay_off(1);
   relay_off(2);
   Stop_Motors();

   init_joystick();   /* get initial position of joystick  */

#ifdef TMR_INTR
   init_timer();
   settimer(ms);      // generate timer interrupt every ms (default=5) ms
#endif

/** initialize each encoder - see manual for detail parameter setting **/
   init_encoder(AXIS_A, MCRE, ICR, OCCR, QR, enc_base); /* init a          */
   init_encoder(AXIS_B, MCRE, ICR, OCCR, QR, enc_base); /* init b          */
   init_encoder(AXIS_C, MCRE, ICR, OCCR, QR, enc_base); /* init c          */
   init_encoder(AXIS_D, MCRE, ICR, OCCR, QR, enc_base); /* init d          */
   printf("\n");
   do {
         printf("\rPlace the robot at the initial position and type y when ready");
         cc1 = getchar();
   }while( cc1 != 'y');

   load_cntr(WR_ALL, 0l, enc_base);   /* zero counters of encoders on linkage   */

   do
   {
         printf("\nTMR>> ");
         ch = getchar();
```

```
switch (ch) {
        case '?' :
                Help_Screen();
                break;

        case 'a' :      // joystick control including rear arm,
                RA_flag = 1;
        begtime = ReadClock();
        no_sampling = 0;
                while( !kbhit() ) {
                        joystick(1);     // forward motion only
                        cet_rt(&Xc,&Yc,&Tc);

                        if (RA_flag) {
                                if (bf >= BL) {
                                        bf = 0;      // if buffer front >= buffer length, return to buffer
                                        nbf++;       // start & increase number of turns
                                }
                                if (movef_flag) {                    // if the robot moves forward,
                                        Xcc[bf] = Xc;                     // store robot posture in buffer.
                                        Ycc[bf] = Yc;
                                        Tcc[bf] = Tc;
                                        bf++;
//              printf("\n-----------1\n");
                                }

                                cosT = cos(Tc);
                                sinT = sin(Tc);
                                inside_arm = 0;
                                outside_arm = 0;

                //      printf("\n-----------2\n");

        //      if (bp == BL) { bp = 0; nbp++; }

                                xcr =  (Xcc[bp] - Xc)*cosT + (Ycc[bp] - Yc)*sinT;
                                ycr = -(Xcc[bp] - Xc)*sinT + (Ycc[bp] - Yc)*cosT + 16.0;
                                xcr = -xcr;
                                ycr = -ycr;
                                radarm = sqrt(xcr*xcr + ycr*ycr);
                //              printf("\n%f %f %f\n",xcr,ycr,radarm);
                                if ( (ycr > 0) && (radarm >= RARM_LENGTH) ) {
                                outside_arm = 1;
                                inside_arm = 0;
                                while(!inside_arm) {
                                                bp++;
                                                if (bp == BL) { bp = 0; nbp++; }
                                                xcr = (Xcc[bp]-Xc)*cosT + (Ycc[bp]-Yc)*sinT;
                                                ycr = -(Xcc[bp]-Xc)*sinT + (Ycc[bp]-Yc)*cosT +
16.0;

                                                radarm = sqrt(xcr*xcr + ycr*ycr);
                                                if (radarm < RARM_LENGTH) {
                                                inside_arm = 1;
                                                xcr = -xcr;
                                                ycr = -ycr;
```

```
                                        arm_angle = aatan(0,0,xcr,ycr) * 120000/PI;
                                        pos_r = (long) arm_angle;
                                        }
                              }
                              }
                              if (inside_arm) bp--;
                              if ( (bp == -1) && (nbp != 0) ) bp = BL - 1;
                    }

          while( (ReadClock()-begtime) < 10 );   // 10 ms sampling time
                    no_sampling++;
                    printf("\rRobot posture: %6.2f %6.2f %6.2f %ld",Xc,Yc,Tc,no_sampling);
                    begtime = ReadClock();
               }
               RA_flag = 0;
               break;

          case 'b' :
               RA_flag = 0;
               break;

     case 'c' :
               cet_rt(&Xc,&Yc,&Tc);
               printf("\nRobot posture: %6.2f %6.2f %6.2f\n",Xc,Yc,Tc);
               break;

     case 'f' :
          relay_off(0);
          relay_off(1);
          relay_off(2);
          RA_flag = 0;
          break;

     case 'h' :
          relay_off(0);
          relay_off(1);
          relay_off(2);
          RA_flag = 0;
          Stop_Motors();
          break;

     case 'j' :
     RA_flag = 0;
     sendline("CALL DEMO");
          while( !kbhit() ) {
               joystick(0);
               cet_rt(&Xc,&Yc,&Tc);
               printf("\rRobot posture: %6.2f %6.2f %6.2f ",Xc,Yc,Tc);
          }
          rsout(ESC);
          break;

     case 'k' :
     relay_off(0);
     relay_off(1);
```

```
                relay_on(2);
                RA_flag = 0;
                while( !kbhit() ) joystick_rear(0);
                relay_off(2);
                break;

/*
        case 'l' :
                ik = Tracking_Control_Laser();
                if ( ik != 0)
                   printf("\n......Tracking crack path. Type any key to stop.");
                else
                   printf("\n......Error on tracking control with laser.");
                break;

        case 'm' :
                ik = Tracking_Control_Laser_real();
                if ( ik != 0)
                   printf("\n......Tracking crack path. Type any key to stop.");
                else
                   printf("\n......Error on tracking control with laser.");
                break;
*/

        case 'o' :
                relay_on(0);
                relay_on(1);
                relay_on(2);
                break;

        case 'p' :
                ik = Tracking_Control();
                if ( ik != 0)
                   printf("\n......Tracking sinusoidal curve. Type any key to stop.");
                else
                   printf("\n......Error on tracking control mode.");
                break;

        case 'q' :
                sendline("STOP");
                Stop_Motors();
                relay_off(0);
                relay_off(1);
                RA_flag = 1;
                begtime = ReadClock();
                pos_r = 0;
                while( ReadClock() - begtime < 2000 );
                relay_off(2);

#ifdef TMR_INTR
                restore_timer();
#endif //TMR_INTR

                exit(1);
```

```
        case 'r' :
                relay_on(2);
                RA_flag = 1;
                printf("\nEnter reference position (0 - 120000): ");
                scanf("%ld",&tmp_pos_r);
                if (tmp_pos_r < 0 || tmp_pos_r > 120000) {
                   Send_Velocity_RearArm(0);
                   break;
                }
                else pos_r = tmp_pos_r;
                break;

        case 's' :
                relay_on(2);
                printf("\n\nInput speeds (left, right, rear arm (RPM)): ");
                scanf("%d %d %d",&wl, &wr, &ra);
                Send_Velocity_Commands(wl,wr);
                Send_Velocity_RearArm( ra );
                break;

        case 'v' :
                _setvideomode( _DEFAULTMODE );
                break;

      };

   }while(1);
}



void Help_Screen()
{
        printf("\n  ? : Help screen ");
        printf("\n  a : Joystick control including rear arm ");
        printf("\n  b : Clear rear arm control flag ");
        printf("\n  c : Read CET ");
        printf("\n  f : Turn off relay ");
        printf("\n  h : Halt all motors ");
        printf("\n  j : Joystick control (not include rear arm) ");
        printf("\n  k : Swing rear arm with joystick ");
        printf("\n  l : Laser tracking control ");
        printf("\n  o : Turn on relay ");
        printf("\n  p : Preprogrammed path ");
        printf("\n  q : Quit! ");
        printf("\n  r : Set rear arm position command (0-120000 = 0-180degree) ");
        printf("\n  s : Send speed commands to motor drives ");
        printf("\n  v : Return to default vedio mode \n");

}

#ifdef TMR_INTR ///////////////////////////////////////////////////////

void interrupt far Timer_Intr_SR(void)
/*    Interrupt Service Routine                    */
```

```
/*    This routine is interrupted whenever timer 0 overflows        */
{
   int ra;
   int RA_flag_1 = 1;

   if (pos_r < 0 || pos_r > 120000) RA_flag_1 = 0;

   if (RA_flag && RA_flag_1) {

          pos_c = Read_Rear_Encoder();
          pos_e = pos_r - pos_c;
          ra = (int) (pos_e / 20);
          if (pos_e < 10000) pos_e_int = pos_e_int + pos_e;
          pos_e_int = pos_e_int / 20;
          ra = ra + pos_e_int;
          Send_Velocity_RearArm( ra );
   }

          no_ticks++;
          outp(INTCTL0, TMREOI);
}


void init_timer(void)
/*    initialize timer and interrupt enable register  */
{
          OldTimerVect = _dos_getvect(TIMER_VECT);   /* save old vector      */
          _disable();
          _dos_setvect(TIMER_VECT, Timer_Intr_SR);  /* set a new vector     */
          _enable();

}

void restore_timer(void)
{
   settimer(-1);
   _dos_setvect(TIMER_VECT, OldTimerVect);     /* restore DOS timer vector */
}

long ReadClock()       // return time in milisecond, resolution is ms
{
   return( ms * no_ticks );
}

/*************************************************************************

PROCEDURE
          settimer - set interrupt interval in millisecond

SYNOPSIS
          settimer( long ms )

PARAMETERS
          ms - interval in millisecond
```

```
REMARKS
        Since the max interval for the IBM-PC corresponds to a max
        count 65535, the maximum value of ms is limited to 54.9 ms.

***************************************************************************/

void settimer( long ms )
{
        long count;

        if ( (ms > 0L) && (ms < 55L ) )
        {
                count = ((CLOCKFREQ * ms) + 500L) / 1000L;

                outp(TIMER_CTL, 0x36);          // mode 3, 16-bit binary count

                outp(TIMER, count & 0xff);      // send least sig byte first,
                outp(TIMER, (count >> 8) & 0xff); // and then most sig byte
        }
        else if (ms <= 0L)      // reset to DOS clock rate
        {
                outp( TIMER_CTL, 0x36);
                outp( TIMER, 0xff);
                outp( TIMER, 0xff);
        }
        else
        {
                printf("settimer: %ld ms out of timer range\n", ms);
        }

}

#endif //////////////////////////////////////////////////////////////////////


void relay_on(int rn)
{
   int base,reg,bitnum, portx;
   char ch;

   base = 0x330;

   reg = rn / 8;
   if (reg == 0) bitnum = rn;
   else bitnum = rn - 8;

   if (reg == 0) {
          portx = inp(base + 4);
          portx = portx | (1 << bitnum);
          outp(base+4,portx);
   }
   else {
          portx = inp(base + 5);
          portx = portx | (1 << bitnum);
          outp(base+5,portx);
```

```
    }
}

void relay_off(int rn)
{
    int base,reg,bitnum, portx;
    char ch;

    base = 0x330;

    reg = rn / 8;
    if (reg == 0) bitnum = rn;
    else bitnum = rn - 8;

    if (reg == 0) {
            portx = inp(base + 4);
            portx = portx & ~(1 << bitnum);
            outp(base+4,portx);
    }
    else {
            portx = inp(base + 5);
            portx = portx & ~(1 << bitnum);
            outp(base+5,portx);
    }
}

/*******************************************************/
void joystick(int flag)
/*******************************************************/
{
    float Volt0, Volt1, Left, Right;
    int wl, wr;

            Volt0 = AD_convert(0) - Volt0_i;
            Volt1 = AD_convert(1) - Volt1_i;
            if (fabs(Volt0) < 0.05) Volt0 = 0;
            if (fabs(Volt1) < 0.05) Volt1 = 0;

            if (Volt0 <= -0.05) movef_flag = 1;  // move forward flag
            else movef_flag = 0;

            if (flag && !movef_flag) Volt0 = 0; // if flag is true, forward motion only

            Left = - Volt0 * 1500 + 1000 * Volt1;
            Right =  Volt0 * 1500 + 1000 * Volt1;

            wl = (int) Left;
            wr = (int) Right;
            Send_Velocity_Commands(wl,wr);


}

/*******************************************************/
void joystick_rear(int flag)
```

```
/*********************************************************/
{
   float Volt0, Volt1, Left, Right;
   int wl, wr;

         Volt0 = AD_convert(0) - Volt0_i;
         Volt1 = AD_convert(1) - Volt1_i;
         if (fabs(Volt0) < 0.05) Volt0 = 0;
         if (fabs(Volt1) < 0.05) Volt1 = 0;

         Left = Volt0 * 500;

         printf("Voltages: %5.3f %5.3f \r", Volt0, Volt1);
         if (flag) {
            Left = Left * 0.2;
            Right = Right * 0.2;
         }
         wl = (int) Left;

         Send_Velocity_RearArm(wl);

//       fprintf(outfile,"%4.2f %4.2f\n",Left,Right);

}

/*********************************************************/
float AD_convert(int ch_no)
/*********************************************************/
{
   unsigned ADC_value, MSB, LSB;
   int i;
   float Volt;

   outp(ADC_CONTROL, ch_no);
   outp(ADC_START, 0);
   for (i=0; i<10; i++);      // wait for a while to aviod over-running the ADC
   while( inp(ADC_STATUS) & 0x80 );
   MSB = inp(ADC_MSB) & 0xff;
   LSB = inp(ADC_LSB) & 0xf0;
   ADC_value = MSB * 16 + LSB / 16;
   Volt = ((float) ADC_value) / 409.5 - 5;
   return(Volt);
}

/*********************************************************/
void init_joystick(void)
/*********************************************************/
{
   int i;

   Volt0_i = 0;
   Volt1_i = 0;
   for (i=0; i<10; i++) {
         Volt0_i = AD_convert(0) + Volt0_i;
         Volt1_i = AD_convert(1) + Volt1_i;
```

```
    }
    Volt0_i = Volt0_i / 10;
    Volt1_i = Volt1_i / 10;
}

/*************************************************************************/
/* Send velocity commands to the motor drives                           */
/*************************************************************************/
void Send_Velocity_Commands(int wl, int wr)
{
    int tmp_read;
    int chl;                    /* Channel and value to write */
    int HByte, LByte;                /* High byte and low byte */

    wl = -wl;
    wr = -wr;

    if (wl > S_limit)  wl = S_limit;
    if (wl < -S_limit)  wl = -S_limit;
    if (wr > S_limit)  wr = S_limit;
    if (wr < -S_limit)  wr = -S_limit;

    wl = wl / 2 + 2047;     /* convert rpm to DAC number    */
    wr = wr / 2 + 2047; /* 0 = -4000 rpm, 2048 = 0 rpm, 4095 = 4000 rpm */

    HByte = wl / 256;               /* Convert to high byte */
    LByte = wl & 0xFF;                /* Convert to low byte */
    chl = 0;
    outp(BaseAddr+chl*2,LByte);        /* Write low byte first */
    outp(BaseAddr+chl*2+1,HByte);        /* Write high byte second */
    HByte = wr / 256;               /* Convert to high byte */
    LByte = wr & 0xFF;                /* Convert to low byte */
    chl = 1;
    outp(BaseAddr+chl*2,LByte);        /* Write low byte first */
    outp(BaseAddr+chl*2+1,HByte);        /* Write high byte second */

}

/*************************************************************************/
/* Send zero velocity commands to the motor drives                      */
/*************************************************************************/
void Stop_Motors()
{
    int wl, HByte, LByte, chl;

    wl =  2047;    /* convert rpm to DAC number    */

    HByte = wl / 256;            /* Convert to high byte */
    LByte = wl & 0xFF;               /* Convert to low byte */
    chl = 0;
    outp(BaseAddr+chl*2,LByte);        /* Write low byte first */
    outp(BaseAddr+chl*2+1,HByte);        /* Write high byte second */
    chl = 1;
    outp(BaseAddr+chl*2,LByte);        /* Write low byte first */
    outp(BaseAddr+chl*2+1,HByte);        /* Write high byte second */
```

```
   chl = 2;
   outp(BaseAddr+chl*2,LByte);        /* Write low byte first */
   outp(BaseAddr+chl*2+1,HByte);      /* Write high byte second */

}

/*************************************************************************/
/* Send velocity commands to the rear arm motor drives                */
/*************************************************************************/
void Send_Velocity_RearArm(int w)
{
   int chl;                        /* Channel and value to write */
   int HByte, LByte;                  /* High byte and low byte */

   w = -w;
   if (w > Sr_limit)   w = Sr_limit;
   if (w < -Sr_limit)  w = -Sr_limit;

   w = w / 2 + 2047;    /* convert rpm to DAC number     */
                          /* 0 = -4000 rpm, 2048 = 0 rpm, 4095 = 4000 rpm */

   HByte = w / 256;                /* Convert to high byte */
   LByte = w & 0xFF;                /* Convert to low byte */
   chl = 2;
   outp(BaseAddr+chl*2,LByte);        /* Write low byte first */
   outp(BaseAddr+chl*2+1,HByte);      /* Write high byte second */

}

/*************************************************************************/
/* Read encoder on rear-arm                                */
/*************************************************************************/
long Read_Rear_Encoder()
{
   long d_cnt;

   d_cnt = read_cntr(AXIS_D, enc_base);
   if ( d_cnt > 8388608 ) d_cnt = 16777215 - d_cnt;
   else d_cnt = - d_cnt;
   return(d_cnt);
}


/*************************************************************************/
/* Real-time solutions for CET measurement                    */
/*************************************************************************/
void cet_rt(float *Xc, float *Yc, float *Tc)
{
   int i,j,k,kk;
   float xx, L1, L2,t1,t2,AA, th;

   get_CET(&L1,&L2,&th);
//   printf("\n%f %f \n",L1,L2);
//  printf("\nEnter L1 L2 :");
//  scanf("%f %f",&L1,&L2);
```

```
//  printf("\n");

// check validity of data, L1,L2.
        if ( (L1+L2 < DD) || (L1+DD < L2) || (L2+DD < L1) )
          printf("\nIt's not a triangle! Try again\n");
        else {
          if ((DD >= L1) && (DD >= L2)) {
            AA = acos((L1*L1+L2*L2-DD*DD)/(2*L1*L2));
            t2 = asin(L1*sin(AA)/DD);
            t1 = asin(L2*sin(AA)/DD);
          }
          else if ((L1 >= DD) && (L1 >= L2 )) {
            t2 = acos((DD*DD+L2*L2-L1*L1)/(2*DD*L2));
            t1 = asin(L2*sin(t2)/L1);
          }
          else {
            t1 = acos((L1*L1+DD*DD-L2*L2)/(2*L1*DD));
            t2 = asin(L1*sin(t1)/L2);
          }

// Initial guess
          x[1] = -DD2 + L1 * cos(t1);
          x[2] =  L1 * sin(t1);
          x[3] = t1;
          x[4] = t2;

//      printf("Starting initial vector \n");
//      for (i=1;i<=4;i++) {
//         printf("%7s%1d%s %5.2f\n",
//              "x[",i,"] = ",x[i]);
//      }
//      printf("\n");
          mnewt(10,N,TOLX,TOLF,L1,L2);

//      usrfun(L1,L2);
//      printf("%5s %13s %13s\n","i","x[i]","f");
//      for (i=1;i<=N;i++)
//         printf("%5d %14.6f %15.6f\n",i,x[i],-bet[i]);
         }

   th = -th*0.00011877 - x[4] + Thr0;

   *Xc = x[1];
   *Yc = x[2];
   *Tc = th;


}


/******************************************************************************/
void    get_CET(float *L1, float *L2, float *th)
/******************************************************************************/
{
   long    a_cnt, b_cnt, c_cnt;                    /* Counter values */
```

```
		a_cnt = read_cntr(AXIS_A, enc_base);		/* Reading counters */
		b_cnt = read_cntr(AXIS_B, enc_base);
		c_cnt = read_cntr(AXIS_C, enc_base);
//	printf("\n%ld %ld %ld\n",a_cnt,b_cnt,c_cnt);

		if ( a_cnt > MaxEncoder2 ) {
			*L1 = MaxEncoder - a_cnt;
		}
		else {
			*L1 = - a_cnt;
		}
		*L1 = *L1/Sensitivity + IL1;

		if ( b_cnt > MaxEncoder2 ) {
			*L2 = MaxEncoder - b_cnt;
		}
		else {
			*L2 = - b_cnt;
		}
		*L2 = *L2/Sensitivity + IL2;

		if ( c_cnt > MaxEncoder2 ) {
			*th = MaxEncoder - c_cnt;
		}
		else {
			*th = - c_cnt;
		}
}


/**************************************************************************/
/* User functions (non-linear simultaneous equations) to be solved     */
/* CET position equations are listed below.                    */
/**************************************************************************/
void usrfun(float L1,float L2)
{
   alpha[1][1] = 0.0;
   alpha[1][2] = 1.0;
   alpha[1][3] = -L1*cos(x[3]) - rp*sin(x[3]) + rp*(PI-x[3])*cos(x[3]) + rp*sin(x[3]);
   alpha[1][4] = 0.0;
   alpha[2][1] = sin(x[3]);
   alpha[2][2] = -cos(x[3]);
   alpha[2][3] = x[2]*sin(x[3]) + (HH+x[1])*cos(x[3]);
   alpha[2][4] = 0.0;
   alpha[3][1] = 0.0;
   alpha[3][2] = 1.0;
   alpha[3][3] = 0.0;
   alpha[3][4] = -L2*cos(x[4]) - rp*sin(x[4]) + rp*(PI-x[4])*cos(x[4]) + rp*sin(x[4]);
   alpha[4][1] = -sin(x[4]);
   alpha[4][2] = -cos(x[4]);
   alpha[4][3] = 0.0;
   alpha[4][4] = x[2]*sin(x[4]) + (HH-x[1])*cos(x[4]);
   bet[1] = L1*sin(x[3]) - rp*(PI-x[3])*sin(x[3]) - x[2] + rp*cos(x[3]);
   bet[2] = x[2]*cos(x[3]) - (HH+x[1])*sin(x[3]) - rp;
```

```
    bet[3] = L2*sin(x[4]) - rp*(PI-x[4])*sin(x[4]) - x[2] + rp*cos(x[4]);
    bet[4] = x[2]*cos(x[4]) - (HH-x[1])*sin(x[4]) - rp;
}

#define TINY 1.0e-20;

void ludcmp(int n,int *indx,float *d)
{
        int i,imax,j,k;
        float big,dum,sum,temp;
        float vv[N+1];

        *d=1.0;
        for (i=1;i<=n;i++) {
                big=0.0;
                for (j=1;j<=n;j++)
                        if ((temp=fabs(alpha[i][j])) > big) big=temp;
                if (big == 0.0) printf("\nSingular matrix in routine LUDCMP\n");
                vv[i]=1.0/big;
        }
        for (j=1;j<=n;j++) {
                for (i=1;i<j;i++) {
                        sum=alpha[i][j];
                        for (k=1;k<i;k++) sum -= alpha[i][k]*alpha[k][j];
                        alpha[i][j]=sum;
                }
                big=0.0;
                for (i=j;i<=n;i++) {
                        sum=alpha[i][j];
                        for (k=1;k<j;k++)
                                sum -= alpha[i][k]*alpha[k][j];
                        alpha[i][j]=sum;
                        if ( (dum=vv[i]*fabs(sum)) >= big) {
                                big=dum;
                                imax=i;
                        }
                }
                if (j != imax) {
                        for (k=1;k<=n;k++) {
                                dum=alpha[imax][k];
                                alpha[imax][k]=alpha[j][k];
                                alpha[j][k]=dum;
                        }
                        *d = -(*d);
                        vv[imax]=vv[j];
                }
                indx[j]=imax;
                if (alpha[j][j] == 0.0) alpha[j][j]=TINY;
                if (j != n) {
                        dum=1.0/(alpha[j][j]);
                        for (i=j+1;i<=n;i++) alpha[i][j] *= dum;
                }
        }
}
```

```
#undef TINY

void lubksb(int n,int *indx)
{
	int i,ii=0,ip,j;
	float sum;

	for (i=1;i<=n;i++) {
		ip=indx[i];
		sum=bet[ip];
		bet[ip]=bet[i];
		if (ii)
			for (j=ii;j<=i-1;j++) sum -= alpha[i][j]*bet[j];
		else if (sum) ii=i;
		bet[i]=sum;
	}
	for (i=n;i>=1;i--) {
		sum=bet[i];
		for (j=i+1;j<=n;j++) sum -= alpha[i][j]*bet[j];
		bet[i]=sum/alpha[i][i];
	}
}


void mnewt(int ntrial,int n,float tolx,float tolf, float L1,float L2)
{
	int k,i,indx[N+1];
	float errx,errf,d;

	for (k=1;k<=ntrial;k++) {
		usrfun(L1,L2);
		errf=0.0;
		for (i=1;i<=n;i++) errf += fabs(bet[i]);
		if (errf <= tolf) return;
		ludcmp(n,indx,&d);
		lubksb(n,indx);
		errx=0.0;
		for (i=1;i<=n;i++) {
			errx += fabs(bet[i]);
			x[i] += bet[i];
		}
		if (errx <= tolx) return;
	}
	return;
}


float aatan(float x1, float y1, float x2, float y2)
{
  float dx, dy, ang, dydx;

  dx = x2 - x1;
  dy = y2 - y1;

  if ( dx == 0 ) {
```

```
        if ( dy > 0 ) ang = PI/2;
        else if ( dy < 0 ) ang = -PI/2;
        else ang = 1000;
  }

  else if ( dx > 0 ) {
        if ( dy == 0 ) ang = 0;
        else if ( dy > 0 ) {
           dydx = dy/dx;
           if ( dydx > 100000 ) ang = PI/2;
           else ang = atan(dydx);
        }
        else {
           dydx = dy/dx;
           if ( dydx < -100000 ) ang = -PI/2;
           else ang = - atan(-dydx);
        }
  }

  else {
        if ( dy == 0 ) ang = PI;
        else if ( dy > 0 ) {
           dydx = dy/dx;
           if ( dydx < -100000 ) ang = PI/2;
           else ang = PI - atan(-dydx);
        }
        else {
           dydx = dy/dx;
           if ( dydx > 100000 ) ang = -PI/2;
           else ang = PI + atan(dydx);
        }
  }
  return(ang);
}


/*************************************************************************/
/* Tracking control with table reference                               */
/*************************************************************************/
int     Tracking_Control(void)
{
  int    wli, wri, ttt, tti;
  float  th1,th2,th3, Xr,Yr,Tr, ur,rr, Xc,Yc,Tc, xa,y,p, X0,Y0,T0;
  float  e = 0, c = 1.2, T2 = 24.0, R = 7.0;
  float  invE[2][2], f[2], K[2][2], z, u[2], u1[2], wl, wr;
  char   sf[20];
  char   buffer1[100], buffer2[100];

  int    j,k, xorigin, yorigin;
  int    left_corner_x, left_corner_y, right_corner_x, right_corner_y;
  int    x_old, x_new, y_old, y_new, x_old_r, y_old_r, x_new_r, y_new_r;
  int    hor_lines, ver_lines, line_start_x, line_start_y;
  char   xvalue, yvalue, thetavalue;
  float  angular_pos, x_pos, y_pos;
```

```
long      begtime;

FILE   *f1;

if ( (f1 = fopen("c:\\hong\\tmr\\ncontrol\\ref_path.dat","r")) == NULL ) {
        printf("\nError! Reference path data file can not be opened");
        return(0);
}

/* Set control gain matrix */
printf("\nInput control gains( K(1,1),K(1,2),K(2,1),K(2,2)): ");
scanf("%f %f %f %f",&K[0][0],&K[0][1],&K[1][0],&K[1][1]);

cet_rt(&X0,&Y0,&T0);
T0 = T0 + 1.5708;
_setvideomode( _VRES16COLOR );
set_workspace();

/* MAKES GRIDLINES FOR WORKSPACE */
xorigin = 9+no_vert_lines/2*xconstant;
yorigin = 65+(no_horiz_lines-2)*yconstant;
mark_origin(xorigin, yorigin);
/* SCANS FIRST POSTURE OF TMR */
x_old = xorigin+(int)(X0*xconstant/12);
y_old = yorigin-(int)(Y0*yconstant/12);

fscanf(f1,"%f %f %f %f %f\n",&Xr,&Yr,&Tr,&ur,&rr);
Yr = Yr + 30;
x_old_r = xorigin+(int)(Xr*xconstant/12);
y_old_r = yorigin-(int)(Yr*yconstant/12);

begtime = ReadClock();

while( !kbhit() && ((fscanf(f1,"%f %f %f %f %f\n",&Xr,&Yr,&Tr,&ur,&rr)) != EOF) ) {
cet_rt(&Xc,&Yc,&Tc);
Yr = Yr + 30;
Tc = Tc + 1.5708;
        /* Calculate error posture in body coordinate */
        xa = (Xr - Xc)*cos(Tc) + (Yr - Yc)*sin(Tc);
        y = -(Xr - Xc)*sin(Tc) + (Yr - Yc)*cos(Tc);
        p = Tr - Tc;
        invE[0][0] = -1;
        invE[0][1] = -y/(e+xa+c);
        invE[1][0] = 0;
        invE[1][1] = -1/(e+xa+c);
        f[0] = ur*cos(p);
        f[1] = ur*sin(p) + c*rr;

        z = y + c*p;
        u1[0] = -f[0] - K[0][0] * xa -K[0][1] * z;
        u1[1] = -f[1] - K[1][0] * xa -K[1][1] * z;
        u[0] = invE[0][0] * u1[0] + invE[0][1] * u1[1];
        u[1] = invE[1][0] * u1[0] + invE[1][1] * u1[1];
        wl = ( u[0] - T2*u[1] ) / R * 9.55;
        wr = ( u[0] + T2*u[1] ) / R * 9.55;
```

```
            wli = (int)wl; wri = (int)wr; wri = -wri;

            Send_Velocity_Commands(wli,wri);

            x_new = xorigin+(int)(Xc*xconstant/12);
            y_new = yorigin-(int)(Yc*yconstant/12);
            x_new_r = xorigin+(int)(Xr*xconstant/12);
            y_new_r = yorigin-(int)(Yr*yconstant/12);

/* DISPAYS X AND Y COORDINATES AND THETA */
      _settextcolor(white);
      _settextposition(3,10);
      sprintf(buffer2,"x: %f in   y: %f in   theta: %f degrees", Xc, Yc, Tc*180/pi);
      _outtext(buffer2);

/* DRAWS REFERENCE PATH */
      _setcolor(green);
      _moveto(x_old_r, y_old_r);
      _lineto(x_new_r, y_new_r);

/* DRAWS TMR PATH */
      _setcolor(lt_magenta);
      _moveto(x_old, y_old);
      _lineto(x_new, y_new);

            x_old = x_new;
            y_old = y_new;

            x_old_r = x_new_r;
            y_old_r = y_new_r;

//      printf("\rRobot posture: %6.2f %6.2f %6.2f",Xc,Yc,Tc);
            while( ReadClock() - begtime < 20 );
            begtime = ReadClock();
//      fprintf(ft,"%lf %lf %lf %lf %lf %lf %lf %lf %lf %lf %lf\n",Xr,Yr,Tr,Xc,Yc,Tc,x,y,p,u[0],u[1]);
//      fprintf(ft2,"%lf\n",tused);


   }

   wli = 0; wri = 0;
   Send_Velocity_Commands(wli,wri);
//  fclose(ft);
   fclose(f1);
   _setvideomode( _DEFAULTMODE );
   return(1);

}


void set_workspace(void)
{
   _setbkcolor (_BLACK);
   _clearscreen(_GCLEARSCREEN);
```

```
    _settextcolor(white);
    _settextposition(1,30);
    _outtext ("WORKSPACE OF TMR");
    create_replace_grid();
}

/* MARKS ORIGIN */
void mark_origin(int xorigin, int yorigin)
{
    xorigin = 9+no_vert_lines/2*xconstant;
    yorigin = 65+(no_horiz_lines-2)*yconstant;
    _setcolor(white);
    _setlinestyle(solid);
    _moveto(xorigin-xconstant, yorigin);
    _lineto(xorigin+xconstant, yorigin);
    _moveto( xorigin,yorigin-yconstant);
    _lineto( xorigin,yorigin+yconstant);
}

/* REPLACES PARITALLY LOST GRID AND ORIGIN MARKER */
void create_replace_grid(void)
{
    int i;
    _setcolor(cyan);
    _rectangle(_GBORDER, 9, 65, 639, 450);
    _settextcolor(white);
    _settextposition(13,0);
    _outtext ("60\n\n\n\n\n\n\n\n\n\n\n0");
    _settextposition(30,18);
    _outtext ("-60                    0                    60");

/* HORIZONTAL LINES */
    for(i = 1; i< no_horiz_lines; i++)
    {
            _setcolor(red);
            _setlinestyle(dashed);
            _moveto(9, 65+i*yconstant);
            _lineto (639, 65+i*yconstant);
    }

/* VERITICAL LINES */
    for(i = 1; i< no_vert_lines; i++)
    {
            _setcolor(red);
            _setlinestyle(dashed);
            _moveto(9+i*xconstant, 65);
            _lineto (9+i*xconstant, 450);
    }

/* DRAWS HALF-CIRCLE */
    _setcolor(yellow);
    _arc(79,135,569,625,569,380,79,380);
}

void draw_tmr(float x, float y, float angular_pos, int xorigin, int yorigin, int x_old, int x_new, int y_old, int y_new)
```

```
{
    int i, j;
        extern int x_pos, y_pos, x0, x1, x2, x3, x4, yy0, yy1, y2, y3, y4;
    extern int tx1, tx2, tx3, tx4, tx5, tx6, tx7, tx8;
    extern int ty1, ty2, ty3, ty4, ty5, ty6, ty7, ty8;
    float tmrlength, tmrwidth, halflength, halfwidth, tirelength, tirewidth;
    char buffer1[100], buffer2[100];

    tmrlength = 30.0/12;
    tmrwidth = 20.0/12;
    halfwidth = tmrwidth/2;
    halflength = tmrlength/2;
    tirelength = 10.5/12;
    tirewidth = 3.5/12;

/*   REDRAWS THE TMR IN BLACK TO HIDE IT    */
    _setcolor(black);
    _moveto(x1, yy1);
    _lineto(x2, y2);
    _lineto(x3, y3);
    _lineto(x4, y4);
    _lineto(x1, yy1);
    _moveto(tx1,ty1);
    _lineto(tx2, ty2);
    _lineto(tx3, ty3);
    _lineto(tx4, ty4);
    _lineto(tx1, ty1);
    _moveto(tx5,ty5);
    _lineto(tx6, ty6);
    _lineto(tx7, ty7);
    _lineto(tx8, ty8);
    _lineto(tx5, ty5);
    _ellipse(_GBORDER, (int)(x_pos-4), (int)(y_pos+4), (int)(x_pos+4), (int)(y_pos-4));

    x_pos = xorigin+(int)(x/12*xconstant);
    y_pos = yorigin-(int)(y/12*yconstant);

/* DISPAYS X AND Y COORDINATES AND THETA */
    _settextcolor(white);
    _settextposition(3,10);
    sprintf(buffer2,"x: %lf in   y: %lf in   theta: %lf degrees", x, y, angular_pos*180/pi);
    _outtext(buffer2);

/* CALCULATES THE CORNER COORDINATES OF THE TMR */
    x0 = (int)(x_pos + xconstant*cga*cos(angular_pos));
    yy0 = (int)(y_pos - yconstant*cga*sin(angular_pos));
    x1 = (int)(x0 + xconstant*halfwidth*sin(angular_pos));
    yy1 = (int)(yy0 + yconstant*halfwidth*cos(angular_pos));
    x2 = (int)(x1 - xconstant*tmrlength*cos(angular_pos));
    y2 = (int)(yy1 + yconstant*tmrlength*sin(angular_pos));
    x3 = (int)(x2 - xconstant*tmrwidth*sin(angular_pos));
    y3 = (int)(y2 - yconstant*tmrwidth*cos(angular_pos));
    x4 = (int)(x1 - xconstant*tmrwidth*sin(angular_pos));
    y4 = (int)(yy1 - yconstant*tmrwidth*cos(angular_pos));
```

```
/* CALCULATES THE TMR'S TIRE COORDINATES */
     tx1 = (int)(x3 - 5*sin(angular_pos));
     ty1 = (int)(y3 - 5*cos(angular_pos));
     tx2 = (int)(tx1 - xconstant*tirewidth*sin(angular_pos));
     ty2 = (int)(ty1 - yconstant*tirewidth*cos(angular_pos));
     tx3 = (int)(tx2 + xconstant*tirelength*cos(angular_pos));
     ty3 = (int)(ty2 - yconstant*tirelength*sin(angular_pos));
     tx4 = (int)(tx1 + xconstant*tirelength*cos(angular_pos));
     ty4 = (int)(ty1 - yconstant*tirelength*sin(angular_pos));
     tx5 = (int)(x2 + 5*sin(angular_pos));
     ty5 = (int)(y2 + 5*cos(angular_pos));
     tx6 = (int)(tx5 + xconstant*tirewidth*sin(angular_pos));
     ty6 = (int)(ty5 + yconstant*tirewidth*cos(angular_pos));
     tx7 = (int)(tx6 + xconstant*tirelength*cos(angular_pos));
     ty7 = (int)(ty6 - yconstant*tirelength*sin(angular_pos));
     tx8 = (int)(tx5 + xconstant*tirelength*cos(angular_pos));
     ty8 = (int)(ty5 - yconstant*tirelength*sin(angular_pos));

/* DRAWS TMR */
     _setcolor(lt_blue);
     _moveto(x1, yy1);
     _lineto(x2, y2);
     _lineto(x3, y3);
     _lineto(x4, y4);
     _lineto(x1, yy1);
//   _setcolor(blue);
     _moveto(tx1,ty1);
     _lineto(tx2, ty2);
     _lineto(tx3, ty3);
     _lineto(tx4, ty4);
     _lineto(tx1, ty1);
     _moveto(tx5,ty5);
     _lineto(tx6, ty6);
     _lineto(tx7, ty7);
     _lineto(tx8, ty8);
     _lineto(tx5, ty5);
     _setcolor(green);
     _ellipse(_GBORDER, (int)(x_pos-4), (int)(y_pos+4), (int)(x_pos+4), (int)(y_pos-4));
     gcvt(x, 7, buffer1);          /* gcvt converts a double to a string */
     gcvt(y, 7, buffer1);
     gcvt(angular_pos, 7, buffer1);

/* DRAWS TMR PATH */
     _setcolor(lt_magenta);
     _moveto(x_old, y_old);
     _lineto(x_new, y_new);

/* ADDING TO DISPLAY TIME */
 /*  for(i = 0; i<20000; i++)
     {
          for(j = 0; j<25; j++);
     } */


/* REPLACES THE ENTIRE GRID AND ORIGIN */
```

```
    create_replace_grid();
    mark_origin(xorigin, yorigin);
}

void sound_on(unsigned freq)
{
        unsigned status, ratio, part_ratio;

        status = inp(OUT_8255);
        outp(TIMER_MODE,TIMER_OSC);
        ratio = (unsigned)(TIMER_FREQ/freq);
        part_ratio = ratio & 0xff;
        outp(TIMER_COUNT,part_ratio);
        part_ratio = (ratio >> 8) & 0xff;
        outp(TIMER_COUNT,part_ratio);
        outp(OUT_8255,(status | SPKRON));
}

void sound_off(void)
{
        unsigned status;
        status = inp(OUT_8255);
        outp(OUT_8255,(status & ~SPKRON));
}
```

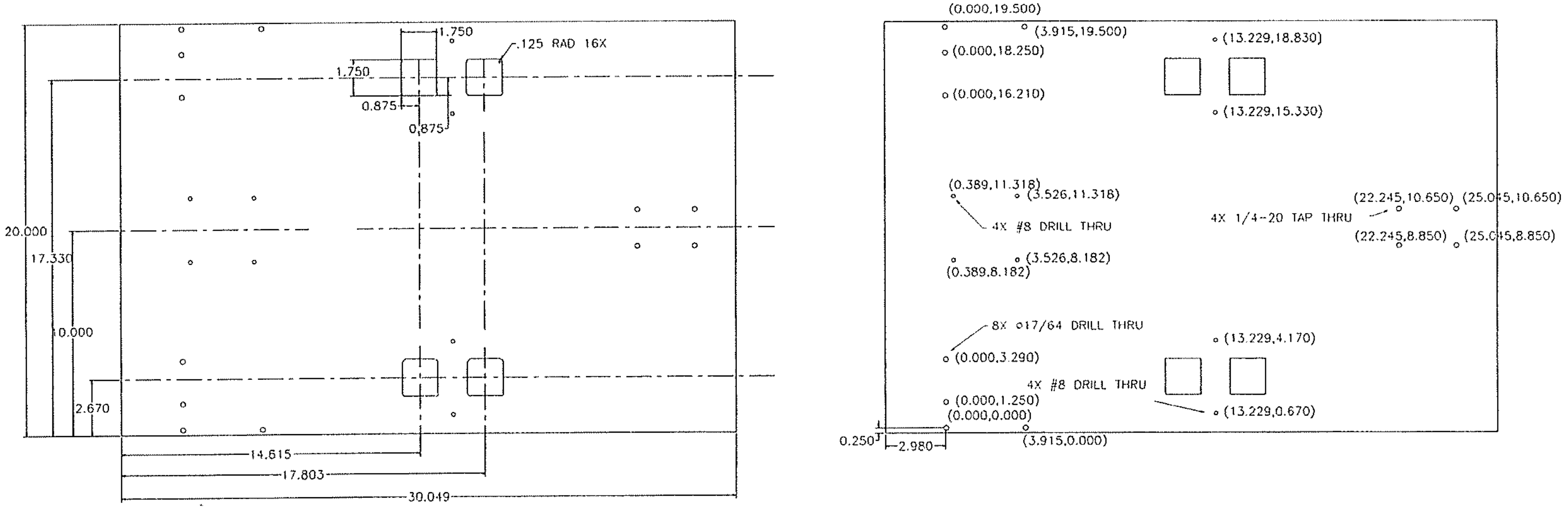
APPENDIX C

TECHNICAL DRAWINGS

Drawing #	**Title**
TMR-001	Base Plate
TMR-002	Applicator Plate
TMR-003	Linear Transducer Base Mount
TMR-004	Set Off Block
TMR-005	Pulley
TMR-006	Pulley Standoffs
TMR-007	Rotation Assembly
TMR-008	Line Connection
TMR-009	Rotary Components
TMR-010	Encoder Platform
TMR-011	Extra Components
TMR-012	Gearbox Adapters
TMR-100	Arm Assembly
TMR-101	Arm Base Mount
TMR-102	Vari Plate
TMR-103	Height Adjusting Rod/Joint Rods
TMR-104	Bearing Capture Versions
TMR-105	Arm Tubes
TMR-106	Outside Pipe
TMR-201	Welded Frame With Gearbox Holes
TMR-201A	Welded Frame With Extender Holes
TMR-202	Frame Components
TMR-203	Index Plate
TMR-204A	Air Spring Supports - Frame
TMR-204B	Air Spring Supports - Router Box
TMR-205	Drive Shaft
TMR-206	Bearing Capture
TMR-207	Air Spring Supports - Router Box Angle
TMR-208	Front Wheel Supports
TMR-209	Welded Extender Frame
TMR-210	Air Spring Supports - Frame Angle
TMR-211	C-channel Hoops on Router Frame
TMR-300	Router Inner Case
TMR-301	Router Inner Case - Back Plate
TMR-302	Router Inner Case - Front Wall
TMR-303	Router Inner Case - Side Walls
TMR-304	Caster Plates and Support Triangles
TMR-401	Base Plate for Large CETS
TMR-402	Set Off Block
TMR-403	Pulley

TMR-404	Pulley Standoffs
TMR-405	Line Connections
TMR-406	Rotary Components
TMR-407	Encoder Platform
TMR-501	Applicator Mount
TMR-502	4-Bar Links
TMR-503	Rotating Attachment
TMR-504	Keyway Attachment
TMR-505	Motor Seat
TMR-601	Support for TMRR
TMR-602	Support Brackets
TMR-603	Support Bar
TMR-604	Support Bar: Rear
TMR-605	Stop Block
TMR-606	Chain Brackets
TMR-607	Plates - Lift Gate
TMR-608	C-Channel: Lift Gate
TMR-609	Base: Lift Gate
TMR-610	Gusset: Lift Gate
TMR-611	Slide Block for ACSM Truck
TMR-612	Slide Plates for ACSM Truck
TMR-701	Laser Sensor Cover
TMR-702	TMRR CET Mount Pulley Assembly
TMR-703	TMRR CET Mount Guide Assembly
TMR-704	TMRR CET Mount Right Face Plate
TMR-705	TMRR CET Mount Left Face Plate
TMR-706	TMRR CET Mount Base Plate
TMR-707	TMRR CET Mount Right Back Plate
TMR-708	TMRR CET Mount Left BackPlate
TMR-709	TMRR Laser Cover Mounting Plate
TMR-800	Indexing Tool
TMR-900	Booth
TMR-901	LEXAN Retatining Strips
TMR-902	Hexagon Die

LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
REVISION					
A		INITIAL RELEASE	3/94	KJM	DAB



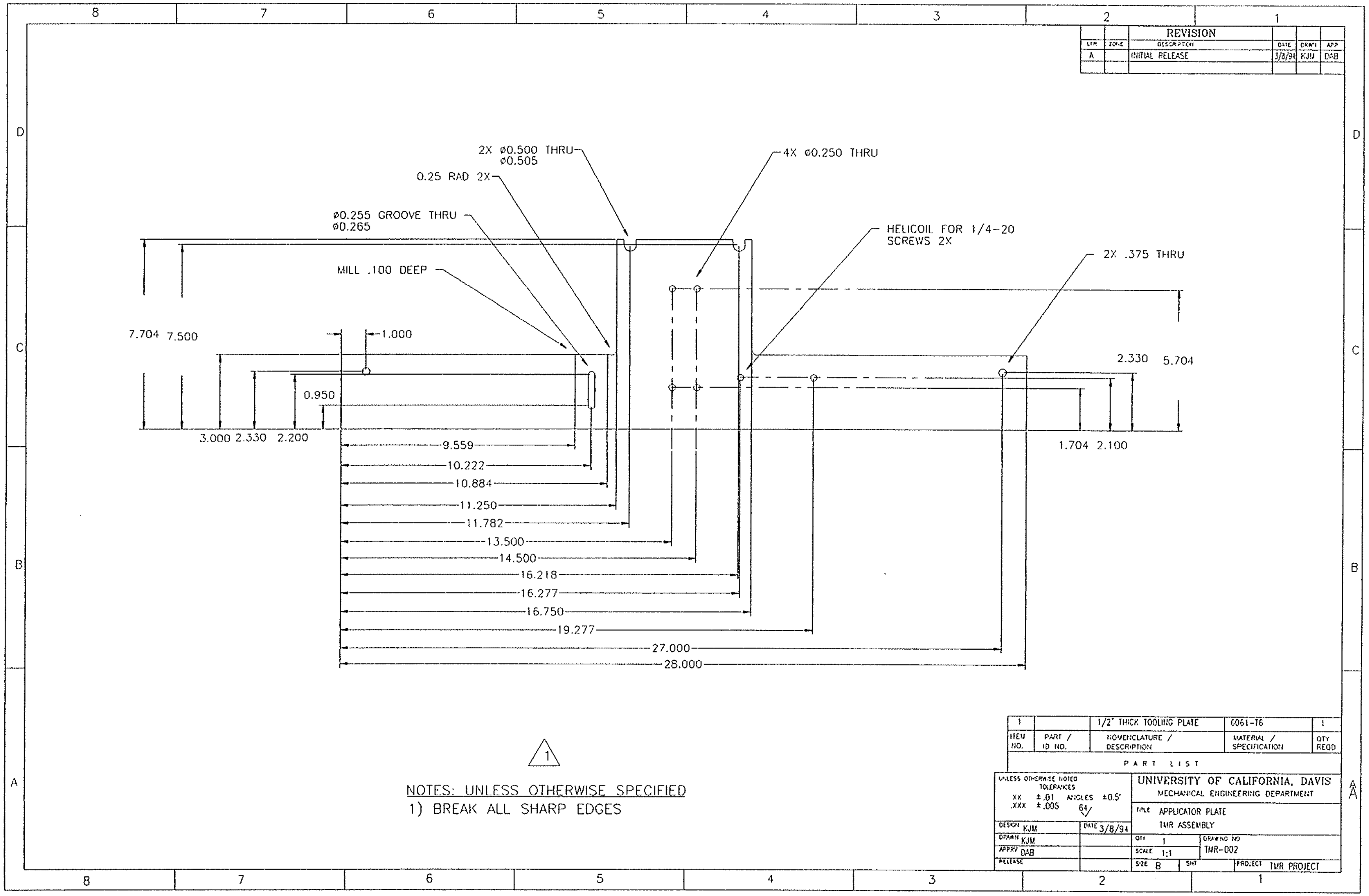
NOTES: UNLESS OTHERWISE SPECIFIED

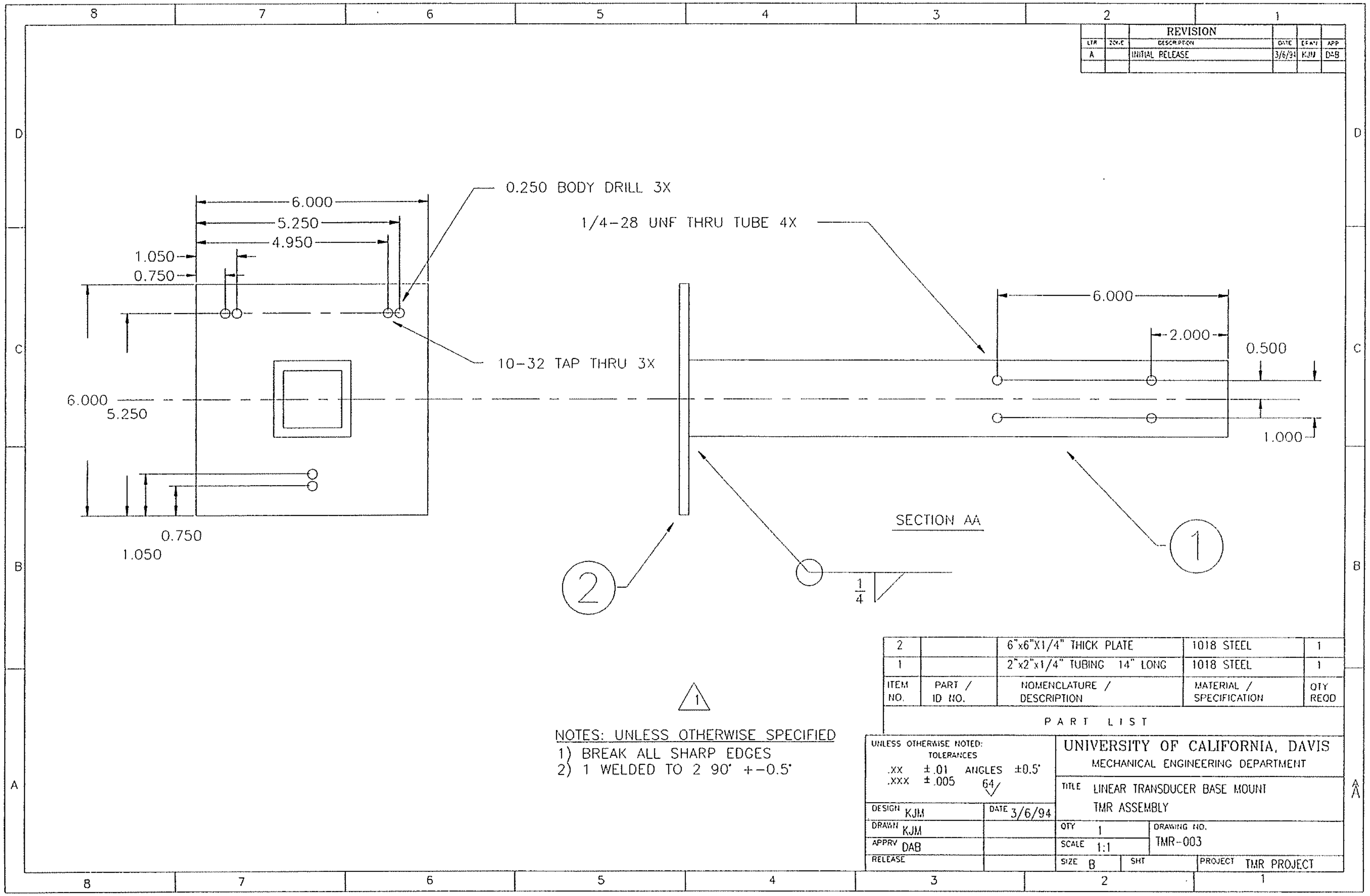
1) BREAK ALL SHARP EDGES

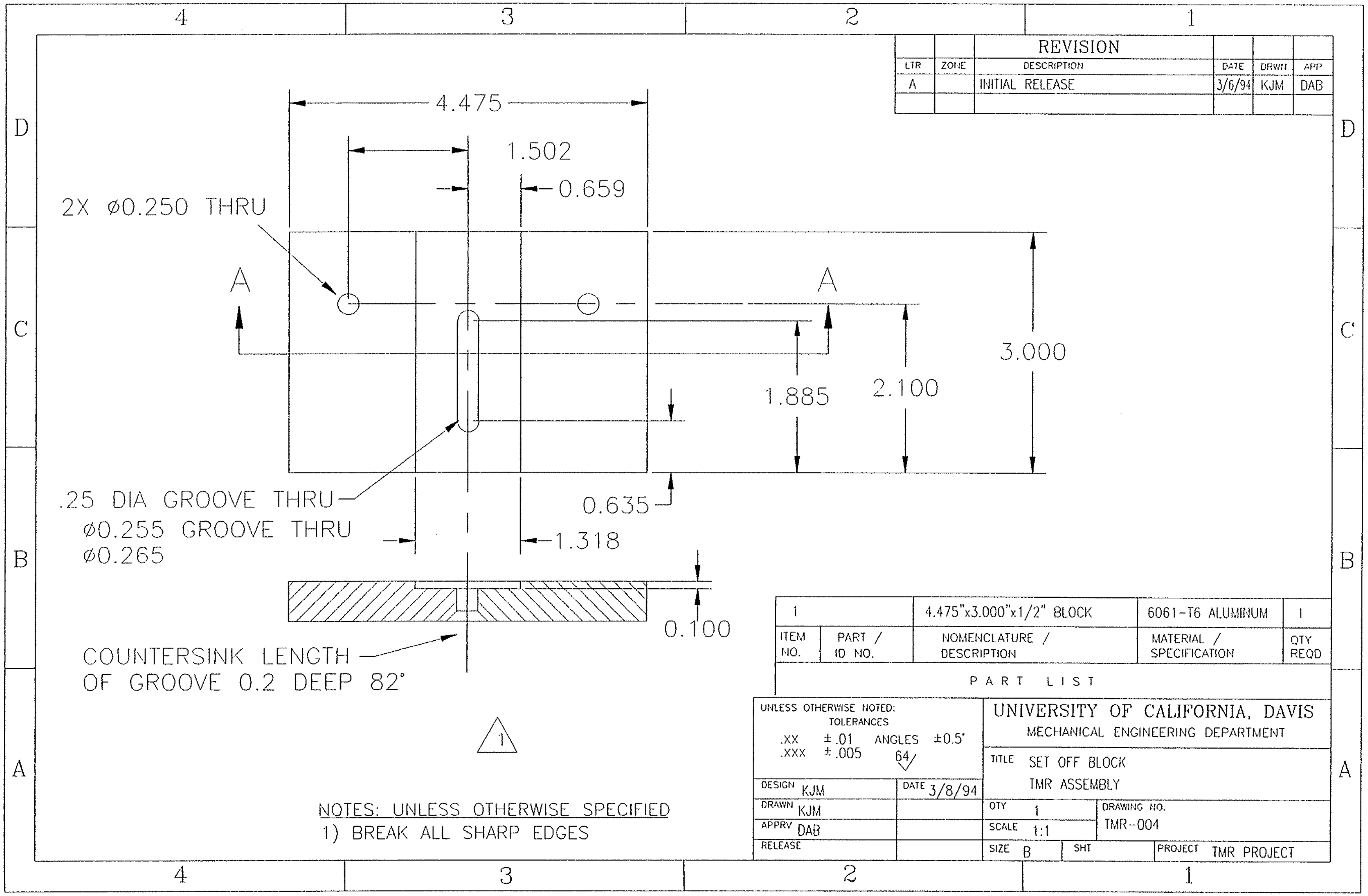
ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
1		30"x20"x1/2" PLATE	6061 ALUMINUM	1

PART LIST

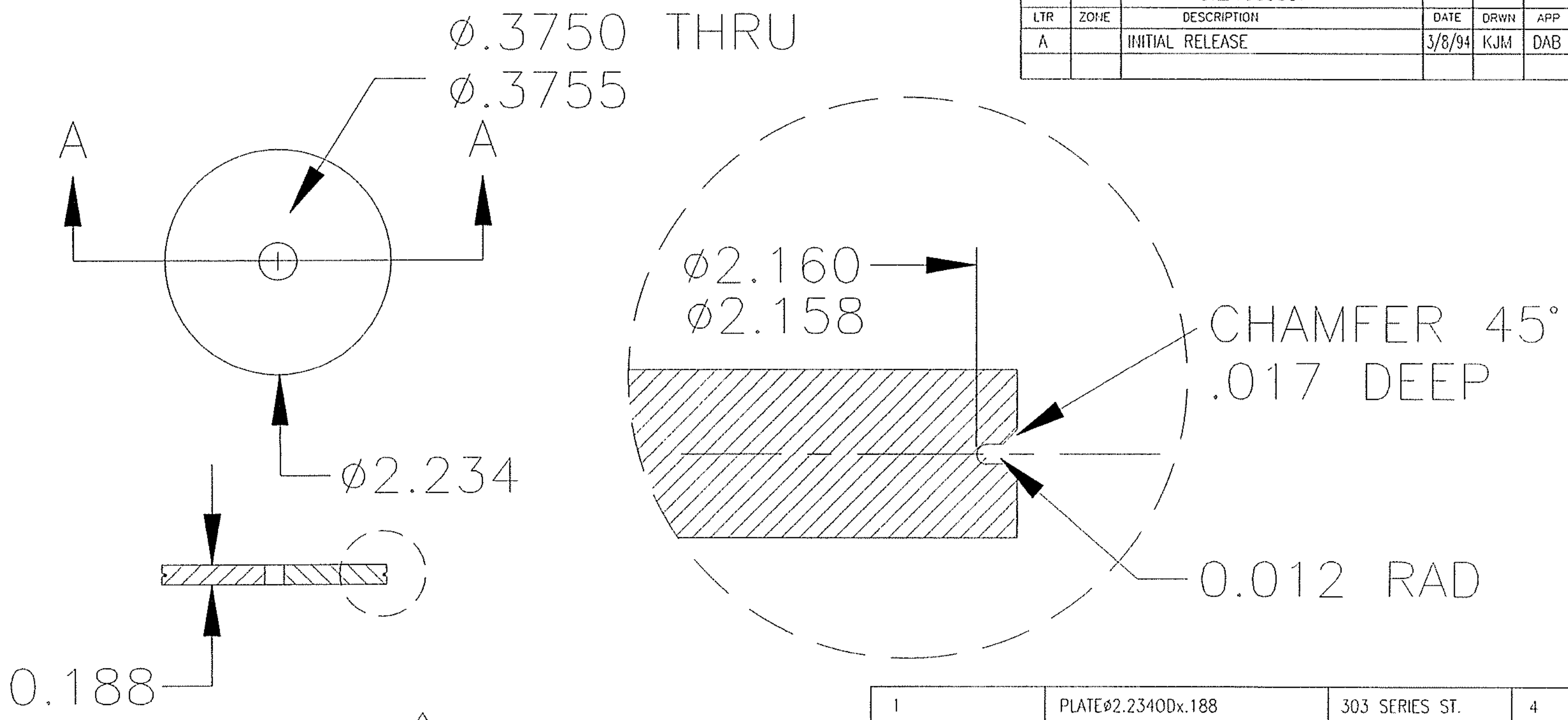
UNLESS OTHERWISE NOTED: TOLERANCES .XX ±.01 .XXX ±.005 ANGLES ±0.5° 64	UNIVERSITY OF CALIFORNIA, DAVIS MECHANICAL ENGINEERING DEPARTMENT
DESIGN KJM / DATE 3/94	TITLE BASE PLATE TMR ASSEMBLY
DRAWN KJM	QTY 1 / DRAWING NO. TMR-001
APPRV DAB	SCALE 1:1
RELEASE	SIZE B / SHT / PROJECT TMR PROJECT


REVISION
LTR ZONE DESCRIPTION DATE DRWN APP
A INITIAL RELEASE 3/8/94 KJM DAB
2X ⌀0.500 THRU
⌀0.505
0.25 RAD 2X
4X ⌀0.250 THRU
⌀0.255 GROOVE THRU
⌀0.265
HELICOIL FOR 1/4-20
SCREWS 2X
2X .375 THRU
MILL .100 DEEP
7.704 7.500
1.000
2.330 5.704
0.950
3.000 2.330 2.200
1.704 2.100
9.559
10.222
10.884
11.250
11.782
13.500
14.500
16.218
16.277
16.750
19.277
27.000
28.000
1
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
1 1/2" THICK TOOLING PLATE 6061-T6 1
ITEM NO. PART / ID NO. NOMENCLATURE / DESCRIPTION MATERIAL / SPECIFICATION QTY REQD
PART LIST
UNLESS OTHERWISE NOTED
TOLERANCES
XX ±.01 ANGLES ±0.5°
.XXX ±.005
64
DESIGN KJM DATE 3/8/94
DRAWN KJM
APPRV DAB
RELEASE
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
TITLE APPLICATOR PLATE
TMR ASSEMBLY
QTY 1
SCALE 1:1
DRAWING NO TMR-002
SIZE B SHT
PROJECT TMR PROJECT


REVISION
LTR ZONE DESCRIPTION DATE DRAWN APP
A INITIAL RELEASE 3/6/94 KJM DAB
0.250 BODY DRILL 3X
1/4-28 UNF THRU TUBE 4X
10-32 TAP THRU 3X
6.000
5.250
4.950
1.050
0.750
6.000
5.250
0.750
1.050
6.000
2.000
0.500
1.000
SECTION AA
1/4
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
2) 1 WELDED TO 2 90° +-0.5°
2 6"x6"X1/4" THICK PLATE 1018 STEEL 1
1 2"x2"x1/4" TUBING 14" LONG 1018 STEEL 1
ITEM NO. PART / ID NO. NOMENCLATURE / DESCRIPTION MATERIAL / SPECIFICATION QTY REQD
PART LIST
UNLESS OTHERWISE NOTED: TOLERANCES .XX ±.01 .XXX ±.005 ANGLES ±0.5° 64
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
TITLE LINEAR TRANSDUCER BASE MOUNT
TMR ASSEMBLY
DESIGN KJM DATE 3/6/94
DRAWN KJM
APPRV DAB
RELEASE
QTY 1
SCALE 1:1
DRAWING NO. TMR-003
SIZE B SHT
PROJECT TMR PROJECT


4 3 2 1
D C B A
REVISION
LTR | ZONE | DESCRIPTION | DATE | DRWN | APP
A | | INITIAL RELEASE | 3/6/94 | KJM | DAB
4.475
1.502
0.659
2X ø0.250 THRU
A
A
3.000
2.100
1.885
0.635
.25 DIA GROOVE THRU
ø0.255 GROOVE THRU
ø0.265
1.318
0.100
COUNTERSINK LENGTH
OF GROOVE 0.2 DEEP 82°
1
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
1 | 4.475"x3.000"x1/2" BLOCK | 6061-T6 ALUMINUM | 1
ITEM NO. | PART / ID NO. | NOMENCLATURE / DESCRIPTION | MATERIAL / SPECIFICATION | QTY REQD
PART LIST
UNLESS OTHERWISE NOTED:
TOLERANCES
.XX ±.01 ANGLES ±0.5°
.XXX ±.005
64
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
TITLE SET OFF BLOCK
TMR ASSEMBLY
DESIGN KJM
DATE 3/8/94
DRAWN KJM
APPRV DAB
RELEASE
QTY 1
SCALE 1:1
SIZE B
SHT
DRAWING NO. TMR-004
PROJECT TMR PROJECT

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	3/8/94	KJM	DAB



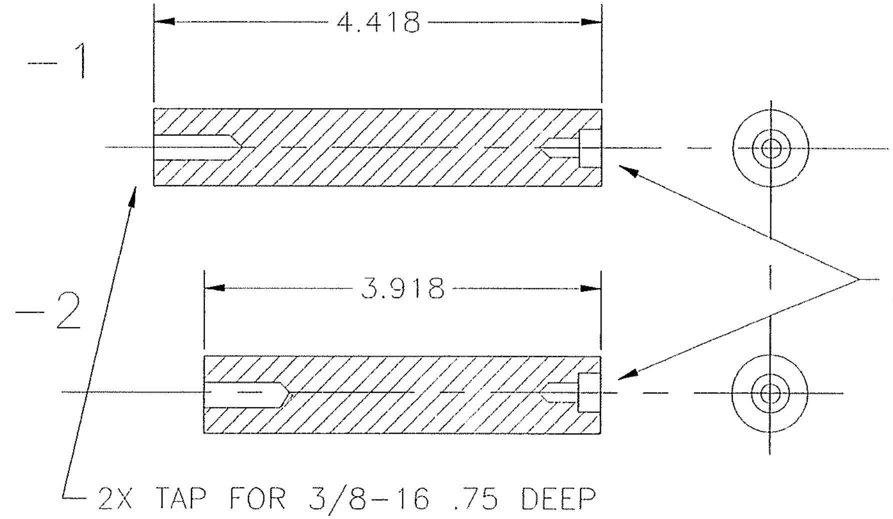
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
1		PLATEø2.234ODx.188	303 SERIES ST.	4

PART LIST

UNLESS OTHERWISE NOTED: TOLERANCES .XX ± .01 .XXX ± .001 ANGLES ±0.5° 64		UNIVERSITY OF CALIFORNIA, DAVIS MECHANICAL ENGINEERING DEPARTMENT	
		TITLE PULLEY TMR ASSEMBLY	
DESIGN KJM	DATE 3/8/94		
DRAWN KJM		QTY 1	DRAWING NO. TMR-005
APPRV DAB		SCALE 1:1	
RELEASE		SIZE B SHT	PROJECT TMR PROJECT

LTR	ZONE	REVISION DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	2/5/94	KJM	DAB



△1 △2

NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
-2		⌀0.750x3.912 ROD	303 SERIES ST.	1
-1		⌀0.750x4.412 ROD	303 SERIES ST.	1

PART LIST

UNLESS OTHERWISE NOTED:
TOLERANCES
.XX ±.01 ANGLES ±0.5°
.XXX ±.003
64√

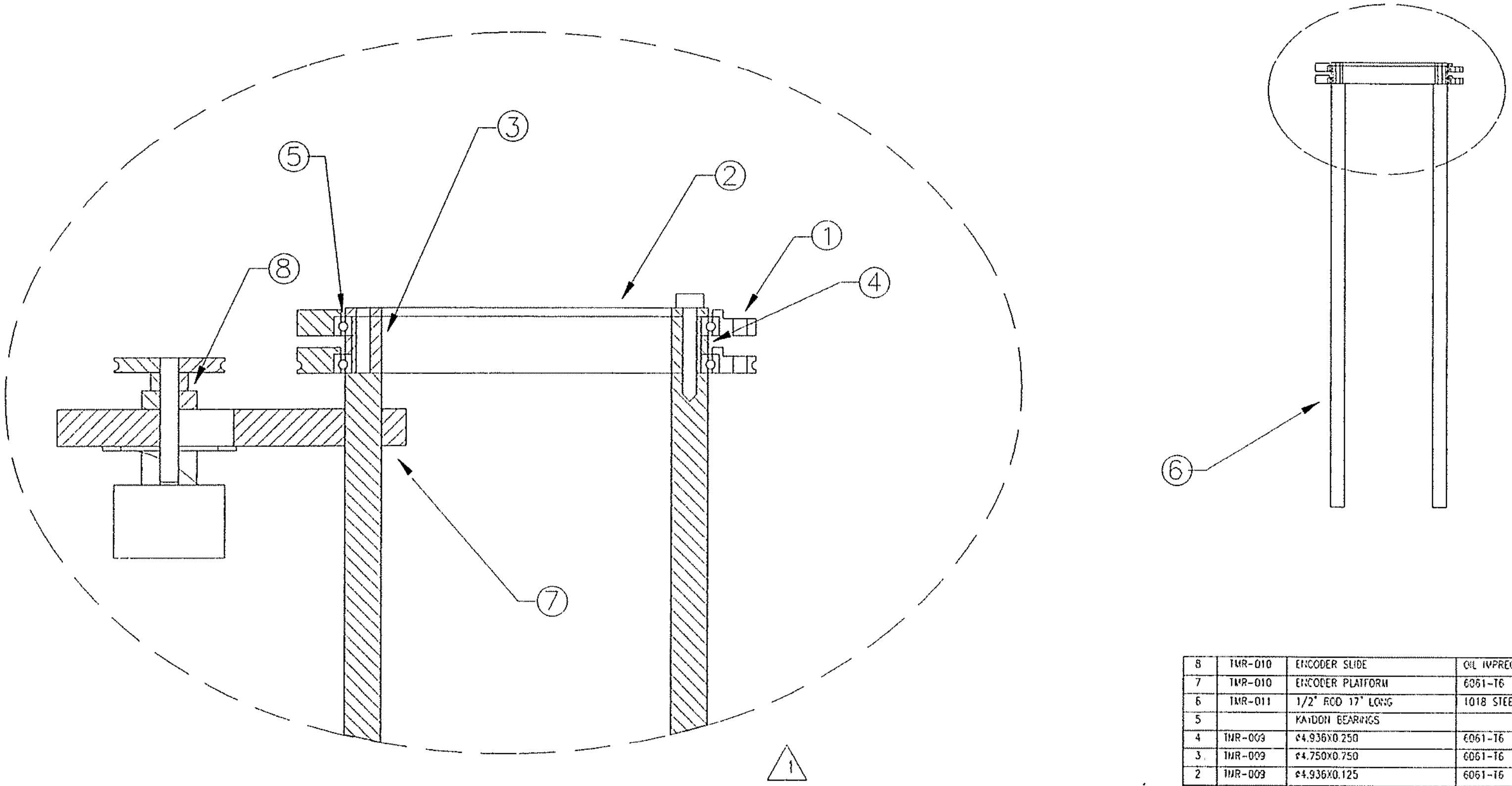
DESIGN KJM DATE 3/11/94
DRAWN KJM
APPRV DAB
RELEASE

UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT

TITLE PULLEY STANDOFFS
TMR ASSEMBLY

QTY 1
SCALE 1:1
SIZE B
SHT
DRAWING NO. TMR-006
PROJECT TMR PROJECT

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	6/2/97	KJM	DAB



NOTES: UNLESS OTHERWISE SPECIFIED
1) DRAWING FOR REFERENCE ONLY

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
8	TMR-010	ENCODER SLIDE	OIL IMPREG BRONZE	2
7	TMR-010	ENCODER PLATFORM	6061-T6	1
6	TMR-011	1/2" ROD 17" LONG	1018 STEEL	4
5		KAYDON BEARINGS		2
4	TMR-009	¢4.936X0.250	6061-T6	1
3	TMR-009	¢4.750X0.750	6061-T6	1
2	TMR-009	¢4.936X0.125	6061-T6	1
1	TMR-008	¢6.25X.35	6061-T6	2

PART LIST

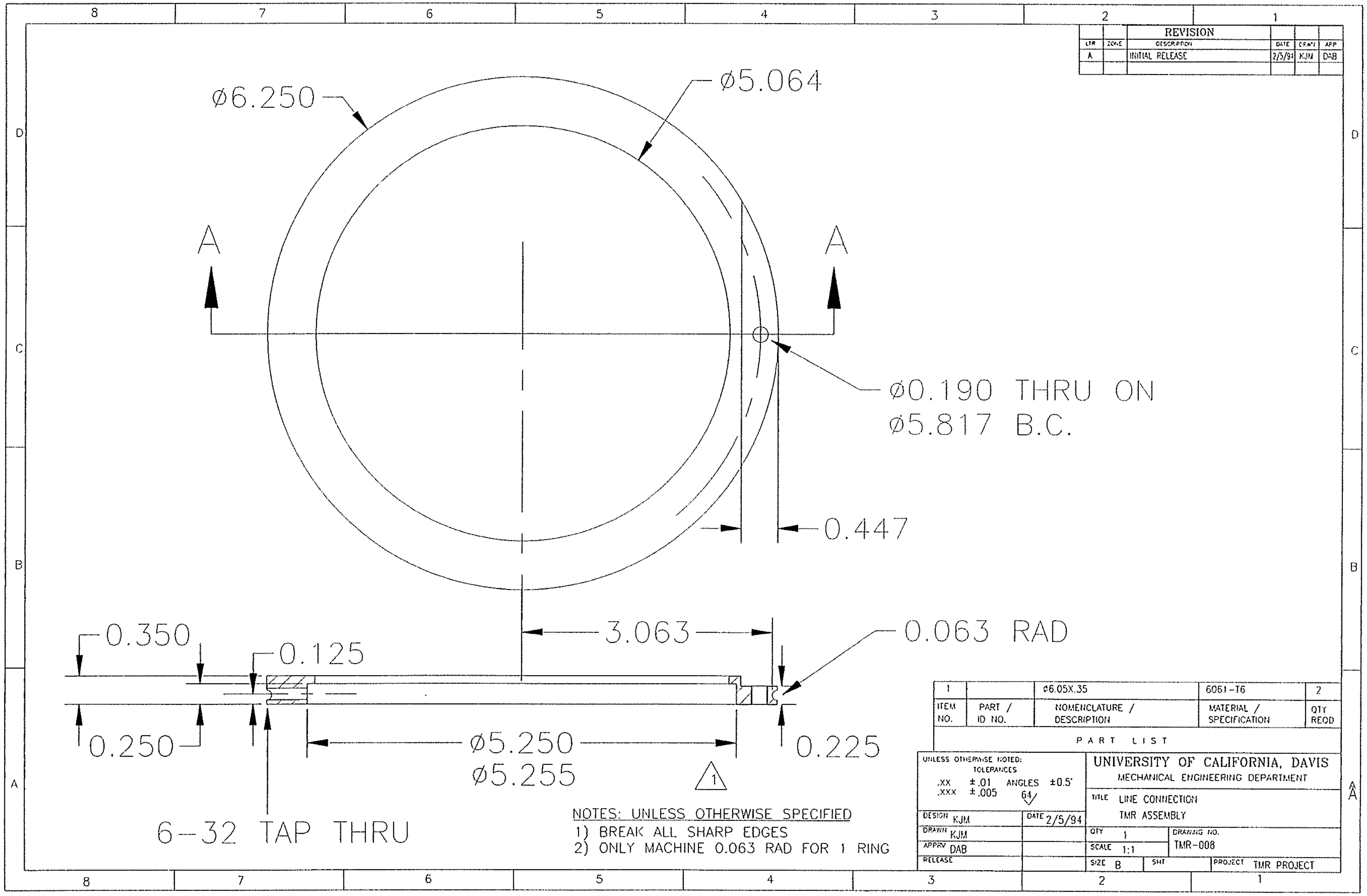
UNLESS OTHERWISE NOTED TOLERANCES
XX ±.01 ANGLES ±0.5°
XXX ±.005 64√

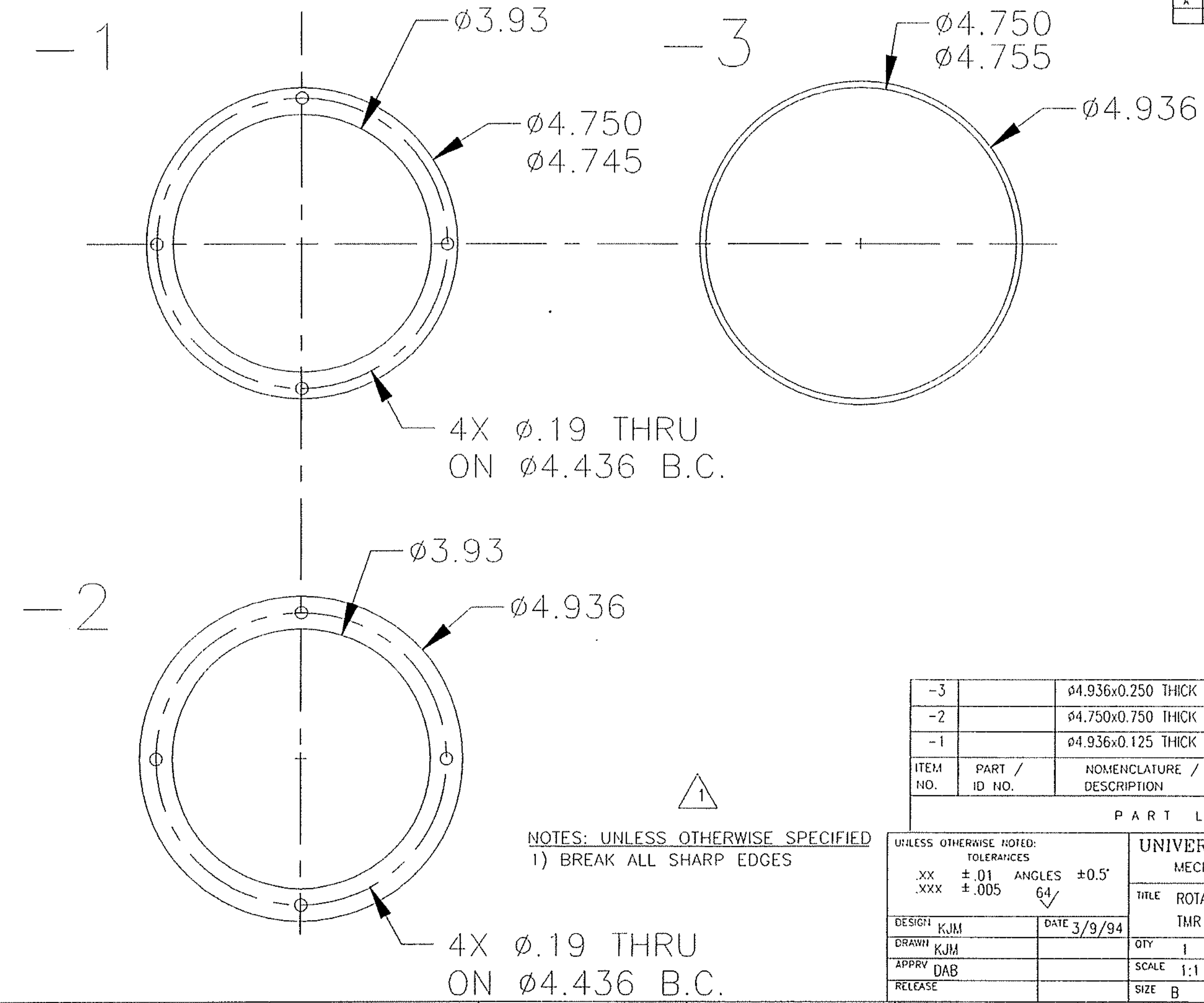
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT

TITLE ROTATION ASSEMBLY
TMR ASSEMBLY

DESIGN KJM DATE 3/8/94
DRAWN KJM
APPRV DAB
RELEASE

QTY 1
SCALE 1:1
DRAWING NO TMR-007
SIZE B SHT
PROJECT TMR PROJECT


REVISION
LTR | ZONE | DESCRIPTION | DATE | DRAWN | APP
A | | INITIAL RELEASE | 2/5/94 | KJM | DAB
Ø6.250
Ø5.064
A
A
Ø0.190 THRU ON
Ø5.817 B.C.
0.447
0.350
0.125
3.063
0.063 RAD
0.250
Ø5.250
Ø5.255
0.225
6-32 TAP THRU
1
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
2) ONLY MACHINE 0.063 RAD FOR 1 RING
1 | | Ø6.05X.35 | 6061-T6 | 2
ITEM NO. | PART / ID NO. | NOMENCLATURE / DESCRIPTION | MATERIAL / SPECIFICATION | QTY REQD
PART LIST
UNLESS OTHERWISE NOTED: TOLERANCES
.XX ±.01 ANGLES ±0.5°
.XXX ±.005
64
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
TITLE LINE CONNECTION
TMR ASSEMBLY
DESIGN KJM
DATE 2/5/94
DRAWN KJM
APPRV DAB
RELEASE
QTY 1
DRAWING NO. TMR-008
SCALE 1:1
SIZE B
SHT
PROJECT TMR PROJECT



REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRAWN	APP
A		INITIAL RELEASE	3/9/94	KJM	DAB

NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
-3		ø4.936x0.250 THICK	6061-T6	1
-2		ø4.750x0.750 THICK	6061-T6	1
-1		ø4.936x0.125 THICK	6061-T6	1

PART LIST

UNLESS OTHERWISE NOTED: TOLERANCES
.XX ±.01 ANGLES ±0.5°
.XXX ±.005 64√

DESIGN KJM	DATE 3/9/94
DRAWN KJM	
APPRV DAB	
RELEASE	

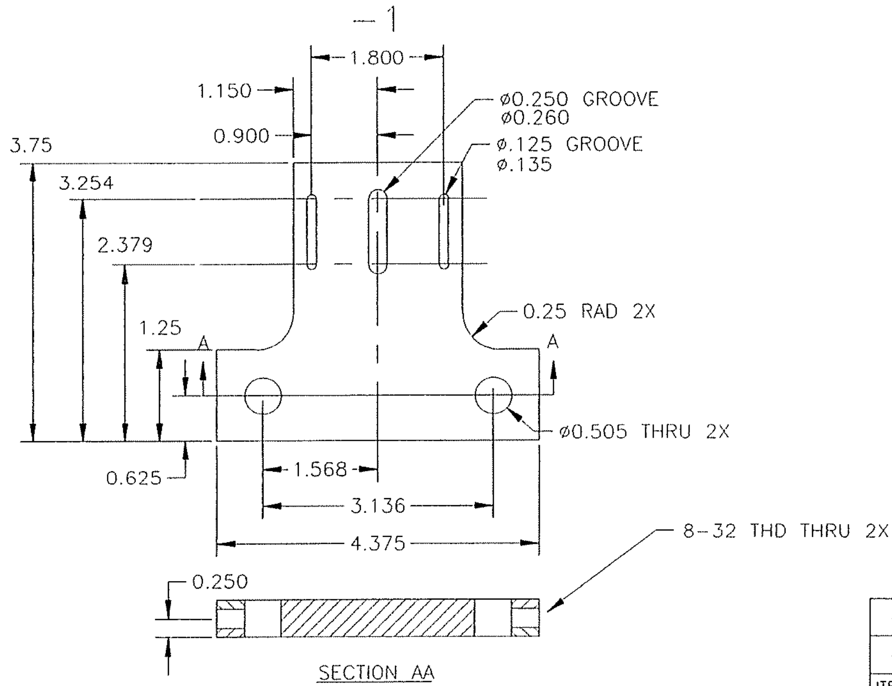
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT

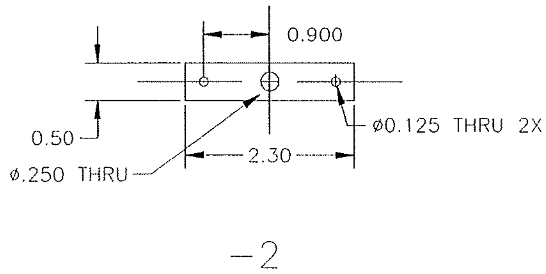
TITLE ROTARY COMPONENTS
TMR ASSEMBLY

QTY 1	DRAWING NO. TMR-009
SCALE 1:1	
SIZE B	SHT
PROJECT TMR ASSEMBLY	

LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	3/14/94	KJM	DAB

REVISION





△1 △2

NOTES: UNLESS OTHERWISE SPECIFIED

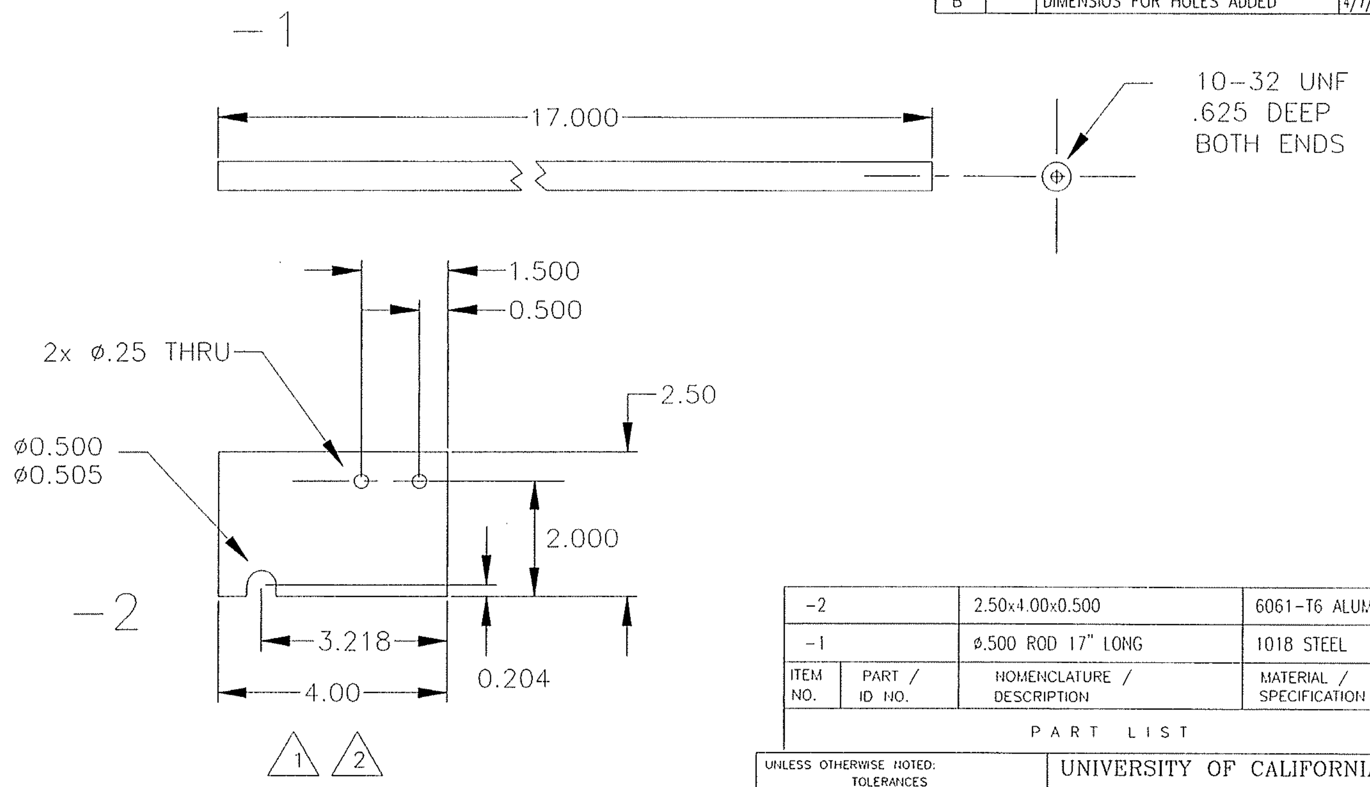
1) BREAK ALL SHARP EDGES

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
-2		0.50x2.30x.125 THICK	OIL IMPREG. BRONZE	2
-1		3.75x4.375x0.500	6061-T6 ALUMINUM	1

PART LIST

UNLESS OTHERWISE NOTED: TOLERANCES .XX ± .01 .XXX ± .005 ANGLES ±0.5° 64√	UNIVERSITY OF CALIFORNIA, DAVIS MECHANICAL ENGINEERING DEPARTMENT
DESIGN KJM DATE 3/14/94	TITLE ENCODER PLATFORM TMR ASSEMBLY
DRAWN KJM	QTY 1 — DRAWING NO. TMR-010
APPRV DAB	SCALE 1:1
RELEASE	SIZE B — SHT — PROJECT TMR PROJECT

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	3/11/94	KJM	DAB
B		DIMENSIOS FOR HOLES ADDED	4/7/94	KJM	DAB

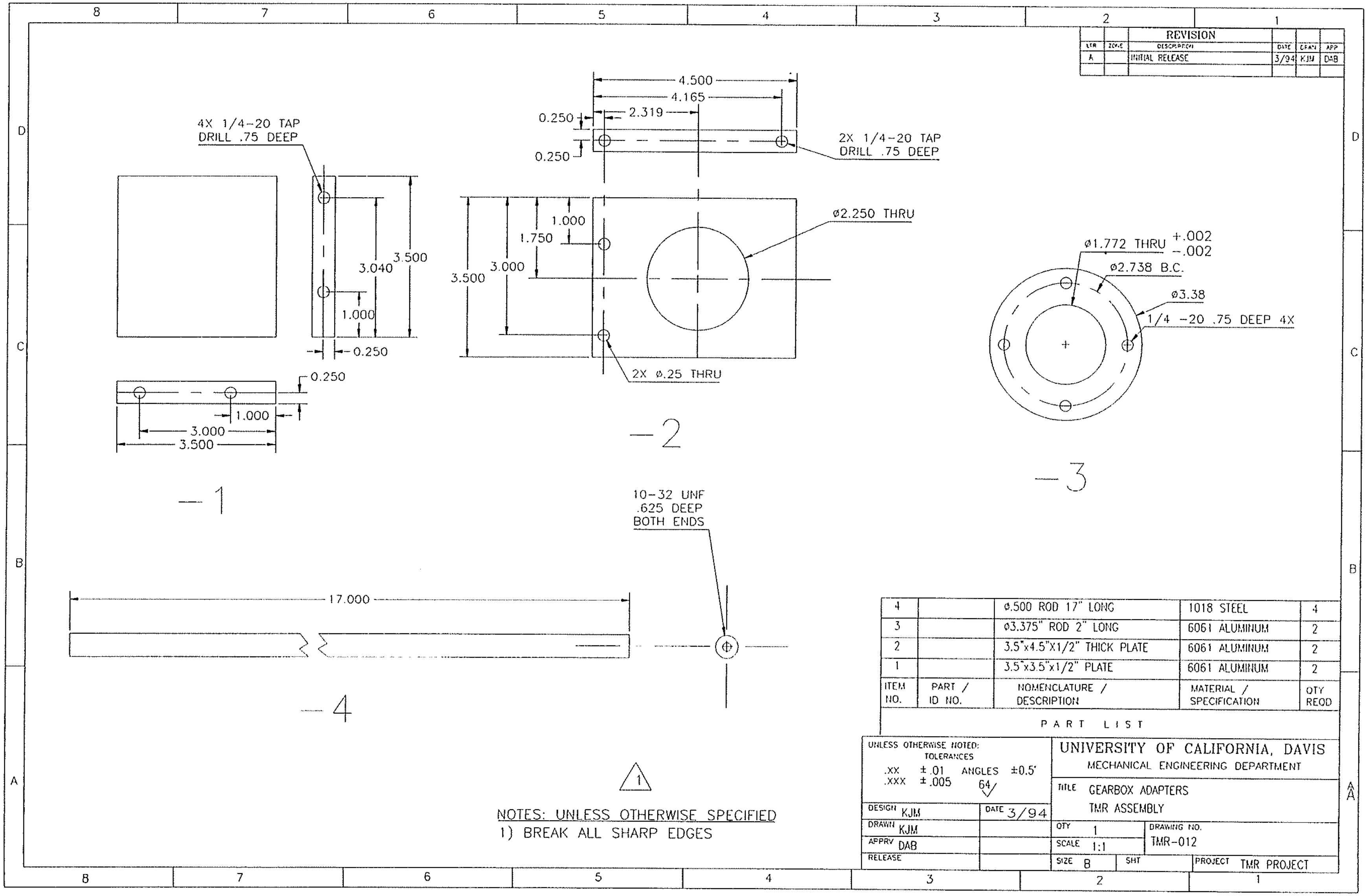


NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
-2		2.50x4.00x0.500	6061-T6 ALUMINUM	1
-1		ø.500 ROD 17" LONG	1018 STEEL	4

PART LIST

UNLESS OTHERWISE NOTED: TOLERANCES .XX ± .01 .XXX ± .005 ANGLES ±0.5° 64√		UNIVERSITY OF CALIFORNIA, DAVIS MECHANICAL ENGINEERING DEPARTMENT	
		TITLE EXTRA COMPONENTS TMR ASSEMBLY	
DESIGN KJM	DATE 3/11/94		
DRAWN KJM		QTY 1	DRAWING NO. TMR-011
APPRV DAB		SCALE 1:1	
RELEASE		SIZE B / SHT	PROJECT TMR PROJECT



ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
4		ø.500 ROD 17" LONG	1018 STEEL	4
3		ø3.375" ROD 2" LONG	6061 ALUMINUM	2
2		3.5"x4.5"X1/2" THICK PLATE	6061 ALUMINUM	2
1		3.5"x3.5"x1/2" PLATE	6061 ALUMINUM	2

PART LIST

UNLESS OTHERWISE NOTED: TOLERANCES .XX ±.01 .XXX ±.005 ANGLES ±0.5° 64

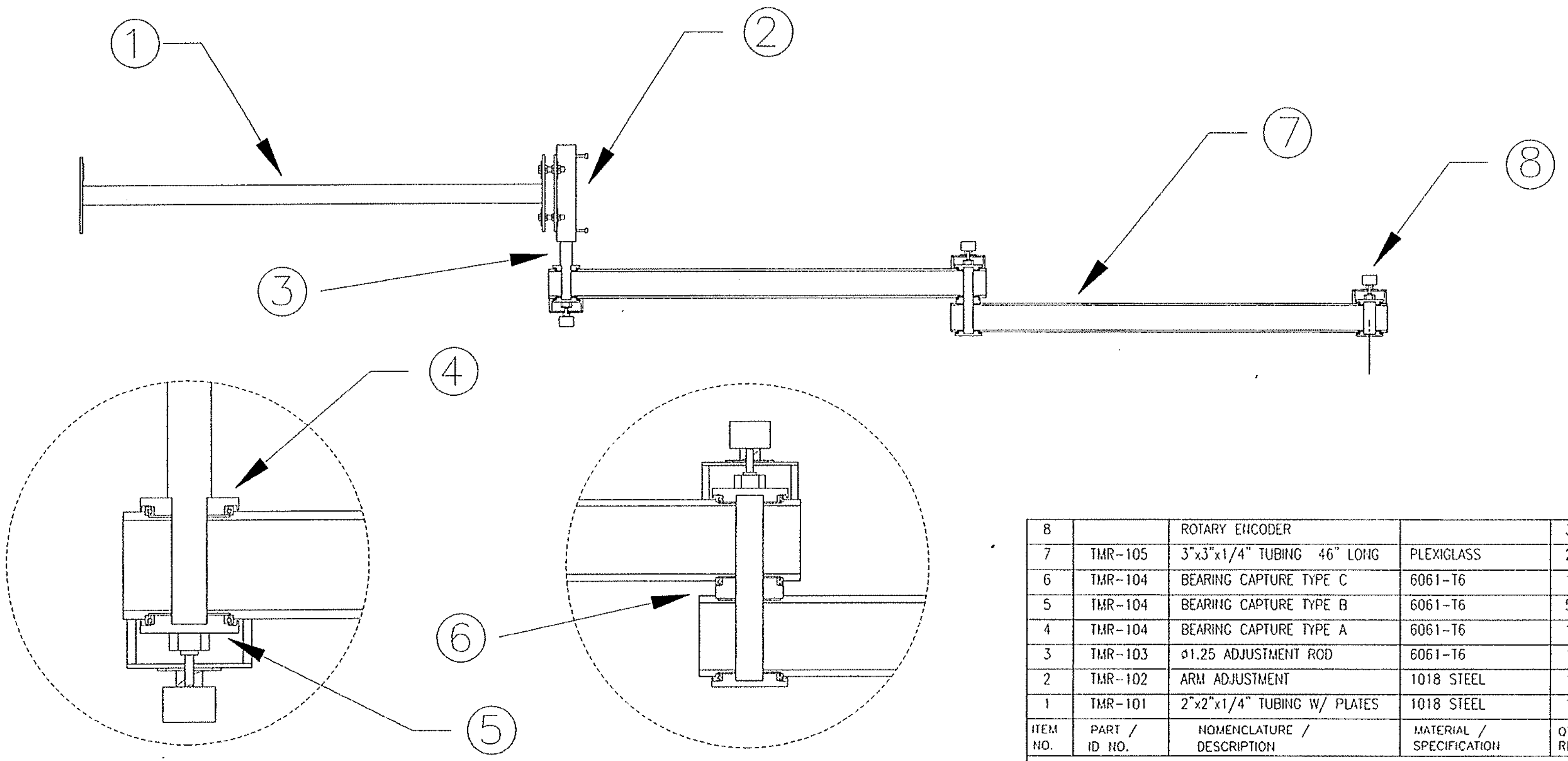
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT

TITLE GEARBOX ADAPTERS TMR ASSEMBLY

DESIGN KJM DATE 3/94
DRAWN KJM
APPRV DAB
RELEASE

QTY 1 DRAWING NO. TMR-012
SCALE 1:1
SIZE B SHT PROJECT TMR PROJECT

LTR	ZONE	REVISION DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	3/6/94	KJM	DAB



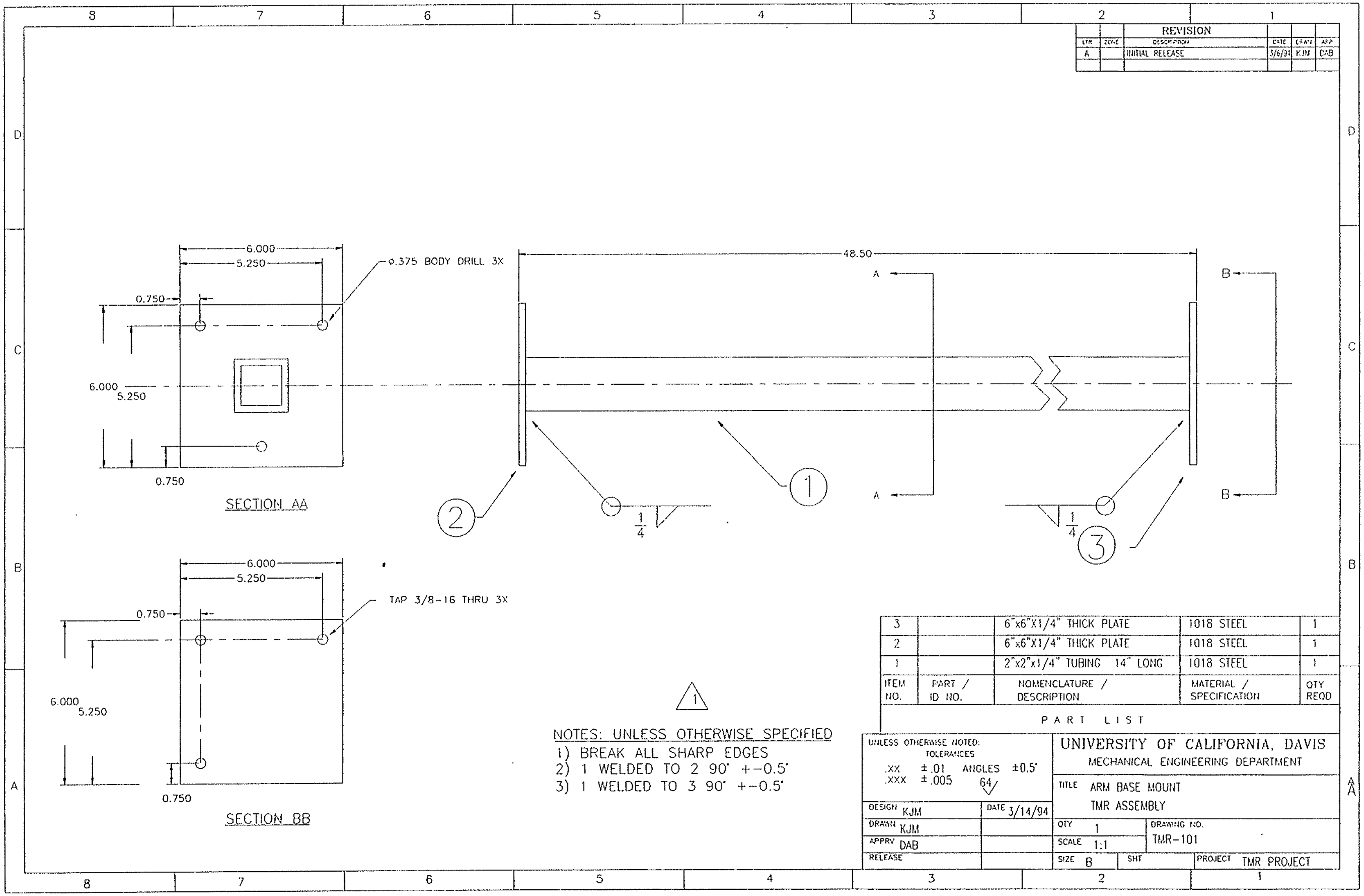
ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
8		ROTARY ENCODER		3
7	TMR-105	3"x3"x1/4" TUBING 46" LONG	PLEXIGLASS	2
6	TMR-104	BEARING CAPTURE TYPE C	6061-T6	1
5	TMR-104	BEARING CAPTURE TYPE B	6061-T6	5
4	TMR-104	BEARING CAPTURE TYPE A	6061-T6	1
3	TMR-103	ø1.25 ADJUSTMENT ROD	6061-T6	1
2	TMR-102	ARM ADJUSTMENT	1018 STEEL	1
1	TMR-101	2"x2"x1/4" TUBING W/ PLATES	1018 STEEL	1

PART LIST

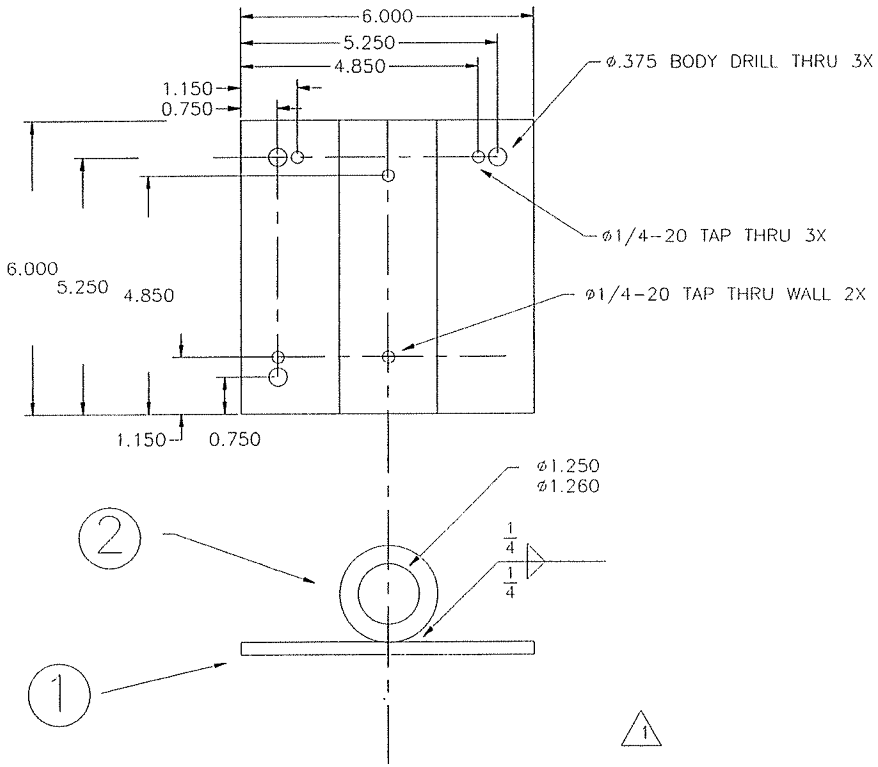
NOTES:
1) DRAWING FOR REFERENCE ONLY
2) HALF VIEW OF ENTIRE ARM

UNLESS OTHERWISE NOTED:
TOLERANCES
.XX ±.01 ANGLES ±0.5'
.XXX ±.005 64√

DESIGN KJM	DATE 3/15/94	UNIVERSITY OF CALIFORNIA, DAVIS MECHANICAL ENGINEERING DEPARTMENT	
DRAWN KJM		TITLE ARM ASSEMBLY TMR ARM ASSEMBLY	
APPRV DAB		QTY 1	DRAWING NO. TMR-100
RELEASE		SCALE 1:1	
		SIZE B	SHT · PROJECT TMR PROJECT


REVISION
A INITIAL RELEASE 3/6/94 KJM DAB
6.000
5.250
0.750
ø.375 BODY DRILL 3X
6.000
5.250
0.750
SECTION AA
48.50
A
A
B
B
1/4
1/4
TAP 3/8-16 THRU 3X
6.000
5.250
0.750
6.000
5.250
0.750
SECTION BB
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
2) 1 WELDED TO 2 90° +-0.5°
3) 1 WELDED TO 3 90° +-0.5°
3 6"x6"X1/4" THICK PLATE 1018 STEEL 1
2 6"x6"X1/4" THICK PLATE 1018 STEEL 1
1 2"x2"x1/4" TUBING 14" LONG 1018 STEEL 1
ITEM NO. PART / ID NO. NOMENCLATURE / DESCRIPTION MATERIAL / SPECIFICATION QTY REQD
PART LIST
UNLESS OTHERWISE NOTED: TOLERANCES
.XX ±.01 ANGLES ±0.5°
.XXX ±.005
64
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
TITLE ARM BASE MOUNT
TMR ASSEMBLY
DESIGN KJM DATE 3/14/94
DRAWN KJM
APPRV DAB
RELEASE
QTY 1
DRAWING NO. TMR-101
SCALE 1:1
SIZE B
SHT
PROJECT TMR PROJECT

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	3/6/94	KJM	DAB

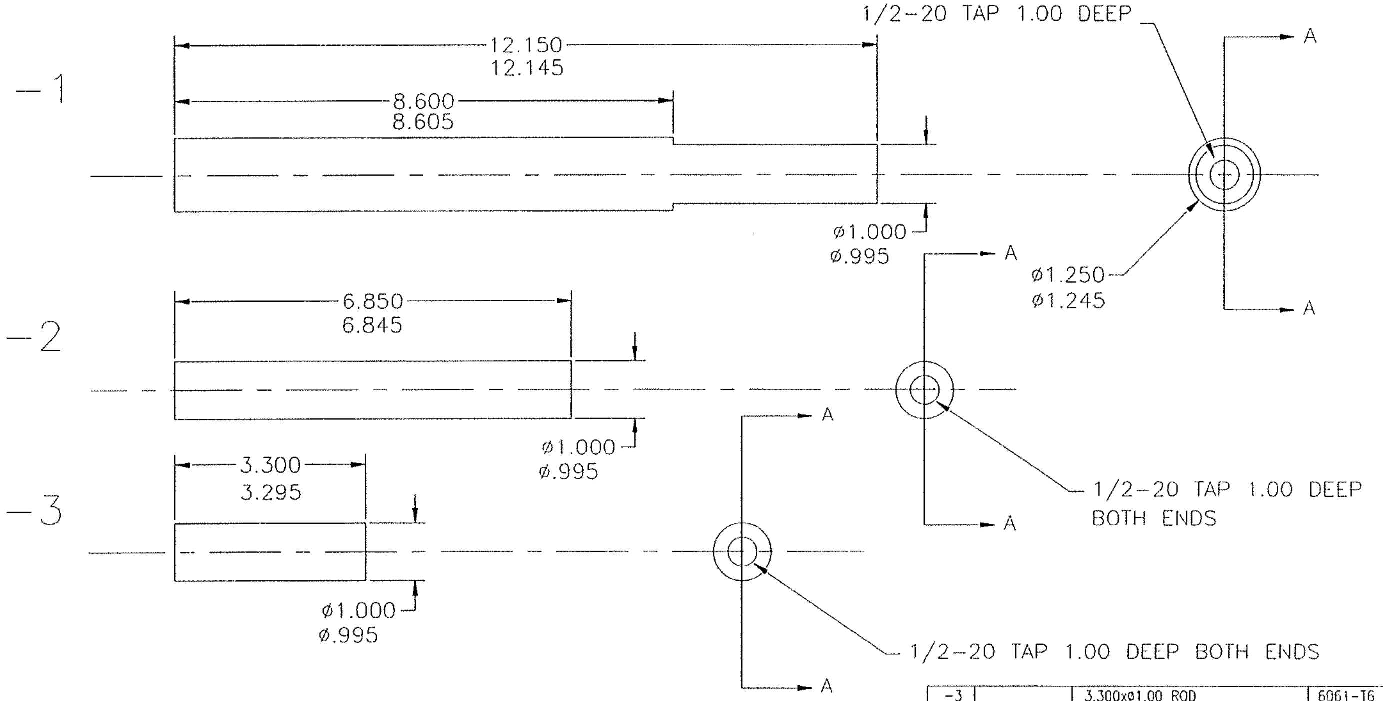


NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
2) 1 WELDED TO 2 90° -+0.5°

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
2		6"xø2" ø1.25 HOLE ROD	1018 STEEL	1
1		6"x6"x1/4" THICK PLATE	1018 STEEL	1

PART LIST

UNLESS OTHERWISE NOTED: TOLERANCES .XX ±.01 .XXX ±.005 ANGLES ±0.5° 64	UNIVERSITY OF CALIFORNIA, DAVIS MECHANICAL ENGINEERING DEPARTMENT
DESIGN KJM DATE 3/10/94	TITLE VARI PLATE TMR ARM ASSEMBLY
DRAWN KJM	QTY 1 DRAWING NO. TMR-102
APPRV DAB	SCALE 1:1
RELEASE	SIZE B SHT PROJECT TMR PROJECT



REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRAWN	APP
A		INITIAL RELEASE	3/6/94	KJM	DAB

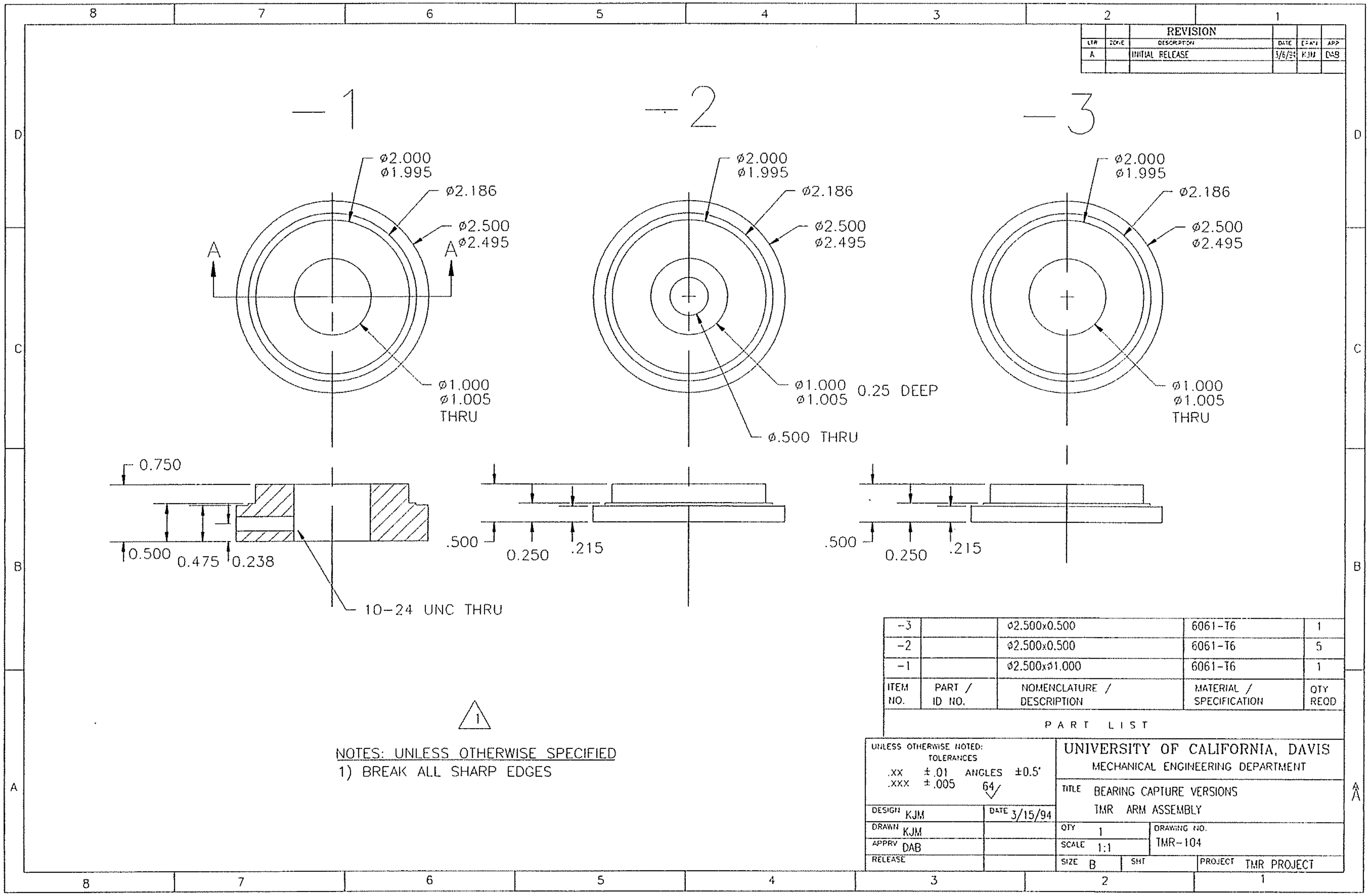
NOTES: UNLESS OTHERWISE SPECIFIED

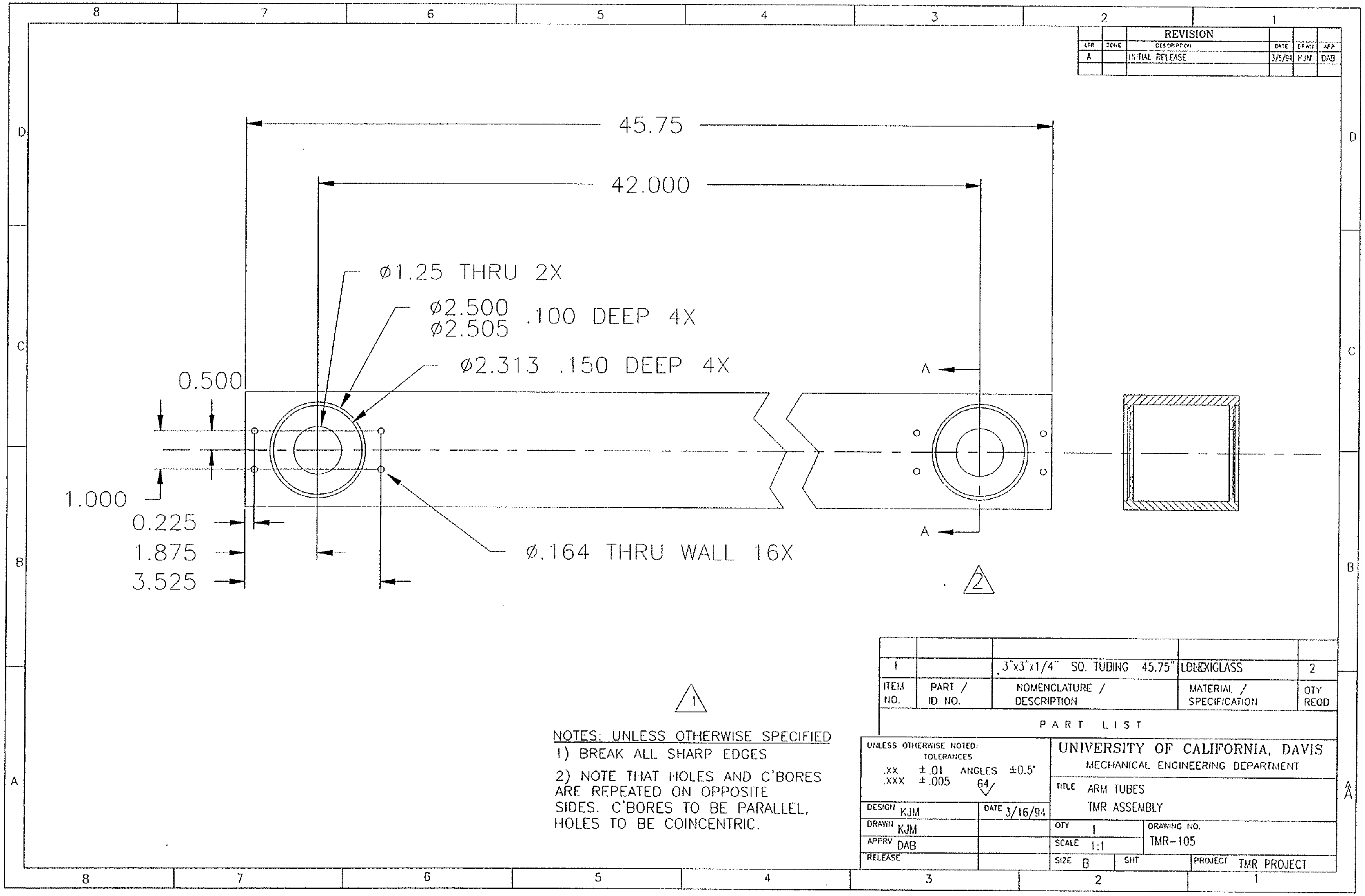
1) BREAK ALL SHARP EDGES

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
-3		3.300xø1.00 ROD	6061-T6	1
-2		7.100xø1.00 ROD	6061-T6	1
-1		12.150xø1.25 ROD	6061-T6	1

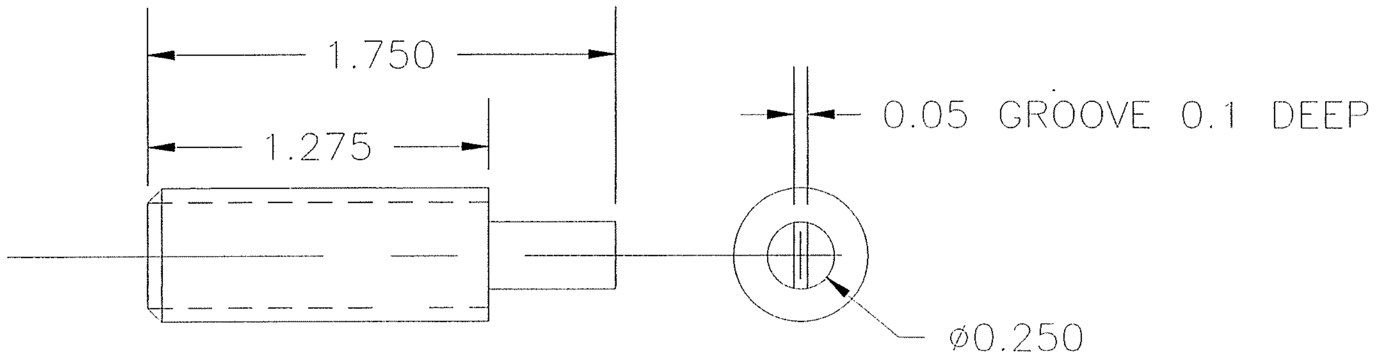
PART LIST

UNLESS OTHERWISE NOTED: TOLERANCES .XX ±.01 .XXX ±.005 ANGLES ±0.5° 64	UNIVERSITY OF CALIFORNIA, DAVIS MECHANICAL ENGINEERING DEPARTMENT
DESIGN KJM DATE 3/15/94	TITLE HEIGHT ADJUSTING ROD/JOINT RODS TMR ARM ASSEMBLY
DRAWN KJM	QTY 1 DRAWING NO. TMR-103
APPRV DAB	SCALE 1:1
RELEASE	SIZE B SHT PROJECT TMR PROJECT


REVISION
LTR | ZONE | DESCRIPTION | DATE | DRAWN | APP
A | | INITIAL RELEASE | 3/6/94 | KJM | DAB
-1
-2
-3
⌀2.000
⌀1.995
⌀2.186
⌀2.500
⌀2.495
A
A
⌀1.000
⌀1.005
THRU
0.25 DEEP
⌀.500 THRU
0.750
0.500
0.475
0.238
10-24 UNC THRU
.500
0.250
.215
-3 | | ⌀2.500x0.500 | 6061-T6 | 1
-2 | | ⌀2.500x0.500 | 6061-T6 | 5
-1 | | ⌀2.500x⌀1.000 | 6061-T6 | 1
ITEM NO. | PART / ID NO. | NOMENCLATURE / DESCRIPTION | MATERIAL / SPECIFICATION | QTY REQD
PART LIST
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
UNLESS OTHERWISE NOTED: TOLERANCES
.XX ± .01 ANGLES ±0.5°
.XXX ± .005
64
DESIGN KJM
DATE 3/15/94
DRAWN KJM
APPRV DAB
RELEASE
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
TITLE BEARING CAPTURE VERSIONS
TMR ARM ASSEMBLY
QTY 1
SCALE 1:1
SIZE B
SHT
DRAWING NO. TMR-104
PROJECT TMR PROJECT


REVISION
LTR | ZONE | DESCRIPTION | DATE | DRAWN | APP
A | | INITIAL RELEASE | 3/5/94 | KJM | DAB
45.75
42.000
ø1.25 THRU 2X
ø2.500
ø2.505 .100 DEEP 4X
ø2.313 .150 DEEP 4X
0.500
1.000
0.225
1.875
3.525
ø.164 THRU WALL 16X
A
A
2
1
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
2) NOTE THAT HOLES AND C'BORES ARE REPEATED ON OPPOSITE SIDES. C'BORES TO BE PARALLEL, HOLES TO BE COINCENTRIC.
1 | | 3"x3"x1/4" SQ. TUBING 45.75" LG. | PLEXIGLASS | 2
ITEM NO. | PART / ID NO. | NOMENCLATURE / DESCRIPTION | MATERIAL / SPECIFICATION | QTY REQD
PART LIST
UNLESS OTHERWISE NOTED: TOLERANCES
.XX ±.01 ANGLES ±0.5°
.XXX ±.005 64
DESIGN KJM DATE 3/16/94
DRAWN KJM
APPRV DAB
RELEASE
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
TITLE ARM TUBES
TMR ASSEMBLY
QTY 1
DRAWING NO. TMR-105
SCALE 1:1
SIZE B SHT
PROJECT TMR PROJECT

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	3/20/94	KJM	DAB

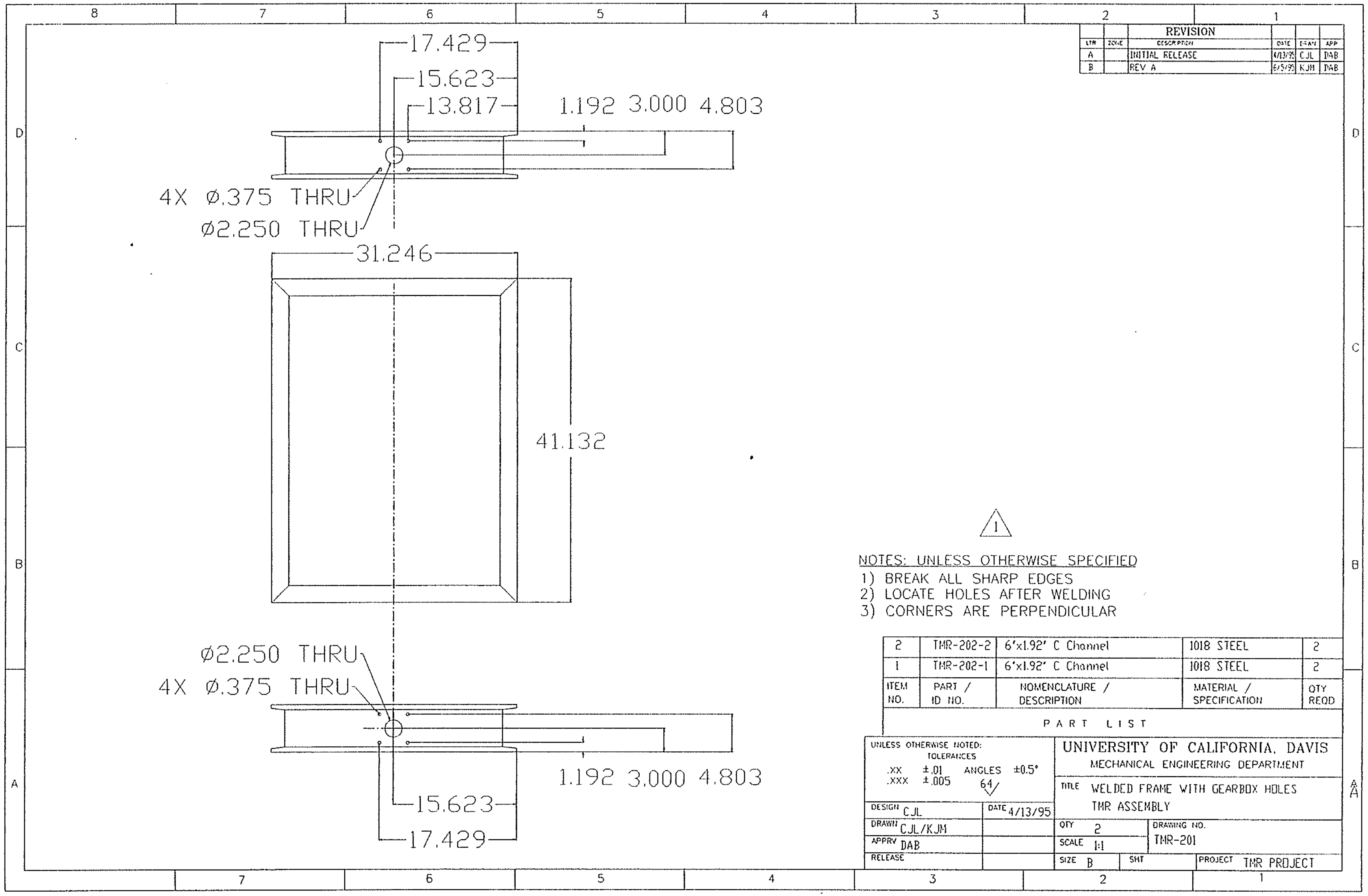


NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES

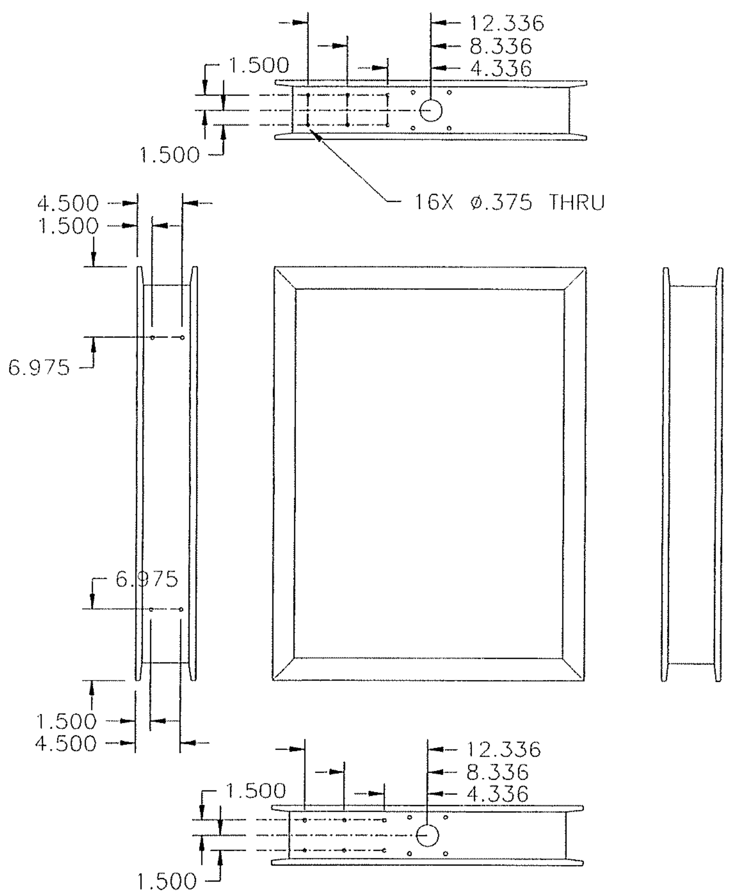
ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
1		1/2-20 THREAD STOCK 1.75"	STEEL	8

PART LIST

UNLESS OTHERWISE NOTED: TOLERANCES .XX ± .01 .XXX ± .005 ANGLES ±0.5° 64		UNIVERSITY OF CALIFORNIA, DAVIS MECHANICAL ENGINEERING DEPARTMENT	
		TITLE OUTSIDE PIPE LINK SCREW	
DESIGN KJM	DATE 3/20/94		
DRAWN KJM		QTY 1	DRAWING NO. TMR-106
APPRV		SCALE 1:1	
RELEASE DAB		SIZE B / SHT	PROJECT TMR PROJECT


REVISION
LTR ZONE DESCRIPTION DATE DRAWN APP
A INITIAL RELEASE 4/13/95 CJL DAB
B REV A 6/5/95 KJM DAB
17.429
15.623
13.817
1.192 3.000 4.803
4X Ø.375 THRU
Ø2.250 THRU
31.246
41.132
Ø2.250 THRU
4X Ø.375 THRU
15.623
17.429
1.192 3.000 4.803
1
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
2) LOCATE HOLES AFTER WELDING
3) CORNERS ARE PERPENDICULAR
2 TMR-202-2 6'x1.92' C Channel 1018 STEEL 2
1 TMR-202-1 6'x1.92' C Channel 1018 STEEL 2
ITEM NO. PART / ID NO. NOMENCLATURE / DESCRIPTION MATERIAL / SPECIFICATION QTY REQD
PART LIST
UNLESS OTHERWISE NOTED: TOLERANCES
.XX ±.01 ANGLES ±0.5°
.XXX ±.005
64
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
TITLE WELDED FRAME WITH GEARBOX HOLES
TMR ASSEMBLY
DESIGN CJL
DATE 4/13/95
DRAWN CJL/KJM
APPRV DAB
RELEASE
QTY 2
DRAWING NO. TMR-201
SCALE 1:1
SIZE B
SHT
PROJECT TMR PROJECT

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	9/5/95	KJM	DAB
B		REV A	6/5/95	KJM	DAB
C		MORE HOLES ADDED	9/5/95	KJM	DAB



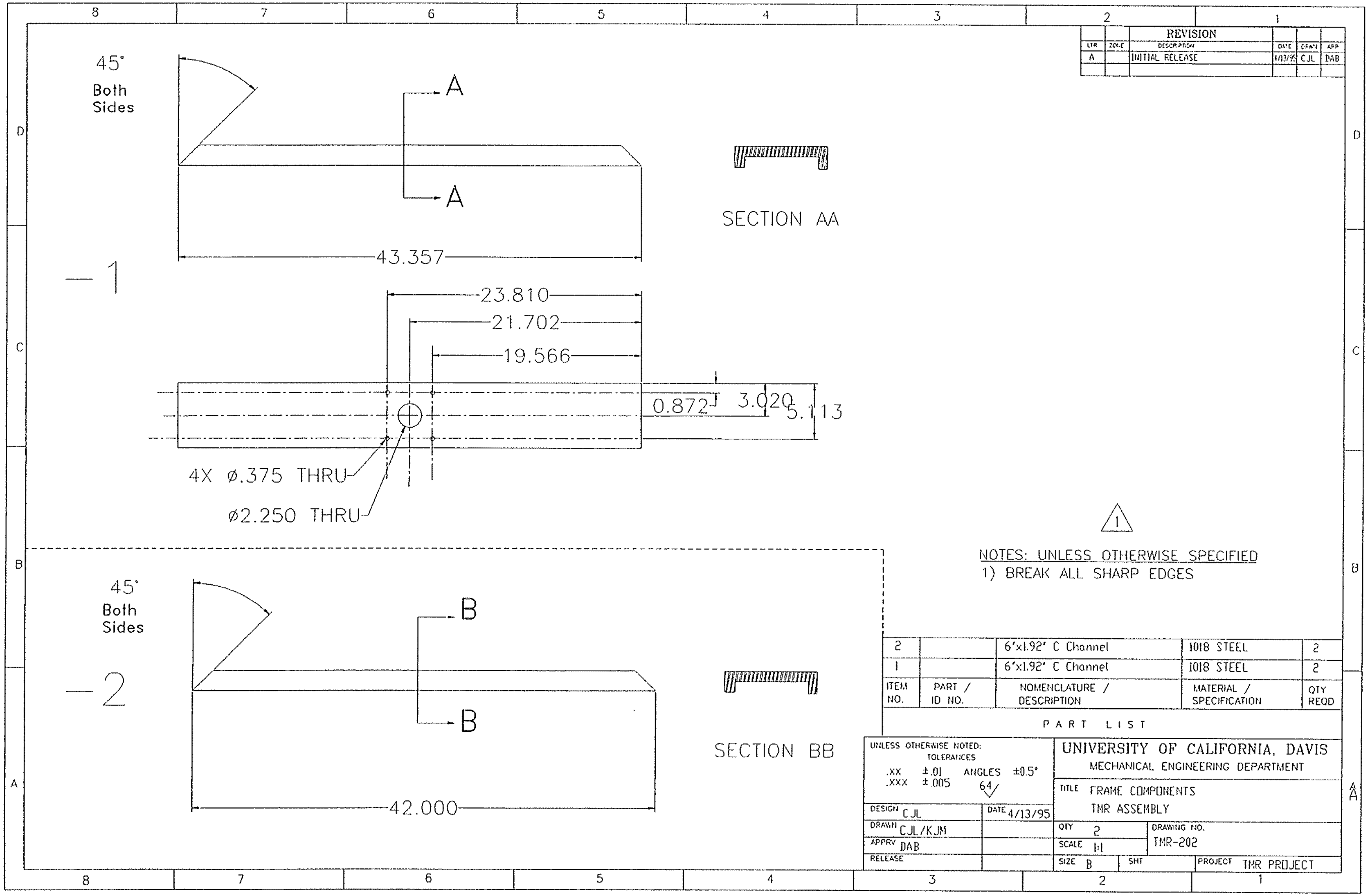
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD

PART LIST

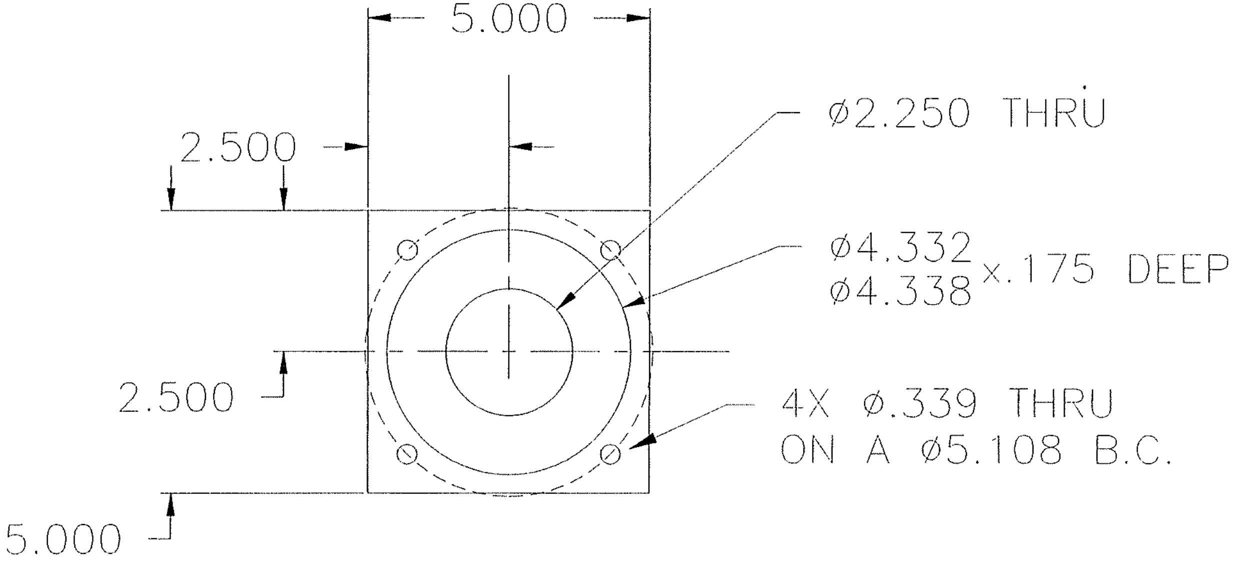
UNLESS OTHERWISE NOTED:
TOLERANCES
.XX ±.01 ANGLES ±0.5°
.XXX ±.005
64

DESIGN KJM	DATE 9/5/95	UNIVERSITY OF CALIFORNIA, DAVIS MECHANICAL ENGINEERING DEPARTMENT	
DRAWN KJM		TITLE WELDED FRAME WITH EXTENDER HOLES TMR ASSEMBLY	
APPRV DAB		QTY 1	DRAWING NO. TMR-201
RELEASE		SCALE 1:1	
		SIZE B SHT	PROJECT TMR PROJECT



REVISION
LTR ZONE DESCRIPTION DATE DRAWN APP
A INITIAL RELEASE 4/13/95 CJL DAB
45°
Both
Sides
A
A
SECTION AA
43.357
— 1
23.810
21.702
19.566
0.872
3.020
5.113
4X ø.375 THRU
ø2.250 THRU
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
45°
Both
Sides
— 2
B
B
SECTION BB
42.000
2 6'x1.92' C Channel 1018 STEEL 2
1 6'x1.92' C Channel 1018 STEEL 2
ITEM NO. PART / ID NO. NOMENCLATURE / DESCRIPTION MATERIAL / SPECIFICATION QTY REQD
PART LIST
UNLESS OTHERWISE NOTED:
TOLERANCES
.XX ±.01 ANGLES ±0.5°
.XXX ±.005
64
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
TITLE FRAME COMPONENTS
TMR ASSEMBLY
DESIGN CJL
DATE 4/13/95
DRAWN CJL/KJM
APPRV DAB
RELEASE
QTY 2
SCALE 1:1
DRAWING NO.
TMR-202
SIZE B
SHT
PROJECT TMR PROJECT

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRAWN	APP
A		INITIAL RELEASE	4/13/95	CJL	DAB

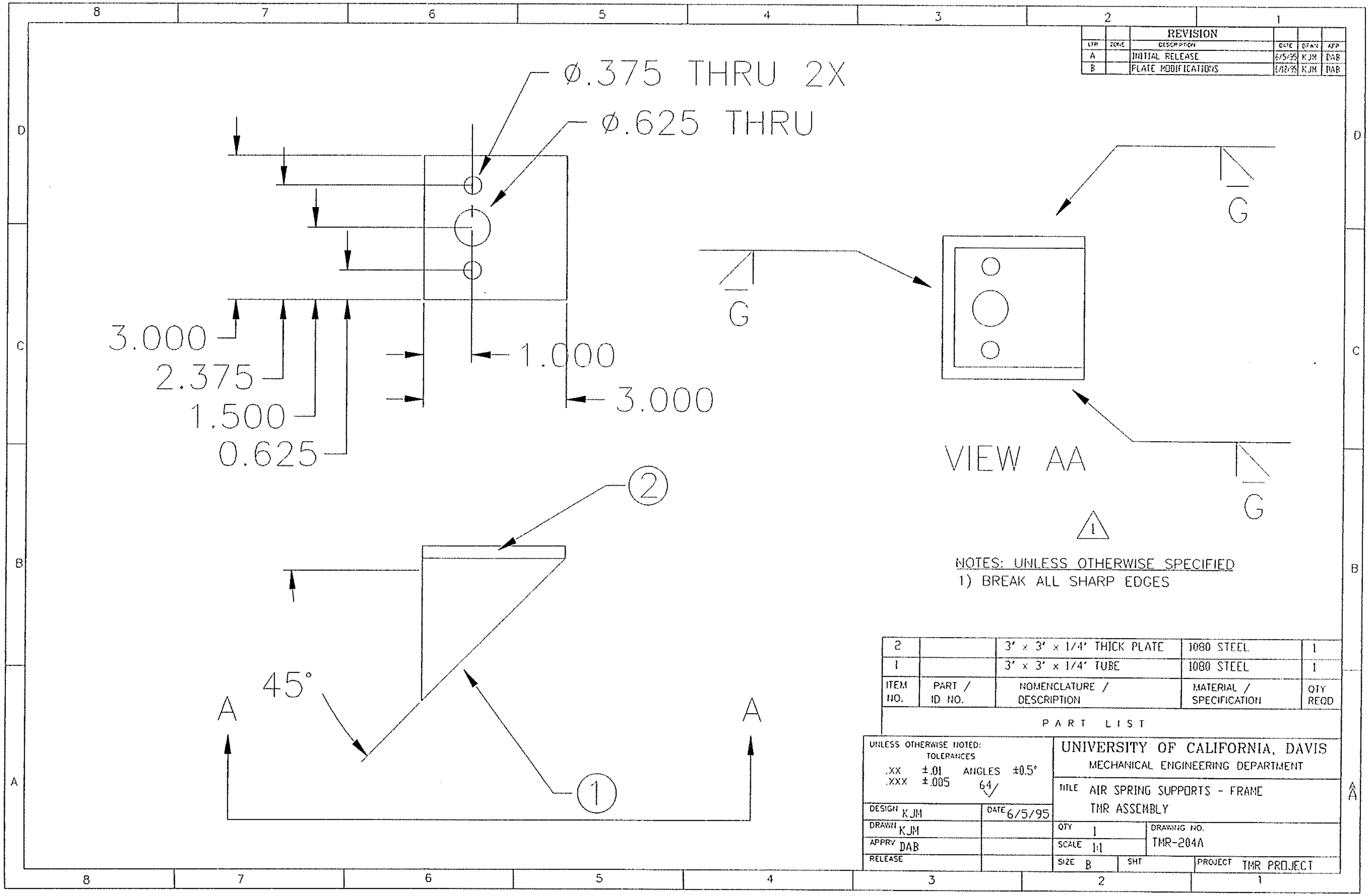


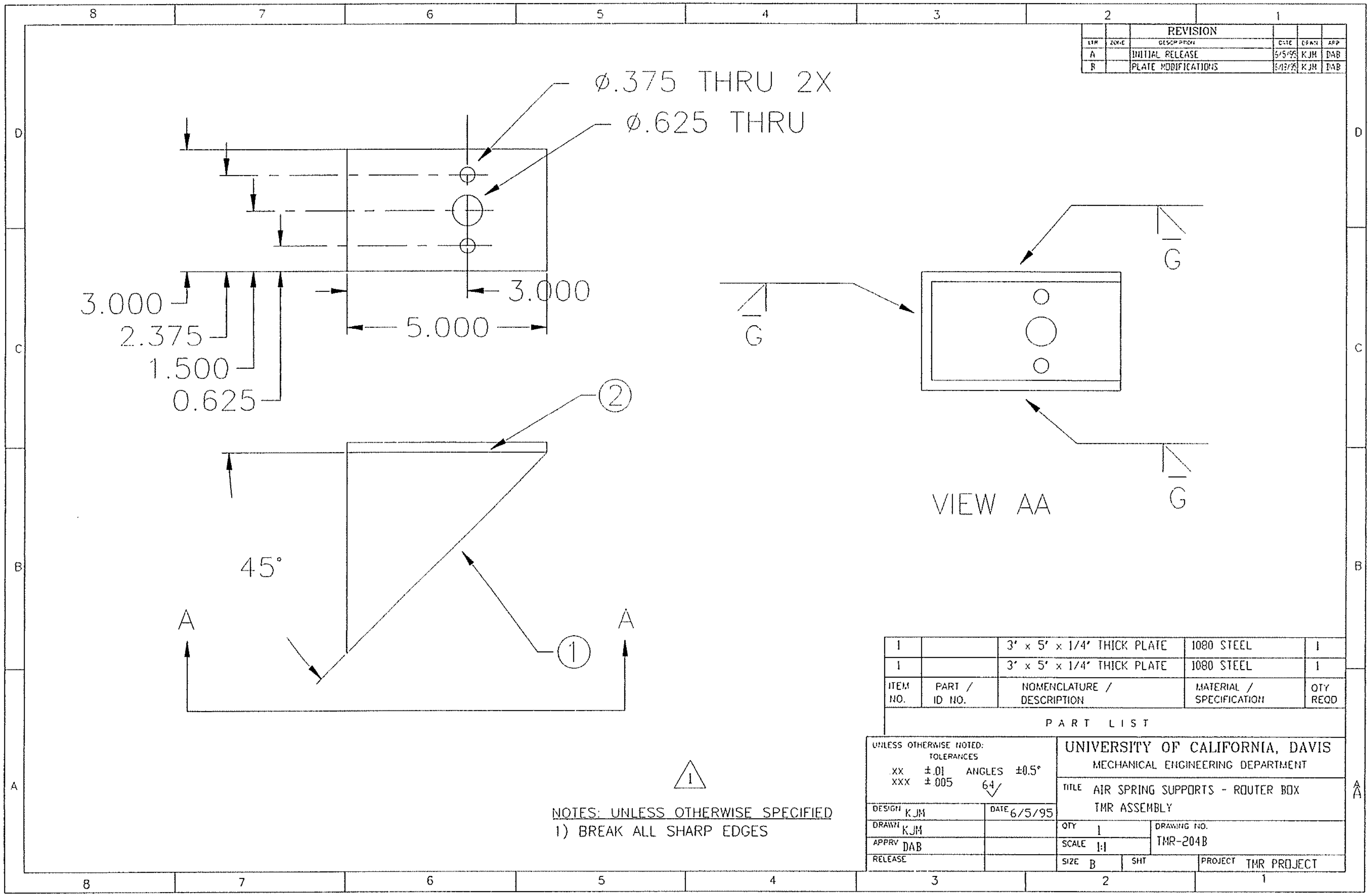
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
2) HARD BLACK ANODIZE

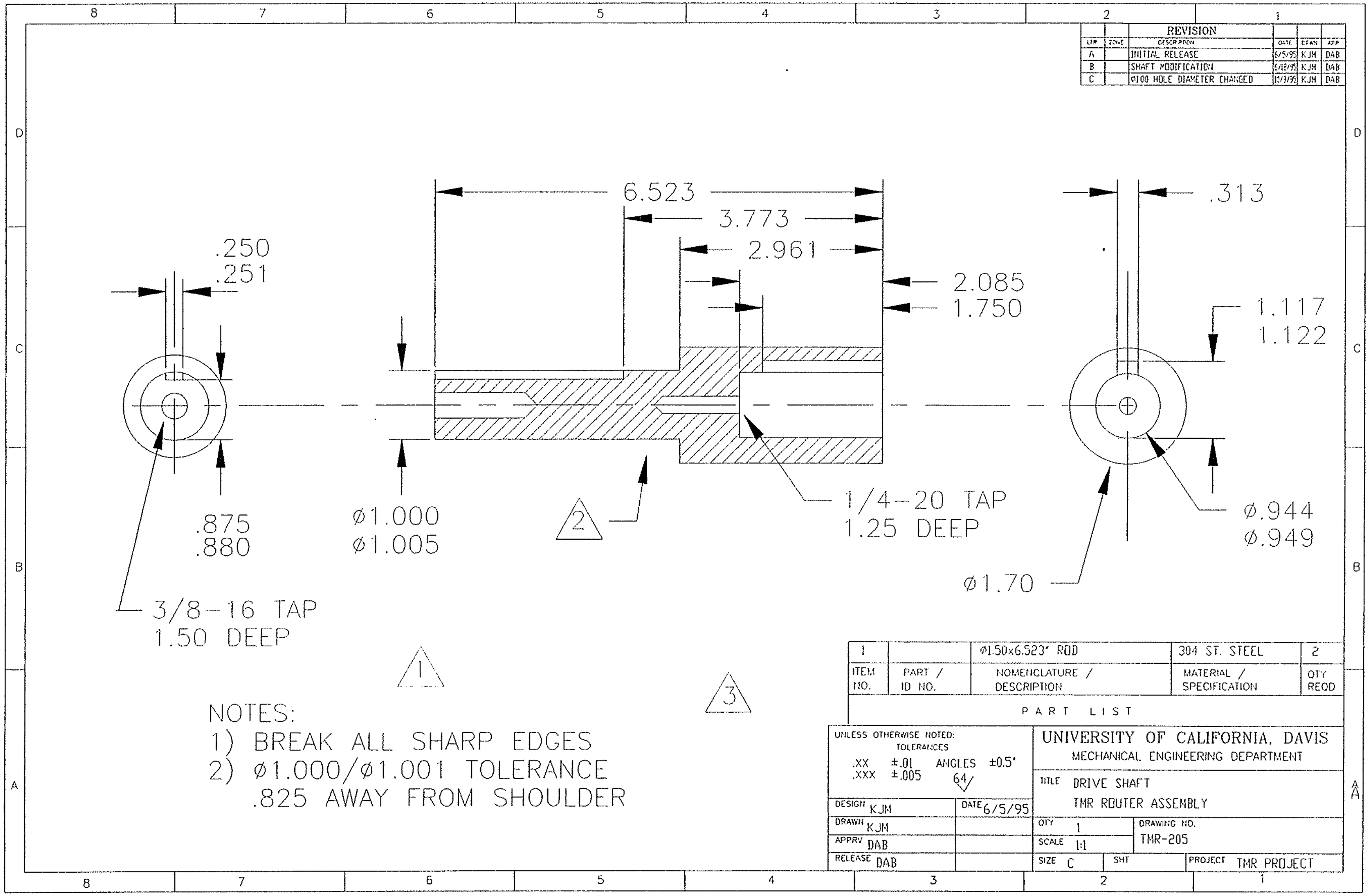
ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
1		5" x 5" x 1/2" THICK PLATE	6061 ALUMINUM	2

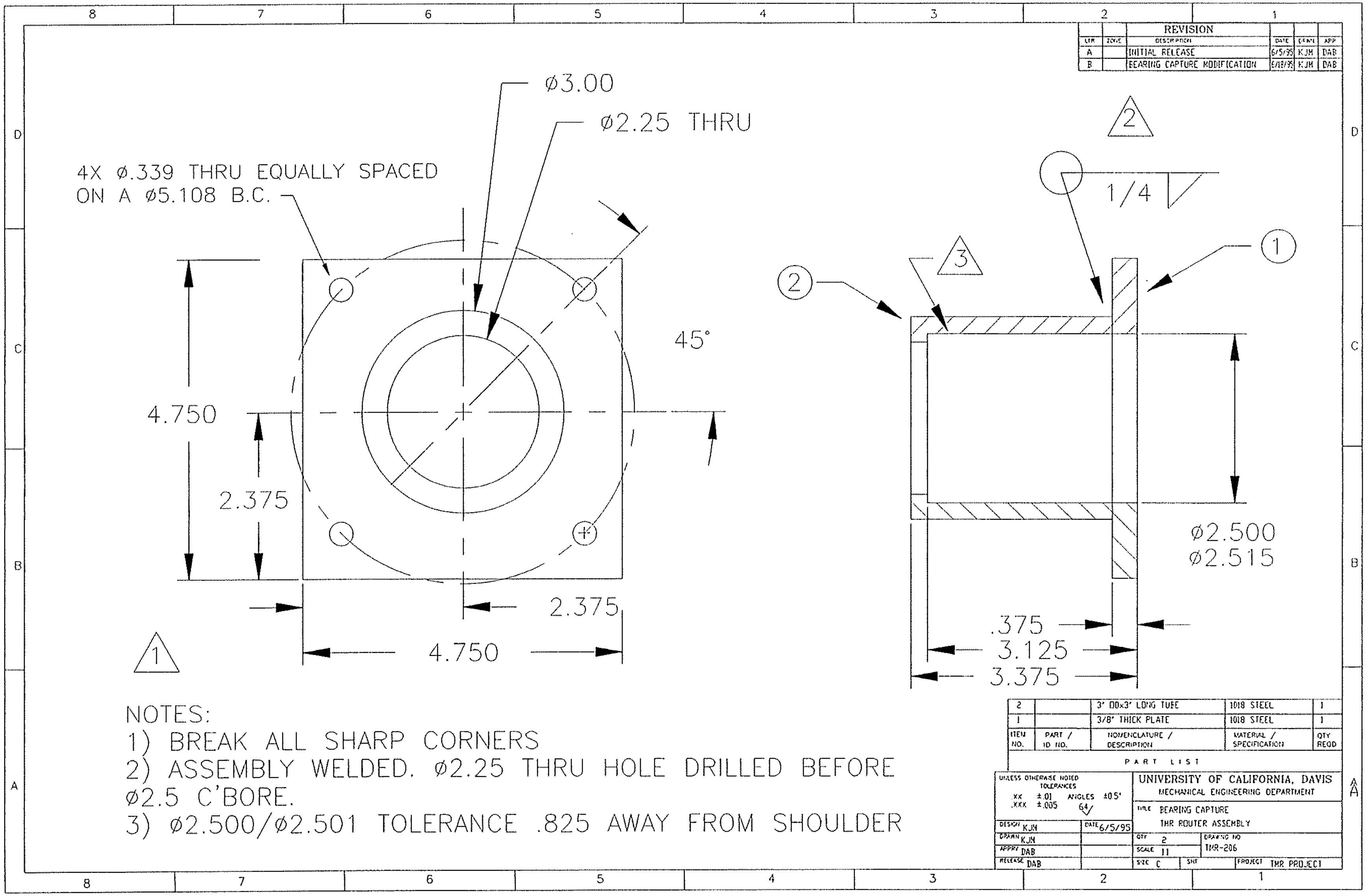
PART LIST

UNLESS OTHERWISE NOTED: TOLERANCES .XX ±.01 .XXX ±.005 ANGLES ±0.5° 64√	UNIVERSITY OF CALIFORNIA, DAVIS MECHANICAL ENGINEERING DEPARTMENT
DESIGN CJL / DATE 4/13/95	TITLE INDEX PLATE TMR ASSEMBLY
DRAWN CJL	QTY 1 / DRAWING NO. TMR-203
APPRV DAB	SCALE 1:1
RELEASE	SIZE B / SHT / PROJECT TMR PROJECT

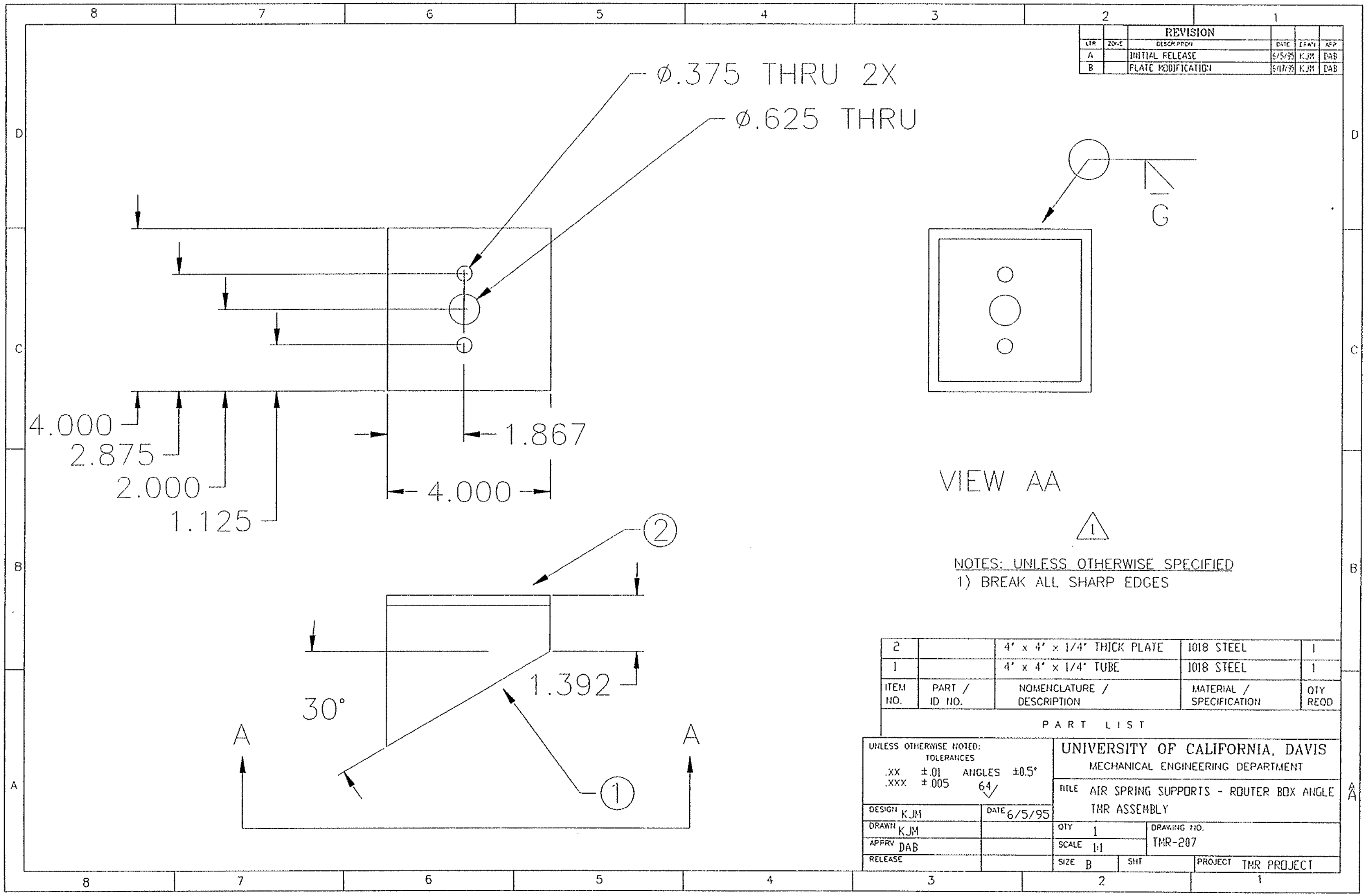

REVISION
LTR ZONE DESCRIPTION DATE DRWN APP
A INITIAL RELEASE 6/5/95 KJM DAB
B PLATE MODIFICATIONS 6/12/95 KJM DAB
Ø.375 THRU 2X
Ø.625 THRU
3.000
2.375
1.500
0.625
1.000
3.000
G
G
G
VIEW AA
2
1
45°
A
A
1
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
2 3' x 3' x 1/4' THICK PLATE 1080 STEEL 1
1 3' x 3' x 1/4' TUBE 1080 STEEL 1
ITEM NO. PART / ID NO. NOMENCLATURE / DESCRIPTION MATERIAL / SPECIFICATION QTY REQD
PART LIST
UNLESS OTHERWISE NOTED: TOLERANCES
.XX ±.01 ANGLES ±0.5°
.XXX ±.005 64
DESIGN KJM DATE 6/5/95
DRAWN KJM
APPRV DAB
RELEASE
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
TITLE AIR SPRING SUPPORTS - FRAME
TMR ASSEMBLY
QTY 1
SCALE 1:1
DRAWING NO. TMR-204A
SIZE B
SHT
PROJECT TMR PROJECT


REVISION
LTR ZONE DESCRIPTION DATE DRWN APP
A INITIAL RELEASE 6/5/95 KJM DAB
B PLATE MODIFICATIONS KJM DAB
Ø.375 THRU 2X
Ø.625 THRU
3.000
2.375
1.500
0.625
3.000
5.000
G
G
G
VIEW AA
2
45°
A
A
1
1 3' x 5' x 1/4' THICK PLATE 1080 STEEL 1
1 3' x 5' x 1/4' THICK PLATE 1080 STEEL 1
ITEM NO. PART / ID NO. NOMENCLATURE / DESCRIPTION MATERIAL / SPECIFICATION QTY REQD
PART LIST
UNLESS OTHERWISE NOTED: TOLERANCES
XX ±.01
XXX ±.005
ANGLES ±0.5°
64
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
TITLE AIR SPRING SUPPORTS - ROUTER BOX
TMR ASSEMBLY
DESIGN KJM
DATE 6/5/95
DRAWN KJM
APPRV DAB
RELEASE
QTY 1
SCALE 1:1
SIZE B
SHT
DRAWING NO. TMR-204B
PROJECT TMR PROJECT

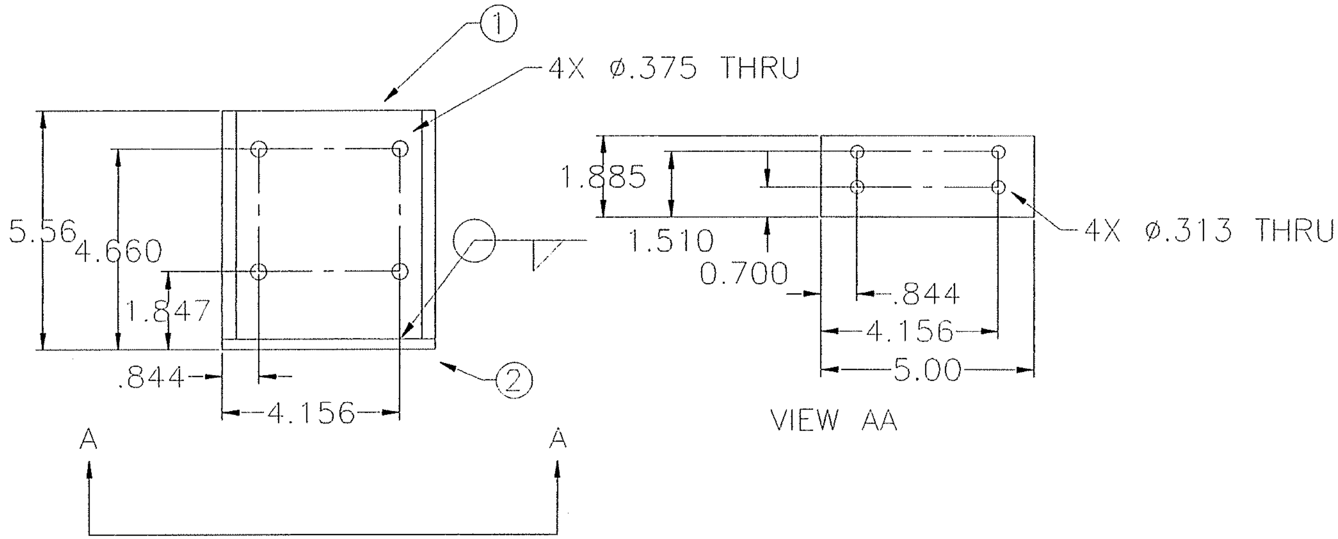

REVISION
LTR | ZONE | DESCRIPTION | DATE | DRAWN | APP
A | | INITIAL RELEASE | 6/5/95 | KJM | DAB
B | | SHAFT MODIFICATION | 6/12/95 | KJM | DAB
C | | Ø100 HOLE DIAMETER CHANGED | 11/3/95 | KJM | DAB
6.523
3.773
2.961
2.085
1.750
.313
.250
.251
1.117
1.122
.875
.880
Ø1.000
Ø1.005
2
1/4-20 TAP
1.25 DEEP
Ø.944
Ø.949
Ø1.70
3/8-16 TAP
1.50 DEEP
1
3
NOTES:
1) BREAK ALL SHARP EDGES
2) Ø1.000/Ø1.001 TOLERANCE
.825 AWAY FROM SHOULDER
1 | | Ø1.50x6.523' ROD | 304 ST. STEEL | 2
ITEM NO. | PART / ID NO. | NOMENCLATURE / DESCRIPTION | MATERIAL / SPECIFICATION | QTY REQD
PART LIST
UNLESS OTHERWISE NOTED:
TOLERANCES
.XX ±.01 ANGLES ±0.5°
.XXX ±.005
64
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
TITLE DRIVE SHAFT
TMR ROUTER ASSEMBLY
DESIGN KJM
DATE 6/5/95
DRAWN KJM
APPRV DAB
RELEASE DAB
QTY 1
SCALE 1:1
DRAWING NO. TMR-205
SIZE C
SHT
PROJECT TMR PROJECT



REVISION
A INITIAL RELEASE 6/5/95 KJH DAB
B BEARING CAPTURE MODIFICATION KJH DAB
Ø3.00
Ø2.25 THRU
4X Ø.339 THRU EQUALLY SPACED ON A Ø5.108 B.C.
45°
4.750
2.375
2.375
4.750
1/4
1
2
3
Ø2.500
Ø2.515
.375
3.125
3.375
NOTES:
1) BREAK ALL SHARP CORNERS
2) ASSEMBLY WELDED. Ø2.25 THRU HOLE DRILLED BEFORE Ø2.5 C'BORE.
3) Ø2.500/Ø2.501 TOLERANCE .825 AWAY FROM SHOULDER
2 3" OD x 3" LONG TUBE 1018 STEEL 1
1 3/8" THICK PLATE 1018 STEEL 1
ITEM NO. PART / ID NO. NOMENCLATURE / DESCRIPTION MATERIAL / SPECIFICATION QTY REQD
PART LIST
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
BEARING CAPTURE
THR ROUTER ASSEMBLY
DESIGN KJH DATE 6/5/95
DRAWN KJH
APPR DAB
RELEASE DAB
QTY 2
SCALE 1:1
SIZE C
THR-206
PROJECT THR PROJECT


REVISION
A INITIAL RELEASE 6/5/95 KJM DAB
B PLATE MODIFICATION 6/17/95 KJM DAB
Ø.375 THRU 2X
Ø.625 THRU
4.000
2.875
2.000
1.125
1.867
4.000
G
VIEW AA
2
1.392
30°
A
A
1
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
2 4" x 4" x 1/4" THICK PLATE 1018 STEEL 1
1 4" x 4" x 1/4" TUBE 1018 STEEL 1
ITEM NO. PART / ID NO. NOMENCLATURE / DESCRIPTION MATERIAL / SPECIFICATION QTY REQD
PART LIST
UNLESS OTHERWISE NOTED: TOLERANCES
.XX ±.01 ANGLES ±0.5°
.XXX ±.005
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
TITLE AIR SPRING SUPPORTS - ROUTER BOX ANGLE
TMR ASSEMBLY
DESIGN KJM DATE 6/5/95
DRAWN KJM
APPRV DAB
RELEASE
QTY 1
SCALE 1:1
DRAWING NO. TMR-207
SIZE B
SHT
PROJECT TMR PROJECT

LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
REVISION					
A		INITIAL RELEASE	9/5/95	KJM	DAB



1

NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
2		5' x 1.885' x 1/4' THICK PLATE	1018 STEEL	1
1		5' x 1.885' C-CHANNEL	1018 STEEL	1

PART LIST

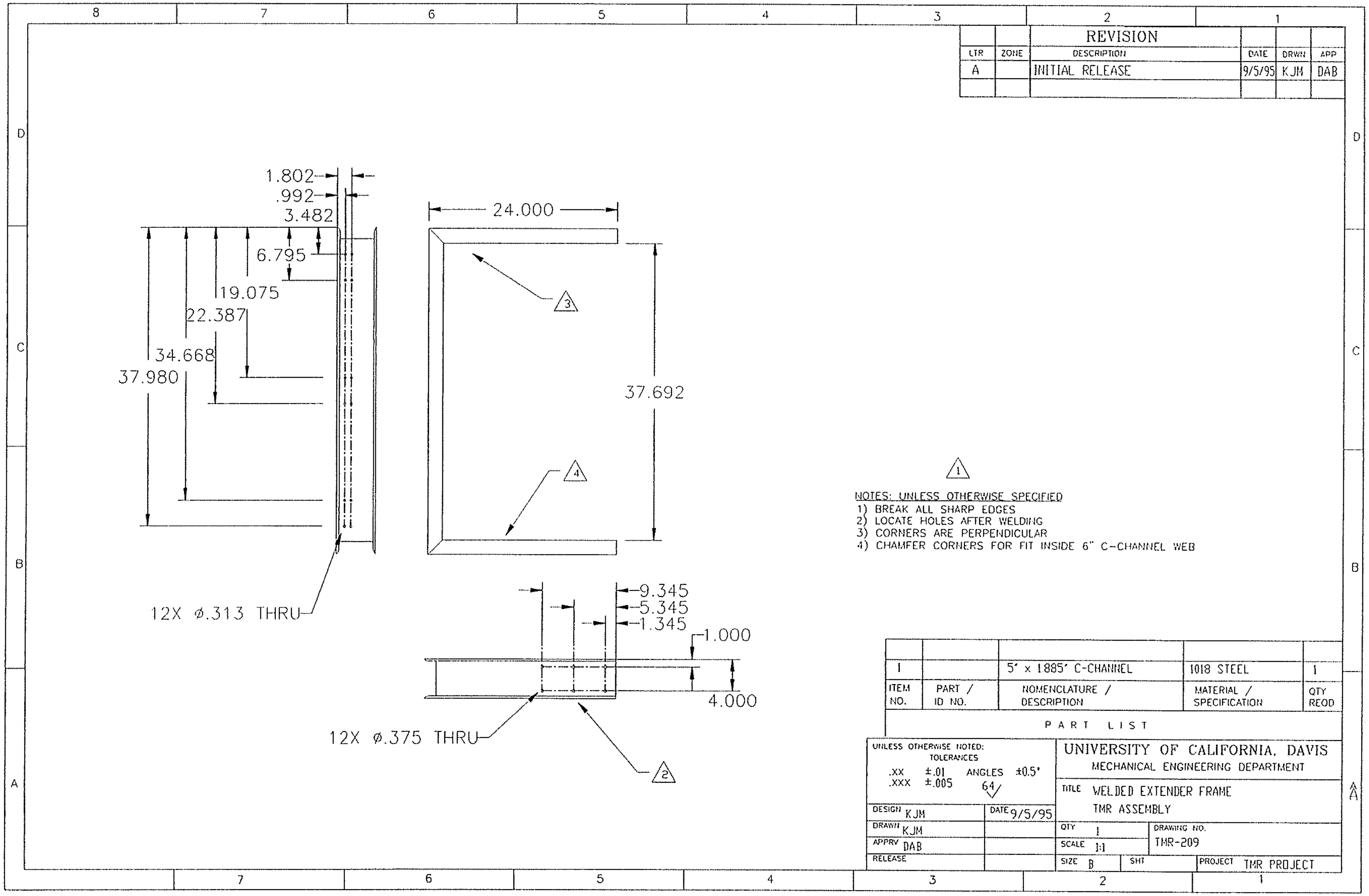
UNLESS OTHERWISE NOTED: TOLERANCES
.XX ±.01 ANGLES ±0.5°
.XXX ±.005
64

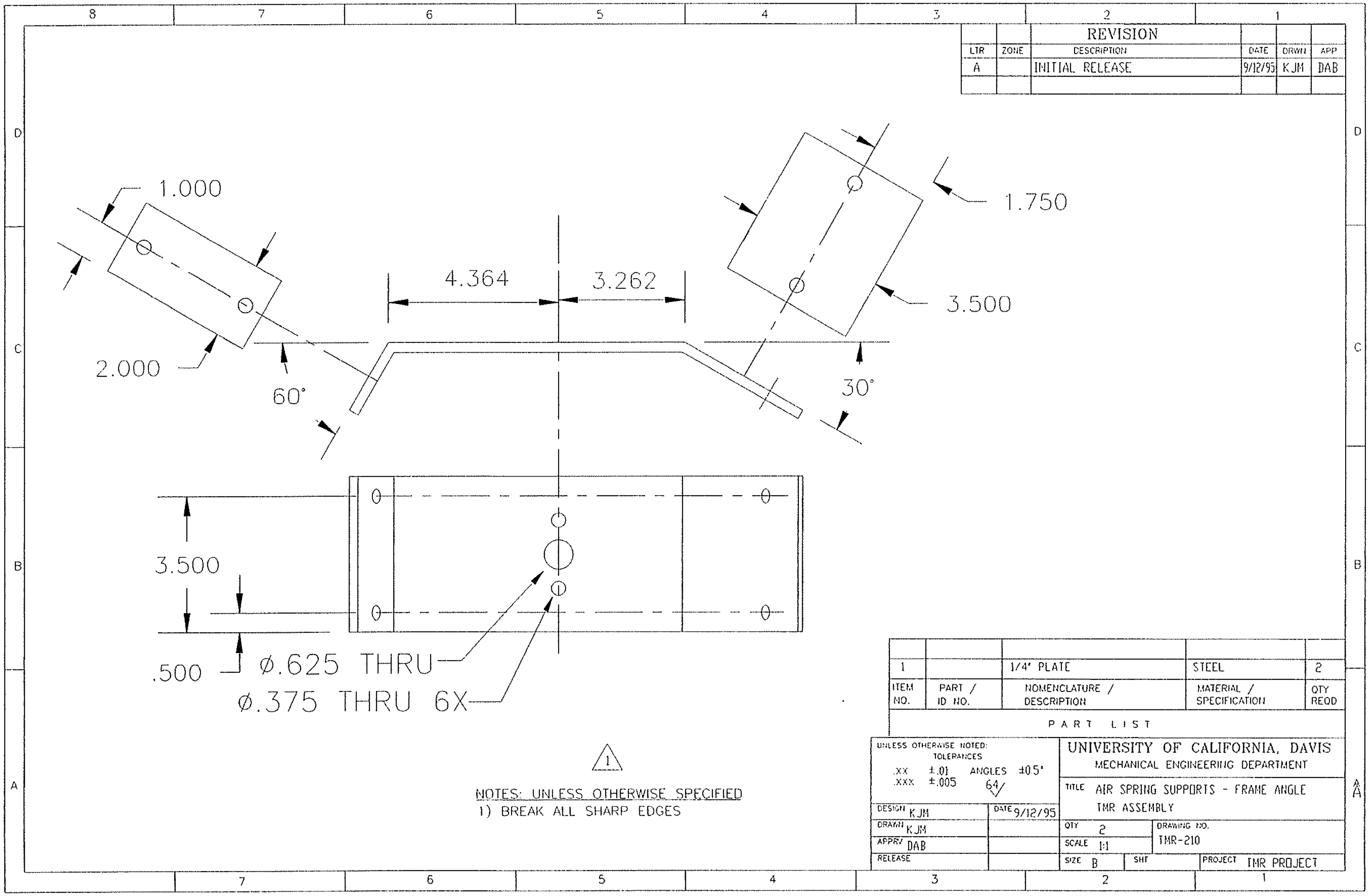
DESIGN KJM DATE 9/5/95
DRAWN KJM
APPRV DAB
RELEASE

UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT

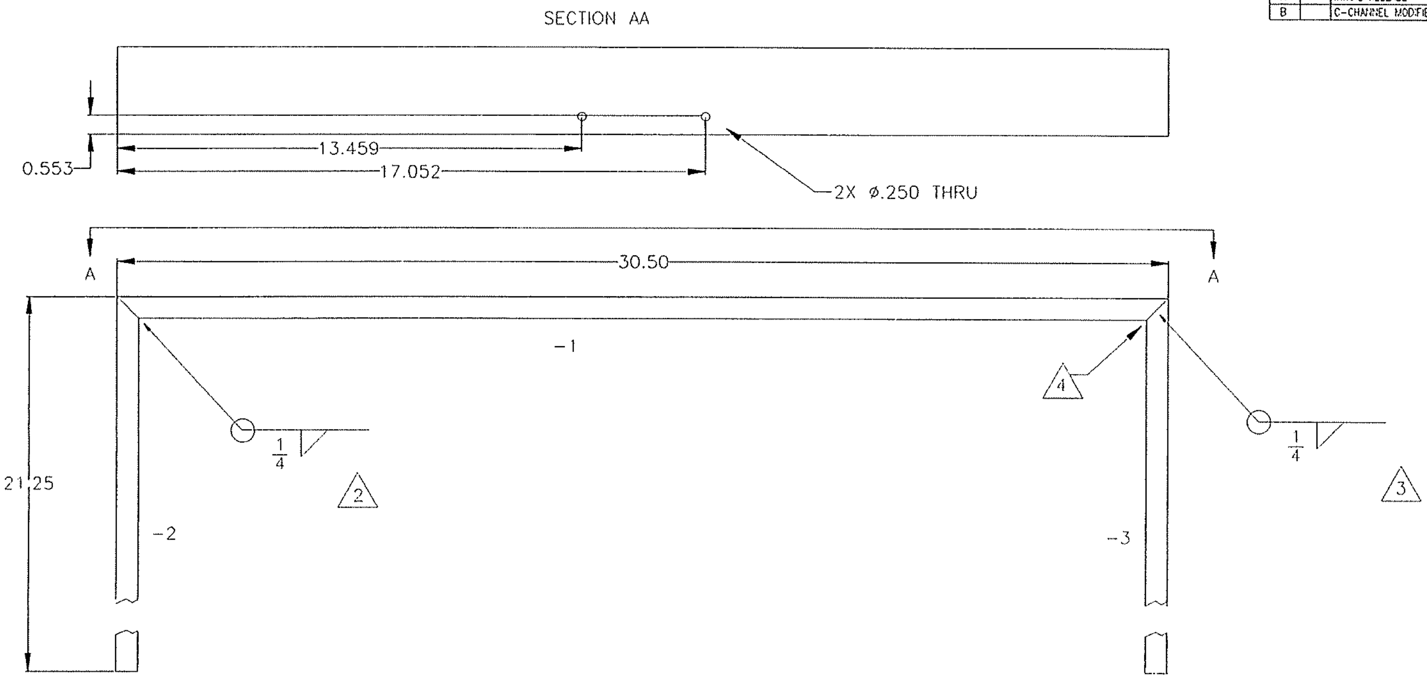
TITLE FRONT WHEEL SUPPORTS
TMR ASSEMBLY

QTY 2 ASSYS
DRAWING NO. TMR-208
SCALE 1:1
SIZE B SHT
PROJECT TMR PROJECT


REVISION
LTR | ZONE | DESCRIPTION | DATE | DRWN | APP
A | | INITIAL RELEASE | 9/5/95 | KJM | DAB
1.802
.992
3.482
6.795
19.075
22.387
34.668
37.980
24.000
37.692
12X ⌀.313 THRU
9.345
5.345
1.345
1.000
4.000
12X ⌀.375 THRU
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
2) LOCATE HOLES AFTER WELDING
3) CORNERS ARE PERPENDICULAR
4) CHAMFER CORNERS FOR FIT INSIDE 6" C-CHANNEL WEB
1 | | 5' x 1885' C-CHANNEL | 1018 STEEL | 1
ITEM NO. | PART / ID NO. | NOMENCLATURE / DESCRIPTION | MATERIAL / SPECIFICATION | QTY REQD
PART LIST
UNLESS OTHERWISE NOTED: TOLERANCES
.XX ±.01 ANGLES ±0.5°
.XXX ±.005
64
DESIGN KJM
DATE 9/5/95
DRAWN KJM
APPRV DAB
RELEASE
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
TITLE WELDED EXTENDER FRAME
TMR ASSEMBLY
QTY 1
DRAWING NO. TMR-209
SCALE 1:1
SIZE B
SHT
PROJECT TMR PROJECT


REVISION
LTR ZONE DESCRIPTION DATE DRWN APP
A INITIAL RELEASE 9/12/95 KJM DAB
1.000
1.750
4.364
3.262
3.500
2.000
60°
30°
3.500
.500
Ø.625 THRU
Ø.375 THRU 6X
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
1 1/4" PLATE STEEL 2
ITEM NO. PART / ID NO. NOMENCLATURE / DESCRIPTION MATERIAL / SPECIFICATION QTY REQD
PART LIST
UNLESS OTHERWISE NOTED: TOLERANCES .XX ±.01 .XXX ±.005 ANGLES ±0.5°
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
TITLE AIR SPRING SUPPORTS - FRAME ANGLE TMR ASSEMBLY
DESIGN KJM DATE 9/12/95
DRAWN KJM
APPR'V DAB
RELEASE
QTY 2
DRAWING NO. TMR-210
SCALE 1:1
SIZE B
PROJECT TMR PROJECT

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRAWN	APP
A		INITIAL RELEASE	11/22/95	KJM	DAB
B		C-CHANNEL MODIFIED	1/10/96	KJM	DAB



ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
3		C3X5 C-CHAN 26.71" LONG	1018 STEEL	1
2		C3X5 C-CHAN 26.92" LONG	1018 STEEL	1
1		C3X5 C-CHAN 26.71" LONG	1018 STEEL	1

PART LIST

1

NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
2) 1 WELDED TO 2 90° +-0.5°
3) 1 WELDED TO 3 90° +-0.5°
4) 45° ANGLES BETWEEN -2, -3 AND -1

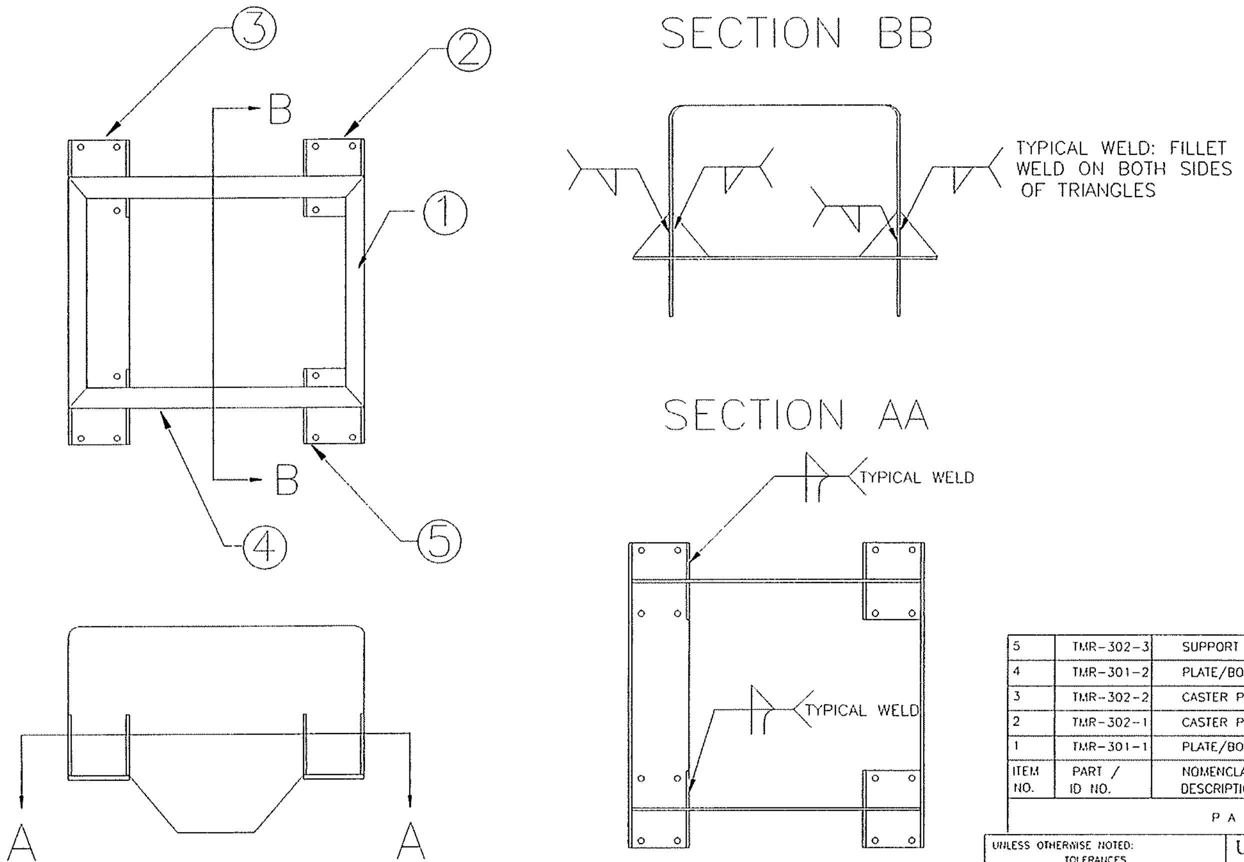
UNLESS OTHERWISE NOTED:
TOLERANCES
.XX ±.01 ANGLES ±0.5°
.XXX ±.005
64

UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT

TITLE C-CHANNEL HOOPS ON ROUTER FRAME
TMR ASSEMBLY

DESIGN KJM	DATE 11/22/95	QTY 2	DRAWING NO. TMR-211
DRAWN KJM		SCALE 1:1	
APPRV DAB		SIZE B	SHT
RELEASE		PROJECT TMR PROJECT	

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRAWN	APP
A		INITIAL RELEASE	10/9/95	KJM	DAB

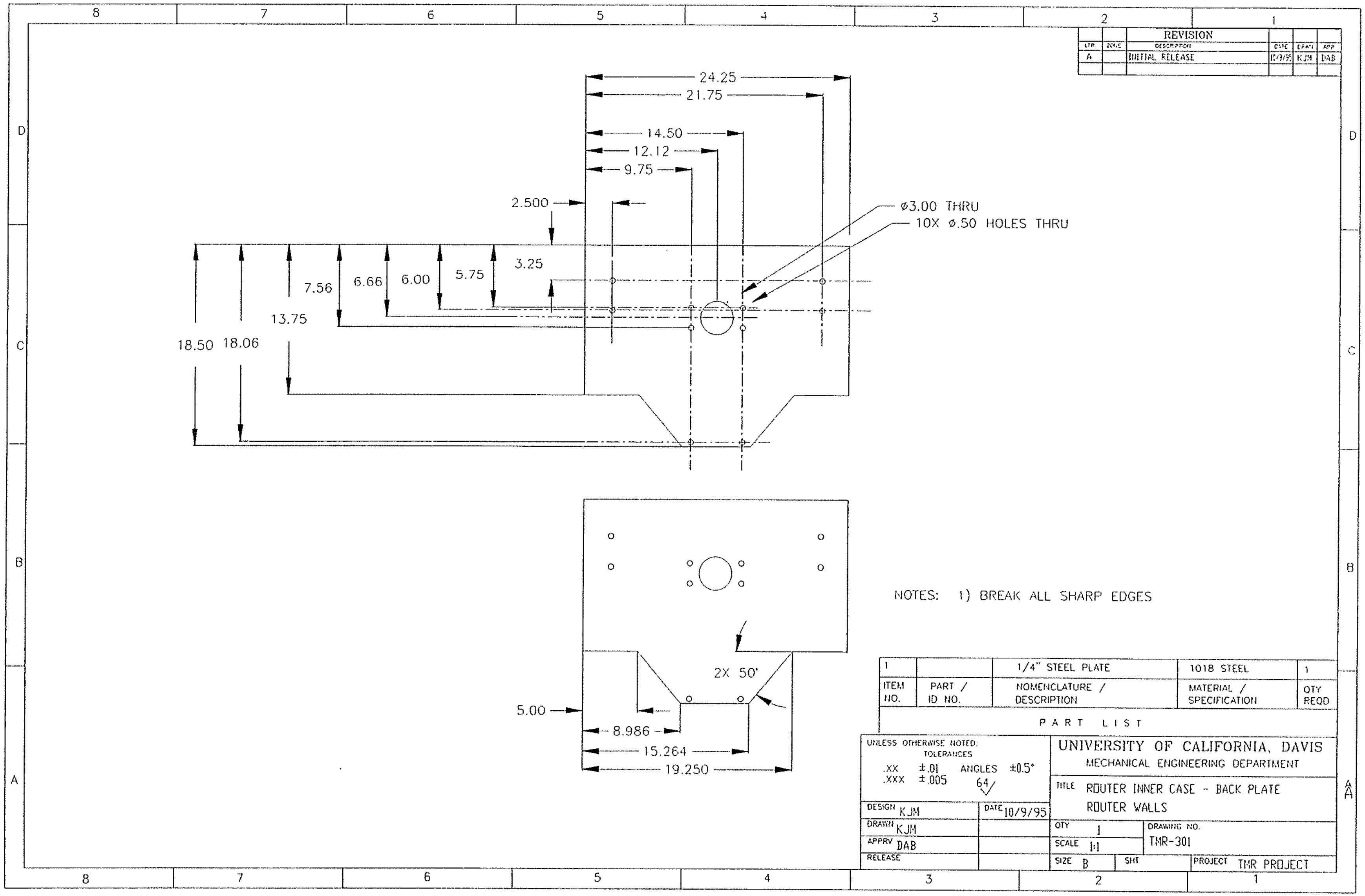


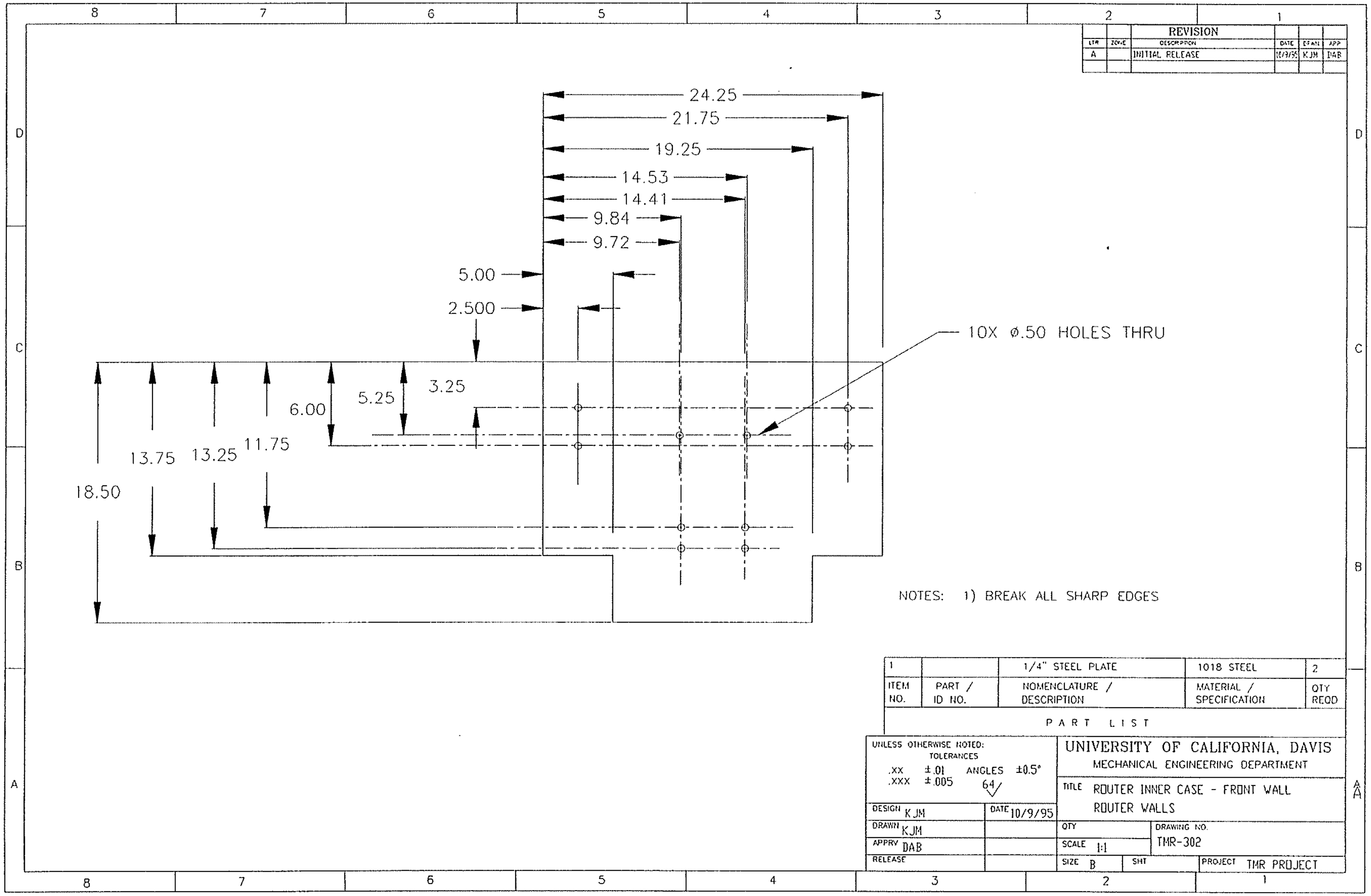
ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
5	TMR-302-3	SUPPORT TRIANGLES	1/4" 1018 STEEL	8
4	TMR-301-2	PLATE/BOX ASSEMBLY	1/4" 1018 STEEL	2
3	TMR-302-2	CASTER PLATE	3/8" 1018 STEEL	1
2	TMR-302-1	CASTER PLATES	3/8" 1018 STEEL	2
1	TMR-301-1	PLATE/BOX ASSEMBLY	1/4" 1018 STEEL	2

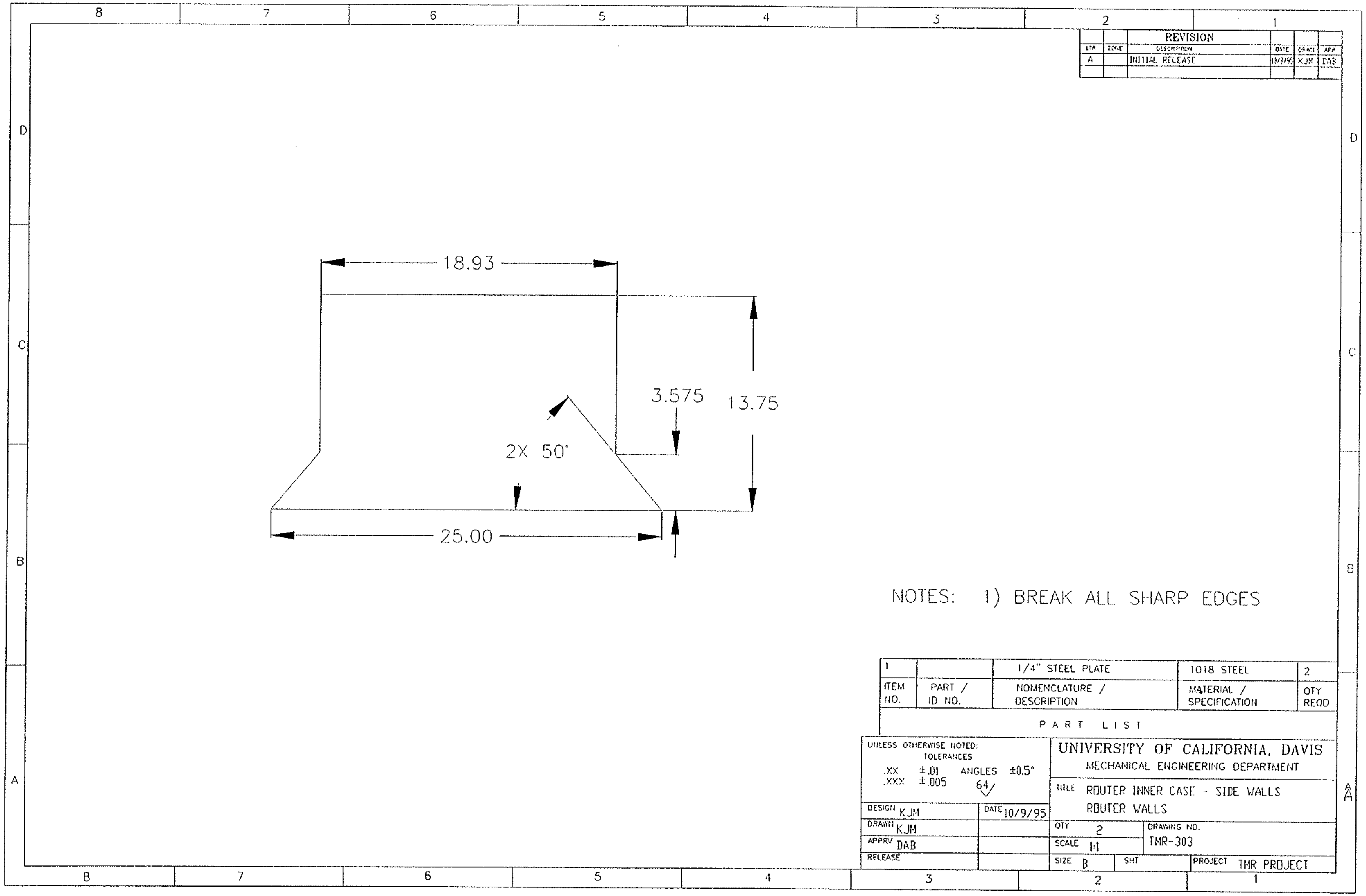
PART LIST

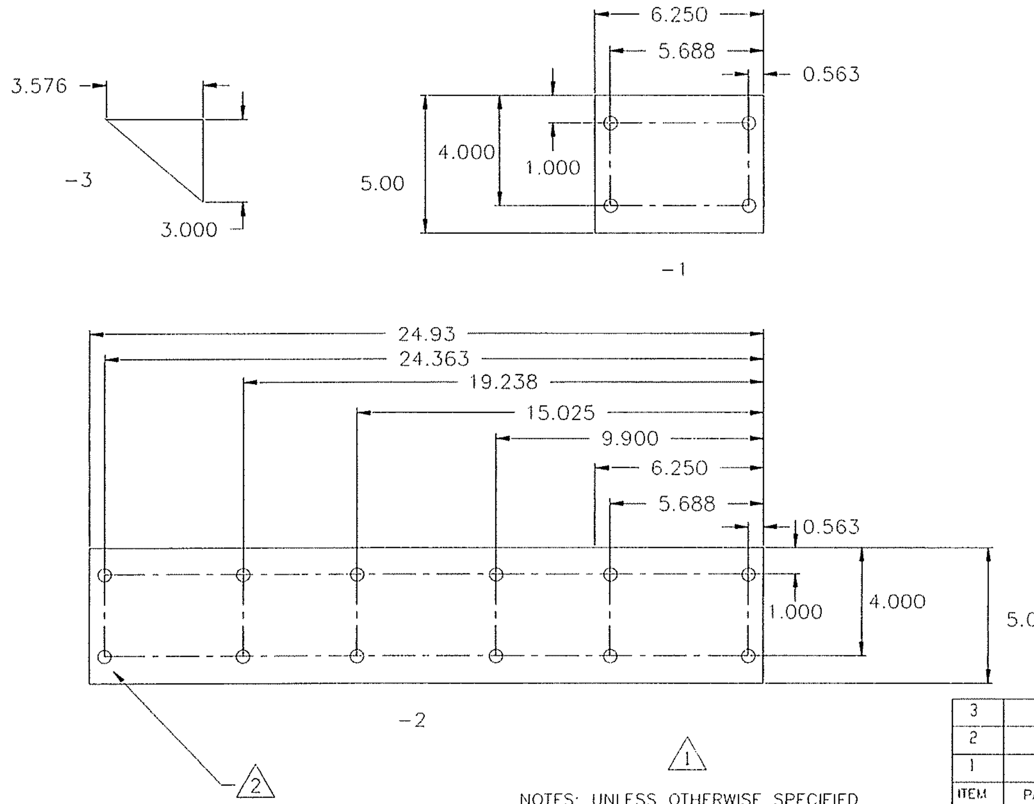
UNLESS OTHERWISE NOTED:
TOLERANCES
.XX ±.01 ANGLES ±0.5°
.XXX ±.005 64

DESIGN KJM	DATE 10/9/95	UNIVERSITY OF CALIFORNIA, DAVIS MECHANICAL ENGINEERING DEPARTMENT	
DRAWN KJM		TITLE ROUTER INNER CASE FINAL ASSEMBLY	
APPRV DAB		QTY 1	DRAWING NO. TMR-300
RELEASE		SCALE 1:1	
		SIZE B SHT	PROJECT TMR PROJECT


REVISION
A INITIAL RELEASE 10/9/95 KJM DAB
24.25
21.75
14.50
12.12
9.75
2.500
ø3.00 THRU
10X ø.50 HOLES THRU
3.25
5.75
6.00
6.66
7.56
13.75
18.50
18.06
2X 50°
5.00
8.986
15.264
19.250
NOTES: 1) BREAK ALL SHARP EDGES
1 1/4" STEEL PLATE 1018 STEEL 1
ITEM NO. PART / ID NO. NOMENCLATURE / DESCRIPTION MATERIAL / SPECIFICATION QTY REQD
PART LIST
UNLESS OTHERWISE NOTED: TOLERANCES
.XX ±.01 ANGLES ±0.5°
.XXX ±.005
64
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
TITLE ROUTER INNER CASE - BACK PLATE
ROUTER WALLS
DESIGN KJM
DATE 10/9/95
DRAWN KJM
APPRV DAB
RELEASE
QTY 1
DRAWING NO. TMR-301
SCALE 1:1
SIZE B
SHT
PROJECT TMR PROJECT


REVISION
LTR ZONE DESCRIPTION DATE DRAWN APP
A INITIAL RELEASE 10/9/95 KJM DAB
24.25
21.75
19.25
14.53
14.41
9.84
9.72
5.00
2.500
10X ø.50 HOLES THRU
3.25
5.25
6.00
11.75
13.25
13.75
18.50
NOTES: 1) BREAK ALL SHARP EDGES
1 1/4" STEEL PLATE 1018 STEEL 2
ITEM NO. PART / ID NO. NOMENCLATURE / DESCRIPTION MATERIAL / SPECIFICATION QTY REQD
PART LIST
UNLESS OTHERWISE NOTED: TOLERANCES
.XX ±.01 ANGLES ±0.5°
.XXX ±.005
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
TITLE ROUTER INNER CASE - FRONT WALL
ROUTER WALLS
DESIGN KJM DATE 10/9/95
DRAWN KJM
APPRV DAB
RELEASE
SCALE 1:1
DRAWING NO. TMR-302
SIZE B
PROJECT TMR PROJECT


REVISION
A INITIAL RELEASE 10/9/95 KJM DAB
18.93
3.575
13.75
2X 50°
25.00
NOTES: 1) BREAK ALL SHARP EDGES
1 1/4" STEEL PLATE 1018 STEEL 2
ITEM NO. PART / ID NO. NOMENCLATURE / DESCRIPTION MATERIAL / SPECIFICATION QTY REQD
PART LIST
UNLESS OTHERWISE NOTED: TOLERANCES
.XX ±.01 ANGLES ±0.5°
.XXX ±.005 64
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
TITLE ROUTER INNER CASE - SIDE WALLS
ROUTER WALLS
DESIGN KJM DATE 10/9/95
DRAWN KJM
APPRV DAB
RELEASE
QTY 2
DRAWING NO. TMR-303
SCALE 1:1
SIZE B SHT
PROJECT TMR PROJECT



NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
2) ALL HOLES ⌀.500 THRU

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	10/9/95	KJM	DAB

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
3		TRIANGULAR 1/4" PLATE	STEEL	8
2		24.926X5.00 3/8" PLATE	STEEL	1
1		6.25X5.00 3/8" PLATE	STEEL	2

PART LIST

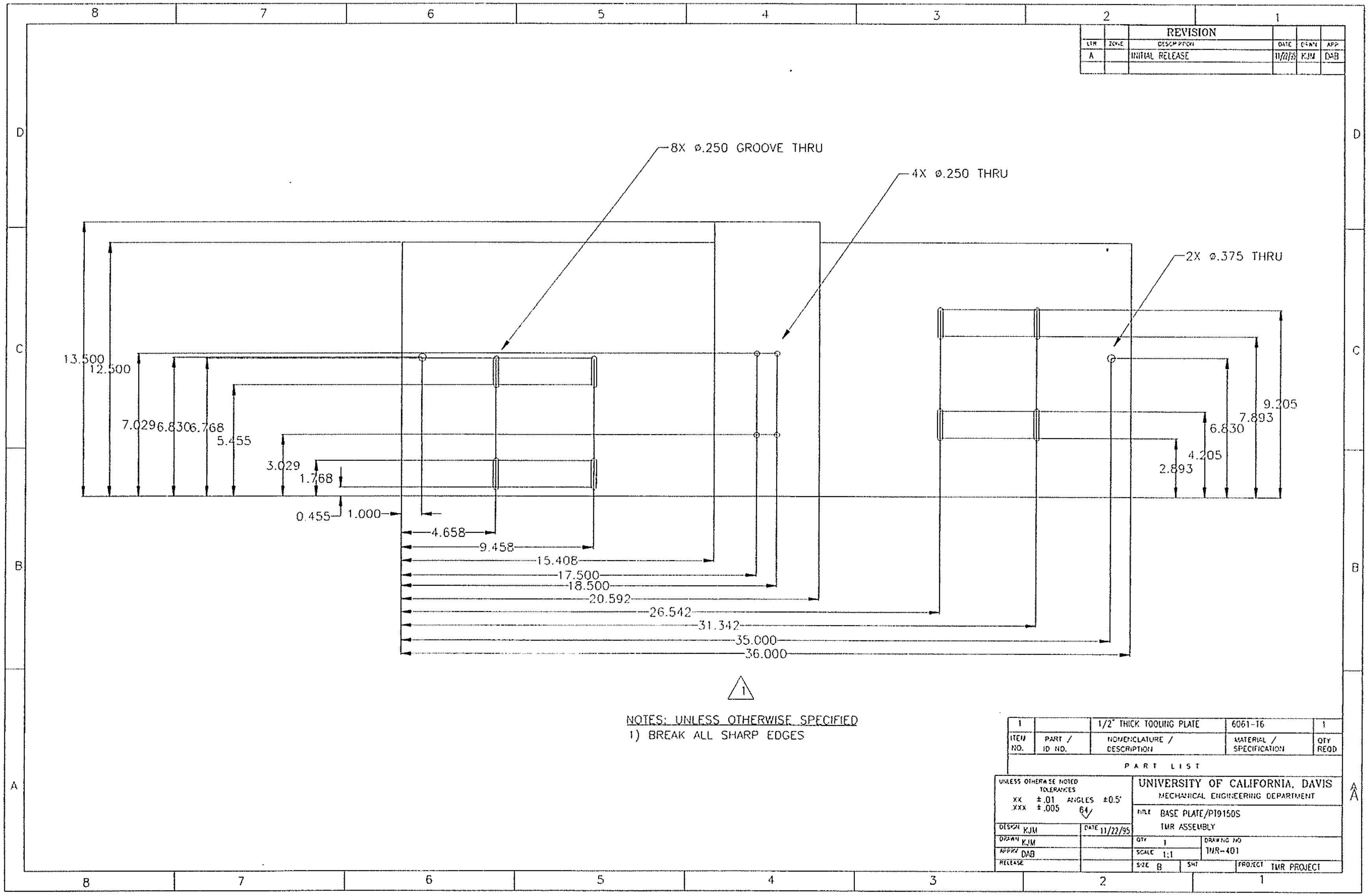
UNLESS OTHERWISE NOTED: TOLERANCES
.XX ±.01 ANGLES ±0.5°
.XXX ±.005 64√

DESIGN KJM	DATE 10/9/95		
DRAWN KJM			
APPRV DAB			
RELEASE			

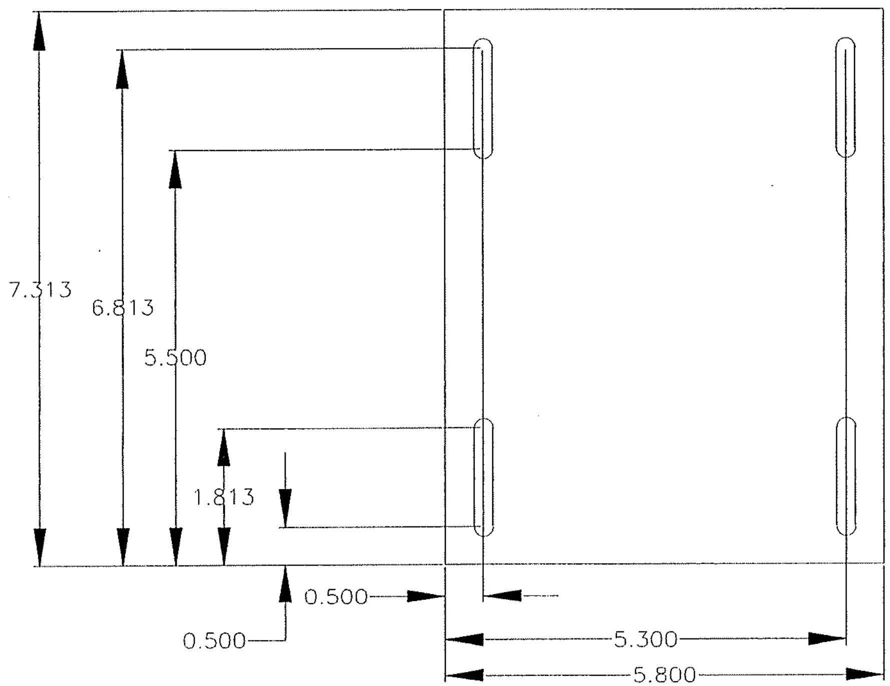
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT

TITLE CASTER PLATES/SUPPORT TRIANGLES
TMR ASSEMBLY

QTY	DRAWING NO. TMR-304
SCALE 1:1	
SIZE B	SHT	PROJECT TMR PROJECT


REVISION
A
INITIAL RELEASE
KJM
DAB
8X ⌀.250 GROOVE THRU
4X ⌀.250 THRU
2X ⌀.375 THRU
13.500
12.500
7.029
6.830
6.768
5.455
3.029
1.768
0.455
1.000
4.658
9.458
15.408
17.500
18.500
20.592
26.542
31.342
35.000
36.000
9.205
7.893
6.830
4.205
2.893
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
1
1/2" THICK TOOLING PLATE
6061-T6
1
ITEM NO.
PART / ID NO.
NOMENCLATURE / DESCRIPTION
MATERIAL / SPECIFICATION
QTY REQD
PART LIST
UNLESS OTHERWISE NOTED TOLERANCES
.XX ±.01 ANGLES ±0.5'
.XXX ±.005
64
DESIGN KJM
DATE 11/22/95
DRAWN KJM
APPRV DAB
RELEASE
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
TITLE BASE PLATE/PI9150S
TMR ASSEMBLY
QTY 1
SCALE 1:1
DRAWING NO TMR-401
SIZE B
SHT
PROJECT TMR PROJECT

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	11/22/95	KJM	DAB



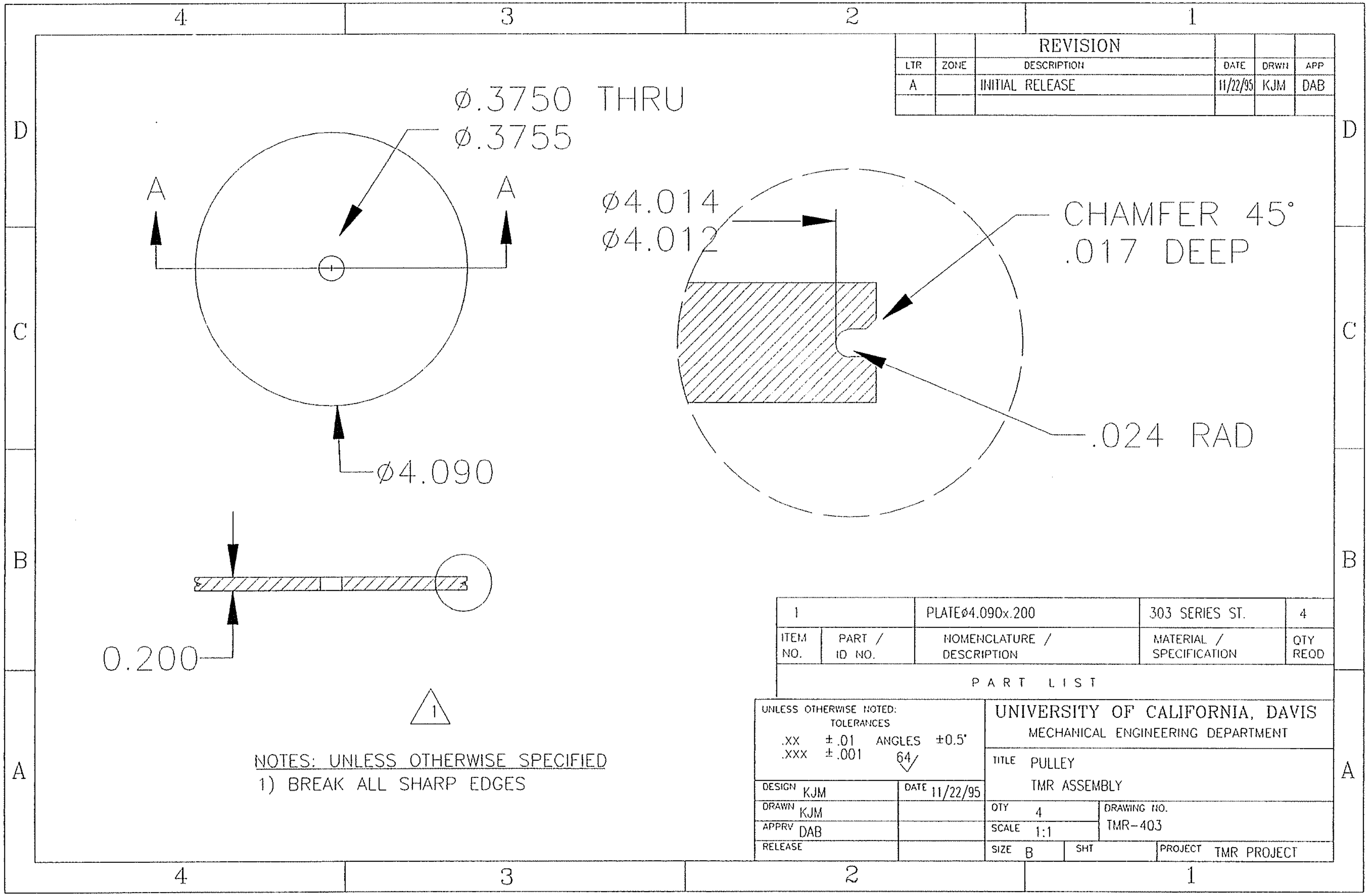
1		7.313"x5.80"x1/2" BLOCK	6061-T6 ALUMINUM	1
ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD

PART LIST

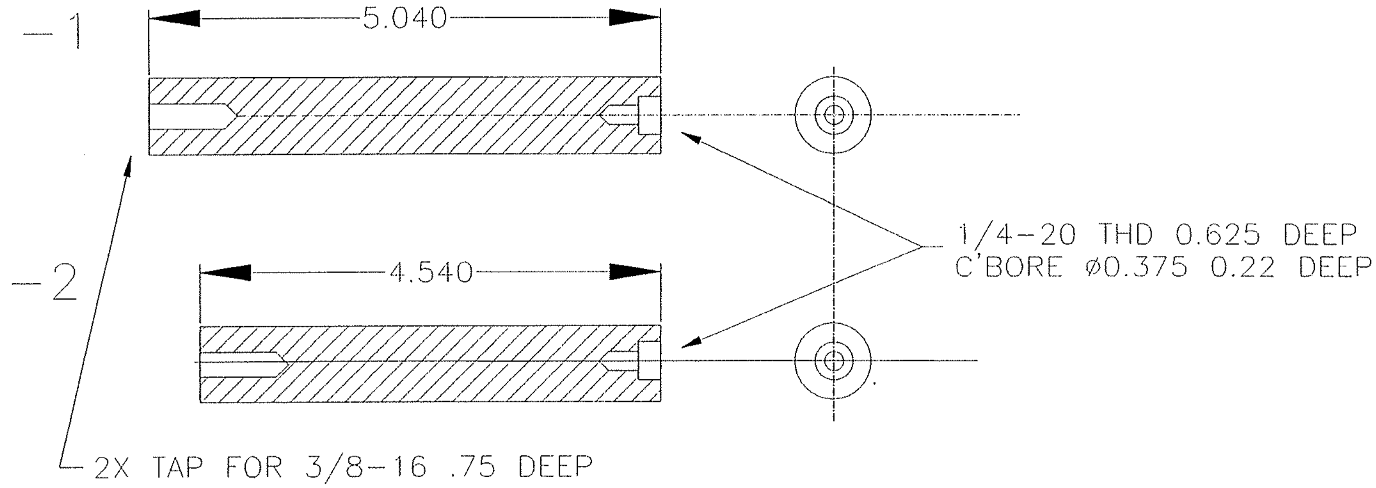
UNLESS OTHERWISE NOTED:
TOLERANCES
.XX ± .01 ANGLES ±0.5°
.XXX ± .005
64

DESIGN KJM	DATE 11/22/95	UNIVERSITY OF CALIFORNIA, DAVIS MECHANICAL ENGINEERING DEPARTMENT	
DRAWN KJM		TITLE SET OFF BLOCK TMR ASSEMBLY	
APPRV DAB		QTY 1	DRAWING NO. TMR-402
RELEASE		SCALE 1:1	
		SIZE B SHT	PROJECT TMR PROJECT

NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES


REVISION
LTR ZONE DESCRIPTION DATE DRWN APP
A INITIAL RELEASE 11/22/95 KJM DAB
ø.3750 THRU
ø.3755
A
A
ø4.090
ø4.014
ø4.012
CHAMFER 45°
.017 DEEP
.024 RAD
0.200
1
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
1 PLATEø4.090x.200 303 SERIES ST. 4
ITEM NO. PART / ID NO. NOMENCLATURE / DESCRIPTION MATERIAL / SPECIFICATION QTY REQD
PART LIST
UNLESS OTHERWISE NOTED: TOLERANCES
.XX ±.01 ANGLES ±0.5°
.XXX ±.001
64
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
TITLE PULLEY
TMR ASSEMBLY
DESIGN KJM DATE 11/22/95
DRAWN KJM
APPRV DAB
RELEASE
QTY 4
SCALE 1:1
DRAWING NO. TMR-403
SIZE B SHT PROJECT TMR PROJECT

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	11/22/95	KJM	DAB



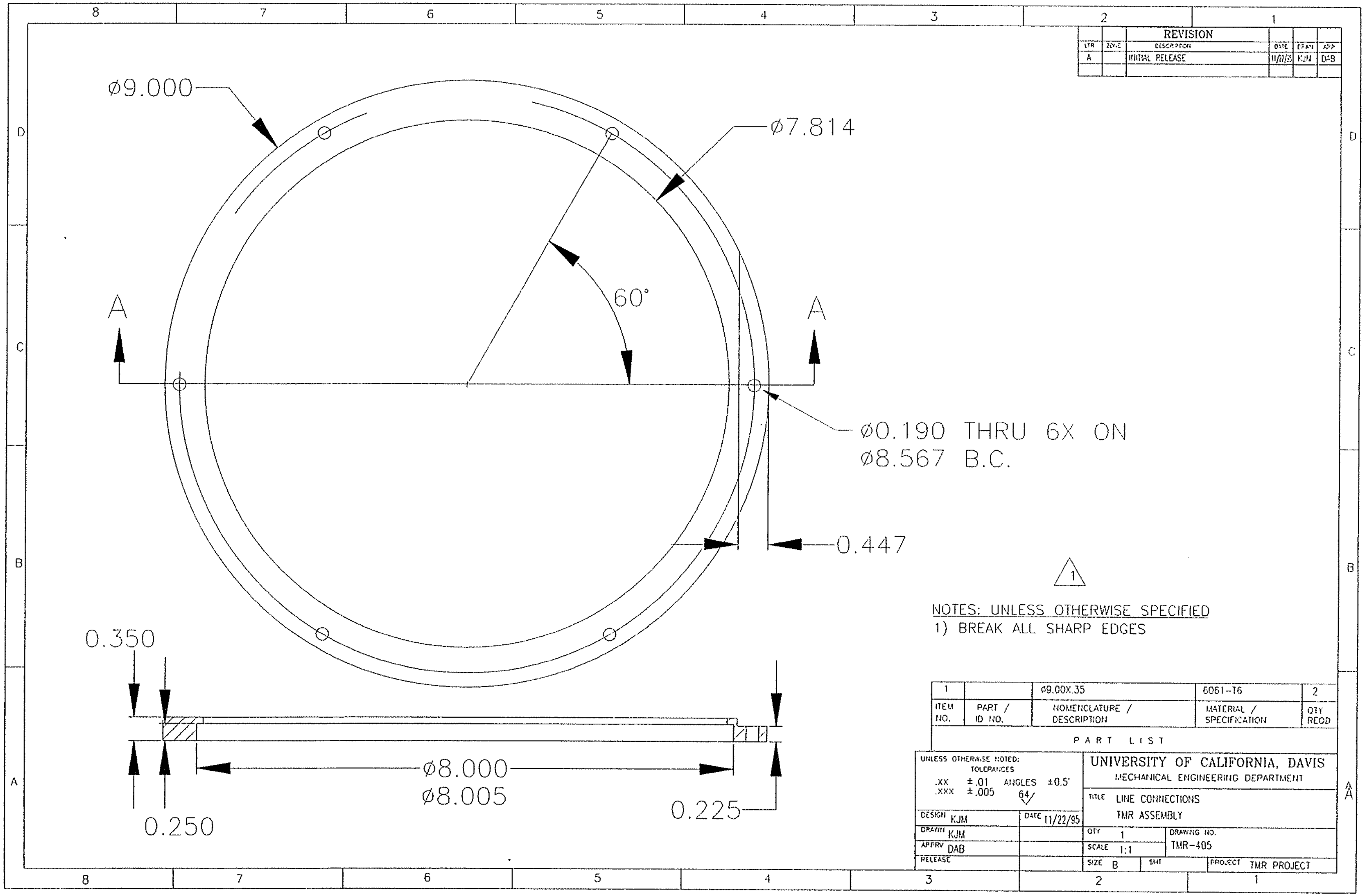
ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
-2		⌀0.750x4.540 ROD	303 SERIES ST.	1
-1		⌀0.750x5.040 ROD	303 SERIES ST.	1

PART LIST

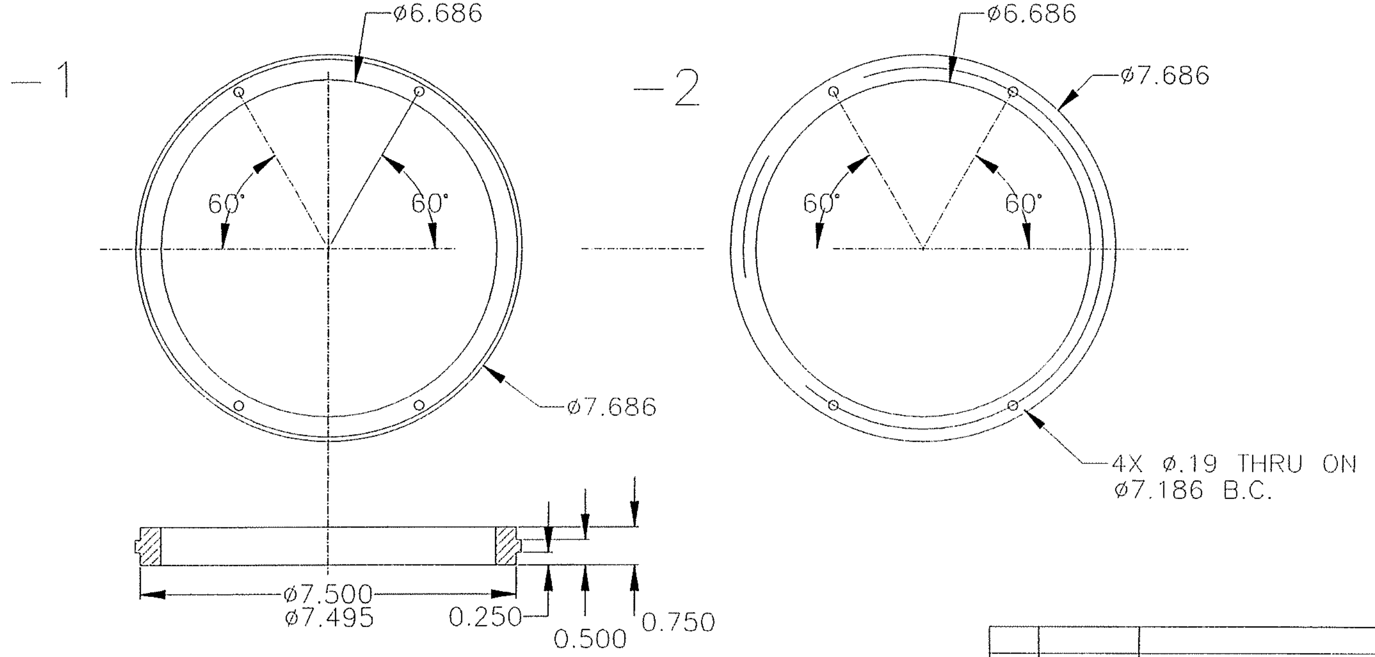
NOTES: UNLESS OTHERWISE SPECIFIED

1) BREAK ALL SHARP EDGES

UNLESS OTHERWISE NOTED: TOLERANCES .XX ± .01 .XXX ± .003 ANGLES ±0.5° 64		UNIVERSITY OF CALIFORNIA, DAVIS MECHANICAL ENGINEERING DEPARTMENT	
DESIGN KJM	DATE 11/22/95	TITLE PULLEY STANDOFFS TMR ASSEMBLY	
DRAWN KJM		QTY 1	DRAWING NO. TMR-404
APPRV DAB		SCALE 1:1	
RELEASE		SIZE B SHT	PROJECT TMR PROJECT


REVISION
LTR ZONE DESCRIPTION DATE DRAWN APP
A INITIAL RELEASE KJM DAB
ø9.000
ø7.814
60°
A
A
ø0.190 THRU 6X ON
ø8.567 B.C.
0.447
0.350
0.250
ø8.000
ø8.005
0.225
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
1 ø9.00X.35 6061-T6 2
ITEM NO. PART / ID NO. NOMENCLATURE / DESCRIPTION MATERIAL / SPECIFICATION QTY REQD
PART LIST
UNLESS OTHERWISE NOTED: TOLERANCES .XX ± .01 .XXX ± .005 ANGLES ±0.5° 64
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
TITLE LINE CONNECTIONS TMR ASSEMBLY
DESIGN KJM DATE 11/22/95
DRAWN KJM
APPRV DAB
RELEASE
QTY 1
DRAWING NO. TMR-405
SCALE 1:1
SIZE B
SHT
PROJECT TMR PROJECT

LTR	ZONE	REVISION DESCRIPTION	DATE	DRAFT	APP
A		INITIAL RELEASE	11/22/95	KJM	DAB



NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
-2		ø7.686x.125 THICK	6061-T6	1
-1		ø7.686x0.75 THICK	6061-T6	1

PART LIST

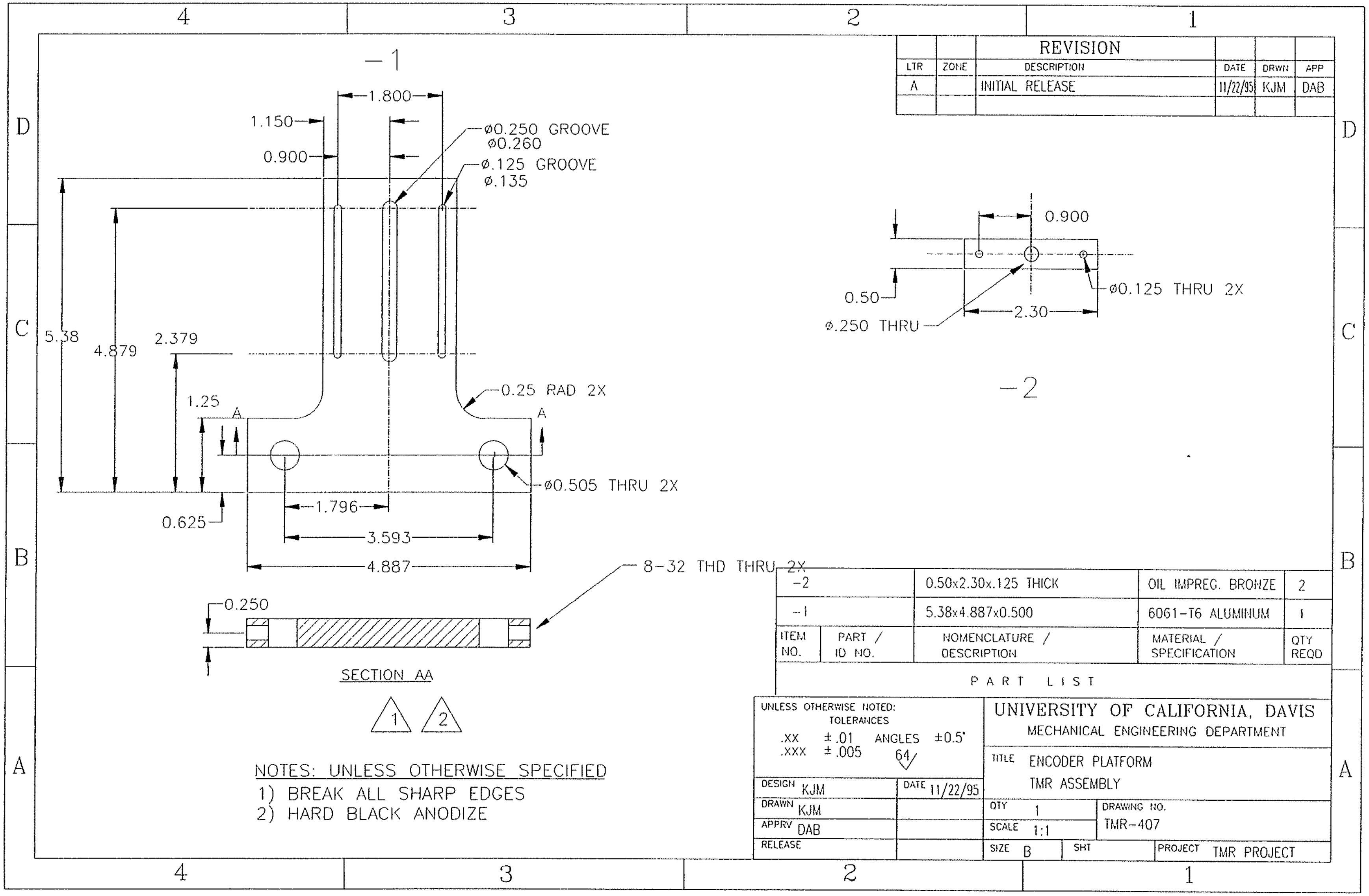
UNLESS OTHERWISE NOTED:
TOLERANCES
.XX ±.01 ANGLES ±0.5°
.XXX ±.005 64√

DESIGN KJM	DATE 11/22/95
DRAWN KJM	
APPRV DAB	
RELEASE	

UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT

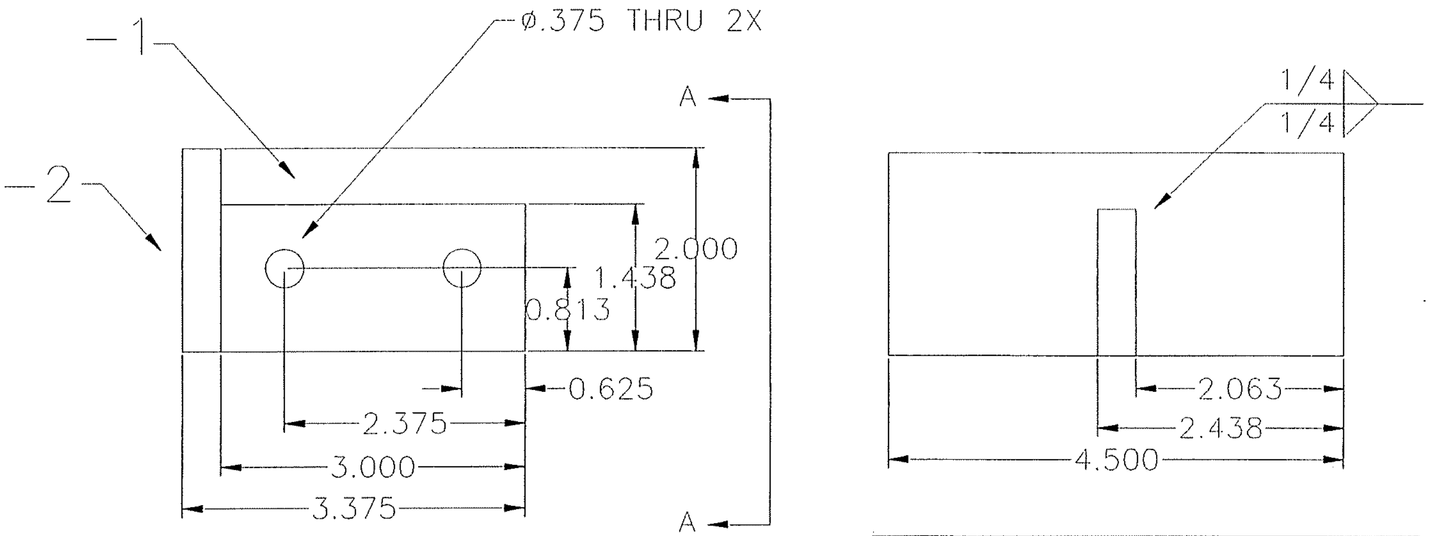
TITLE ROTARY COMPONENTS
TMR ASSEMBLY

QTY 1	DRAWING NO. TMR-406	
SCALE 1:1		
SIZE B	SHT	PROJECT TMR ASSEMBLY



REVISION
LTR ZONE DESCRIPTION DATE DRWN APP
A INITIAL RELEASE 11/22/95 KJM DAB
−1
1.800
1.150
0.900
ø0.250 GROOVE ø0.260
ø.125 GROOVE ø.135
5.38
4.879
2.379
1.25
0.25 RAD 2X
A
ø0.505 THRU 2X
0.625
1.796
3.593
4.887
8−32 THD THRU 2X
0.250
SECTION AA
1
2
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
2) HARD BLACK ANODIZE
0.900
0.50
ø.250 THRU
ø0.125 THRU 2X
2.30
−2
−2 0.50x2.30x.125 THICK OIL IMPREG. BRONZE 2
−1 5.38x4.887x0.500 6061−T6 ALUMINUM 1
ITEM NO. PART / ID NO. NOMENCLATURE / DESCRIPTION MATERIAL / SPECIFICATION QTY REQD
PART LIST
UNLESS OTHERWISE NOTED: TOLERANCES
.XX ±.01 ANGLES ±0.5°
.XXX ±.005
64
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
TITLE ENCODER PLATFORM
TMR ASSEMBLY
DESIGN KJM DATE 11/22/95
DRAWN KJM
APPRV DAB
RELEASE
QTY 1
SCALE 1:1
DRAWING NO. TMR−407
SIZE B SHT
PROJECT TMR PROJECT

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	11/22/95	KJM	DAB



ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
-2		2.000x4.500x.375	6061-T6	1
-1		3.00x1.438x.375	6061-T6	1

PART LIST

NOTES: UNLESS OTHERWISE SPECIFIED

1) BREAK ALL SHARP EDGES

2) 2 WELDED TO 1 90° +-0.5°

UNLESS OTHERWISE NOTED: TOLERANCES
.XX ± .01 ANGLES ±0.5°
.XXX ± .003 64√

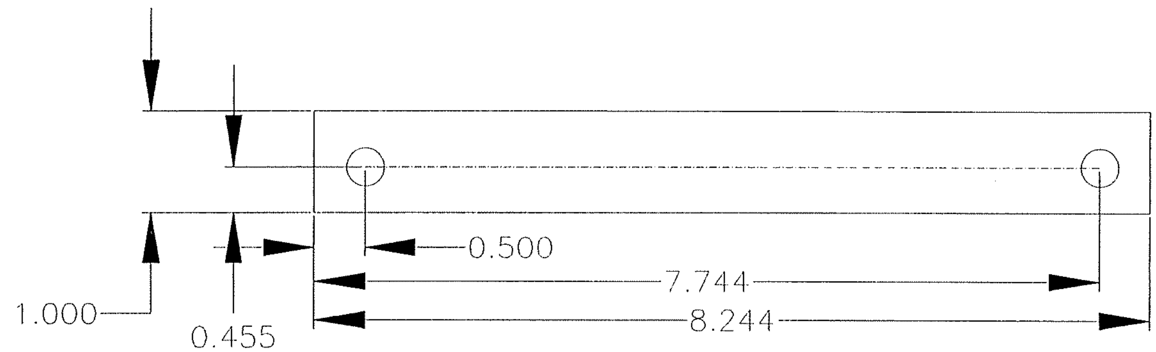
DESIGN KJM	DATE 11/22/95
DRAWN KJM	
APPRV DAB	
RELEASE	

UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT

TITLE APPLICATOR MOUNT
TMR ASSEMBLY

QTY 1	DRAWING NO. TMR-501	
SCALE 1:1		
SIZE B	SHT	PROJECT TMR PROJECT

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	11/22/95	KJM	DAB



NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES

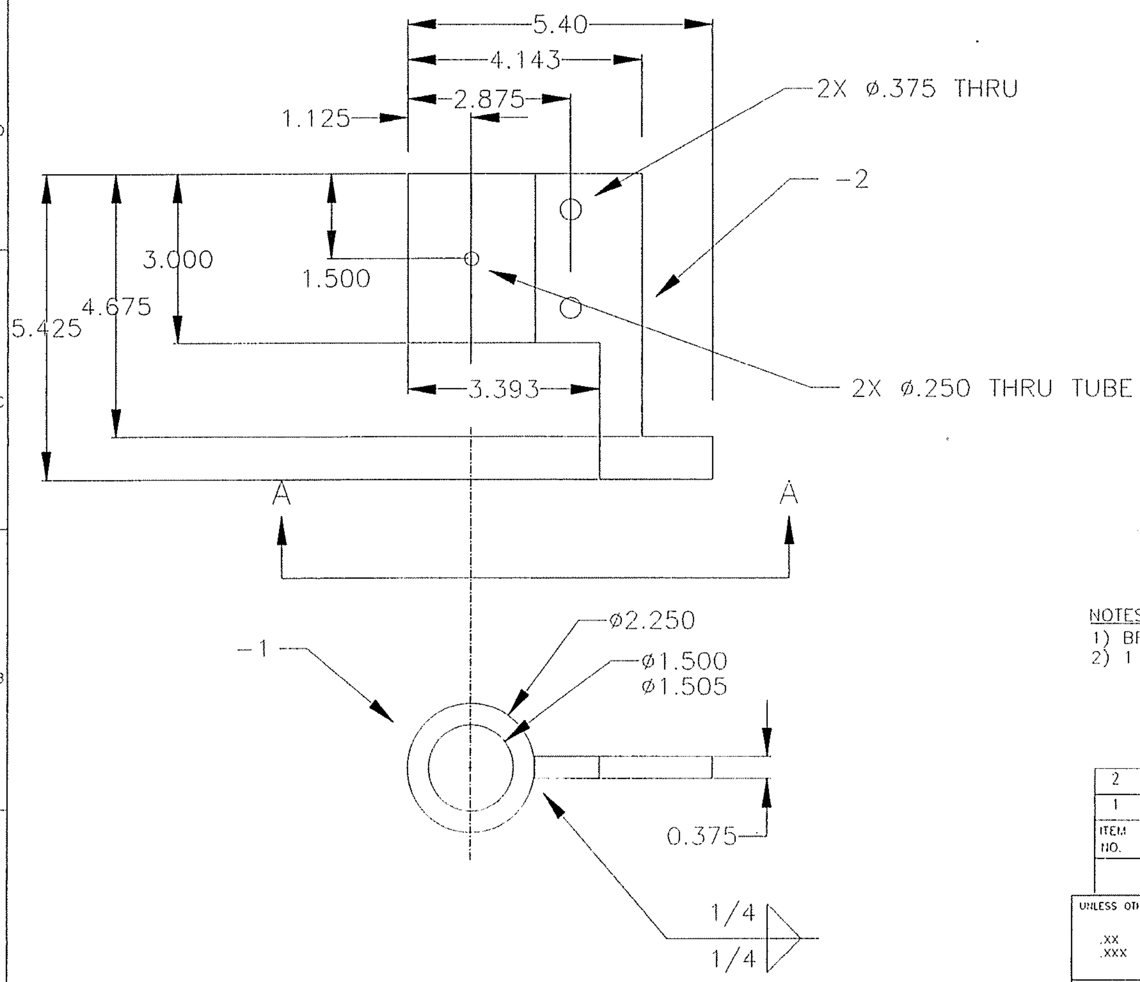
ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
-1		1.000x8.244 ANGLE (1x1x.25)	1018 Series S.	4

PART LIST

UNLESS OTHERWISE NOTED: TOLERANCES
.XX ± .01 ANGLES ±0.5°
.XXX ± .003
64√

UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT

DESIGN KJM	DATE 11/22/95	TITLE 4-BAR LINKS TMR ASSEMBLY	
DRAWN KJM		QTY 4	DRAWING NO. TMR-502
APPRV DAB		SCALE 1:1	
RELEASE		SIZE B	SHT / PROJECT TMR PROJECT



REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRAWN	APP
A		INITIAL RELEASE	11/22/95	KJM	DAB

△1

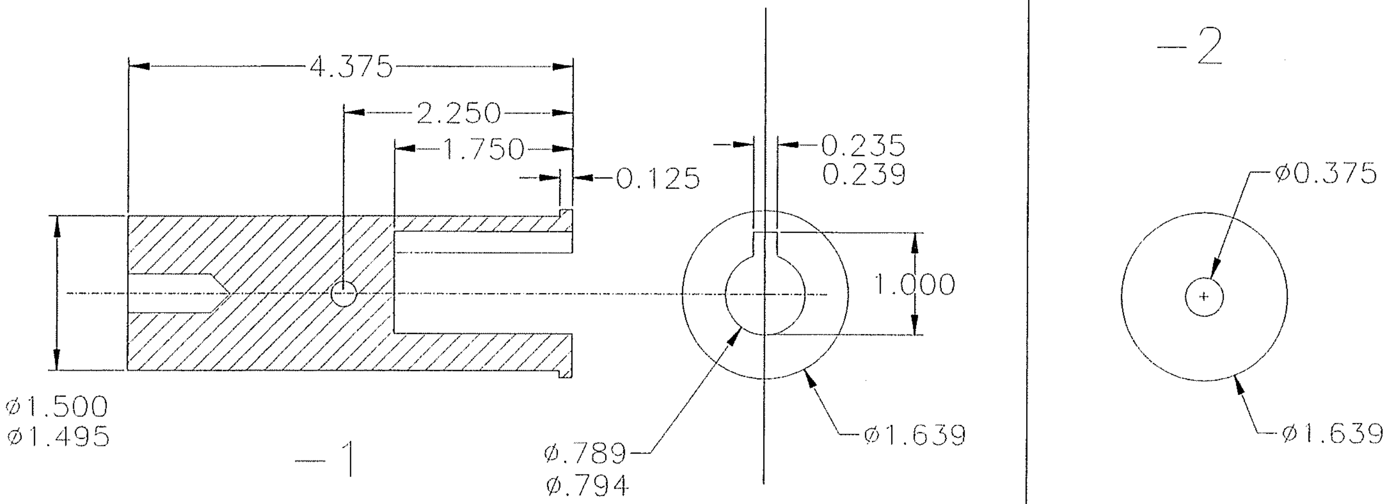
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
2) 1 WELDED TO 2 90° +- 0.5°

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
2		.375" THICK PLATE	6061 ALUMINUM	1
1		⌀1.500ID,⌀2.250OD×3.00" TUBE	6061 ALUMINUM	1

PART LIST

UNLESS OTHERWISE NOTED: TOLERANCES .XX ±.01 .XXX ±.005 ANGLES ±0.5° 64	UNIVERSITY OF CALIFORNIA, DAVIS MECHANICAL ENGINEERING DEPARTMENT
DESIGN KJM	DATE 11/22/95
DRAWN KJM	TITLE ROTATING ATTACHMENT TMR ASSEMBLY
APPRV DAB	QTY 1 DRAWING NO. TMR-503
RELEASE	SCALE 1:1
	SIZE B SHT PROJECT TMR PROJECT

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	11/22/95	KJM	DAB



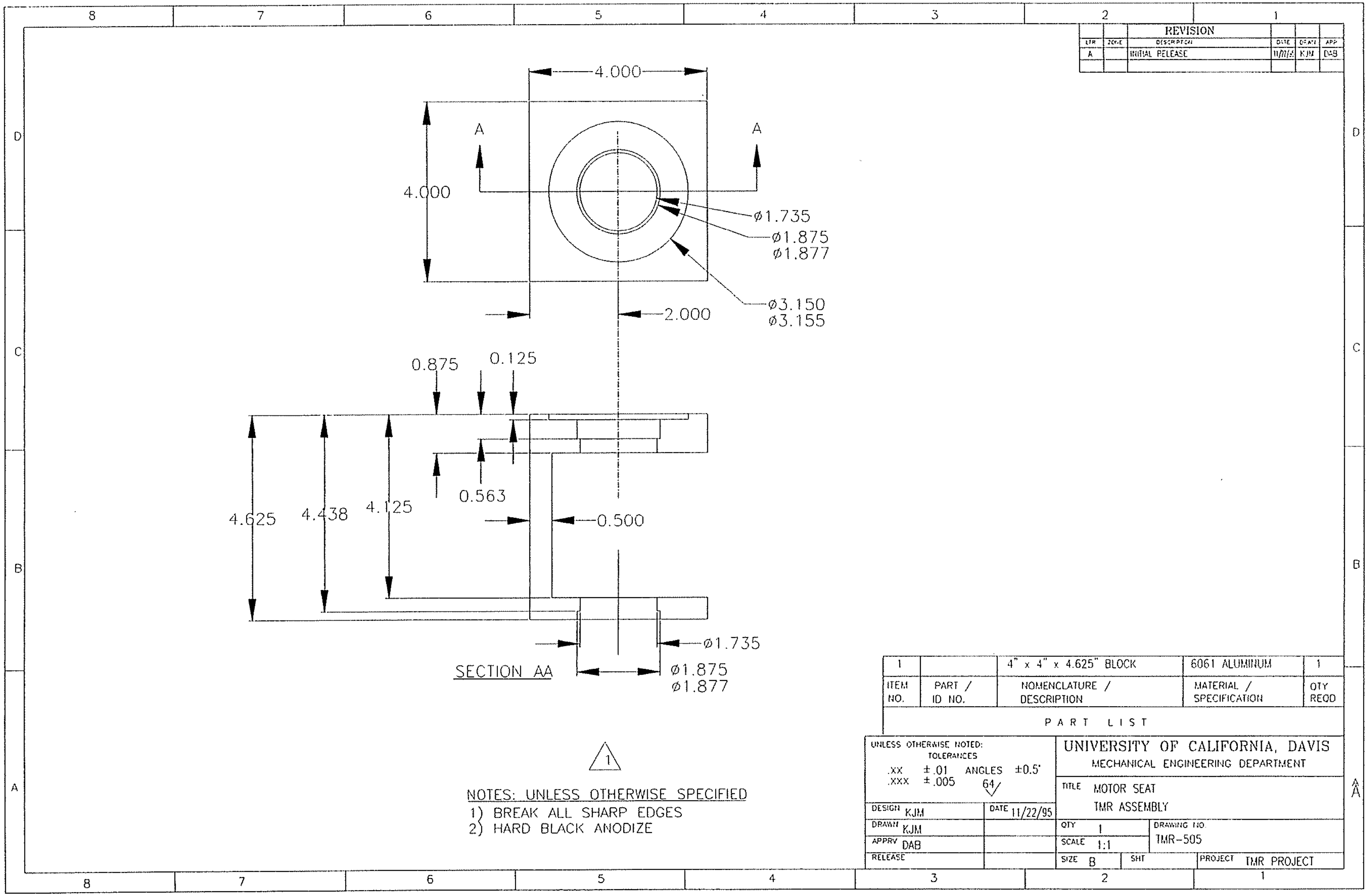
-2		ø1.639x.125 WASHER	6061-T6	1
-1		ø1.639x4.375 ROD	6061-T6	1
ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD

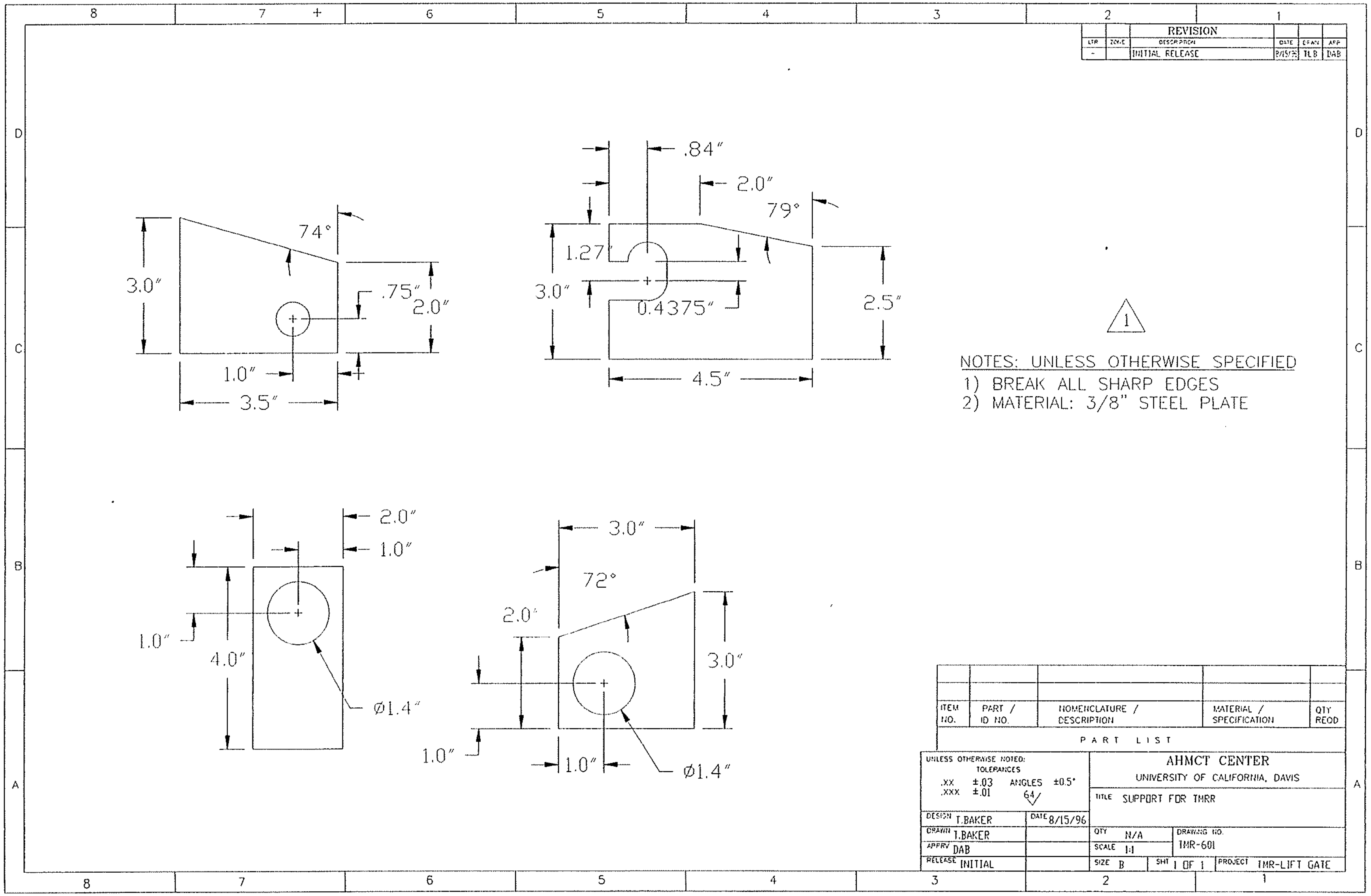
PART LIST

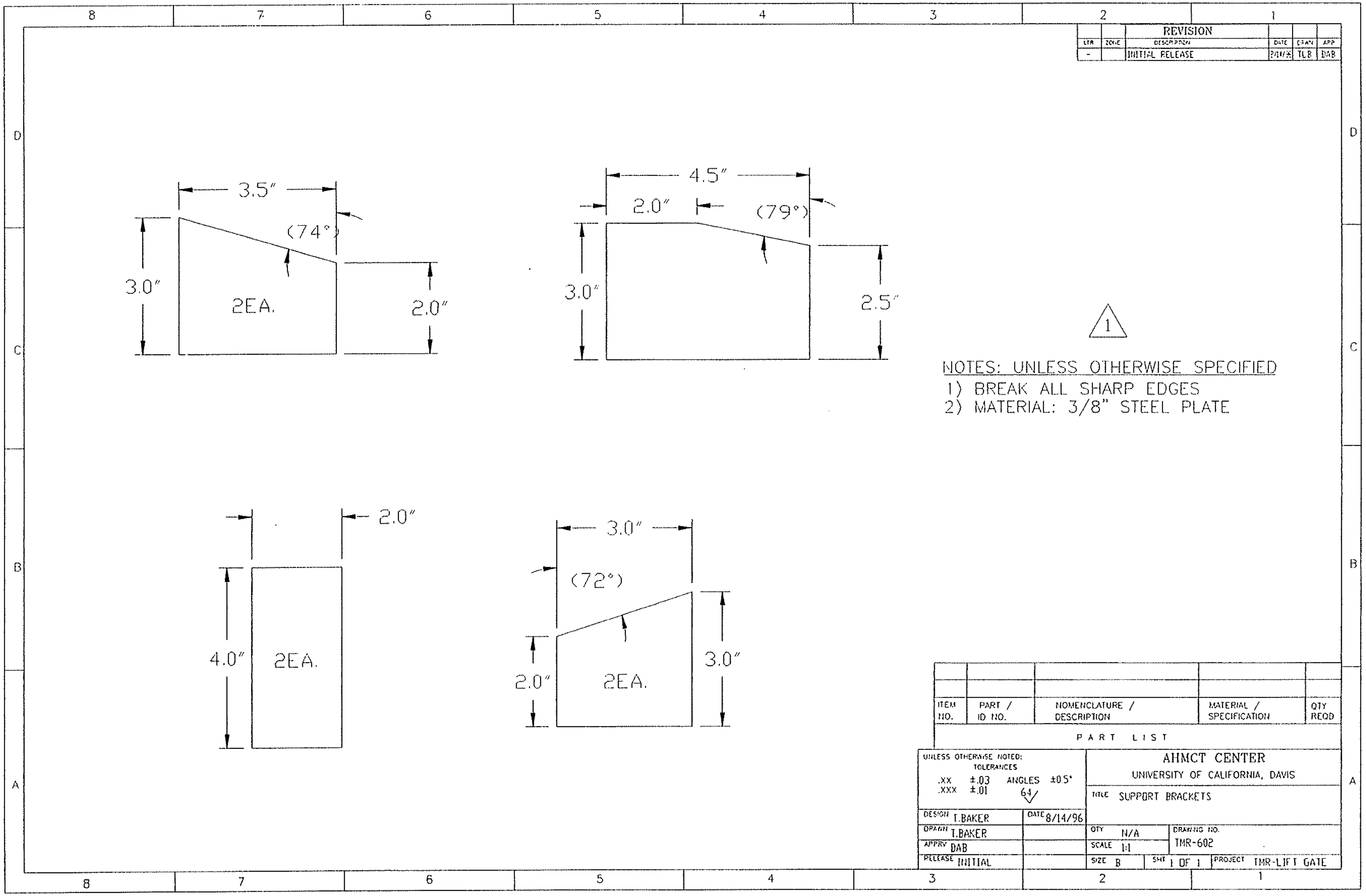
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES

UNLESS OTHERWISE NOTED:
TOLERANCES
.XX ± .01 ANGLES ±0.5°
.XXX ± .003
64

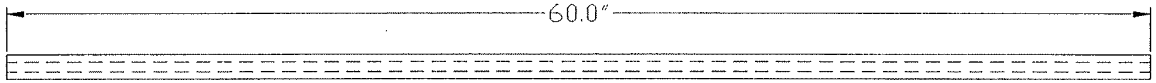
DESIGN KJM	DATE 11/22/95	UNIVERSITY OF CALIFORNIA, DAVIS MECHANICAL ENGINEERING DEPARTMENT		
DRAWN KJM		TITLE KEYWAY ATTACHMENT TMR ASSEMBLY		
APPRV DAB		QTY 1	DRAWING NO. TMR-504	
RELEASE		SCALE 1:1		
		SIZE B	SHT	PROJECT TMR PROJECT


REVISION
A INITIAL RELEASE KJM DAB
4.000
4.000
A
A
ø1.735
ø1.875
ø1.877
ø3.150
ø3.155
2.000
0.875
0.125
0.563
4.625
4.438
4.125
0.500
ø1.735
ø1.875
ø1.877
SECTION AA
1
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
2) HARD BLACK ANODIZE
1 | 4" x 4" x 4.625" BLOCK | 6061 ALUMINUM | 1
ITEM NO. | PART / ID NO. | NOMENCLATURE / DESCRIPTION | MATERIAL / SPECIFICATION | QTY REQD
PART LIST
UNLESS OTHERWISE NOTED: TOLERANCES
.XX ±.01 ANGLES ±0.5°
.XXX ±.005
64
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
TITLE MOTOR SEAT
TMR ASSEMBLY
DESIGN KJM
DATE 11/22/95
DRAWN KJM
APPRV DAB
RELEASE
QTY 1
SCALE 1:1
DRAWING NO. TMR-505
SIZE B
SHT
PROJECT TMR PROJECT


REVISION
INITIAL RELEASE
TLB
DAB
.84″
2.0″
79°
74°
1.27″
3.0″
0.4375″
2.5″
.75″
2.0″
1.0″
3.5″
4.5″
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
2) MATERIAL: 3/8" STEEL PLATE
2.0″
1.0″
3.0″
72°
2.0″
4.0″
3.0″
Ø1.4″
1.0″
Ø1.4″
ITEM NO.
PART / ID NO.
NOMENCLATURE / DESCRIPTION
MATERIAL / SPECIFICATION
QTY REQD
PART LIST
UNLESS OTHERWISE NOTED: TOLERANCES
.XX ±.03 ANGLES ±0.5°
.XXX ±.01
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE SUPPORT FOR TMRR
DESIGN T.BAKER
DATE 8/15/96
DRAWN T.BAKER
APPRV DAB
RELEASE INITIAL
QTY N/A
SCALE 1:1
SIZE B
SHT 1 OF 1
DRAWING NO. TMR-601
PROJECT TMR-LIFT GATE


REVISION
LTR ZONE DESCRIPTION DATE DRAWN APP
- INITIAL RELEASE TLB DAB
3.5"
(74°)
3.0"
2EA.
2.0"
4.5"
2.0"
(79°)
3.0"
2.5"
1
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
2) MATERIAL: 3/8" STEEL PLATE
2.0"
4.0"
2EA.
3.0"
(72°)
2.0"
2EA.
3.0"
ITEM NO.
PART / ID NO.
NOMENCLATURE / DESCRIPTION
MATERIAL / SPECIFICATION
QTY REQD
PART LIST
UNLESS OTHERWISE NOTED: TOLERANCES
.XX ±.03 ANGLES ±0.5°
.XXX ±.01
64
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE SUPPORT BRACKETS
DESIGN T.BAKER
DATE 8/14/96
DRAWN T.BAKER
APPRV DAB
RELEASE INITIAL
QTY N/A
SCALE 1:1
DRAWING NO. TMR-602
SIZE B
SHT 1 OF 1
PROJECT TMR-LIFT GATE

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
-		INITIAL RELEASE	8/15/96	TLB	DAB



1

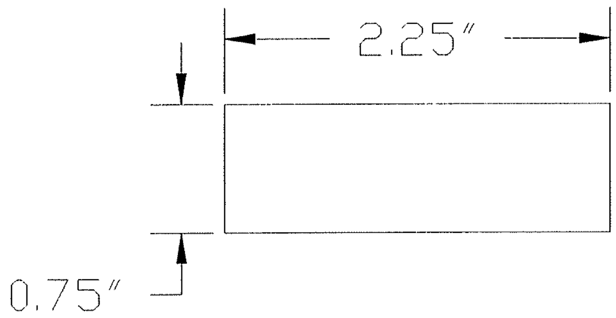
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
2) MATERIAL: ø 1.25"x3/8" WALL STEEL TUBING

1		ø 1.25'x3/8' TUBING	STEEL	1
ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD

PART LIST

UNLESS OTHERWISE NOTED: TOLERANCES .XX ±.03 .XXX ±.01 ANGLES ±0.5° 64√		AHMCT CENTER UNIVERSITY OF CALIFORNIA, DAVIS	
		TITLE SUPPORT BAR	
DESIGN T.BAKER	DATE 8/15/96		
DRAWN T.BAKER		QTY 1	DRAWING NO. TMR-603
APPRV DAB		SCALE 1:1	
RELEASE INITIAL		SIZE B SHT 1 OF 1	PROJECT TMR-LIFT GATE

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRAWN	APP
-		INITIAL RELEASE	8/15/96	TLB	DAB



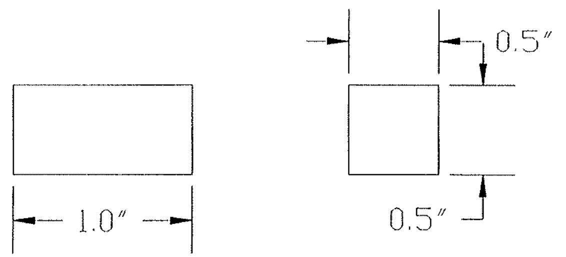
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
2) MATERIAL: ø .75" STEEL BAR

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
1		ø .75′ BAR	STEEL	1

PART LIST

UNLESS OTHERWISE NOTED: TOLERANCES .XX ±.03 .XXX ±.01 ANGLES ±0.5° 64		AHMCT CENTER UNIVERSITY OF CALIFORNIA, DAVIS	
		TITLE SUPPORT BAR : REAR	
DESIGN T.BAKER	DATE 8/15/96		
DRAWN T.BAKER		QTY 1	DRAWING NO. TMR-604
APPRV DAB		SCALE 1:1	
RELEASE INITIAL		SIZE B / SHT 1 OF 1	PROJECT TMR-LIFT GATE

LTR	ZONE	REVISION DESCRIPTION	DATE	DRAWN	APP
-		INITIAL RELEASE	[illegible]	TLB	DAB



△1

NOTES: UNLESS OTHERWISE SPECIFIED
1) MATERIAL: STEEL
2) QUANTITY: 2EA.

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
1				
2				

PART LIST

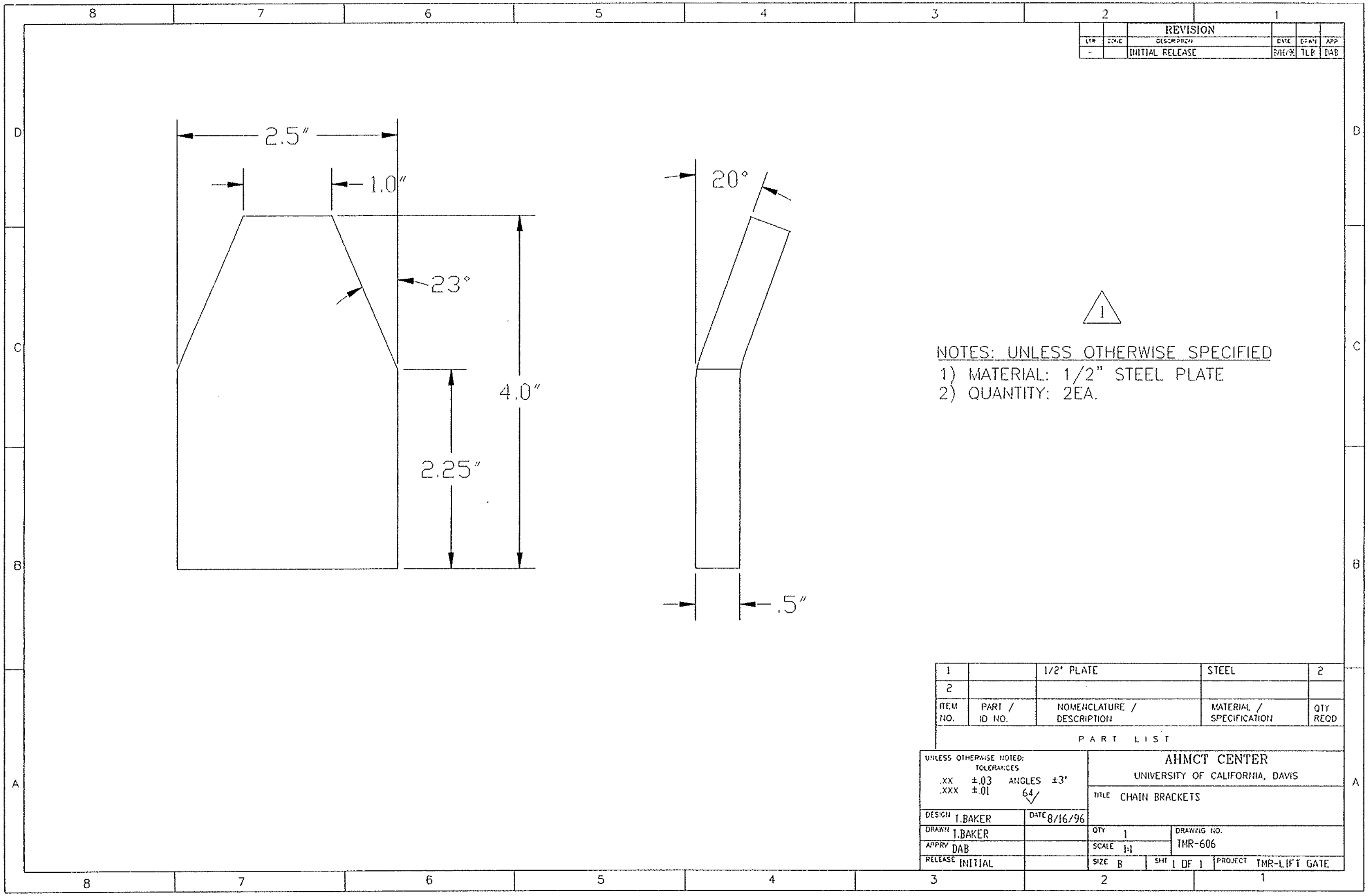
UNLESS OTHERWISE NOTED:
TOLERANCES
.XX ±.03 ANGLES ±0.5°
.XXX ±.01
64√

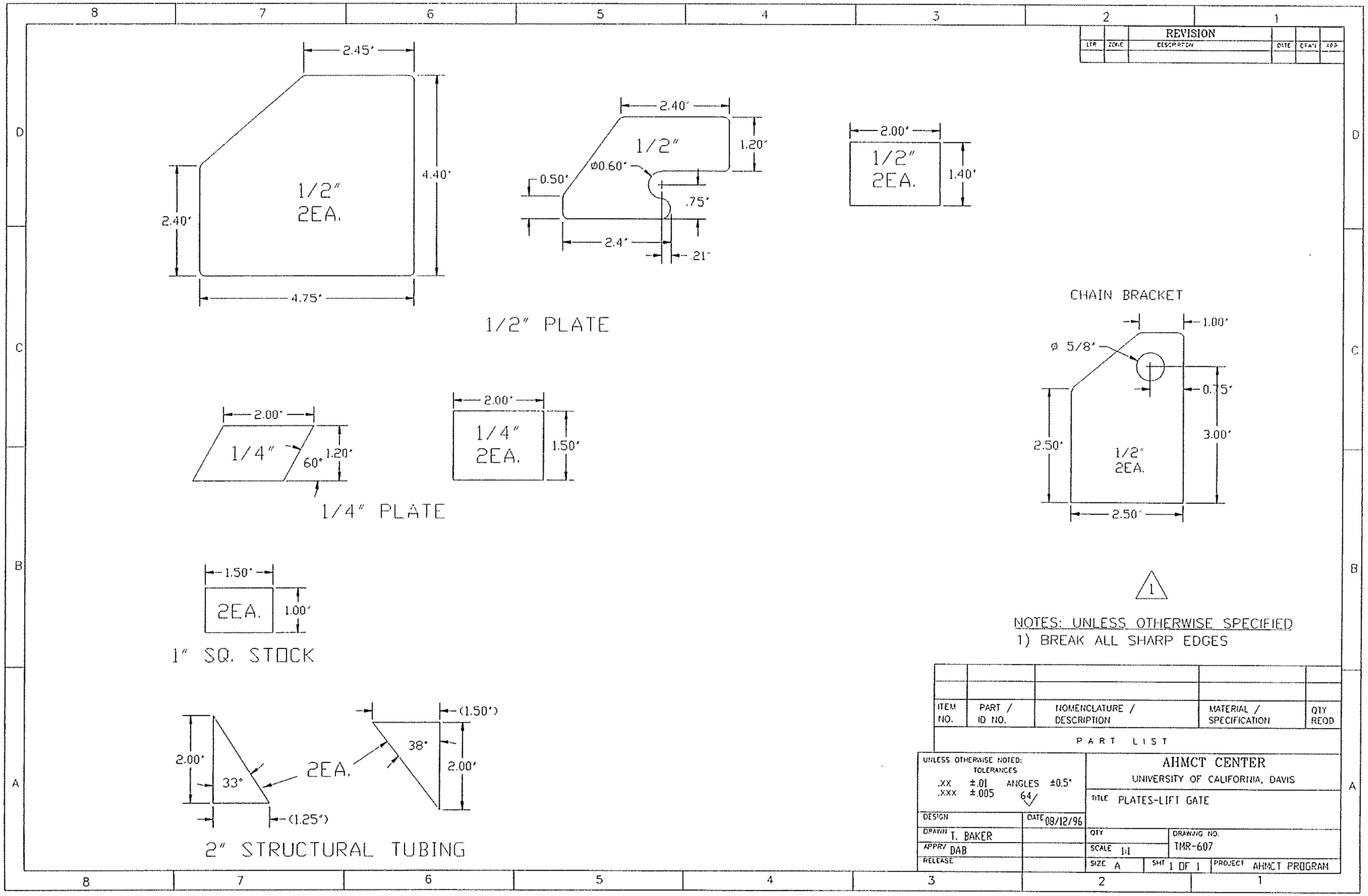
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS

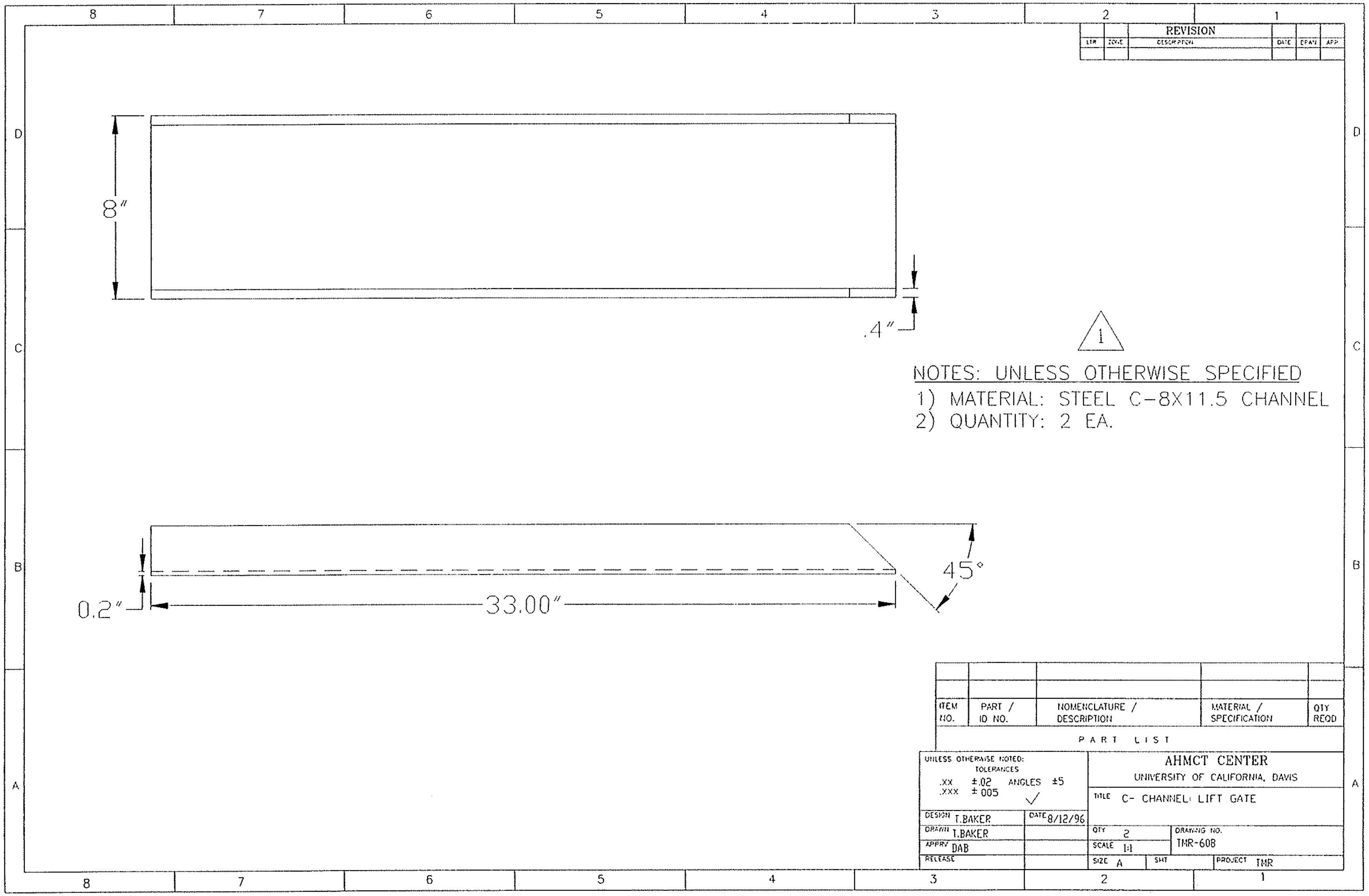
TITLE STOP BLOCK

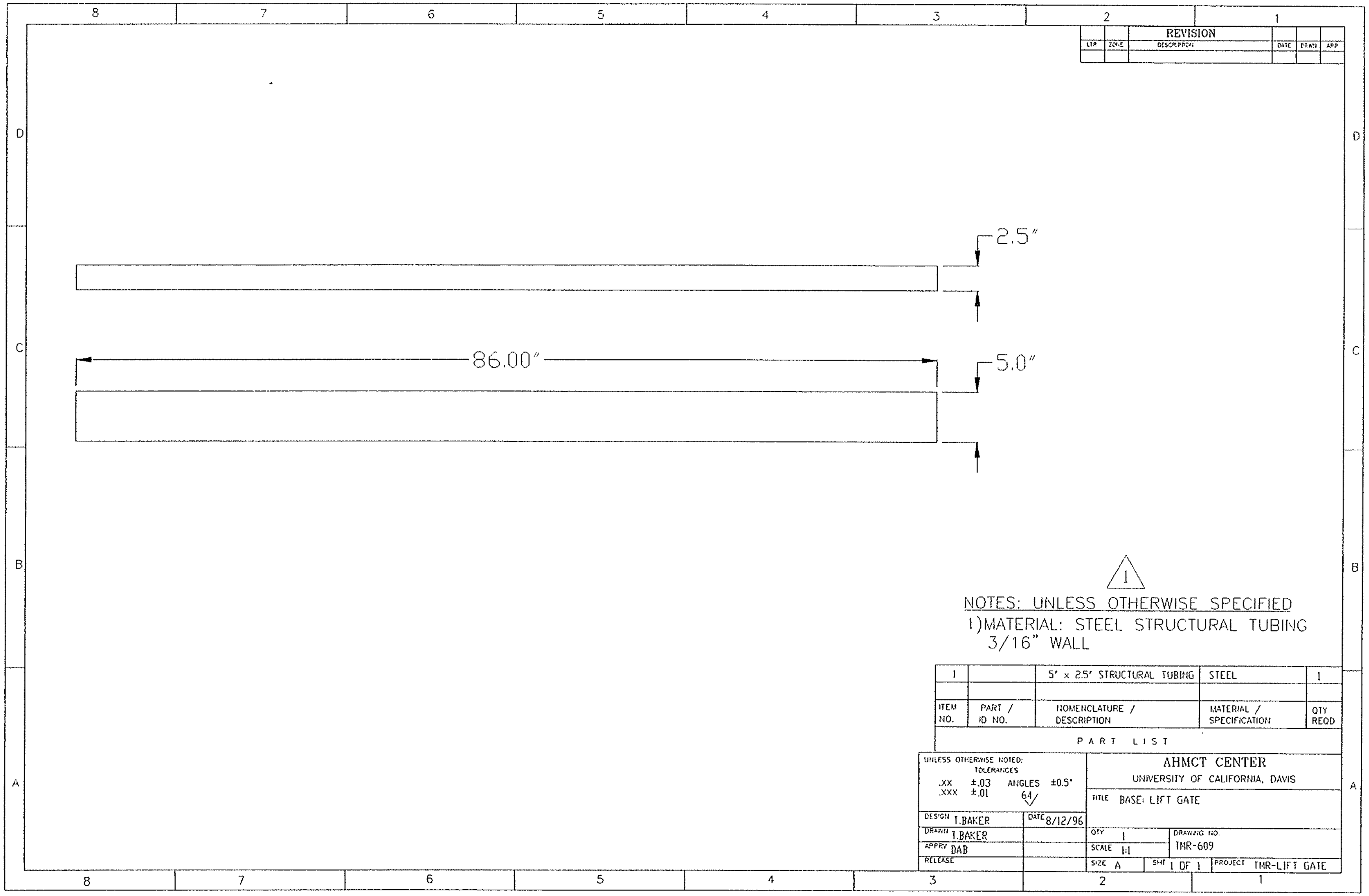
DESIGN T.BAKER	DATE 8/16/96
DRAWN T.BAKER	
APPRV DAB	
RELEASE INITIAL	

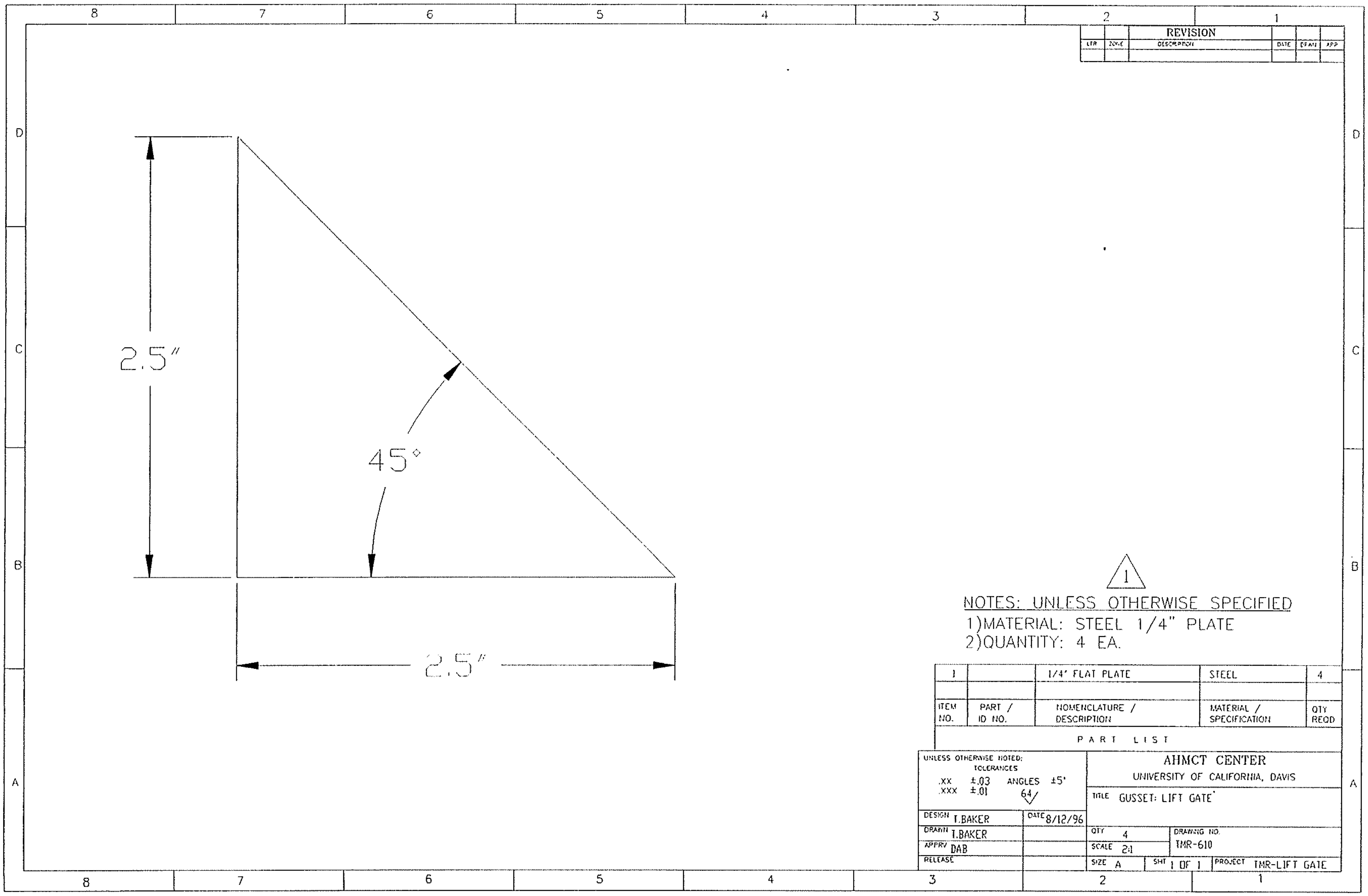
QTY 1	DRAWING NO. TMR-605	
SCALE 1:1		
SIZE B	SHT 1 OF 1	PROJECT TMR-LIFT GATE


REVISION
LTR ZONE DESCRIPTION DATE DRAWN APP
- INITIAL RELEASE 8/16/96 TLB DAB
2.5″
1.0″
23°
4.0″
2.25″
20°
.5″
NOTES: UNLESS OTHERWISE SPECIFIED
1) MATERIAL: 1/2" STEEL PLATE
2) QUANTITY: 2EA.
1 1/2" PLATE STEEL 2
2
ITEM NO. PART / ID NO. NOMENCLATURE / DESCRIPTION MATERIAL / SPECIFICATION QTY REQD
PART LIST
UNLESS OTHERWISE NOTED: TOLERANCES
.XX ±.03 ANGLES ±3'
.XXX ±.01
64
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE CHAIN BRACKETS
DESIGN T.BAKER DATE 8/16/96
DRAWN T.BAKER
APPRV DAB
RELEASE INITIAL
QTY 1
SCALE 1:1
DRAWING NO. TMR-606
SIZE B SHT 1 OF 1 PROJECT TMR-LIFT GATE

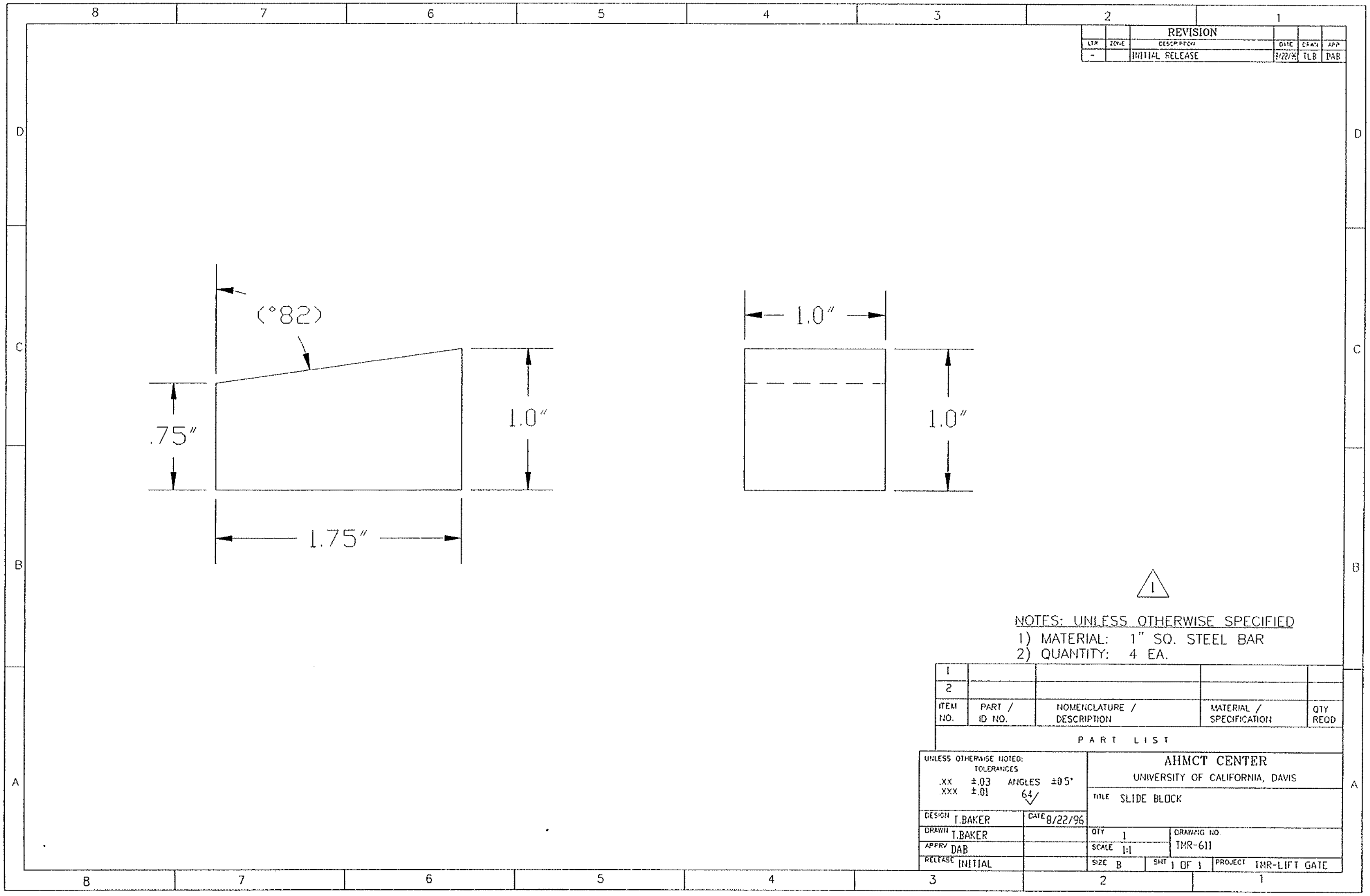

REVISION
LTR ZONE DESCRIPTION DATE DFT'N APP
1/2" 2EA.
2.45'
4.40'
2.40'
4.75'
1/2"
2.40'
1.20'
0.50'
ø0.60'
.75'
2.4'
.21'
1/2" 2EA.
2.00'
1.40'
1/2" PLATE
CHAIN BRACKET
1.00'
ø 5/8'
0.75'
2.50'
3.00'
1/2" 2EA.
2.50'
1/4"
2.00'
1.20'
60°
1/4" 2EA.
2.00'
1.50'
1/4" PLATE
2EA.
1.50'
1.00'
1" SQ. STOCK
2.00'
33°
(1.25')
2EA.
(1.50')
38°
2.00'
2" STRUCTURAL TUBING
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
ITEM NO.
PART / ID NO.
NOMENCLATURE / DESCRIPTION
MATERIAL / SPECIFICATION
QTY REQD
PART LIST
UNLESS OTHERWISE NOTED: TOLERANCES
.XX ±.01 ANGLES ±0.5°
.XXX ±.005
64
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE PLATES-LIFT GATE
DESIGN
DATE 08/12/96
DRAWN T. BAKER
APPRV DAB
RELEASE
QTY
SCALE 1:1
DRAWING NO. TMR-607
SIZE A
SHT 1 OF 1
PROJECT AHMCT PROGRAM

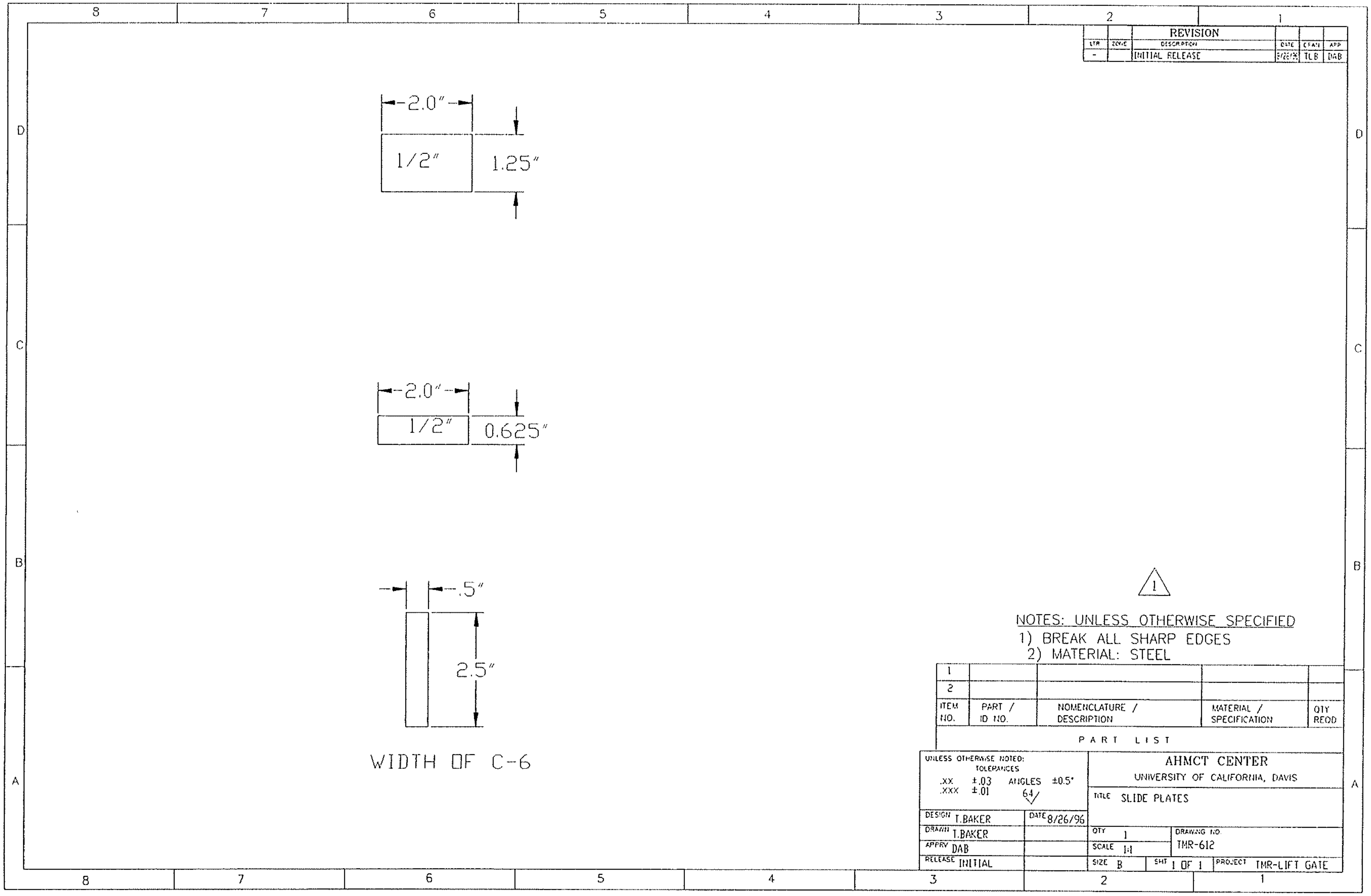

REVISION
LTR ZONE DESCRIPTION DATE DRAWN APP
8″
.4″
NOTES: UNLESS OTHERWISE SPECIFIED
1) MATERIAL: STEEL C-8X11.5 CHANNEL
2) QUANTITY: 2 EA.
45°
0.2″
33.00″
ITEM NO.
PART / ID NO.
NOMENCLATURE / DESCRIPTION
MATERIAL / SPECIFICATION
QTY REQD
PART LIST
UNLESS OTHERWISE NOTED: TOLERANCES
.XX ±.02 ANGLES ±5
.XXX ±.005
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE C- CHANNEL: LIFT GATE
DESIGN T.BAKER
DATE 8/12/96
DRAWN T.BAKER
APPRV DAB
RELEASE
QTY 2
DRAWING NO. TMR-608
SCALE 1:1
SIZE A
SHT
PROJECT TMR

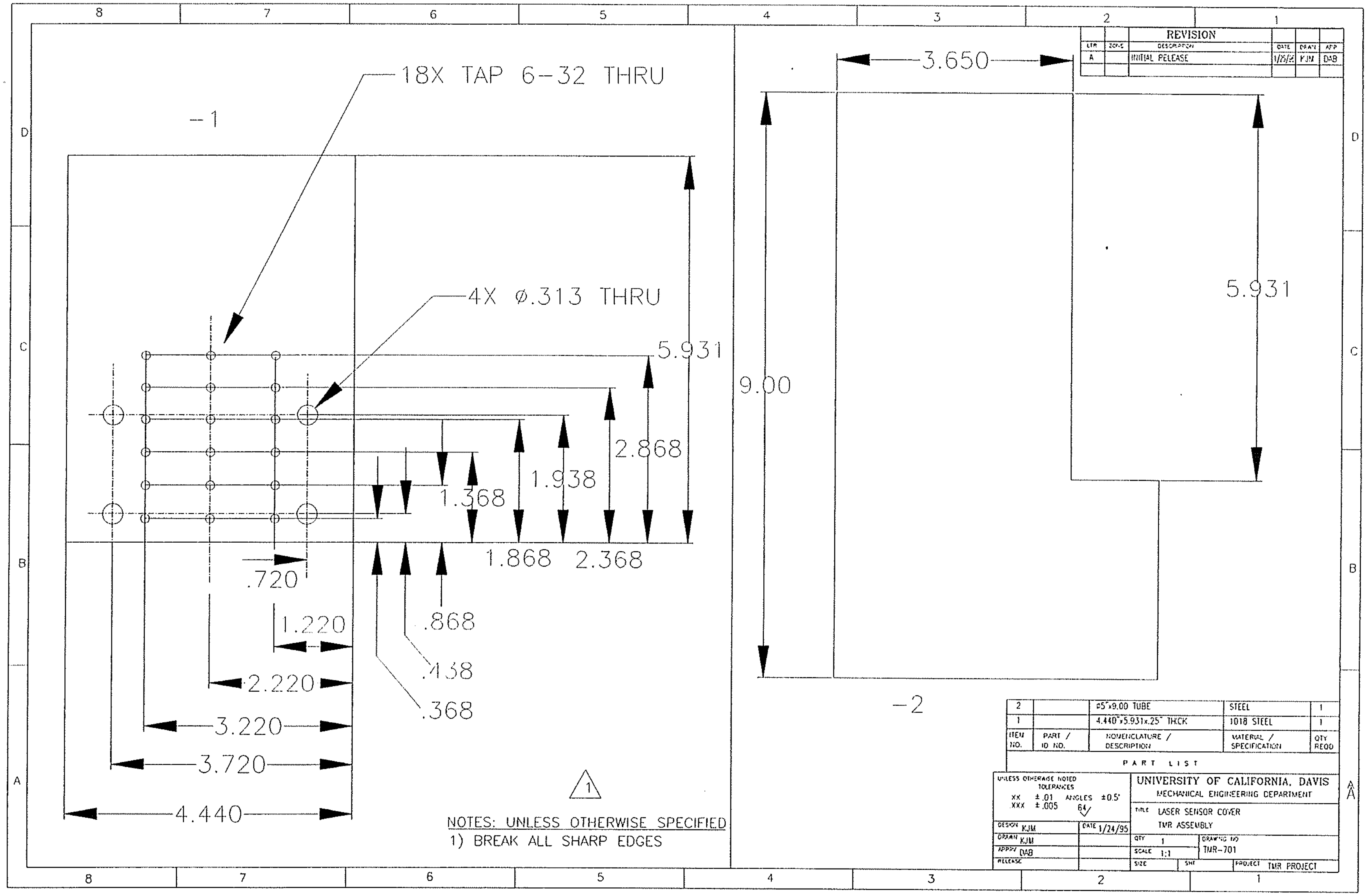

REVISION
LTR ZONE DESCRIPTION DATE DRAWN APP
2.5"
86.00"
5.0"
1
NOTES: UNLESS OTHERWISE SPECIFIED
1)MATERIAL: STEEL STRUCTURAL TUBING
3/16" WALL
1 | 5' x 2.5' STRUCTURAL TUBING | STEEL | 1
ITEM NO. | PART / ID NO. | NOMENCLATURE / DESCRIPTION | MATERIAL / SPECIFICATION | QTY REQD
PART LIST
UNLESS OTHERWISE NOTED: TOLERANCES
.XX ±.03 ANGLES ±0.5°
.XXX ±.01
64
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE BASE: LIFT GATE
DESIGN T.BAKER
DATE 8/12/96
DRAWN T.BAKER
APPRV DAB
RELEASE
QTY 1
SCALE 1:1
DRAWING NO. TMR-609
SIZE A
SHT 1 OF 1
PROJECT TMR-LIFT GATE



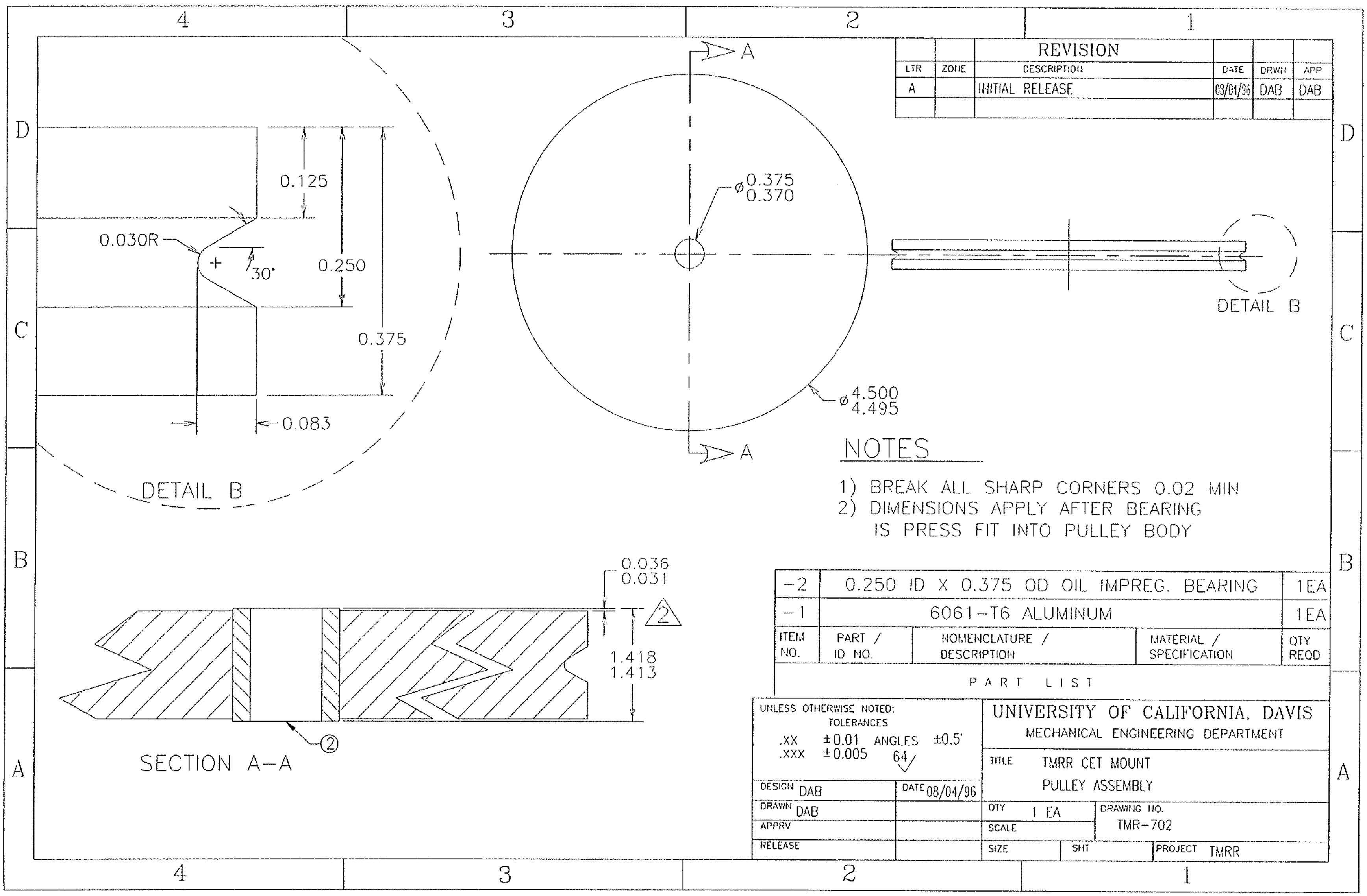
REVISION
LTR ZONE DESCRIPTION DATE DRAWN APP
2.5"
45°
2.5"
1
NOTES: UNLESS OTHERWISE SPECIFIED
1)MATERIAL: STEEL 1/4" PLATE
2)QUANTITY: 4 EA.
1 | 1/4' FLAT PLATE | STEEL | 4
ITEM NO. | PART / ID NO. | NOMENCLATURE / DESCRIPTION | MATERIAL / SPECIFICATION | QTY REQD
PART LIST
UNLESS OTHERWISE NOTED: TOLERANCES
.XX ±.03 ANGLES ±5'
.XXX ±.01
64
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE GUSSET: LIFT GATE
DESIGN T.BAKER
DATE 8/12/96
DRAWN T.BAKER
APPRV DAB
RELEASE
QTY 4
SCALE 2:1
DRAWING NO. TMR-610
SIZE A
SHT 1 OF 1
PROJECT TMR-LIFT GATE

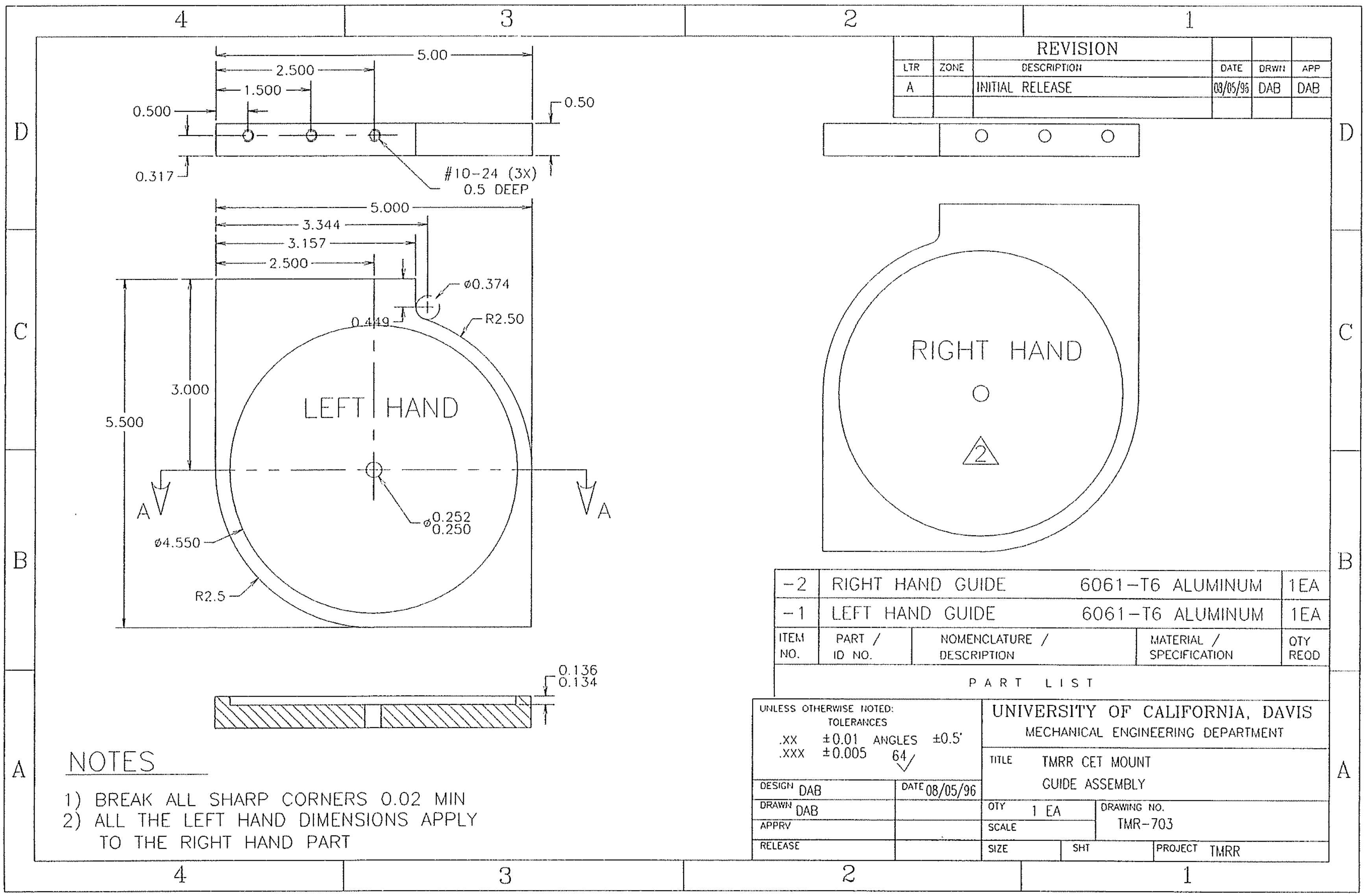

REVISION
LTR ZONE DESCRIPTION DATE DRAWN APP
- INITIAL RELEASE 8/22/96 TLB DAB
(°82)
.75″
1.75″
1.0″
1.0″
1.0″
1
NOTES: UNLESS OTHERWISE SPECIFIED
1) MATERIAL: 1″ SQ. STEEL BAR
2) QUANTITY: 4 EA.
ITEM NO.
PART / ID NO.
NOMENCLATURE / DESCRIPTION
MATERIAL / SPECIFICATION
QTY REQD
PART LIST
UNLESS OTHERWISE NOTED: TOLERANCES
.XX ±.03 ANGLES ±0.5°
.XXX ±.01
64
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE SLIDE BLOCK
DESIGN T.BAKER
DATE 8/22/96
DRAWN T.BAKER
APPRV DAB
RELEASE INITIAL
QTY 1
SCALE 1:1
DRAWING NO TMR-611
SIZE B
SHT 1 OF 1
PROJECT TMR-LIFT GATE


REVISION
INITIAL RELEASE
TLB
DAB
2.0″
1/2″
1.25″
2.0″
1/2″
0.625″
.5″
2.5″
WIDTH OF C-6
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
2) MATERIAL: STEEL
ITEM NO.
PART / ID NO.
NOMENCLATURE / DESCRIPTION
MATERIAL / SPECIFICATION
QTY REQD
PART LIST
UNLESS OTHERWISE NOTED: TOLERANCES
.XX ±.03 ANGLES ±0.5°
.XXX ±.01
DESIGN T.BAKER
DATE 8/26/96
DRAWN T.BAKER
APPRV DAB
RELEASE INITIAL
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE SLIDE PLATES
QTY 1
DRAWING NO TMR-612
SCALE 1:1
SIZE B
SHT 1 OF 1
PROJECT TMR-LIFT GATE

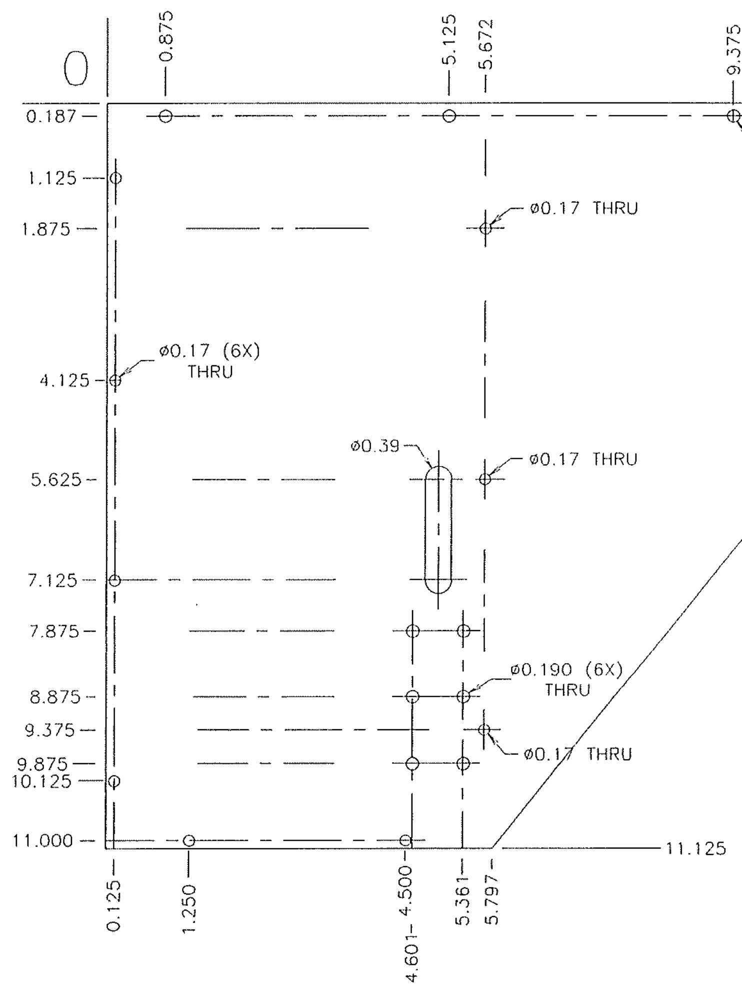


-1
18X TAP 6-32 THRU
4X ⌀.313 THRU
5.931
2.868
1.938
1.368
1.868
2.368
.720
1.220
2.220
3.220
3.720
4.440
.868
.438
.368
-2
3.650
9.00
5.931
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
REVISION
INITIAL RELEASE
PART LIST
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
LASER SENSOR COVER
TMR ASSEMBLY
TMR-701
TMR PROJECT


REVISION
LTR ZONE DESCRIPTION DATE DRWN APP
A INITIAL RELEASE 08/04/96 DAB DAB
A
A
⌀0.375 0.370
⌀4.500 4.495
DETAIL B
0.125
0.030R
30°
0.250
0.375
0.083
DETAIL B
NOTES
1) BREAK ALL SHARP CORNERS 0.02 MIN
2) DIMENSIONS APPLY AFTER BEARING IS PRESS FIT INTO PULLEY BODY
0.036 0.031
2
1.418 1.413
2
SECTION A-A
-2 0.250 ID X 0.375 OD OIL IMPREG. BEARING 1EA
-1 6061-T6 ALUMINUM 1EA
ITEM NO. PART / ID NO. NOMENCLATURE / DESCRIPTION MATERIAL / SPECIFICATION QTY REQD
PART LIST
UNLESS OTHERWISE NOTED: TOLERANCES
.XX ±0.01 ANGLES ±0.5°
.XXX ±0.005 64
DESIGN DAB DATE 08/04/96
DRAWN DAB
APPRV
RELEASE
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
TITLE TMRR CET MOUNT PULLEY ASSEMBLY
QTY 1 EA
DRAWING NO. TMR-702
SCALE
SIZE SHT PROJECT TMRR


REVISION
LTR ZONE DESCRIPTION DATE DRWN APP
A INITIAL RELEASE 08/05/96 DAB DAB
5.00
2.500
1.500
0.500
0.50
0.317
#10-24 (3X)
0.5 DEEP
5.000
3.344
3.157
2.500
ø0.374
0.449
R2.50
3.000
5.500
LEFT HAND
A
A
ø0.252
0.250
ø4.550
R2.5
0.136
0.134
RIGHT HAND
2
-2 RIGHT HAND GUIDE 6061-T6 ALUMINUM 1EA
-1 LEFT HAND GUIDE 6061-T6 ALUMINUM 1EA
ITEM NO. PART / ID NO. NOMENCLATURE / DESCRIPTION MATERIAL / SPECIFICATION QTY REQD
PART LIST
NOTES
1) BREAK ALL SHARP CORNERS 0.02 MIN
2) ALL THE LEFT HAND DIMENSIONS APPLY TO THE RIGHT HAND PART
UNLESS OTHERWISE NOTED: TOLERANCES
.XX ±0.01 ANGLES ±0.5'
.XXX ±0.005 64
DESIGN DAB DATE 08/05/96
DRAWN DAB
APPRV
RELEASE
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
TITLE TMRR CET MOUNT GUIDE ASSEMBLY
QTY 1 EA
DRAWING NO. TMR-703
SCALE
SIZE SHT PROJECT TMRR

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	08/05/96	DAB	DAB



NOTES

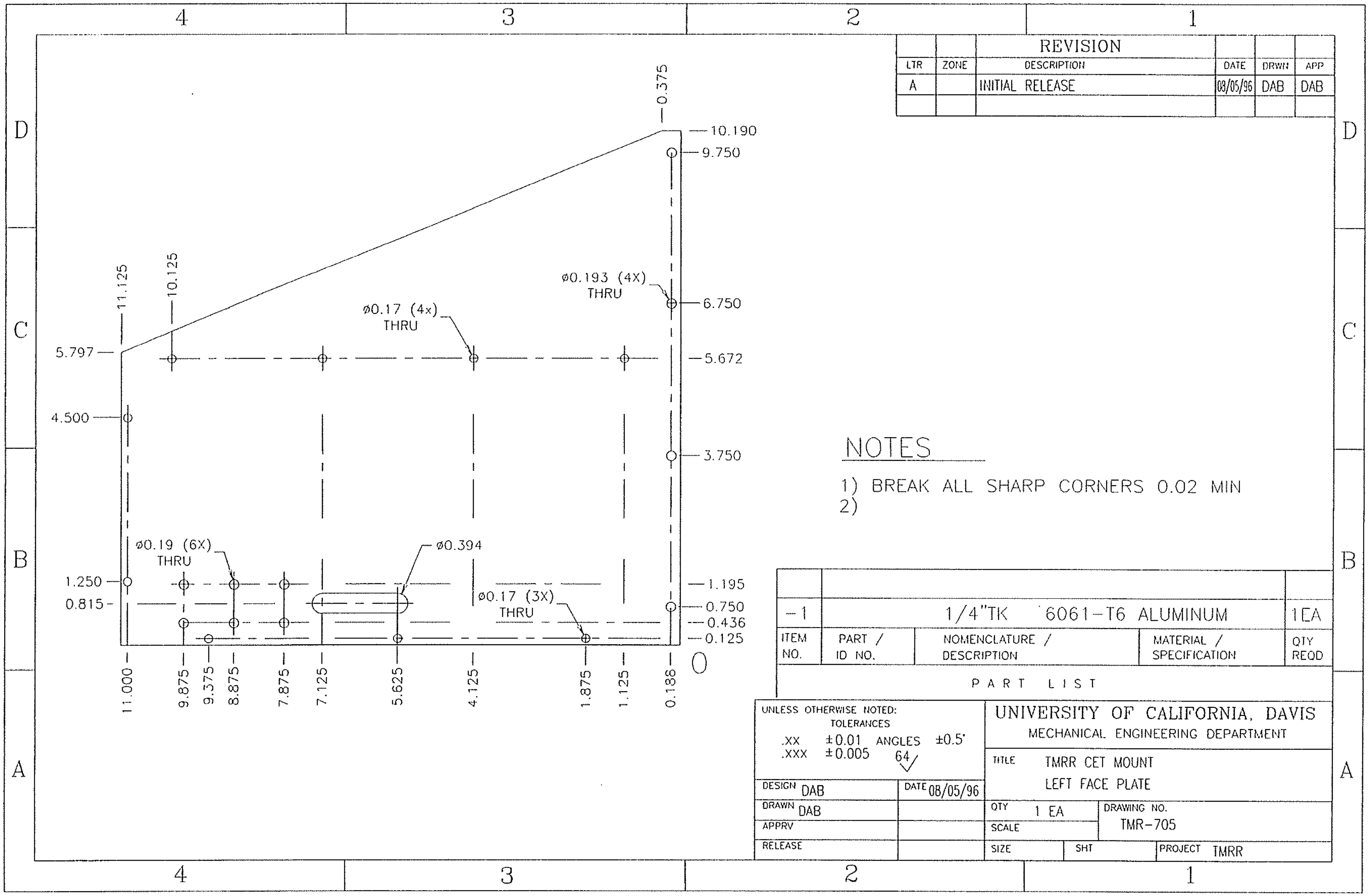
1) BREAK ALL SHARP CORNERS 0.02 MIN
2)

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
-1		1/4"TK 6061-T6 ALUMINUM		1EA

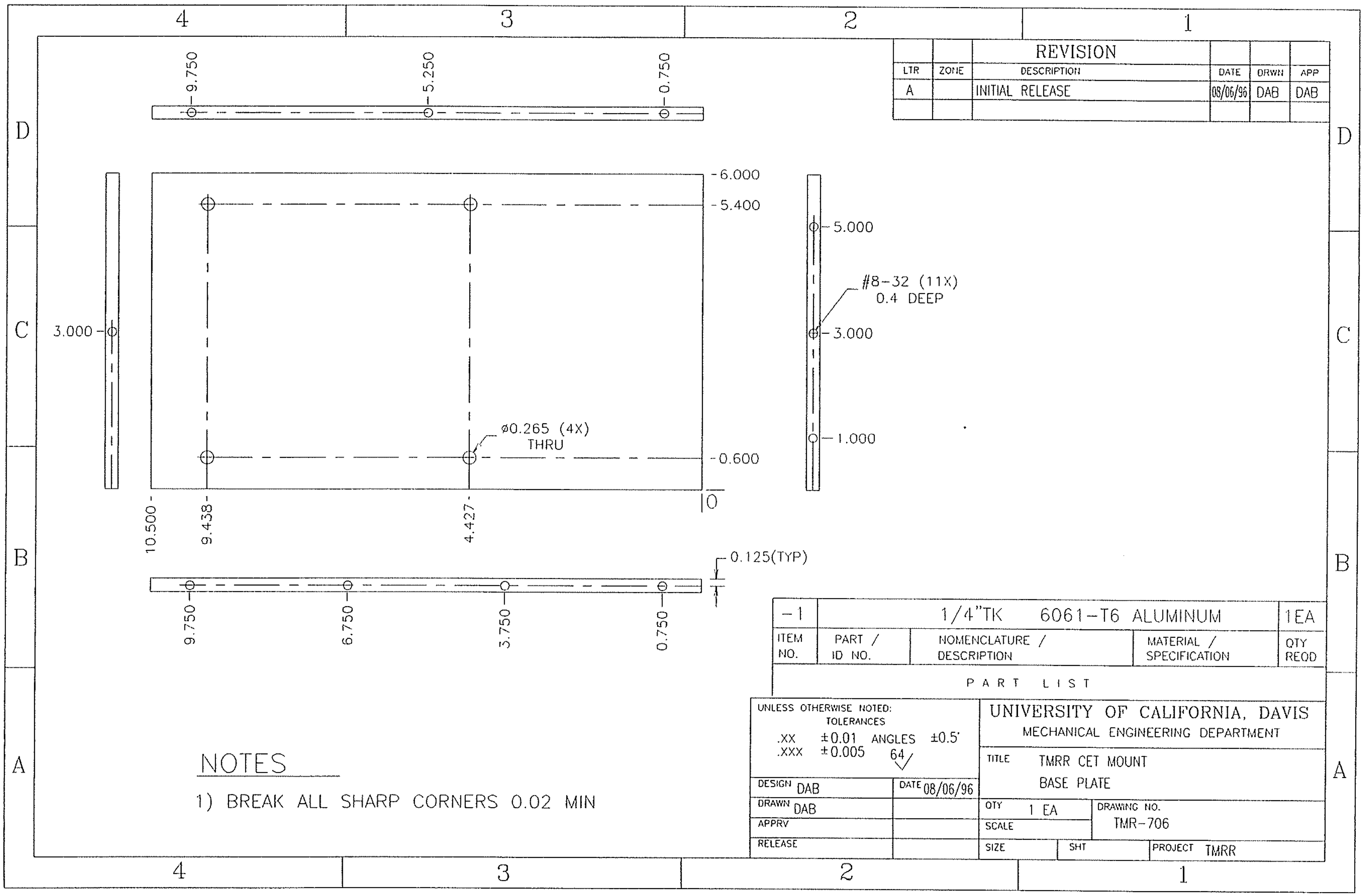
PART LIST

UNLESS OTHERWISE NOTED:
TOLERANCES
.XX ±0.01 ANGLES ±0.5°
.XXX ±0.005 64√

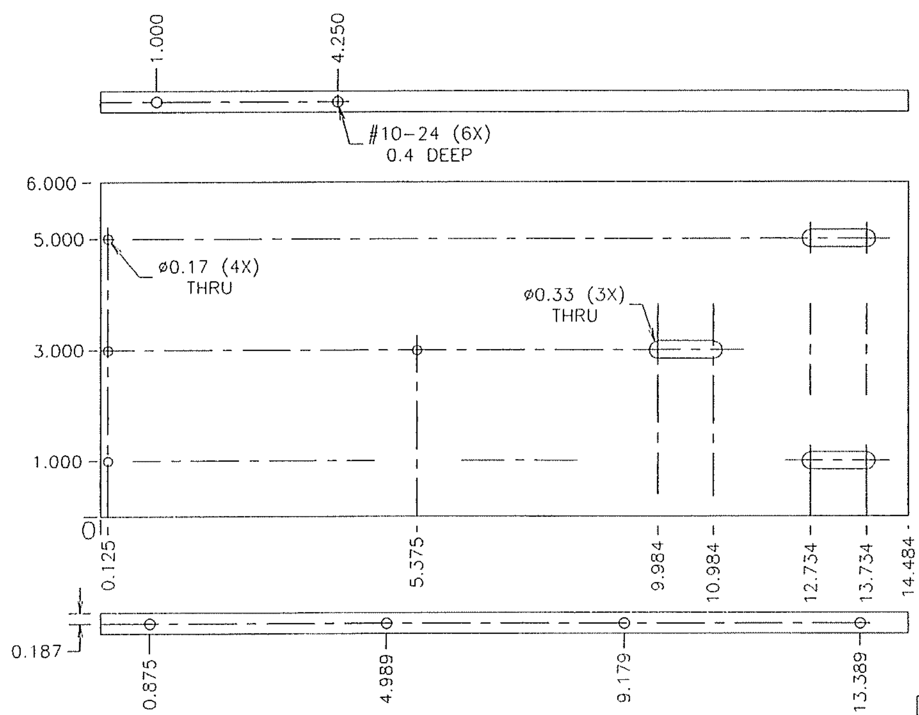
DESIGN DAB	DATE 08/05/96	UNIVERSITY OF CALIFORNIA, DAVIS MECHANICAL ENGINEERING DEPARTMENT	
DRAWN DAB		TITLE TMRR CET MOUNT RIGHT FACE PLATE	
APPRV		QTY 1 EA	DRAWING NO. TMR-704
		SCALE	
RELEASE		SIZE SHT	PROJECT TMRR


REVISION
LTR ZONE DESCRIPTION DATE DRWN APP
A INITIAL RELEASE 08/05/96 DAB DAB
0.375
10.190
9.750
11.125
10.125
ø0.193 (4X) THRU
6.750
ø0.17 (4x) THRU
5.797
5.672
4.500
3.750
NOTES
1) BREAK ALL SHARP CORNERS 0.02 MIN
2)
ø0.19 (6X) THRU
ø0.394
1.250
0.815
ø0.17 (3X) THRU
1.195
0.750
0.436
0.125
11.000
9.875
9.375
8.875
7.875
7.125
5.625
4.125
1.875
1.125
0.188
0
-1 1/4"TK 6061-T6 ALUMINUM 1EA
ITEM NO. PART / ID NO. NOMENCLATURE / DESCRIPTION MATERIAL / SPECIFICATION QTY REQD
PART LIST
UNLESS OTHERWISE NOTED: TOLERANCES
.XX ±0.01 ANGLES ±0.5'
.XXX ±0.005
64
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
TITLE TMRR CET MOUNT
LEFT FACE PLATE
DESIGN DAB
DATE 08/05/96
DRAWN DAB
APPRV
RELEASE
QTY 1 EA
SCALE
DRAWING NO. TMR-705
SIZE
SHT
PROJECT TMRR

129


REVISION
LTR | ZONE | DESCRIPTION | DATE | DRWN | APP
A | | INITIAL RELEASE | 08/06/96 | DAB | DAB
9.750
5.250
0.750
6.000
5.400
5.000
#8-32 (11X)
0.4 DEEP
3.000
3.000
1.000
ø0.265 (4X)
THRU
0.600
0
10.500
9.438
4.427
0.125(TYP)
9.750
6.750
3.750
0.750
-1 | 1/4"TK | 6061-T6 ALUMINUM | 1EA
ITEM NO. | PART / ID NO. | NOMENCLATURE / DESCRIPTION | MATERIAL / SPECIFICATION | QTY REQD
PART LIST
UNLESS OTHERWISE NOTED:
TOLERANCES
.XX ±0.01 ANGLES ±0.5°
.XXX ±0.005
64
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
TITLE TMRR CET MOUNT
BASE PLATE
DESIGN DAB
DATE 08/06/96
DRAWN DAB
APPRV
RELEASE
QTY 1 EA
DRAWING NO. TMR-706
SCALE
SIZE
SHT
PROJECT TMRR
NOTES
1) BREAK ALL SHARP CORNERS 0.02 MIN

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	08/06/96	DAB	DAB



ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
-1		3/8"TK	6061-T6 ALUMINUM	1EA

PART LIST

UNLESS OTHERWISE NOTED:
TOLERANCES
.XX ±0.01 ANGLES ±0.5°
.XXX ±0.005 64√

DESIGN DAB	DATE 08/06/96
DRAWN DAB	
APPRV	
RELEASE	

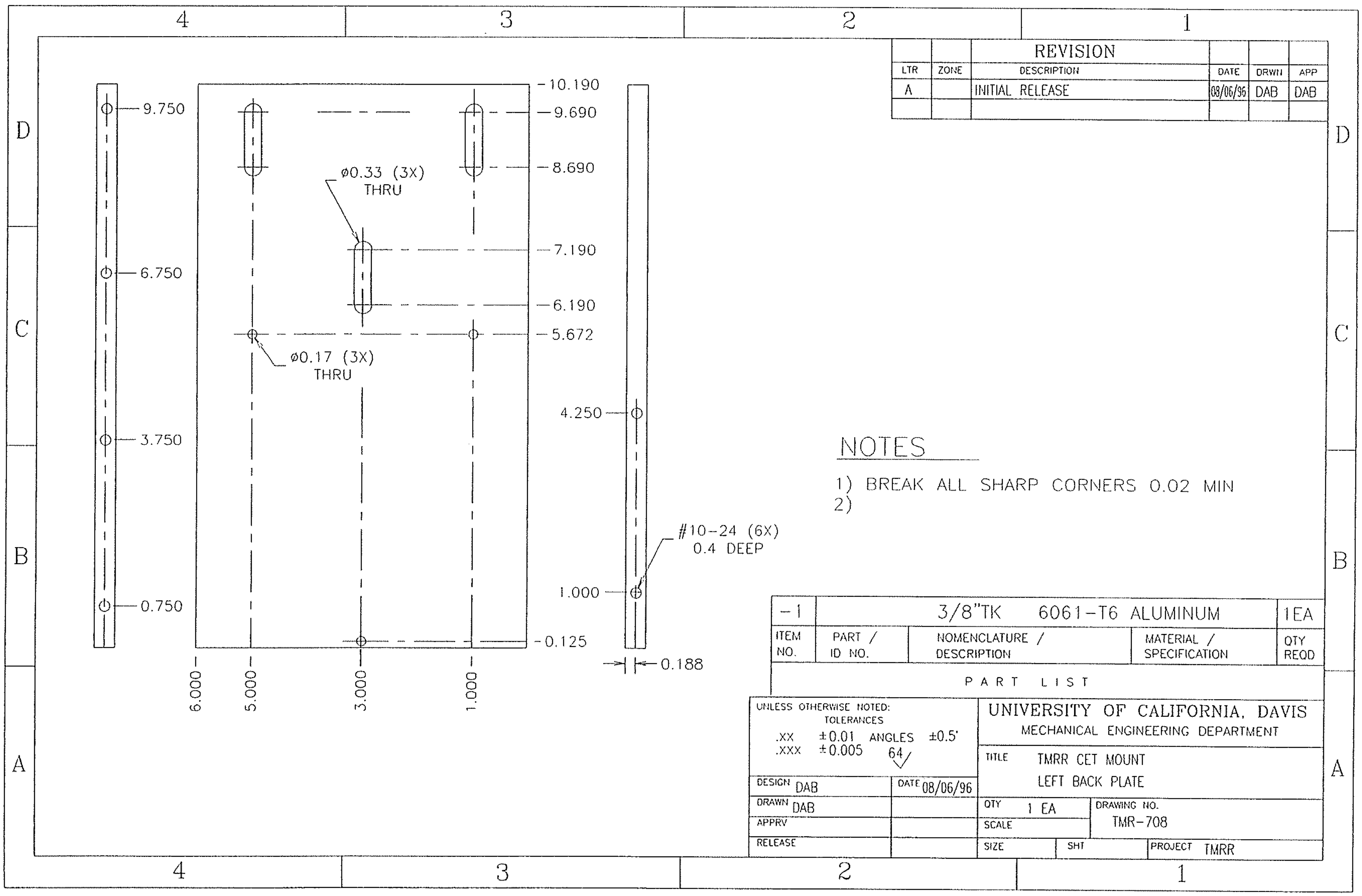
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT

TITLE TMRR CET MOUNT
RIGHT BACK PLATE

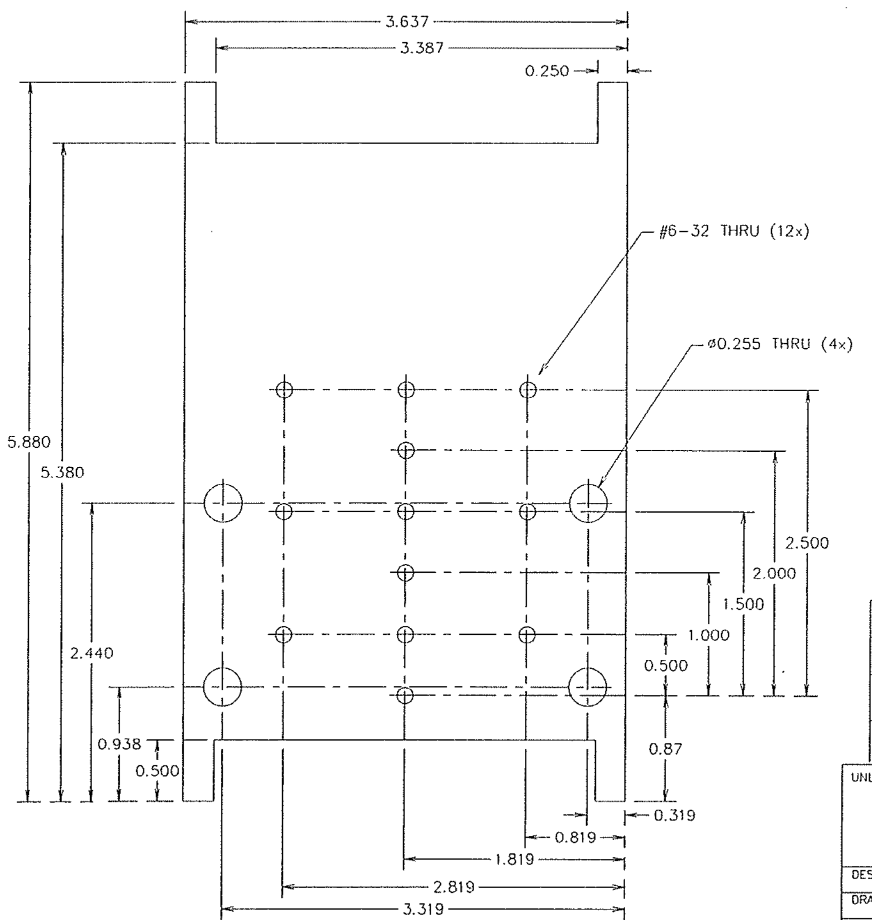
QTY 1 EA	DRAWING NO. TMR-707	
SCALE		
SIZE	SHT	PROJECT TMRR

NOTES

1) BREAK ALL SHARP CORNERS 0.02 MIN


REVISION
LTR | ZONE | DESCRIPTION | DATE | DRWN | APP
A | | INITIAL RELEASE | 08/06/96 | DAB | DAB
9.750
6.750
3.750
0.750
10.190
9.690
8.690
7.190
6.190
5.672
0.125
ø0.33 (3X) THRU
ø0.17 (3X) THRU
6.000
5.000
3.000
1.000
4.250
1.000
0.188
#10-24 (6X) 0.4 DEEP
NOTES
1) BREAK ALL SHARP CORNERS 0.02 MIN
2)
-1 | 3/8"TK 6061-T6 ALUMINUM | 1EA
ITEM NO. | PART / ID NO. | NOMENCLATURE / DESCRIPTION | MATERIAL / SPECIFICATION | QTY REQD
PART LIST
UNLESS OTHERWISE NOTED: TOLERANCES
.XX ±0.01 ANGLES ±0.5'
.XXX ±0.005 64
DESIGN DAB DATE 08/06/96
DRAWN DAB
APPRV
RELEASE
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
TITLE TMRR CET MOUNT
LEFT BACK PLATE
QTY 1 EA
DRAWING NO. TMR-708
SCALE
SIZE
SHT
PROJECT TMRR

LTR	ZONE	REVISION DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	10/14/96	DAB	DAB



NOTES

1) BREAK ALL SHARP CORNERS 0.02 MIN
2)

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
-1		1/4"TK	6061-T6 ALUMINUM	1EA

PART LIST

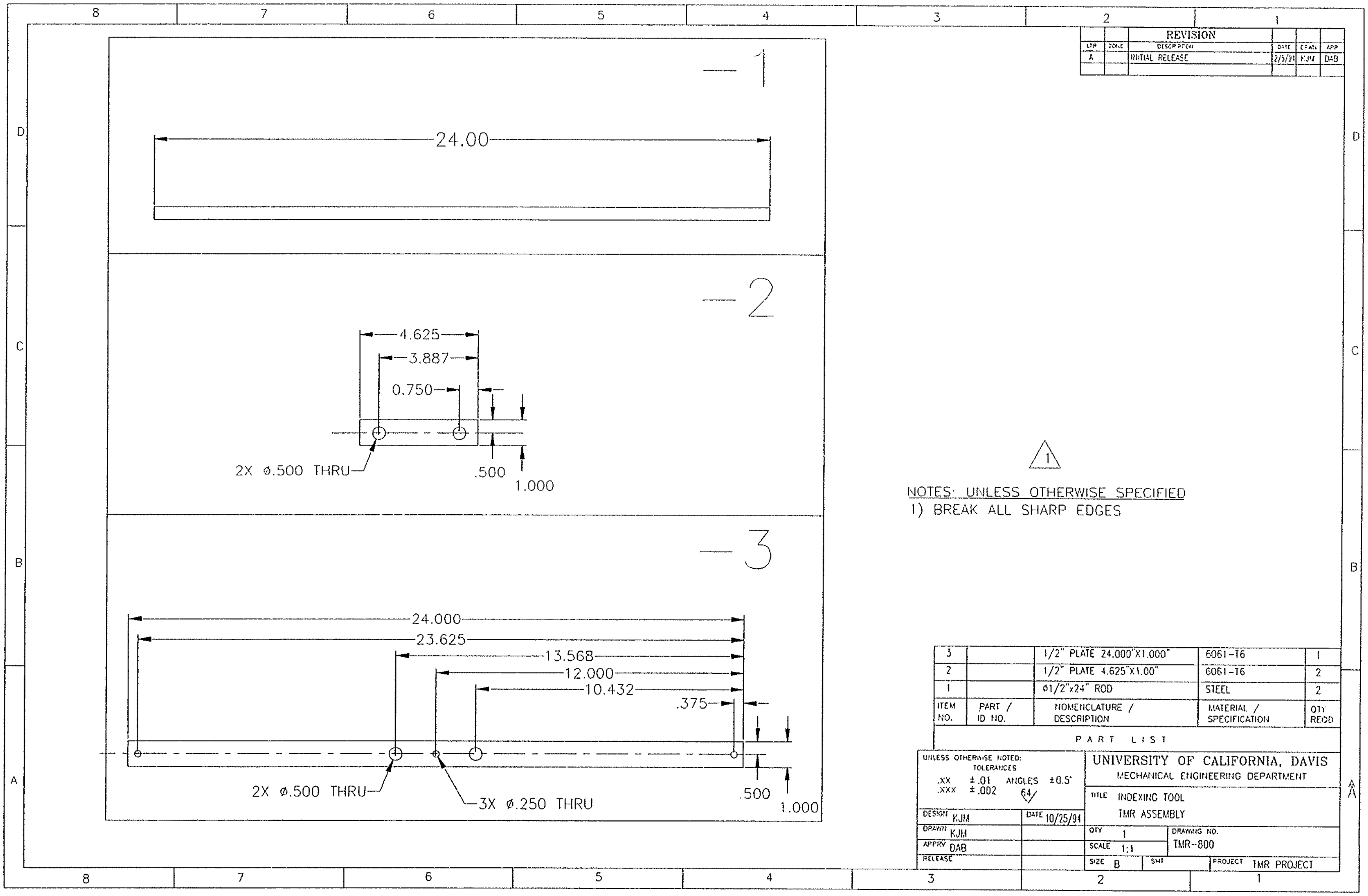
UNLESS OTHERWISE NOTED:
TOLERANCES
.XX ±0.01 ANGLES ±0.5°
.XXX ±0.005 64√

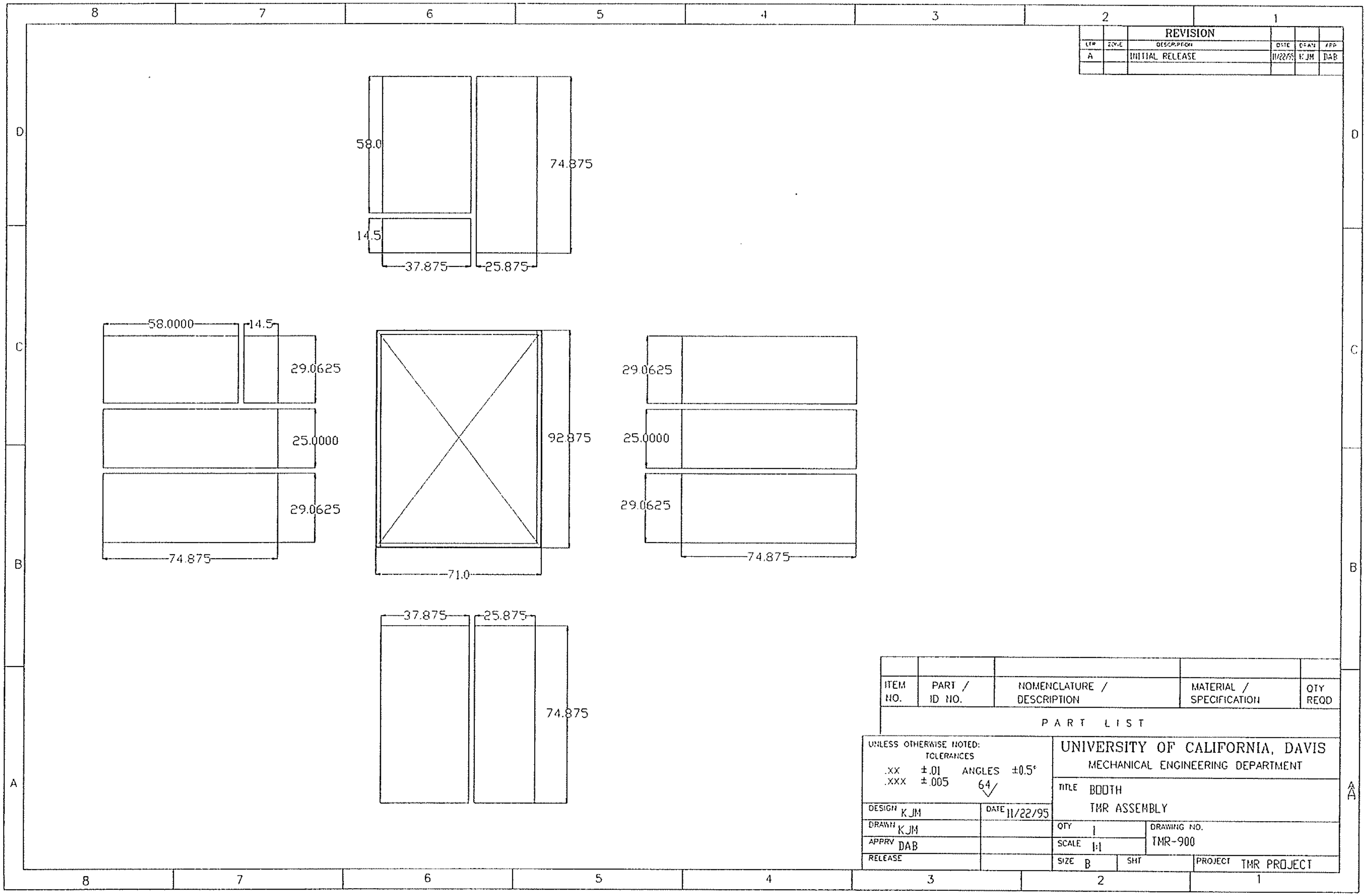
DESIGN DAB	DATE 10/14/96
DRAWN DAB	
APPRV	
RELEASE	

UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT

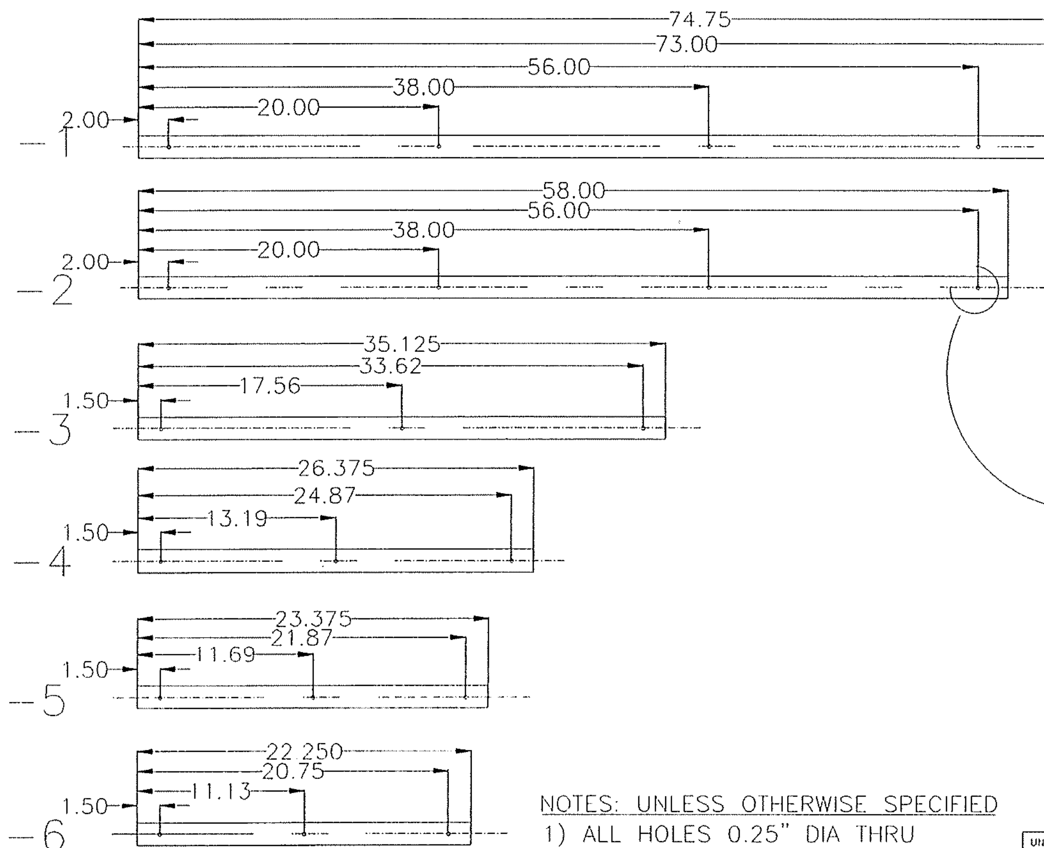
TITLE TMRR LASER COVER MOUNTING PLATE

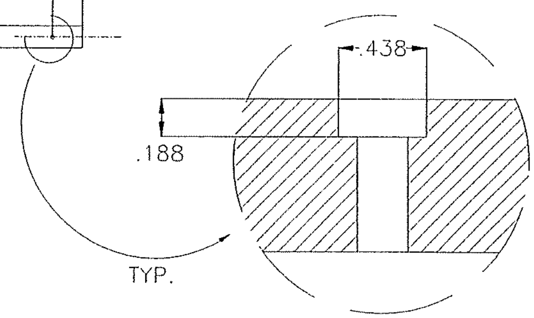
QTY 1 EA	DRAWING NO. TMR-709
SCALE	
SIZE	SHT
PROJECT TMRR	


REVISION
LTR | ZONE | DESCRIPTION | DATE | CHKD | APP
A | | INITIAL RELEASE | 2/5/31 | KJM | DAB
-1
24.00
-2
4.625
3.887
0.750
2X ø.500 THRU
.500
1.000
-3
24.000
23.625
13.568
12.000
10.432
.375
2X ø.500 THRU
3X ø.250 THRU
.500
1.000
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
3 | 1/2" PLATE 24.000"X1.000" | 6061-T6 | 1
2 | 1/2" PLATE 4.625"X1.00" | 6061-T6 | 2
1 | ø1/2"x24" ROD | STEEL | 2
ITEM NO. | PART / ID NO. | NOMENCLATURE / DESCRIPTION | MATERIAL / SPECIFICATION | QTY REQD
PART LIST
UNLESS OTHERWISE NOTED: TOLERANCES .XX ±.01 .XXX ±.002 ANGLES ±0.5°
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
TITLE INDEXING TOOL TMR ASSEMBLY
DESIGN KJM DATE 10/25/94
DRAWN KJM
APPRV DAB
RELEASE
QTY 1
DRAWING NO. TMR-800
SCALE 1:1
SIZE B
PROJECT TMR PROJECT


REVISION
INITIAL RELEASE
11/22/95
KJM
DAB
58.0
14.5
74.875
37.875
25.875
58.0000
29.0625
25.0000
92.875
71.0
ITEM NO.
PART / ID NO.
NOMENCLATURE / DESCRIPTION
MATERIAL / SPECIFICATION
QTY REQD
PART LIST
UNLESS OTHERWISE NOTED: TOLERANCES
.XX ±.01
.XXX ±.005
ANGLES ±0.5°
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
TITLE BOOTH
TMR ASSEMBLY
DESIGN KJM
DATE 11/22/95
DRAWN KJM
APPRV DAB
RELEASE
QTY 1
SCALE 1:1
DRAWING NO. TMR-900
SIZE B
SHT
PROJECT TMR PROJECT

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRAWN	APP
A		INITIAL RELEASE	6/26/96	KJM	DAB
B		COUNTERBORED HOLES	8/11/96	KJM	DAB





NOTES: UNLESS OTHERWISE SPECIFIED
1) ALL HOLES 0.25" DIA THRU
7/16" COUNTERBORE 3/16" DEEP

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
6		22.250"x1.50"x0.75"	6061 ALUMINUM	2
5		23.375"x1.50"x0.75" THICK	6061 ALUMINUM	2
4		26.375"x1.50"x0.75"	6061 ALUMINUM	2
3		33.125"x1.50"x0.75" THICK	6061 ALUMINUM	2
2		58.00"x1.50"x0.75" THICK	6061 ALUMINUM	4
1		74.75"x1.50"x0.75" THICK	6061 ALUMINUM	14

PART LIST

UNLESS OTHERWISE NOTED:
TOLERANCES
.XX ± .01 ANGLES ±0.5°
.XXX ± .005
64√

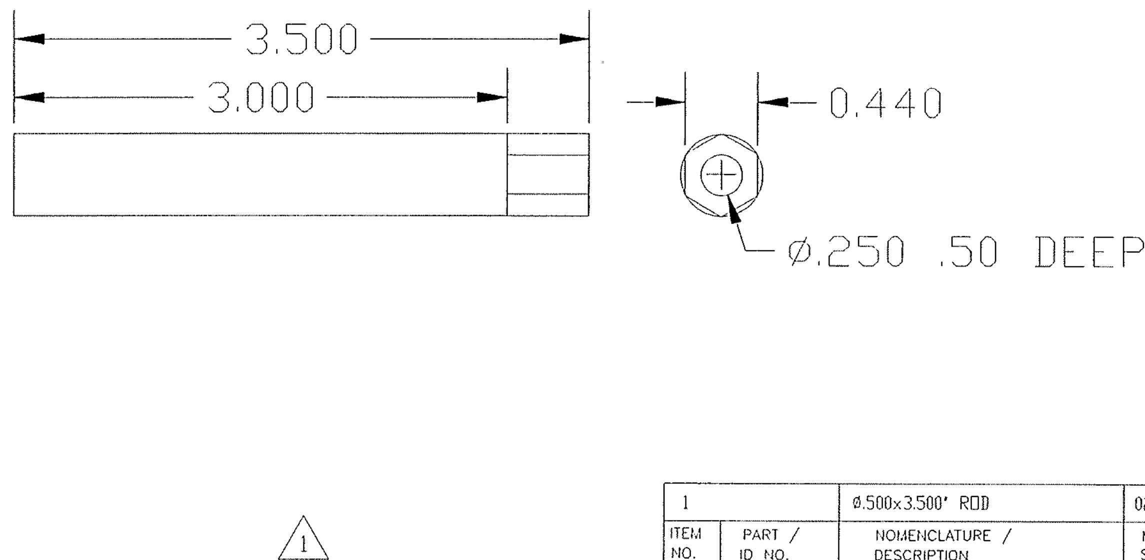
DESIGN KJM/JMS DATE 6/26/96
DRAWN KJM
APPRV DAB
RELEASE

UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT

TITLE LEXAN RETAINING STRIPS
BOOTH ASSEMBLY

QTY 1
SCALE 1:1
SIZE B
SHT
DRAWING NO. TMR-901
PROJECT TMR PROJECT

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	7/18/96	KJM	DAB



NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
2) MATERIAL HARDENED Rc 57-62

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
1		Ø.500x3.500" ROD	02 TOOLING STEEL	1

PART LIST

UNLESS OTHERWISE NOTED:
TOLERANCES
.XX ±.01 ANGLES ±0.5°
.XXX ±.005
64√

DESIGN KJM	DATE 7/18/96
DRAWN KJM	
APPRV DAB	
RELEASE	

UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT

TITLE HEXAGON DIE
TMR ASSEMBLY

QTY 1	DRAWING NO. TMR-902
SCALE 1:1	
SIZE B	SHT
PROJECT TMR PROJECT	

APPENDIX D

MANUFACTURERS' SPECIFICATIONS

Chapter 1: Introduction

General

The SB586P(V) series CPU board is a full featured, industrialized, single board computer supporting the Intel® Pentium™ processor. It combines many of the features normally needed for system operation (high speed serial ports, parallel port, disk controllers) on one board. This reduces the number of slots required on the passive backplane, allowing room for additional feature cards. All of the onboard controllers may be totally disabled through the system BIOS if desired.

The CPU board uses the Peripheral Component Interconnect (PCI) bus to communicate with the onboard features. The external bus architecture complies with the Industrial Standard Architecture (ISA) with a PCI bus extension. The PCI bus extension supports the DEC bridge chip, allowing additional peripherals on the PCI bus.

A full range of Pentium processors with speeds ranging from 75MHz to 133MHz are supported on the SB586P(V) board. The processor is installed in a Low Insertion Force (LIF) socket and includes a heat sink to dissipate the excess heat it may generate. In environments exceeding +40°C, a fan cooled heat sink is recommended.

The board has four SIMM sockets, arranged in two banks, and will accept up to 192MB of RAM using 36 bit SIMMs. A 256k or 512k onboard cache option is available and is upgraded with plug-in Cache Modules.

On-Board Controllers

On-board controllers are incorporated into the design of the SB586P(V) series CPU for disk drives, serial and parallel ports, and video except on the SB586P models. All on-board controllers are individually enabled or disabled with the system BIOS.

Display

The SB586PV contains a SVGA controller which offers 1MB of DRAM and is upgradable to 2MB. The SVGA controller offers resolutions of up to 1280 x 1024 with 256 colors. The display portion includes a VESA feature connector, allowing other peripherals to share signals and control of the VGA circuitry. The PV Series Display Drivers and Utilities set is included with the CPU board and offers programs for display enhancements: Disk 1 is for DOS; Disk 2 and 3 are for Windows 3.1 and OS/2 2.1; Disk four is for OS/2 2.1X through 3.0. Please refer to Appendix B for further information on the video drivers. A video controller is not included on the SB586P series CPU.

Resolution	1 Meg	2 Meg
640 x 480	16M	16M
800 x 600	64k	16M
1024 x 768	256	64k
1280 x 1024	N/A	256

Table 1-1: Video Resolutions and Colors

Disk Drive

Disk controllers are provided for floppy disk drives and SCSI devices, and a drive interface is provided for IDE fixed disk drives. The IDE interface, located on the PCI local bus, supports two drives and includes LBA and PIO mode 3 support allowing up to 12MB/sec throughput speeds. The floppy drive controller also supports two drives, ranging in density from 360K to 2.88MB floppy drives.

The SCSI controller is a single-ended SCSI-2 Wide and Fast controller, and is Adaptec AHA 2940 compatible. The bus width is jumper selectable as 8 bit or 16 bit to maintain maximum compatibility. With the 16 bit bus width selected (Wide SCSI), throughputs of up to 20MB/sec are possible.

Connection to the SCSI controller is provided through a Single-Ended, 68 pin "P" connector. The included SCSI cable allows for full use of 16 bit wide bus transfers. A 68 pin to 50 pin adapter is available to channel the SCSI bus signals to the standard 8 bit, 50 pin connection for older SCSI peripherals.

Normal SCSI and SCSI Wide devices may be used on the same SCSI bus via an optional adapter. If this is done, it is recommended to **have a terminated SCSI Wide Device at the end of the cable** to insure proper termination of all SCSI signals.

Please see the SCSI Connection section in Chapter 2 for further information.

I/O Ports

Two serial ports compatible with the 16550 UART are available on the SB586P(V) CPU. The serial ports are extended through 10 pin headers on the board to bracket mounted DB-9 connectors. Also included is an Enhanced parallel port, capable of Bi-directional communication. The parallel port is accessible through the DB-25 connector on the rear bracket of the CPU board.

Watch Dog Circuit

The watch dog circuit is a hardware timer that resets the CPU if the timer is not refreshed periodically. The circuit is refreshed by a trigger pulse provided by the BALE bus line. Any event, such as a read or write to memory, disk drive activity, video refresh, etc., will trigger the BALE line and thus reset the timer. If the processor should become hung-up, the watch dog circuit will time out and reset the CPU. The watchdog circuit is set to reset the CPU if it is not refreshed for 150msec or greater. Also, a power monitor, built into the same circuit, is set to reset the CPU if the +5VDC power varies by more than 5%.

Specifications

Processors Supported

Intel Pentium in a LIF (Light Insertion Force) Socket

Processor Clock Rate

75MHz, 90MHz, 100MHz, 120MHz, or 133MHz

Chip Set

Neptune II

BIOS

Hi-Flex Pentium AMIBIOS, Flash EPROM Support

ISA Bus Clock Rate

8.33Mhz

PCI Bus Clock Rate

25Mhz, 30Mhz, or 33Mhz

Memory Capacity

192MB Maximum On-board

SIMM Support

2 Banks, 2 Sockets each, 72-Pin

Supports 256k x 36(1MB), 1M x 36(4MB), 2M x 36(8MB), 4M x 36(16MB), 8M x 36(32MB), and 16M x 36(64M) SIMMs.

Note: Only Bank 0 supports 16M x 36 SIMMs.

Memory Speed Required

70ns or faster

Video Controller - SB586PV

SVGA Video

1MB DRAM installed, Sockets for additional 1MB DRAM

VESA Feature Connector

Driver Support under supported operating systems

Rear Panel DB-9, High Density, 15 pin connector, female

Cache Memory

16kB Internal Pentium Chip Cache

256kB or 512kB Cache Options, plug in modules

IDE Disk Controller

2 Fixed Disk Drives Supported on the PCI Local Bus
Secondary Controller Support
LBA and PIO Mode 3 Support

SCSI Disk Controller

SCSI-2 Fast, Wide controller, Located on PCI Local Bus
8-bit or 16-bit bus, Jumper Selectable
To 20MB/sec Throughput
Adaptec AIC-7870 Single-Chip Host Adapter

Floppy Controller

2 Floppy Drives, up to 2.88MB Supported

Serial Ports

2, RS232, 16550 Compatible, FIFO Buffer
Isolated to ±1500V ESD
MAX211E Component incorporated for enhanced ESD protection

Parallel Port

1, Centronics Compatible, Bi-directional Compatibility
EPP and ECP Enhanced Port Modes

Keyboard, Speaker, & Reset Port

Single 8 pin Header Connector for System Interface

Note: The keyboard may be selected as *absent* or *present* by the system BIOS. This will allow the system to boot without a keyboard attached.

Watchdog Timer

Reset CPU automatically if CPU stops operating
Reset CPU automatically if +5VDC varies more than 5%

CMOS Battery

On-board, Included

Supported Operating Systems

Windows NT$_{TM}$ V3.1 and later
Windows '95$_{TM}$
SCO Unix$_{TM}$
MS-DOS$_{TM}$
Windows 3.11$_{TM}$
QNX$_{TM}$
OS/2$_{TM}$ V2.0 and later

Operating Environment

Temperature: -10°C to +55°C
Humidity: 5% to 95% RHNC
Shock: 5G, Any Axis
Vibration: .5G, 10-500Hz, Any Axis
Altitude: 0 to 10,000ft

Storage Environment

Temperature: -40°C to +85°C
Humidity: 5% to 95% RHNC
Shock: 10G, Any Axis
Vibration: 1G, Any Axis

MTBF

Calculated with Mil-Hndbk-217e
>92,500 P.O.H. @ 25°C

Power Requirements

+5V @ 2.8A Typical, No DRAM or Cache
+12V @ <100mA Typical
-12V @ <100mA Typical

Compatibility Testing

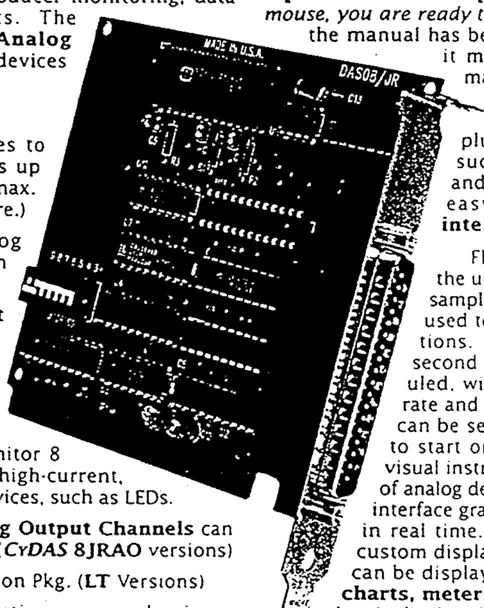
XXCAL Labs Gold Certification

CyDAS™ 8JR Multifunction A/D Boards from $99!

The Lowest-Cost Solution for Data Acquisition

The *CyDAS* **8JR Series** of multifunction analog and digital I/O boards plug directly into a PC expansion slot. They're designed specifically for educational & high-volume OEM applications where cost is the primary consideration. With Labtech NOTEBOOK software, you get **a complete data acquisition solution for only $199!**

The *CyDAS* 8JR is ideal for low-speed (up to 20kHz) data acquisition applications with signals in the ±5V range, such as: test and measurement, process control, transducer monitoring, data collection, and laboratory experiments. The ***CyDAS* 8JRAO, with 2 channels of Analog Output (D/A),** can be used to control devices such as proportional valves.



CyDAS **8JR Series** boards feature:

- **12-bit A/D** converter which resolves to 2.4mV steps. Sustained Sample Rates up to **20,000/sec.** (1,000 samples/sec. max. using bundled ver. of NOTEBOOK software.)
- **8 Channels of Single Ended** Analog Input (A/D) with overvoltage protection to ±30V max., continuous.
- Analog Inputs have a **fixed ±5V input range.** A 2µsec sample & hold captures the signal for the A/D converter. Acquisition/transfer cycles can only be triggered via a software command.
- **16 bits of Digital I/O,** 8 out/8 inputs can control 8 discrete devices, & monitor 8 contact closures. Digital outputs are high-current, able to sink 24mA to drive electronic devices, such as LEDs.
- **Option: 2 Independent 12-bit Analog Output Channels** can output voltage at ±5V, in 2.4mV steps. (***CyDAS* 8JRAO** versions)
- **Option: LABTECH NOTEBOOK** Solution Pkg. (**LT** Versions)
- All the analog and digital I/O connections are made via an industry-standard 37-pin "D-type" connector at the rear of the PC. A selection of matching, economically-priced terminal boards and interface cables is available starting on page 124.

CYDAS 8JR + LABTECH NOTEBOOK™ = Solution Package

CyberResearch has developed a new Solution Package which includes the **CyDAS 8JR** with a Special Version of the powerful **LABTECH NOTEBOOK** software package for DOS or Windows, complete with all necessary drivers for the CyDAS 8JR. **This is the full $495 version of LABTECH NOTEBOOK,** with limited speed capability, and drivers for use with the CyDAS 8JR series only.

The ***CyDAS* 8JRLT solution package converts your PC into a powerful data acquisition system.** *With just 2 clicks of the mouse, you are ready to collect data.* The product is so simple that the manual has been replaced by extensive on-line help. Yet it maintains the powerful features that have made NOTEBOOK such a popular program for data acquisition and control. You can collect, analyze, display, & store data, plus monitor and control physical variables such as force, pressure, temperature, flow, and transducer outputs. Setups are fast and easy with NOTEBOOK's **iconic graphical interface** and **Windows® On-Line Help.**

Flexible process monitoring capabilities allow the user to configure applications with a variety of sampling rates and sensor types. Simple menus are used to initiate data logging, and real-time calculations. Sampling rates from a thousand points per second (max) to a few points per day may be scheduled, with each I/O point having its own sampling rate and triggering conditions. **Software triggering** can be set on an analog, digital, or calculated value, to start or stop monitoring of an I/O point, or offer visual instructions to the operator. For accurate control of analog devices, **PID control is included**. The operator interface graphically displays data and controls processes in real time. Users can quickly design and implement custom displays using the **Windows Icon tool-bar**. Data can be displayed in a number of formats, including **strip charts, meters, and bar charts**. You can change the way data is displayed while it is being acquired. **Users can create knobs, dials, slide bars, and buttons**; and use the powerful drawing and animation tools to customize displays which can be **animated** to best demonstrate what is happening **in real time.**

1.1 SUMMARY OF DDA-06 FUNCTIONS

The DDA-06 is an analog/digital I/O expansion board for the IBM Personal Computer[1] providing 6 channels of 12-bit analog output and 24 lines of digital I/O. The following functions are implemented on the DDA-06:

1. 6 independent 12-bit D/A converters are provided. Each is individually switch and jumper selectable to any of the following ranges:

   0 to +10 V
   0 to +5 V
   -2.5 V to +2.5 V
   -5 V to +5 V
   -10 V to +10 V
   4-20 mA current loop (sink)

   Each D/A has a double buffered input for single step update and occupies its own I/O location. By means of jumper blocks, it is possible to select any or all of the D/As to update simultaneously. Since each D/A output uses one pin of the rear 37-pin D-type connector, D/As may be operated in either voltage output mode or current output (but not both together). In voltage mode, output settling time is typically 3 microseconds to 0.01% for a full-scale step.

2. 24 bits of digital I/O are provided on the rear connector consisting of 3 ports of 8 bits. Each port may be independently programmed as an input or output and is TTL/CMOS compatible. An 8255 programmable peripheral interface chip is used for digital I/O and can be operated in any of the 8255 modes 0-2 (straight I/O, strobed I/O, and bidirectional I/O).

The following utility software is included with the DDA-06 on a single sided PC DOS 1.10 format 5 1/4-inch floppy disk (compatible with DOS 2.0/2.1/3.0 etc.):

1) DDA06.EXE/.BAS - A comprehensive installation, switch setting, calibration, and test program.

2) EX.BAS - A "mergeable" BASIC D/A driver subroutine.

1. Registered trademark of International Business Machines Corporation.

A system block diagram appears in Fig. 1-1. To extend the capabilities of the DDA-06, the following expansion modules can be connected via flat insulation displacement cable to the main 37-pin D-type connector:

1) SCREW TERMINAL CONNECTOR BOARD - The STA-U universal screw connector board can be used for making screwdriver connections to all the I/O functions. The STA-U also provides a "daisy-chain" socket for connection to further accessories, e.g. ERB-24 relay board.

2) ERB-24 ELECTROMECHANICAL RELAY BOARD - This board provides 24 D.P.D.T. (double pole changeover) relays, each driven by one of the DDA-06 digital I/O lines. It is directly plug compatible with the DDA-06.

1 Introduction and Installation

1.1 Description

The Model 5312B Quadrature Encoder Input card is PC Bus compatible. It provides inputs and decoding for up to four incremental quadrature encoders depending on the model purchased. The card also may be used as a high-speed pulse counter (up/down and pulse/direction) for general counting applications. Figure 1.1 shows a functional block diagram.

NOTE: This manual is model independent. For models not utilizing all encoder ports, disregard the appropriate upper axes.

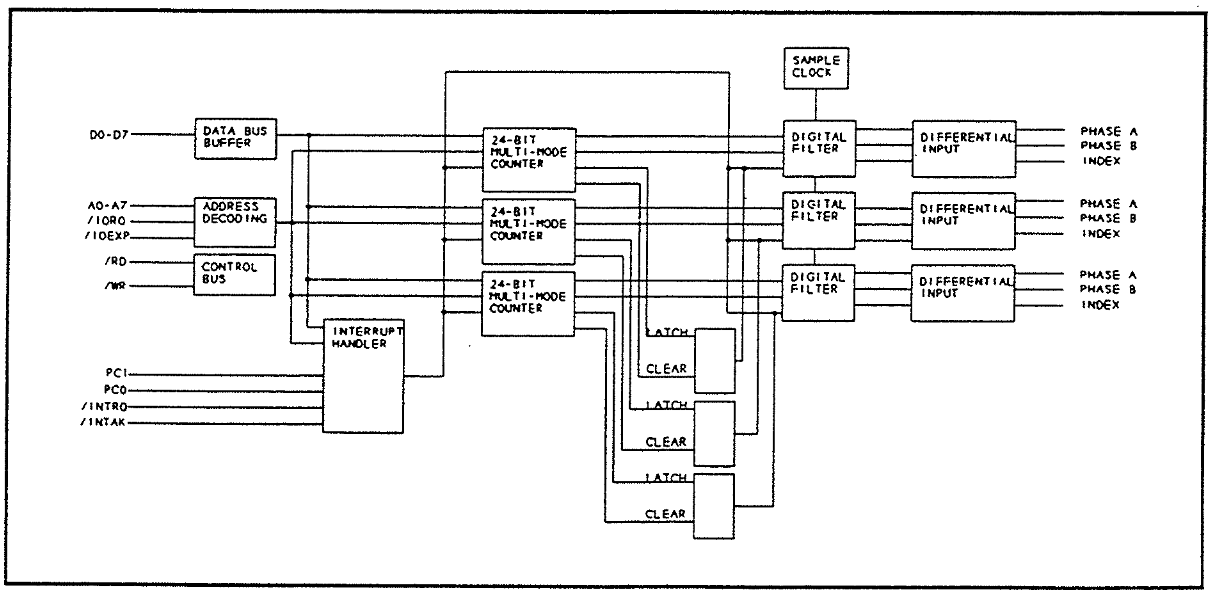


Figure 1.1 Functional block diagram for the 5312

For each encoder circuit, Phase A (Phase 0), Phase B (Phase 90), and Index pulse inputs are provided. Jumper options on the board allow inputs to be configured as single-ended TTL or differential (the recommended connection method). Individual connectors for each encoder provide power (+5V) and ground for the encoder if needed.

The Model 5312B may also be used as an event (pulse) counter. Four independent events may be counted, or the counters may be cascaded to provide high speed pulse counting over an extended count range.

Inputs are conditioned by a four-stage digital filter. The filter clock is one of five jumper-selectable sampling frequencies ranging up to 10 MHz. Selecting the lowest frequency compatible with the highest expected input rate will maximize noise immunity. The maximum input rate per phase in Quadrature Decode Mode is approximately 333 kHz. The maximum input rate in the Count Mode is approximately 1.25 MHz. Sample clock frequency selection is described in detail in section 2.

The conditioned inputs are applied to a 24-bit counter provided for each encoder. The counters may be used for quadrature decoding, pulse and direction input counting, or as a pulse input up/down counter. Count output is available for the PC Bus in binary or binary coded decimal (BCD) form. The count value may be latched on command, latched on an index pulse, or latched with a new count value when an index pulse occurs.

The Model 5312B is capable of generating interrupts. Maskable interrupts may come from a valid index pulse, counter overflow/underflow, or on count value match with a preset compare value.

1.2 Technical Specifications

- **Voltage Requirements**
  - PC Bus: 5 Volts at:

4-axis	1.5A (typical)	2.0A (maximum)
3-axis	1.25A (typical)	1.75A (maximum)
2-axis	1.0A (typical)	1.5A (maximum)
1-axis	0.9A (typical)	1.25A (maximum)

- **Compatibility**
  - PC/XT/AT
  - Single-ended or Differential
  - Incremental Encoders
  - TTL or CMOS Signal Sources
- **Operating Range:** 0 to 70 degrees Celsius
- **Mating Connectors**
  - 9-pin D-sub
  - Ansley *609-9p*
  - Amphenol *841-17-DEFR-B09P*
- **Card Dimensions:** 13.3 x 4.2 x 0.5 inches

PC7166 PC to Incremental Encoder Interface Card

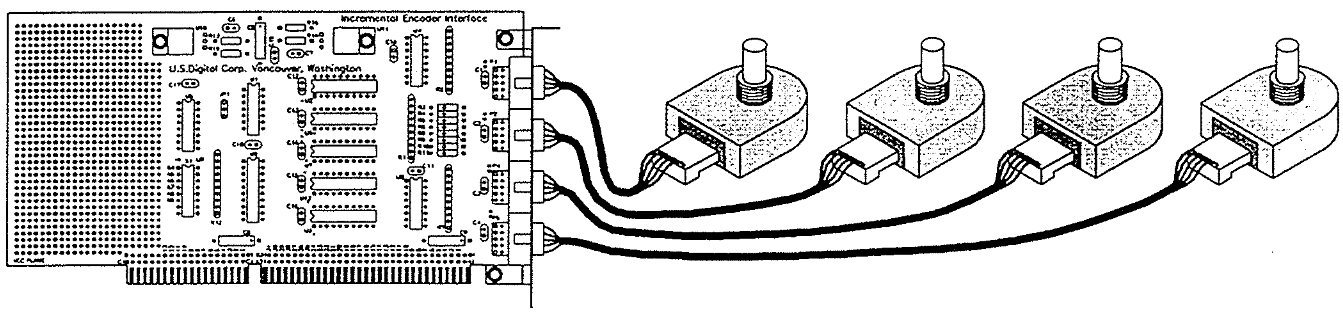
Technical Data, Rev. 05.09.96, May 1996

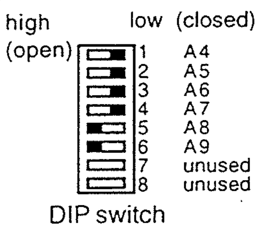
The **PC7166** daughter board plugs into a standard 8 or 16 bit ISA slot of IBM PC compatible computers. It includes four LS7166 24-bit quadrature counters and accepts single ended TTL signals or RS422 differential quadrature inputs. This card also provides 5V power to the encoders.

Software with source code in C for DOS, Windows 3.1, and Windows 95/NT is included. The software displays the position of each encoder and allows the user to change the parameters of the PC7166. This is a good starting point for the development of your custom software.

Features
- 4 channels
- Preloadable up/down 24 bit counters
- Latched counter outputs
- X1, X2, X4 resolution multiplier
- TTL and RS422 differential interface
- Interfaces to S1, S2, E2 encoders and T2 inclinometers
- Demo software
- Prototyping area on board

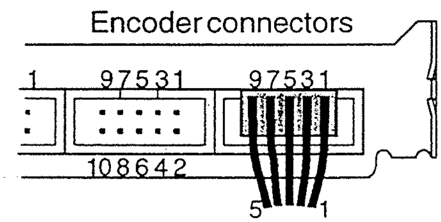
PC7166 Incremental Encoders





The PC7166 card uses 16 consecutive IO addresses. The location is determined by the setting of addresses A4 to A9 on the DIP switch. This address block must not be used by other devices on the bus. Probable choices are: 220, 240, 250, 260, 300, 310, 330, 340, 350, 360 hex (factory default is 300).

When using a 5 pin connector in place of a 10-pin connector, use the upper row (pin 1 to pin 1).



The connector should be centered and well seated.

Functional pin description

Pin	Name	Description
1	GND	Ground, common for power and data.
2	GND	Ground, common for power and data.
3, 4		No connection
5	A-	Quadrature input, differential or TTL, see note 1.
6	A+	Quadrature input, differential only, see note 1.
7	PWR	Power supply output to encoder (190 mA max per encoder).
8	PWR	Power supply output to encoder (190 mA max per encoder).
9	B-	Quadrature input, differential or TTL, see note 1.
10	B+	Quadrature input, differential only, see note 1.

Part Number:

PC7166

PC7166 Price:
$155 / 100
$205 / 10
$225 / 2
$250 / 1

Absolute maximum ratings

Parameter	Min.	Max.	Units
Storage temperature	-40	100	°C
Operating temperature	0	70	°C
Humidity (non-condensing)	0	95	%

Phone (360) 696-2468 • Sales (800) 736-0194 • Fax-Back (360) 696-3836 • Fax (360) 696-2469
Internet E-Mail: sales@usdigital.com • World Wide Web: http://www.usdigital.com
U.S. Digital Corporation • 3800 N.E. 68th Street, Suite A3 • Vancouver, WA 98661-1353

DC Electrical Characteristics

Over operating temperature range. Typical values are specified at 25°C

Parameter	Min	Typ.	Max.	Units	Notes
+5V input current (from ISA bus)			310	mA	independent of load
+12V input current (from ISA bus)			80	mA	no load. See note 1
Output voltage PWR (to encoders)	5.00	5.25	5.50	Volts	See note 1
Output current (per encoder)			190	mA	See note 1
Differential input voltage IA+ - A-I , IB+ - B-I	0.2		14	Volts	See note 2
Common mode input voltage (A-+A+)/2, (B-+B+)/2	-7		12	Volts	See note 2
Input current (Vin = 0 to 5V) A-, B-	-0.4		2.7	mA	no termination
A+ , B+	-2.7		2.7	mA	resistors installed
Single ended input voltage low A- , B-			1.8	Volts	See note 2
Single ended input voltage high A- , B-	3.2			Volts	See note 2
Count frequency	0		10	MHz	

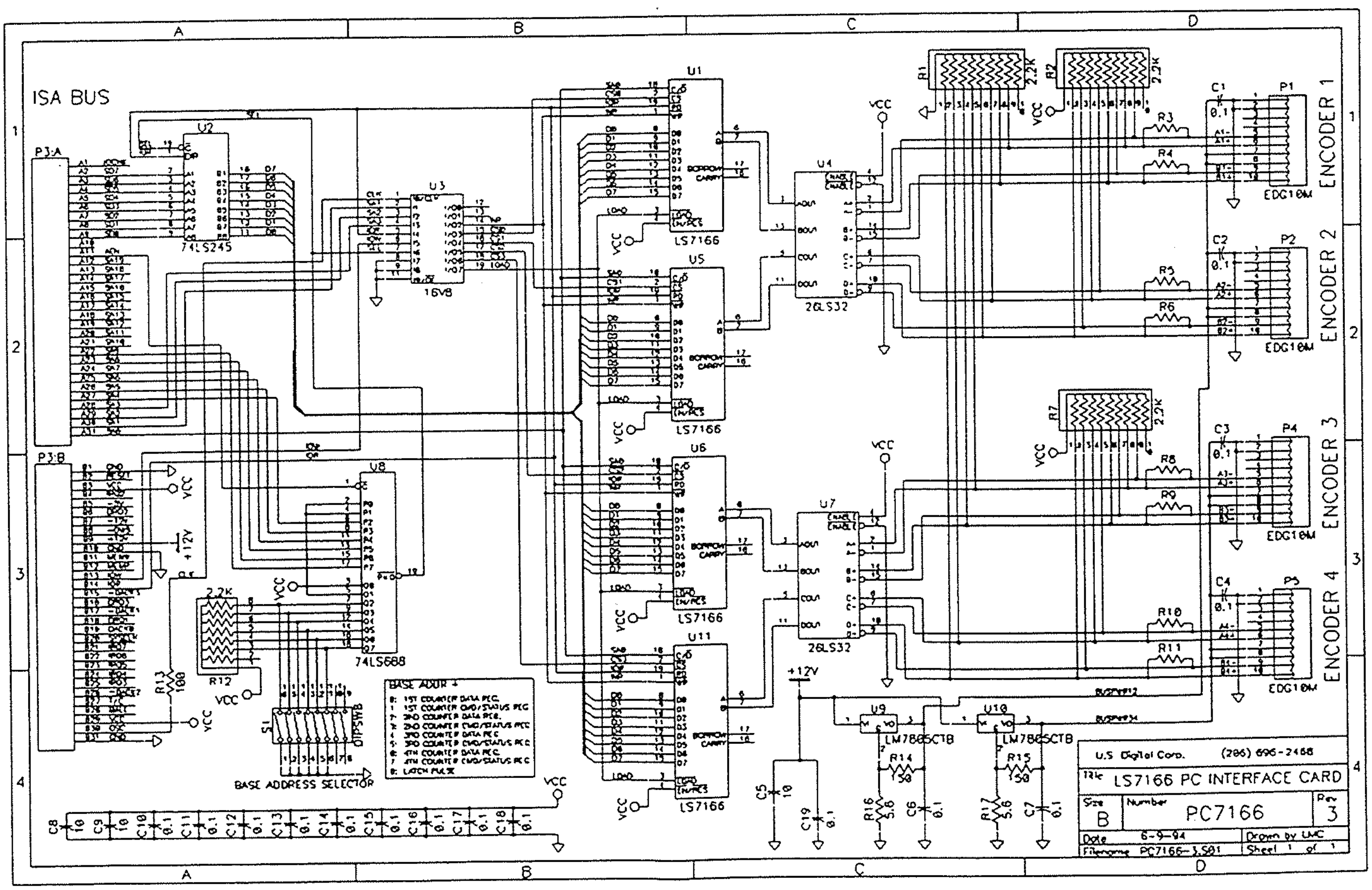
Notes:

1) The power output (PWR) to the encoders is +5.25V regulated from the +12V supply of the ISA bus. Therefore the current drawn from the +12V supply is ≤ 80mA plus current drawn by the encoders (and termination resistors, if installed). The power output to the encoders is protected against shorts, but a peak current of about 2.5A can occur for each encoder pair during a short. When using long cables, consider the voltage drop due to the current consumption of the encoder.

2) The quadrature inputs are setup to receive differential signals (RS422) or single ended TTL signals. When using the single ended interface, use A- (pin 5) and B- (pin 9). Those pins have a 2.2 kΩ pullup to +5V. The A+ and B+pins have 2.2 kΩ resistors to +5V and topins have 2.2 kΩ resistors to +5V and to ground, effectively 1.1 kΩ to 2.5 V, to keep them at that level when they are not used.

3) When using the differential interface, termination resistors can be optionally installed in the socket provided (R3 & R4 for encoder 1, R5 & R6 for encoder 2, R8 & R9 for encoder 3, R10 & R11 for encoder 4). Those termination resistors must be removed if a single ended, TTL encoder is to be used. For twisted pair cables, the typical termination resistor value is 100 Ω.

4) Differential interface is recommended for noisy environments, cables longer than 6 feet, and high speed applications. The PC4 option can be added to our S1, S2, E2, E3, H1, H3 and T2 encoders to convert them to differential outputs.



All information subject to change without notice.

Phone (360) 696-2468 • Sales (800) 736-0194 • Fax-Back (360) 696-3836 • Fax (360) 696-2469
Internet E-Mail: sales@usdigital.com • World Wide Web: http://www.usdigital.com
U.S. Digital Corporation • 3800 N.E. 68th Street, Suite A3 • Vancouver, WA 98661-1353

1

Overview

The PIO-32 Series boards are part of a family of digital input and output (I/O) boards for the IBM® PC/XT™ and PC AT® computers and compatibles. These boards provide a flexible interface for a variety of parallel I/O devices, including instruments, displays, and control systems.

The members of the PIO-32 Series are as follows:

- PIO-32I/O, which provides 16 digital inputs and 16 digital outputs
- PIO-32IN, which provides 32 digital inputs
- PIO-32OUT, which provides 32 digital outputs

The major features of all PIO-32 Series boards include the following:

- 300 V isolation, channel-to-channel and channel-to-computer
- Input level (if included) of 3.5 VDC to 28 VDC
- Output relay contacts (if included), Form A, 0.75 A at 200 VDC
- Connections through on-board ribbon headers
- High-density channel count
- Only one slot required for the board

2

Functional Description

This chapter describes the general layout of the PIO-32 Series boards and provides schematics of the typical input and output circuits.

The PIO-32 Series boards are channel-to-channel isolated and handle digital voltages in a broader range than standard TTL levels. Optional accessories for the board include screw terminal panels (STPs) and the C-3200 cables. The C-3200 cables are 30-inches long; they let you route the signals from 40-pin headers on the board through a slot in the rear panel bracket to 37-D male connectors. You connect the 37-D connectors to the optional STPs.

Figure 2-1 shows the general layout of PIO-32 Series boards. Note the ribbon headers, labeled J1 and/or J2, on your board; these ribbon headers provide 16 digital input or output channels each. The orientation of the headers differs among the boards, as shown in Figure 2-1.

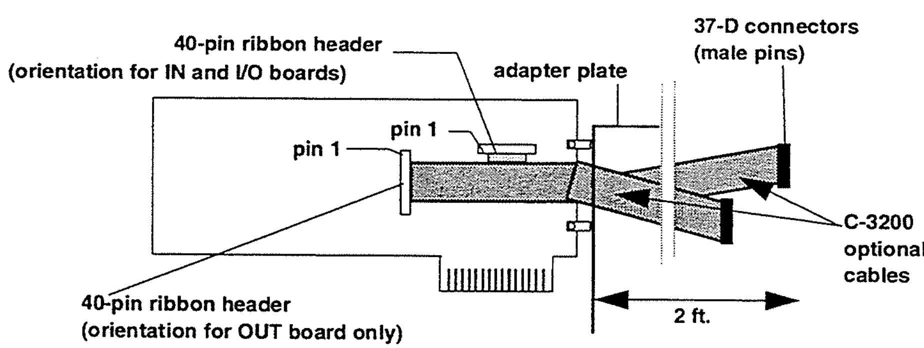


Figure 2-1. General Layout of PIO-32 Series Boards

Input Circuitry

The PIO-32I/O has 16 digital input channels and uses the J1 ribbon header (channels 0 to 15). The PIO-32IN has 32 digital input channels and uses the J1 and J2 ribbon headers (channels 0 to 31). Each input channel is rated to 500 V of optical isolation; however, ribbon cables such as the C-3200 limit isolation to 300 V. Figure 2-2 shows each input channel schematically. Voltages greater than 28 VDC require external resistors. In addition, you must limit the input current to 15 mA maximum. The positive input signals are labeled P*n*P (where *n* is the bit number, 0 to 31); the negative input signals are labeled P*n*N (where *n* is the bit number, 0 to 31).

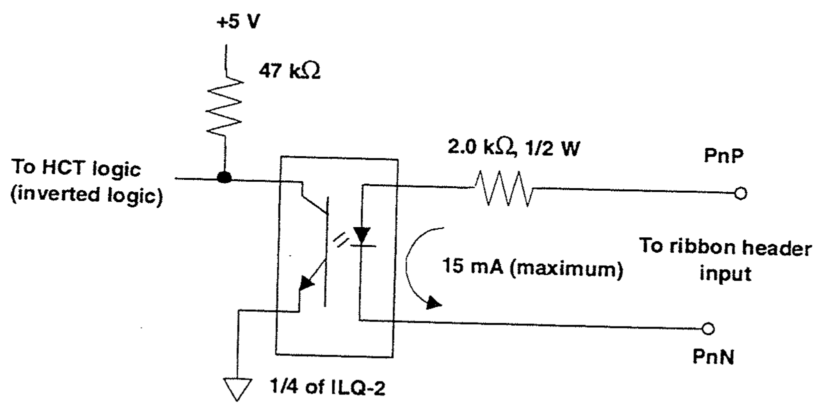


Figure 2-2. Typical Input Circuit

Output Circuitry

The PIO-32I/O has 16 digital output channels and uses the J2 ribbon header (channels 16 to 31). The PIO-32OUT has 32 digital output channels and uses the J1 and J2 ribbon headers (channels 0 to 31). Figure 2-3 shows the output channels schematically. The output channels are reed relays (form A) rated to 10 W at 0.75 A or 200 VDC (resistive) and rated to 500 VDC isolation, with the exception that ribbon cables such as the C-3200 limit isolation to 300 VDC. The relay connections are not polarized (positive or negative equivalent) and are labeled P*n*P and P*n*N (where *n* is the bit number, 0 to 15).

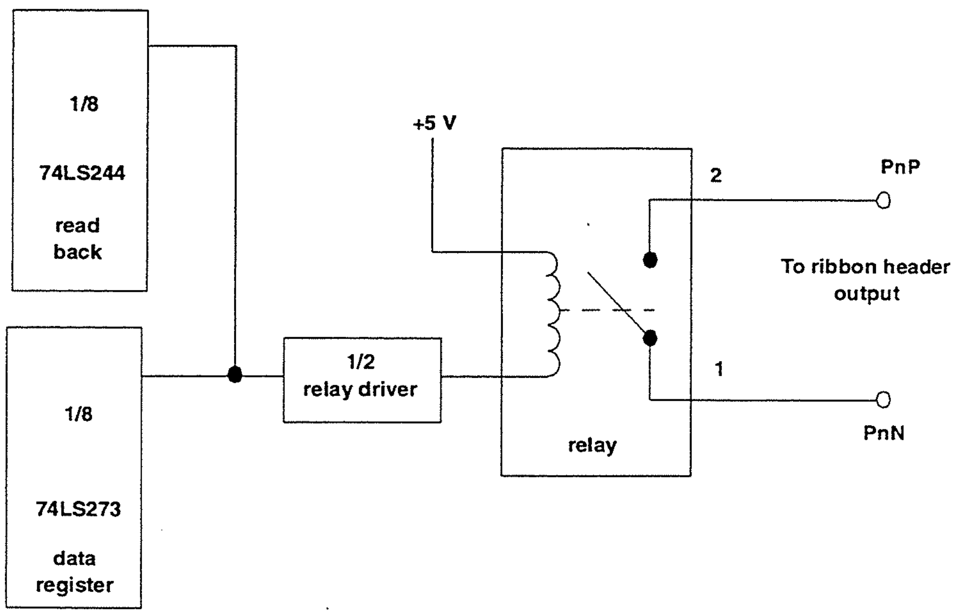
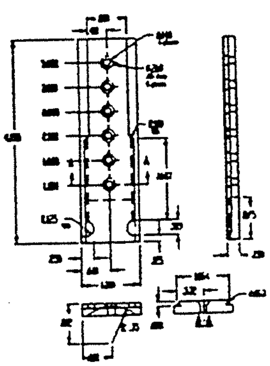


Figure 2-3. Typical Output Circuit

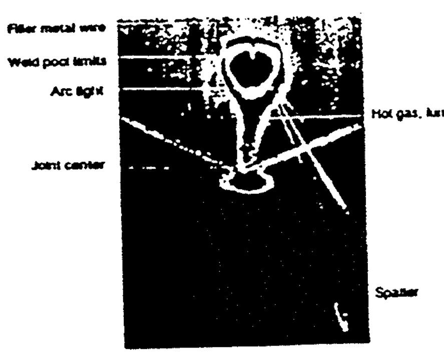
Resolution and Accuracy

The Laser Vision camera is calibrated to work in the above mentioned optimum area. All accuracy and resolution specifications are specified for this area.

	Horizontal		Vertical
Speed images/sec	60	30	
Resolution:	0.005" 0.125mm	0.0025" 0.064mm	0.006" 0.15mm
Accuracy position:	0.006" 0.15mm	0.003" 0.076mm	0.008" 0.2mm
Accuracy mismatch:			0.002" 0.05mm
Accuracy gap:	0.012" 0.3mm	0.006" 0.15mm	



Camera Bracket



MVS-30 Weld pool

Mounting

The LaserVision sensor is mounted on the torch using the camera bracket supplied. This **precision machined** part should be installed without any warping on a custom machined and **insulated** bracket mounted on the welding torch. Mounting should ensure flexibility of vertical or lateral adjustment. A 5° sensor tilt towards the torch tip is recommended. The distance to torch tip should be as short as possible, but at least 0.5" longer than the longest expected tack weld.

Applications

The **MVS-30** LaserVision sensor is a **medium resolution** sensor specifically designed for both **tracking and inspection robotic** applications. The elongated field of view helps in the initial part location, as well as the **weld pool** observation. It is best used for **V-grooved butt** joints, **large lap** joints and **fillet joints**. The maximum lap joint height is about 1" or 25mm. MVS-30 sensor is designed for **MIG**, **subarc**, **plasma** and **fluxcore** with welding currents up to 900A.

Specifications

Speed: 60 images per second - RS170
50 images per second - CCIR standard

Cooling: liquid 1/4 US gallon (1l) per minute (air cooling for subarc and currents up to 50 A)

Air: 0.11 CFM (3l per minute)

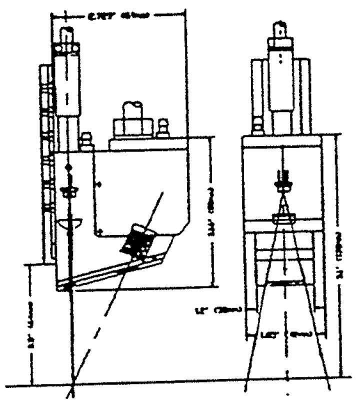
Weight: 9oz (250g)

MVS Modular Vision Systems Inc., 3195 De Miniac, Montreal, Canada, H4S-1S9, (514)-333-0140, FAX (514)-333-8636

LaserVision Sensor MVS-30 Specifications

General

LaserVision is a new generation of highly ***reliable*** laser range (profile) sensors with ***no moving parts***, specifically designed for welding and sealant dispensing applications. It is the first really ***affordable*** vision based sensor, providing ***high processing speed*** and reliable tracking with more than adequate information for statistical process control and improved parameter control. At the same time, LaserVision is ***simple to use*** and ***rugged*** enough to provide trouble free service in any welding or other hostile industrial environment. A unique patented[1] design allows for ***over 200 hours of maintenance free operation*** under extreme spatter conditions (900A fluxcore). The output from the sensor is a common TV signal, allowing the images to be recorded for the Quality Assurance on a standard VCR.

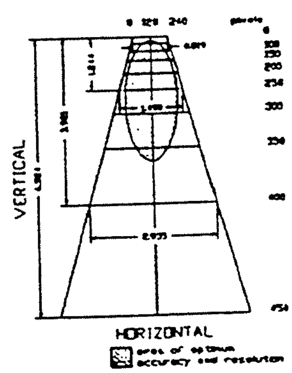


MVS-30 Outline and Optics

Principle of Operation

The LaserVision sensor uses a laser light projected in a plane approximately perpendicular to the observed joint. The cross section of the laser plane of light and the part produces a bright line. When this line is observed by a CCD camera at an angle (20° to 30°) it shows the surface features.

A dedicated vision processor board LPB-200 extracts the surface profile of 60 times per second - even under extreme arc light and spatter conditions. The relative distance of the surface points under the sensor is then calculated (by triangulation) and features of the profile, such as joint position and geometry, are extracted and measured.



MVS-30 Field of View

Field of View

The field of view is trapezoidal in shape (see drawing) due to the angle of observation of the laser plane. An important feature of this approach is that a straight line remains a straight line, but angles are not preserved. This geometry allows for all the tracking algorithms to be performed in the camera space. A simple set of equations, with eight coefficients obtained by the LaserVision camera calibration procedure, describes the camera space and all the range points can be easily calibrated. The shaded area is the optimum working area for the LaserVision camera where resolution is highest, focus for both the laser line and the camera is optimal and distortion of the optics is minimal.

[1] US patent #4,859,829, August 22, 1989. Canada, Western Europe and Japan applied for.

3 LASERVISION SENSOR AND PROCESSOR

3.1 Introduction

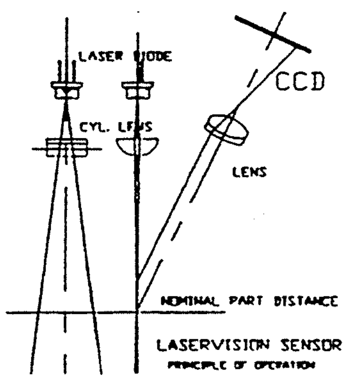


Figure 3.1.1 LaserVision Sensor Optics and Principle of Operation

The LaserVision sensor is a range type sensor. It uses a laser light projected in a plane approximately perpendicular to the observed joint. The cross section of the laser plane of light and the part produces a bright line. When this line is observed by a CCD camera at an angle (20° to 30°) it shows the surface features. A dedicated vision processor board LPB-200 extracts this ***profile*** of the surface 60 times per second even under extreme arc light and spatter conditions. A relative distance of the surface points under the sensor is then calculated (by triangulation) and features of the profile, as joint position and geometry, are calculated by an array processor SKY-320 and the AT-PC compatible computer. Each calculated joint position point is further verified, filtered and stored into the memory as a ***trajectory queue***. This point is then output at appropriate moment to the positioning subsystem when the torch arrives at the position where this particular joint position is measured (see the Motion Control section of this manual).

3.2 The LaserVision Sensor

Warning: Please read LASER SAFETY INFORMATION! A serious eye injury can result if the laser safety is not respected.

The LaserVision sensor consists of a CCD camera (a solid state TV camera) and a semiconductor laser. A pinhole, lens and filter combination serves as the objective for the CCD camera. A cylindrical lens is used to focus the laser beam into a plane of light. The beam is further restricted by the slot on the sliding protective plate. Small glass windows are used behind the slots and in front of the lens in order to further protect the lenses from spatter and metal fumes.

The entire camera is pressurized to prevent welding fumes from entering. Pressure is relieved through both the laser slot and the pinhole. In order not to disturb a gas shield around the torch the direction of the blown gas is away from the weld pool and the amount of the gas used is minimal (3.5 litres, or slightly less than one US gallon per minute). A clean pressurized air or inert gas should be used. If shop compressed air is used a reliable water, oil and dust filter should be installed in the air line. 1/8" barbed connectors are used for air and cooling water connection, suitable for 1/8" PVC tubing. The connector is rated for 150 psi of pressure when proper tubing is used.

Water cooling is mandatory for open arc currents of more than 50A. Air cooling can also be used for applications of less than 50A on open arc or a subarc system with currents up to 200-300A.

The interference filters are:

- 30nm bandwidth for TIG arc up to 100A and wire feeder in front; up 50A TIG without wire feeder in front and subarc applications.
- 10nm bandwidth for higher current TIG, plasma, MIG and flux core wire.
- 5nm bandwidth for some very bright arcs, usually plasma, with use of a fibre optic laser.

In case of 10nm filter bandwidth chilled (and heated in case of low operating temperatures) water is required to maintain a precise operating temperature for the laser (±3°C).

For more information consult the LaserVision sensor data sheets.

3.3 LaserVision Sensor Control and Processing

The camera video and synchronization signals are fed via the camera power supply to the LaserVision Processing Board LPB-200 (200-SYS-01). The camera power supply is factory adjusted. If required, please refer to the CCD camera and power supply information included.

The laser intensity is also controlled by the same processor board via signal IPUL (ILIN in earlier versions). A Laser Filter Board LFB-265 (265-SYS-02) provides optical isolation for the laser intensity control signal and a dedicated *floating* laser power supply connections. The laser control signal is a pulse with modulated signal with 60Hz base frequency. Maximum intensity and linearity of the control is adjusted by the potentiometer P1.

The laser power supply +5.25V and -12.0V is switched by the relay R1 by the interconnection board IB-240. The IB-240 board enables the laser only if:

- the EMERGENCY STOP is not pressed,
- there is no ALARM condition (watch-dog timer) and
- the LASER push button is engaged.

The signal received by the LPB-200 board as well as the processed profiles and tracking cursors can be observed on a profile monitor fed by the LPB-200.

For more information on the LaserVision Processing Board see the LaserVision Profile Processing Board - Technical Description

For the maintenance consult the LaserVision Camera Maintenance section.

4 LASERVISION PROFILE PROCESSING BOARD LPB-200

4.1 Introduction

MVS LaserVision Profile Board (LPB) is an image processing board specifically designed for extracting profiles of objects using a structured light and CCD camera. These profiles are generated by projecting a laser line on an object and observing it at an angle with a standard CCD video camera. Digital filtering techniques are used in order to ensure reliable operation in a high noise environment (i.e. arc welding) and suppress reflection artifacts.

LPB plugs into a single slot of an IBM-AT compatible computer.

4.2 LPB Main Features

The LPB can be used either alone as the only vision module in the system or with additional modules for increased performance, such as the DSP board with the Texas Instrument DSP processor TMS32010. A separate output port is provided for the transfer of profile data to the DSP board.

The principal features of the LPB module:

- Camera input, digitized at 8 bit per pixel.
- High resolution of 512 pixels per line standard.
- Highly stable digital phase locked loop synchronization of the internal pixel clock to the horizontal sync signal. A non cumulative jitter is less than +/- 12% of the pixel clock period, allowing for sub-pixel measurement accuracy. A reliable operation is achieved even with the standard VCR.
- Two groups of 2Kx8 (8Kx8 optional) bit input Look-up Tables, one group for processing and other for histogram.
- Monitor output with 8Kx8 (32kx8 optional) bit output Look-up Tables.
- Histogram circuit for 256 possible levels operating either on entire frame or area of interest window.
- Real time digital filter for the accurate feature extraction (profile)
- Profile extractor stores x, y coordinates and intensities of the most probable line points into 2Kx16 (8Kx16 optional) profile memory capable to contain 4 (16) profile vectors of 240 coordinates. This memory is accessible either to the AT host or a separate DSP processor board via a DSP output port.
- Eight selectable Area of Interest windows, easily movable around the picture area by specifying only the X-Y offset coordinates. Both histogram and profile extractor can be set to work only within this area of interest window.

- Flexible RAM based video clock and cursor generation allows for easy synchronization with wide range of standard and nonstandard video inputs.
- Capability to display "raw" profile or other intermediate results by simply loading pixel coordinate for each line into FIFO circuit.
- Laser intensity control output at 8 bit resolution.

4.3 Functional Overview

Main functions of the LaserVision Profile Board are shown on the Block Diagram (LPB.DWG).

The LaserVision camera is connected directly to the LPB via the provided cable. External synchronization is normally used, but there is a provision to use internal sync extraction from the video signal (VCR use) with some sacrifice in vertical positioning accuracy. Generation of internal synchronization signals is RAM based and allows for nonstandard video signals.

Initialization program supplied with the LPB loads necessary values for the RS-170 standard (North American B&W video) or CCIR standard (European) depending on type of camera. Same memory also serves for generation of two independent cursors.

The video signal coming from the camera is first conditioned then digitized to 8 bit accuracy. Two sets of look-up tables are provided, one for the digital filter and other for the histogram circuit. This allows entirely independent operation of the histogram circuit.

The digital filter is optimized for both noise suppression and laser line signal extraction. The laser line signals are enhanced and all other noise signals as ambient light are attenuated.

The digital filter circuit is followed by the profile extraction circuit. This circuit selects the peak of the laser line signal for each active video line and stores the result into Profile Memory during the horizontal blanking interval.

Results stored in the Profile Memory are accessible for further processing either by the host computer or via the DSP Output Port by the DSP board.

In order to further improve the noise immunity of the processing the LPB features the Area of Interest Window. Up to 8 different windows can be stored into window memory. Windows are selected through the control registers and they can easily be moved around the active video frame via X-Y offset registers. Both Histogram and Peak detector circuits can be set to operate only within the window and to ignore areas outside the window.

Typically the window shape is selected to closely match the expected joint profile. Once the joint profile is recognized and tracked, the window is set to closely follow the joint profile. Thus any noise outside the window of interest is automatically rejected. The described windowing technique also improves rejection of reflection artifacts.

The calculated profile or results of other intermediate calculations can be displayed on the monitor via the FIFO (first in first out) circuit. The FIFO has depth of 512 9 bit words, and it can be accessed via a single port. Total of 512 accesses fills the FIFO memory. When activated, the content of the FIFO memory is read synchronously with every active video line starting from the "zero" location. A single dot is output to the screen for every of 480 active lines at the pixel position equal to the address value stored into the corresponding FIFO location. The same output is automatically replayed every video frame without further program intervention.

The Output Look-Up Table circuit assigns gray levels to the digital filter results and the filtering operation can be observed in real time on the monitor. Windows, profile (FIFO) and cursors are displayed as bright overlay.

4.4 Specifications

Camera Input:	Video: 1Vpp Sync: TTL compatible, Standard RS170 or CCIR, other standards can be programmed.
Monitor Output:	RS170 or CCIR Composite sync.
Digitization:	Rate: 9.8304 Mhz standard Resolution: 8 bits. Jitter: less than +/- 12% of pixel width, Non cumulative.
Processor:	IBM-AT compatible, up to 8 Mhz, bus speed, requires 64K memory mapped space.
Output Port:	16 bit data, TTL compatible handshake control, up to 10 Mhz transfer rate, SKY320 compatible.
Measurements:	Width resolution: 240 points at 60 images per second, 480 points at 30 images per second, RS170 standard, or 256 points at 50 images per second, 512 points at 25 images per second, CCIR standard. Height resolution: 512 points. Nonlinear field of view due to triangulation technique used; however straight lines in actual space remain straight lines in transformed (camera) space. Calibration can be applied on final results only (i.e. after segmentation).

2.3 S-Series Motor Specifications (TENV) [5]

Model	S-2003	S-2005	S-3007	S-3016	S-4030	S-4050	S-4075	S-6100	S-6200	S-6300	S-8350	S-8500
Stall Torque (lb-in)	2.7	5.0	7.0	20	30	60	90	100	200	325	350	450
(Nm)	0.30	0.56	0.79	2.26	3.39	6.78	10.2	11.3	22.6	36.7	39.5	50.8
Speed [1] (rpm)	6000	6000	5000	5000	4000	4000	3000	3000	3000	3000	2000	2000
Kt [2] (lb-in/A)	1.17	1.17	2.5	2.5	4.4	4.4	6.7	6.0	5.8	6.2	7.6	8.2
(Nm/A)	0.13	0.13	0.28	0.28	0.50	0.50	0.76	0.68	0.66	0.70	0.86	0.92
Ke [3] (V/krpm)	16	16	34	34	60	60	90	82	80	85	104	112
R [4] (ohms)	7.3	2.6	6.6	1.3	2.0	0.8	0.9	0.49	0.18	0.12	0.13	0.10
L [4] (mH)	9.7	4.1	12.0	3.4	9.0	3.3	5.4	4.4	2.2	1.2	2.5	2.4
J ($lb\text{-}in\text{-}s^2$)	0.00007	0.00013	0.00027	0.00072	0.0022	0.0041	0.006	0.012	0.021	0.030	0.056	0.083
($kg\text{-}m^2$)	.000008	0.000015	0.00003	0.00008	0.00025	0.00046	0.00068	0.0013	0.0024	0.0034	0.0063	0.0094
BRU-500	—	—	DM-25	DM-25	DM-25	DM-50	DM-50	DM-50	DM-100	DM-150	DM-100	DM-150
BRU-200	DM-10	DM-10	DM-10	DM-20	DM-20	DM-30	DM-30	—	—	—	—	—

[1] maximum continuous operating speed

[2] peak amps of per phase sine wave

[3] peak volts of line to line sine wave

[4] phase to phase

[5] totally enclosed nonventilated

SECTION II - SPECIFICATIONS

2.1 Drive Module Specifications

BRU-500 Model	DM-25	DM-50	DM-100	DM-150	DM-150X
Continuous Amps[1]	20	40	50	65	85
Peak Amps[1]	25	50	100	150	150
Bus Voltage	125-375 VDC (325 VDC with 230 VAC input)				
Command Signal Input Range	± 10 VDC (13.3k Ohms impedance)				
Ambient Temp.	32° -122° F (0° -50° C)				
Weight	24.2 lbs (11.0 kg)				

BRU-200 Model	DM-10	DM-20	DM-30
Continuous Amps [1]	5	10	15
Peak Amps [1]	10	20	30
Input Volts	88-265 VAC RMS (Single Phase)		
Internal DC Bus Voltage	125-375 VDC (325 VDC with 230 VAC Input)		
Command Signal Input Range	± 10 VDC (13.3k Ohms impedance)		
Continuous Shunt Power [2]	50 W		
Peak Shunt Power [2]	4.5 kW		
Ambient Temp.	32° -122° F (0° -50° C)		
Weight	11 lbs (5 kg)		

[1] peak value of sine wave per phase

[2] DM-30 has provision for optional external shunt resistor that provides 200 W continuous and 6000 W peak shunt power. See drawing 9101-1104 in Section X for additional details.

Linear Positioner Series Introduction

General

Jasta-Dynact's Linear Positioner or "Rodless Cylinder" series are high quality units designed for applications where long stroke lengths, high velocities, and precise resolution and repeatability are necessary.

Stroke length

See the table below for all stroke lengths available per series. Final stroke length depends on screw velocity desired.

Gearing

Jasta-Dynact's standard gear ratios for the linear positioners are also listed in the table below. The letter "D" designates "direct drive" and The letter "T" represents a "timing" belt drive. All numbers following each specified letter represent the ratio available. Please refer to page 6 for more information.

Drive screws and Drive Chains

"Screw" drive linear positioners use 3 types of drive screws: Vee (V), Acme (A), and Ball (B). The number after the letter designates the screw pitch, as listed in the table below. Please refer to pages 4-5 for more information on drive screws. "High-velocity" or "Cable chain" drive linear positioners use drive chains for maximum velocity, (see page 47).

Motors

Jasta-Dynact offers a wide variety of motors. Any number preceding the letter "D" relates to the voltage of the motor, and the number preceding the letter "S" relates to the frame size of the step motor. The number following the letters "D", "BU", and "S" designates the size of the motor relative to the sizes within its category. Please refer to pages 13-16 for more information.

Model	*Stroke Length (*Approximate)	Gearing	Drive Screws	Motors
LP 050	0-20 Inches	D1	V40, V20, A4, A2, A1	17S1, 24D1 & BU50
LP 100	0-72 Inches	D1, T1, T2 & T2.67	V20, B8, B8.5, A10, A5, A2 & A1	24D4, 90D2, BU100, & 23S4
LP 150	0-72 Inches	D1, T1 & T2	V20, A10, A5, A2, B5 & B2	24D5, 90D3, BU200, & 34S1
LP 100 HV	0-20 Feet	D1 & T2	N/A	24D4, 90D2, BU100, & 23S4
LP 150 HV	0-20 Feet	D1 & T2	N/A	24D5, 90D3, BU200, & 34S1

Options

Various options adding to the operation of the linear positioners are (BR) Electromechanical Fail-Safe Brake, (MSR) Magnetic Switch Relay, (MS) Magnetic Reed Switch, (ES) Environmentally Sealed, (ZN) Anti-Backlash Nut, (LZ) Low-Backlash Ball Nut, (EN) Optical Encoder, (CN) Brake or Encoder Canister, (CND) Brake and Encoder Canister, and (GRS) Guide-Rail Supports. Please refer to pages 53-55 for more information.

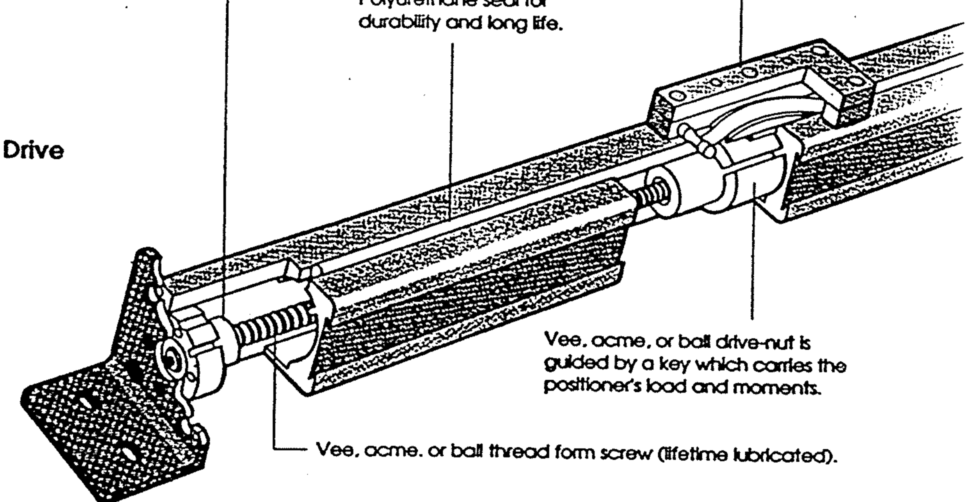
Mounting

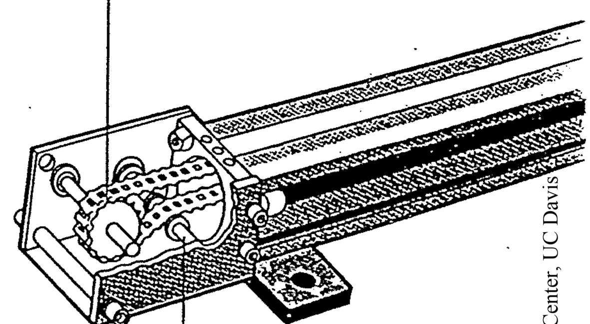
"Screw" drive linear positioners can also be manufactured where the motor is mounted parallel to the drive screw, as in the case of an actuator for instance. This alternative method of operation is available for the linear positioner "screw" drive series only, (refer to page 51). "High-velocity" linear positioners are mounted where the motor is perpendicular to the cylinder body.

Clamp-On Foot Mount (CFM) option: The "Clamp-on Foot Mount" (CFM) may be substituted for the standard linear positioner foot mounts. (See pages 38, 41 and 42).

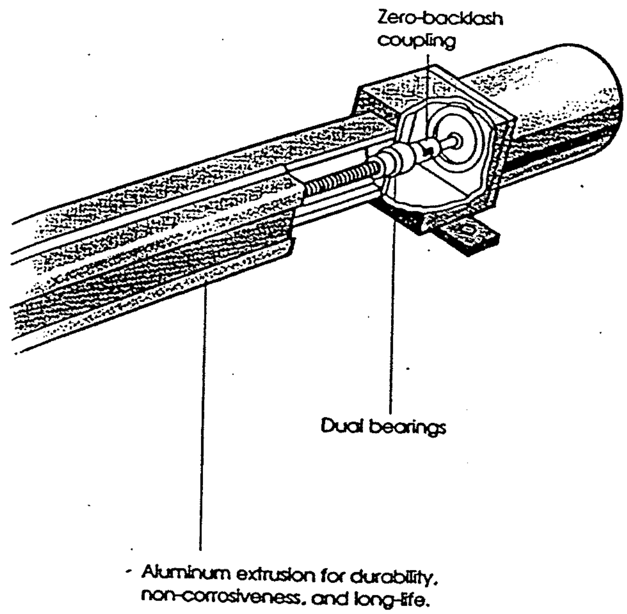
Linear Positioner Features

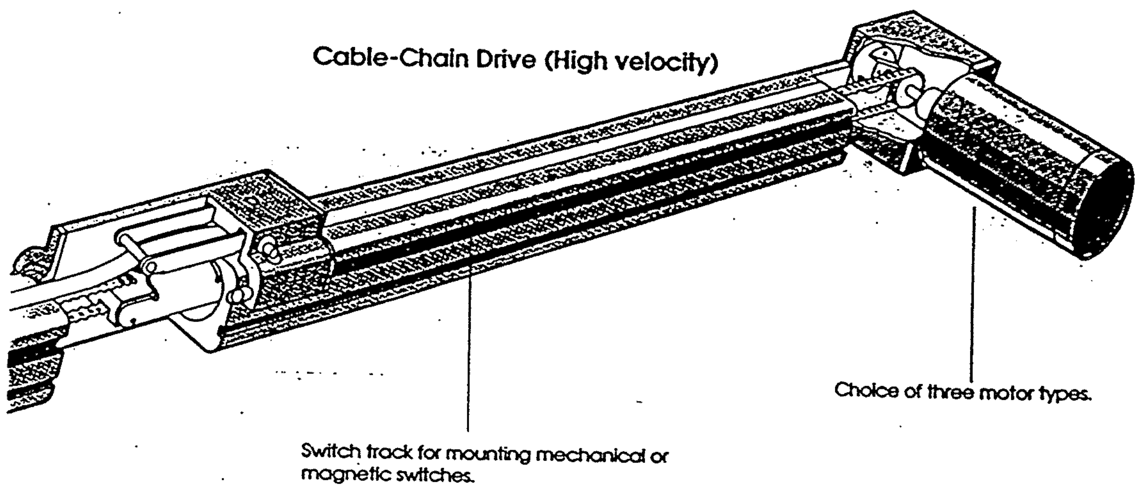
Screw Drive





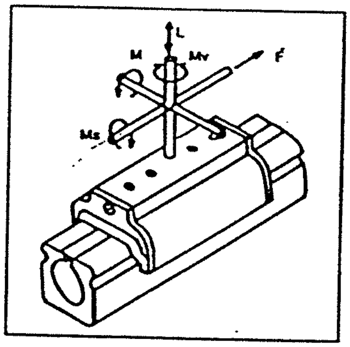
Linear Positioner Features





Linear Positioner Specifications

Screw Drive



Load, Thrust, and Bending Moments Diagram

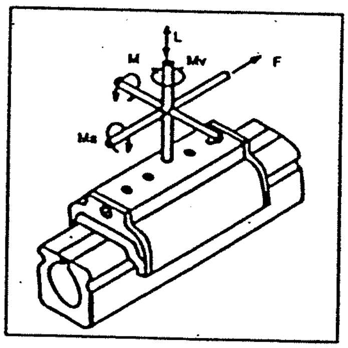
Load, Thrust, and Bending Moments Specifications

Model Number	Maximum Bending Moment			Maximum Load/lbs. (L)	Maximum Thrust/lbs. (F)
	Pitch (M) in./lbs.	Roll (Ms) in./lbs.	Yaw (Mv) in./lbs.		
LP 050	.10	5.5	.6	10	10
LP 100	100	55	30	60	200
LP 150	500	175	200	180	400

Weight Specification Table

Model Number	Base Weight w/Motor	Weight per Inch of Stroke
LP 050	1.3 lbs.	.04 lbs.
LP 100	6.2 lbs.	.23 lbs.
LP 150	19 lbs.	.50 lbs.

Belt Drive (High-Velocity)



Load, Thrust, and Bending Moments Diagram

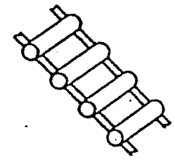
Load, Thrust, and Bending Moments Specifications

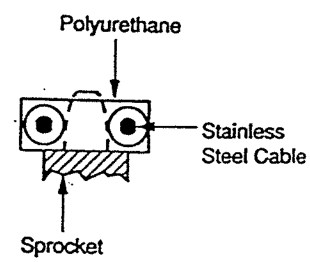
Model Number	Maximum Bending Moment			Maximum Load/lbs. (L)	Maximum Thrust/lbs. (F)
	Pitch (M) in./lbs.	Roll (Ms) in./lbs.	Yaw (Mv) in./lbs.		
LP 100 HV	100	55	30	60	50
LP 150 HV	500	175	200	180	60

Cable Chain Specification Table

Model Number	Drive Pulley Circumference	Maximum Thrust
LP 100 HV	2.50 inches	100 Lbs.
LP 150 HV	4.00 inches	100 Lbs.

Cable Chain





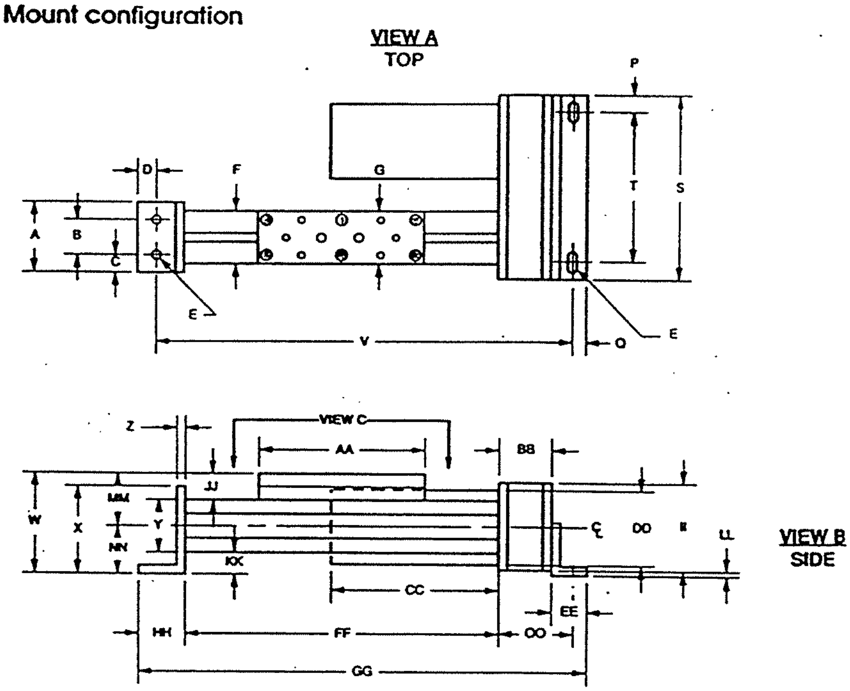
Weight Specification Table

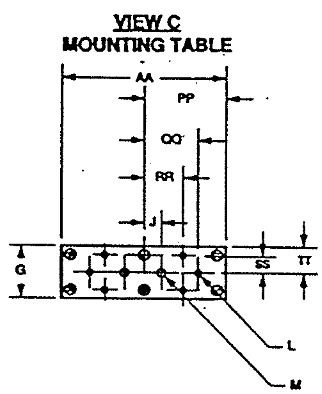
Model Number	Base Weight w/Motor	Weight per Inch of Stroke
LP 100 HV	6 lbs.	.18 lbs.
LP 150 HV	18 lbs.	.34 lbs.

daedal

Linear Positioner Dimensions (Screw Drive)

Parallel Mount configuration





LP100 DIMENSIONS

A	B	C	D	E	F	G	J
2.6"	1.5"	.30"	.300"	.25"W x .5"L	1.5"	1.5"	.300"
L	M	P	Q	S	T		V
10-32 UNF X .25" DP., 6 PLCS.	1/4-20 UNC X .25" DP., 2 PLCS.	.30"	.405"	5.25"	4.25"		6.82" + §
W	X	Y	Z	AA	BB	CC	DD
2.875"	2.5"	1.5"	.25	4.75"	1.5"	*	*
EE	FF	GG	HH	II	JJ	KK	LL
1.5"	5.67" + §	8.72" + §	1.36"	2.5"	.57"	.400"	.125"
MM	NN	OO	PP	QQ	RR	SS	TT
1.725"	1.150"	2.125"	2.375"	1.57"	1.125"	.300"	.750"

*For motor dimensions, refer to page 14 § = Stroke

LP150 DIMENSIONS

A	B	C	D	E	F	G	J
3.4	1.5"	.35"	1.25"	.40"W x .80"L	2.25"	2.25"	1.00"
L	M	P	Q	S	T		V
5/16-18 UNC x .375" DP., 2 PLCS	1/4-20 UNC X .25" DP., 6 PLCS	1.0"	.625"	6.50"	4.50"		12.525" + §
W	X	Y	Z	AA	BB	CC	DD
4.2"	3.65"	2.25"	.25	5.50"	2.00"	*	*
EE	FF	GG	HH	II	JJ	KK	LL
1.5"	8.80" + §	14.575" + §	2.25"	3.5"	1.10"	.8125"	.125"
MM	NN	OO	PP	QQ	RR	SS	TT
2.25"	1.95"	2.875"	2.75"	2.125"	1.50"	.75"	1.13"

ZY^{2}.

Drive Screws and Nuts

General Description

The screws used in Jasta actuators and positioners are "rolled" screws with a lead accuracy of ±.003 to ±.005 inch per foot of screw. "Ground" screws are available at a considerably higher price. The ground screw lead error is ± 0.0005 inch per foot of length, non-accumulative.

Lubrication

All Jasta actuators and linear positioners are factory lubricated with the proper screw lubricants for the life of the particular unit. For special applications; i.e., extremely high or low temperature or for vacuum operation, Jasta will lubricate accordingly.

Materials

Jasta Vee and Acme screws are cold-rolled 1018 steel or stainless steel if required. Most Jasta Ball screws are 1018 steel hardened to RC65.

Designation

The screw designation is used throughout this catalog. To interpret the designation, the letter (V, A, or B) designates the screw type, and the number following the letter designates the screw pitch, as described in the table below.

Pitch

This designates the number of threads per inch of screw (i.e., V20 is a Vee thread form with 20 threads per linear inch).

Lead

The screw lead is the linear distance the screw drive nut will move for each revolution of the screw (i.e., V20 = 1.00 inch/20 threads = 0.05 inch/revolution.

Efficiency (e)

The screw efficiency is determined by measuring the torque required to rotate the screw in order for the drive nut to lift a known load.

$$e = \text{Load (Lbs.)} \times \text{screw lead} \times 16\ \text{oz/lb.} \div 2\pi \times \text{Torque (oz/in.)}$$

Specifications

Jasta linear actuators and positioners utilize the drive screws listed in the Table below. Each actuator is given a catalog size reference . For example:

Size 1 = Mite, Mini-Pulse, PP I, and Mini-Jac
Size 2 = Act I, Act II, Jasta-Jac, PPII and PPIII
Size 3 = Brute

Type

Jasta actuators and positioners are available with three types of screws: Vee thread, Acme thread, and Ball thread. Vee thread screws offer very fine leads and are quite useful for applications not requiring high velocities, high loads or high duty cycles. Acme screws are very useful in applications where noise is a consideration because they are generally quieter running. The acme also offers a wide variety of screw diameters and leads, can be self-locking and is less expensive when compared to ball screws. Ball screws have many advantages over acme and vee thread screws such as: higher efficiencies, higher speeds, higher loads, higher duty cycles, less friction and longer life.

*Efficiencies in the table below are based on Delrin AF drive nuts on the Vee and Acme screws, and ball nuts on the ball screws.

For Bronze nuts reduce the efficiency of Delrin AF nuts in the Table by 5%..

Drive Screw Data

Designation	V40	V20	A10	A5	A2	A1	B8.5	B8	B5	B2
Thread Form	Vee	Vee	Acme	Acme	Acme	Acme	Ball	Ball	Ball	Ball
Pitch	40	20	10	5	2	1	8.5	8	5	2
Lead	.025"	.05"	.10	.2"	.5"	1.00"	.118"	.125"	.20"	.50"
Efficiency	.18	.25	.30	.40	.60	.65	.90	.90	.90	.90
Backdrive*	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Max. Duty	40%	50%	60%	60%	70%	80%	100%	100%	100%	100%
Actuator Size 1 Diameters	.375"	.375"	.375"	.375"	.375"	.375"	.397"	.375"	N/A	N/A
Actuator Size 2 Diameters	N/A	.50"	.50"	.50"	.50"	.50"	N/A	N/A	.625"	.50"
Actuator Size 3 Diameters	N/A	.75"	.75"	N/A	N/A	N/A	N/A	N/A	.75"	.75"

*The higher the lead of the screw the less effort required to backdrive either the screw or the nut. As a rule, the lead of the screw should be more than 1/3 the diameter of the screw to satisfactorily backdrive.

N/A = Non-Applicable

Drive Screws and Nuts

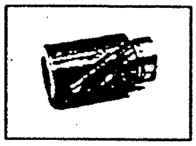
Screw Linear Velocity

All screw types are limited as to the speed to which a screw may be rotated. At a particular speed for a particular screw, the "critical velocity" of the screw will be reached, causing the screw to whip and vibrate, thereby becoming unstable and unusable. This critical velocity is a result of screw rotational speed, screw diameter, and screw length (refer to page 11).

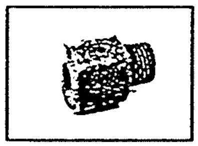
Screw Life

The operating life of Jasta linear actuators and positioners is dependent on numerous factors: stroke velocity, thrust, load, moment, environment, screw type, motor type and duty. Upon selecting an actuator or positioner for a continuous duty operation, choose a ball screw and nut along with a motor rated for continuous duty (100%). Acme screws (with leads below .5") and nuts are relatively high-friction with efficiencies of less than 60%, and generate heat at high linear velocities and high duty cycles. Ball screw/nut combinations have efficiencies of 90% and are designed for higher loads and speeds. Once an actuator is properly selected, the life can range to a high-end of 50 million cycles for a ball screw model under normal conditions.

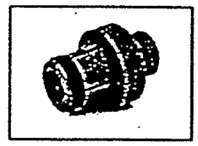
Drive Nuts



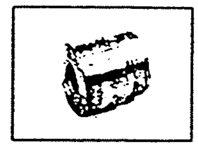
Ball Nut



Delrin AF Nut



Anti-Backlash Acme Nut



Bronze Nut

Ball Nut

Jasta "Ball" nuts utilize high quality steel ball nuts with recirculating steel balls for long life and heavy loads. Normal backlash is approximately .002" to .004".

Delrin AF Nut

The "Delrin AF" drive nut is a combination delrin and teflon plastic drive nut, utilized in all Jasta acme and vee threads for actuator loads under 500 lbs. Some advantages of this nut are its quiet running and low friction operation.

Anti-Backlash Acme Nut

The Delrin AF "ZN" nut (Anti-backlash Acme Nut) is available with a zero backlash design. This is accomplished by preloading the nut by spring compression.

Bronze Nut

A Bronze drive nut is used on acme screws in applications where thrust requirements exceed 500 lbs. It's main advantage is its heavy load capability.

Gearing

Jasta actuators are driven by three types of gear reduction:

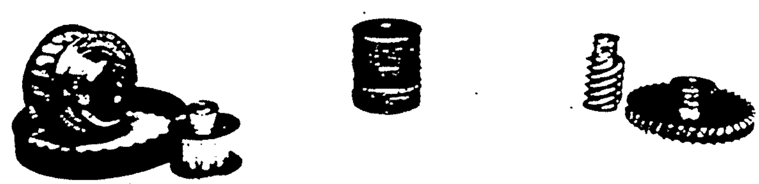
1. Synchronous (timing) belts and pulleys
2. Worm gear drives
3. Inline drive (no gear reduction)

Designation

All gearing has a specific designation thru-out this catalog. "T" represents a "timing belt drive". "W" represents a "worm gear" or "right angle" drive, and "D" represents a "direct drive."

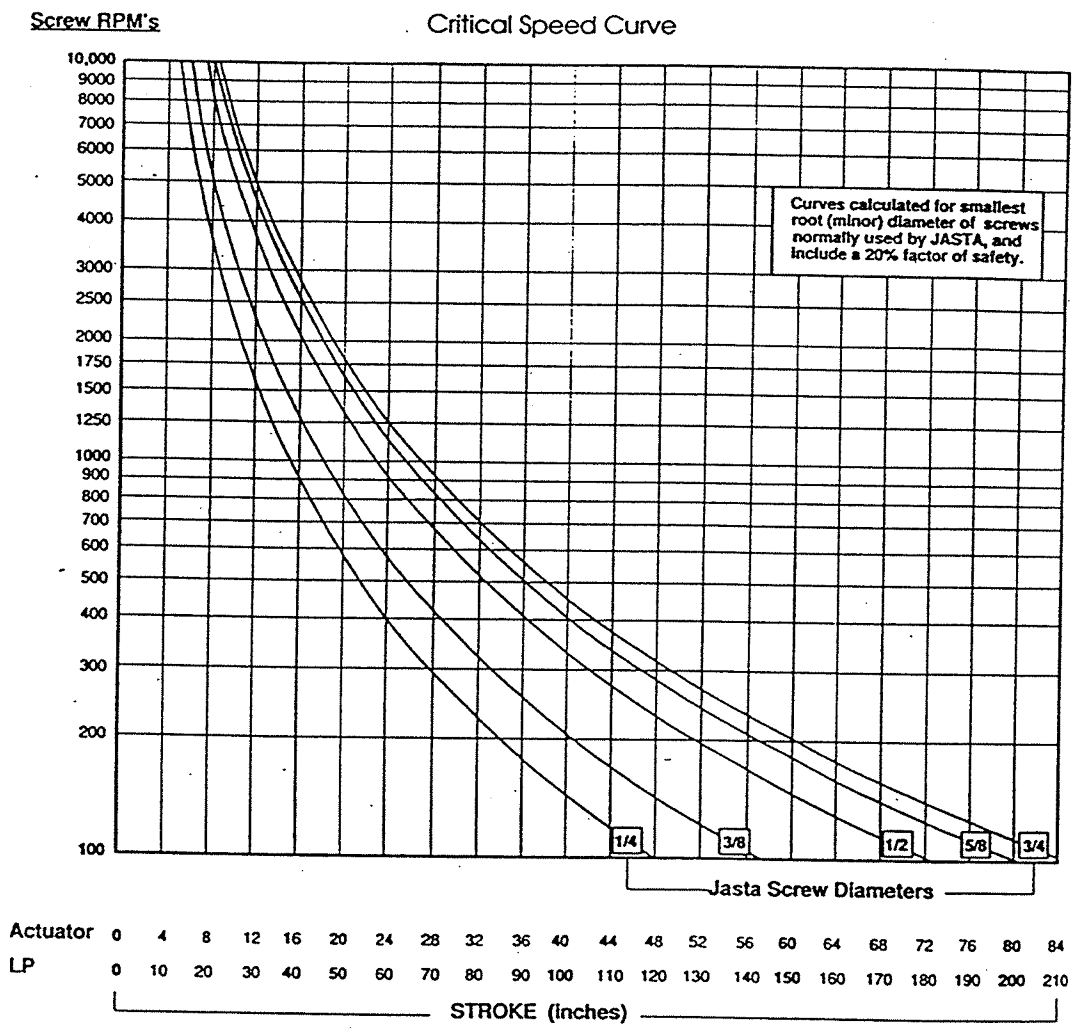
Ratios

Ratios are described by the number following the letter representing the type of gearing.
For instance: T2 = Timing belt (2:1 ratio) D1 = Direct drive (1:1 ratio) W10 = Worm gear (10:1 ratio)



Synchronous Belts and Pulleys:	Worm Gear (Right angle) Drives:	Inline Drive (Direct Coupled):
The majority of Jasta actuators use a no-slip, very low backlash, synchronous belt drive known as timing belts. Timing belts and pulleys have the following advantages over spur and worm gears: A) Long life B) Low backlash C) No lubication required D) Quiet running E) Unaffected by minor mis-alignments F) High efficiency ~ 90% +	Jasta utilizes worm gear drives in the Jasta Jac and Mini Jac series of actuators. The advantage of the worm gear is a high ratio in a small space and high loading capability; however, the gear efficiency is low ~50%. Jasta worm gear ratios available: • 10:1 • 20:1 • 40:1 *The 40:1 ratio with a ball screw will not backdrive under load.	Jasta Pulse Power series use a direct drive with no gear reduction. The motor shaft is coupled directly to the drive screw with a high quality zero-backlash coupling. The advantages with direct inline coupling are: A) Zero-backlash B) Long life C) No gear noise D) Highest efficiency

Selecting an Actuator



Selecting an Actuator

Step 9: Using the motor curve selected from STEP 8, verify that the required torque and speed fall into the correct duty cycle area, as indicated within the curve area by being either shaded or nonshaded; i.e., 100%, 60%, 30%, or 10%.

Step 10: Use the table in FIGURE 7 to determine the resolution and repeatability of the actuator selected.

Screw	Screw Lead (in.)	Repeatability ± in.			Resolution (in.)
		*24VDC Motor	*90VDC Motor	Step Motor	200 steps per screw rotation
V40	.025	.003	.005	.0005	125×10^{-6}
V20	.05	.003	.005	.0005	25×10^{-5}
A10	.10	.003	.006	.0005	5×10^{-4}
B8-B8.5	.125/.118	.003	.006	.0005	6.25×10^{-4}
A5-B5	.20	.004	.006	.0005	1×10^{-3}
A2-B2	.50	.008	.010	.0005	2.5×10^{-3}
A1-B1	1.00	.010	.015	.0005	5×10^{-3}

*Repeatability figures are based on positioning by limit switches.

Figure 7

Step 11: Consider the environmental requirements that may be involved in the particular application; i.e., dust, water, wash downs, extremely high or low temperature, corrosives, etc.
Jasta actuators can handle many extreme conditions. Check with the factory for special requirements.

Step 12:
Ensure the load is acting down the centerline of the translating tube as shown in FIGURE 8. Only the linear positioners can take bending moments. External linear guides should be incorporated to eliminate bending moments on all other Jasta actuators.

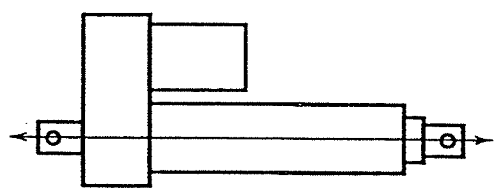


Figure 8

Step 13: Mounting requirements can be determined by referring to the "Mounting Components" section on pages 37-43.

Step 14: Refer to pages 54-56 for options that may be added to enhance actuator performance.

Motor Data

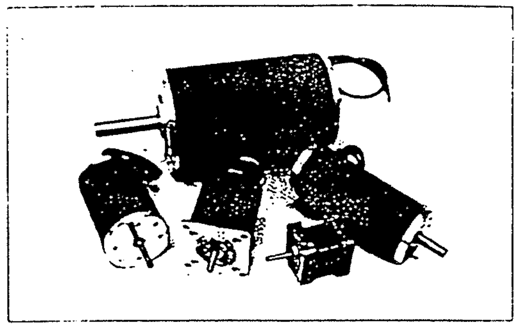
The motors utilized by Jasta on linear actuators and positioners fall into one of four categories:

1. Permanent magnet, brush type direct current motors, which are available in 12, 24, and 90 VDC.

2. Permanent magnet, brush type servo motors: which are available in 24 and 90 VDC.

3. Permanent magnet, direct current two and four phase step motors, with 200 or 400 steps per revolution.

4. Brushless servo motors with complete control systems, which are available in 115 VAC or 230 VAC input to amplifier.



*Jasta will also install the motor of your choice if it meets Jasta's installation requirements.

Motor Type	Advantages	Disadvantages
Permanent Magnet DC Brush	•Economical •Fast acceleration •High speed •High Torque in a small frame •Maximum Torque at stall •No starting capacitors required •Speed controllable	•Brush wear •Electromagnetic Interference
Permanent Magnet DC Servo	•All of the above •Better precision •Better brushes	•Same as above
Step Motor	•Long life •No brushes •Moderate cost •High Torque •Continuous duty •Precision	•Low to moderate speed •Electromagnetic Interference •Hot running
Brushless Servo	•No brushes •High Speed •High Torque in a small frame •Fast acceleration/deceleration •Incremental or Absolute encoder •Speed and/or positioning control •Continuous duty •Long life	•Most expensive

Motor Specifications

DC Motors Motor Number	Voltage (DC)	Stall Torque (in.-oz)	Cont. Torque (in.-oz)	Stall Current (Amp)	KT (in.-oz /Amp)	KE (Volts/ Krpm)	Resist-ance (Ohm)	Induct -ance (Mh)	No Load Speed (rpm)
12D4	12	204	32	43.7	4.33	3.21	.27	.4	3700
24D1	24	24	4	3.3	4.0	3.2	4.1	3.3	7300
24D2	24	42	7	8	5.3	3.7	3.1	5.1	5100
24D3	24	107	16	13.9	7.8	5.77	1.73	2.54	4087
24D4	24	275	40	33.3	8.4	6.2	.72	4.0	4300
24D5	24	1000	90	136	7.35	5.56	.5	5.0	3500
90D1	90	90	5	2.0	46.0	34.0	45.0	4.0	2500
90D2	90	200	40	4.5	44.0	33.3	18.5	18.0	2700
90D3	90	650	81	13	59.1	45.0	6.8	12.0	2000
90D4	90	3800	416	50	61.0	45.1	1.4	6.5	2000

Step Motors Motor Number	Voltage (DC)	Stall Torque (in.-oz)	Cont. Torque (in.-oz)	Max. Allow. Amp/Ph.	Min. Req'd Volts/Ph.	KE (Volts /Krp)	Resist-ance (Ohm)	Induct-ance (MHz)	No Load Speed (rpm)
17S1	12-60	44.4	•	1.2	4.0	NA	3.3	3	•
23S1	12-60	53	•	1	5.0	NA	5.1	10	•
23S1-02*	160	60	•	1.0	5.0	NA	5.0	8	•
23S2	12-60	53	•	3.8	1.2	NA	.33	.6	•
23S3	12-60	100	•	4.7	1.6	NA	.35	.8	•
23S3-06*	160	150	•	2.9	3.4	NA	1.2	2.9	•
23S4	12-60	150	•	4.6	2.2	NA	.4	1.1	•
34S1	12-60	450	•	4.8	3.3	NA	.65	4.2	•
34S3-11*	160	450	•	5.5	2.9	NA	.52	2.2	•
42S2-12*	160	1100	•	6.1	3.6	NA	.6	3.6	•

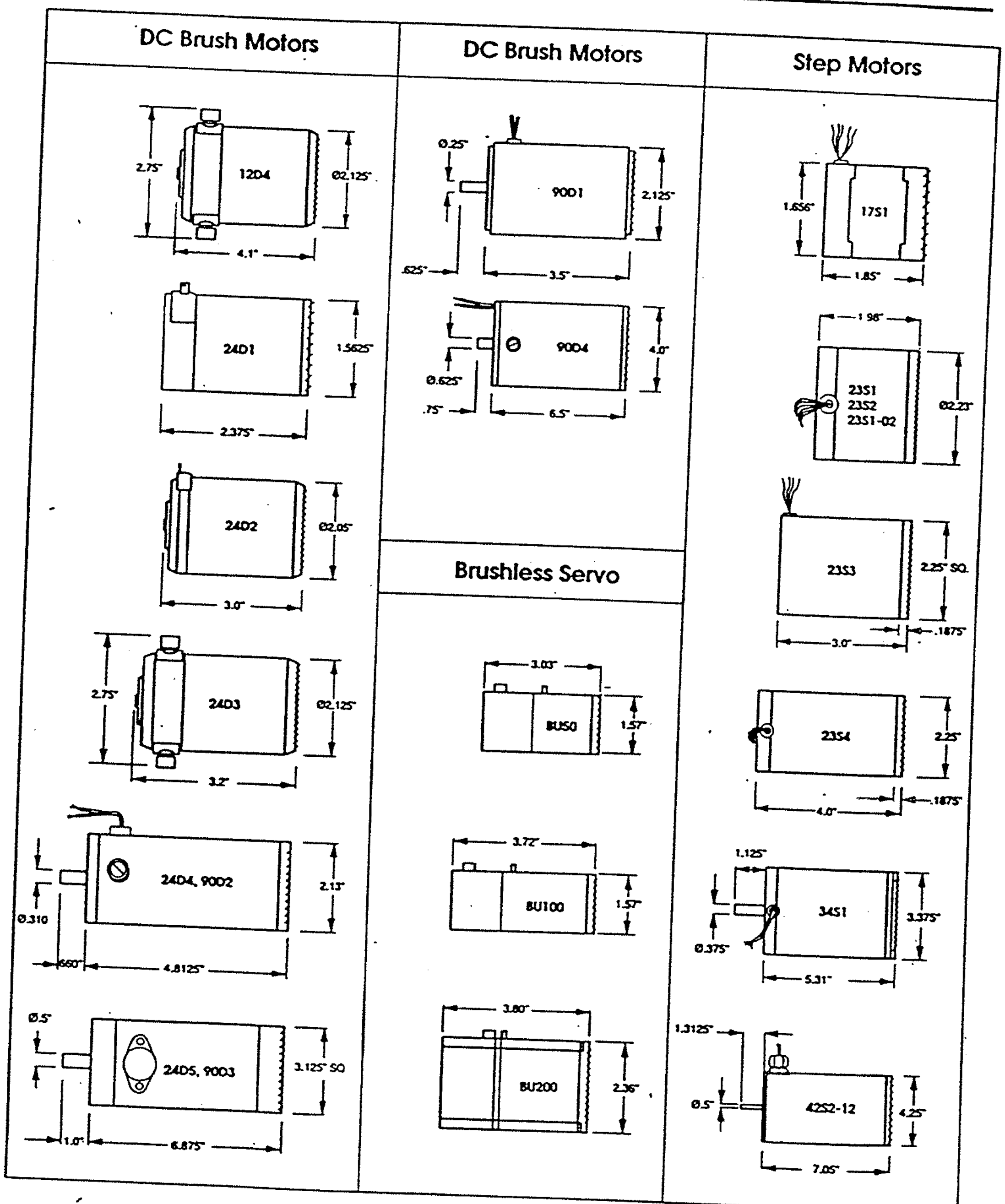
Note: Step Motor performance for speed and torque is based on the type of control used. See motor curves on pages 13-14. *These motors come equipped with a six foot length of cable and are encoder ready.

Brushless Servo Motors Motor Number	Voltage (AC)	Peak Torque (in./oz.)	Cont. Torque (in.-oz)	Peak Current (Amps)	No Load Speed (RPM)
BU50	110/220	68	23	2.9	4500
BU100	110/220	135	45	7.1	4500
BU200	110/220	270	90	8.4	4500

Note:

Brushless Servo Motor Specifications are based in conjunction with the use of the JBU100 Control as found on pages 63-64.

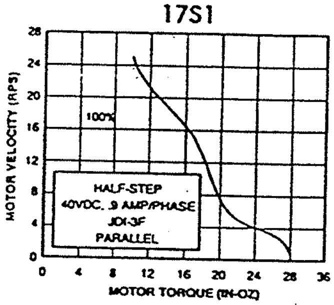
Motor Dimensions



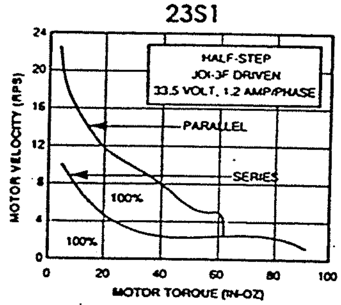
Note: represents the side of motor mounted to actuator.

DC Step Motor Torque vs. Speed Curves

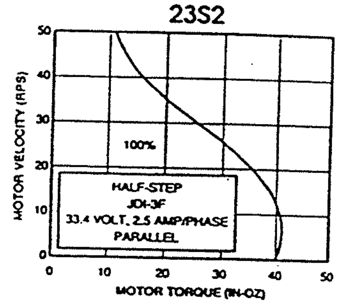
17S1



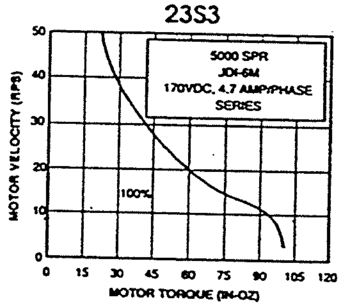
23S1



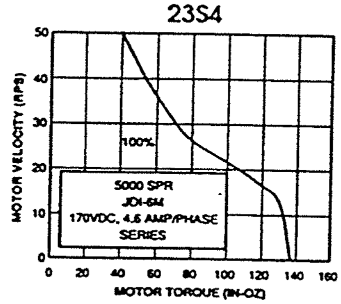
23S2



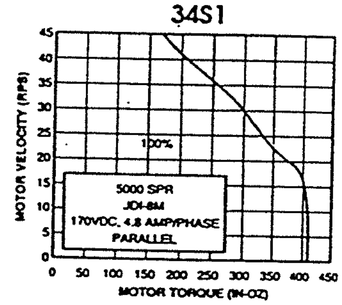
23S3



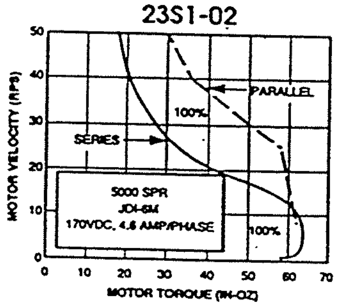
23S4



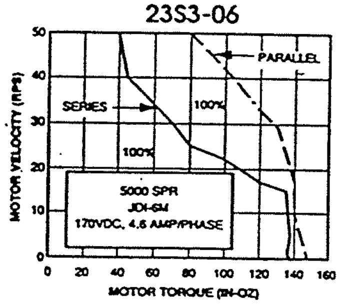
34S1



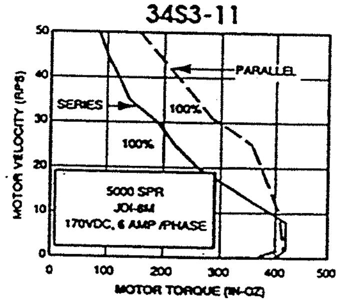
23S1-02



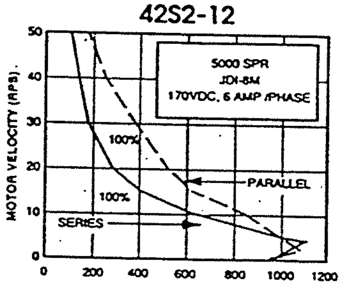
23S3-06



34S3-11



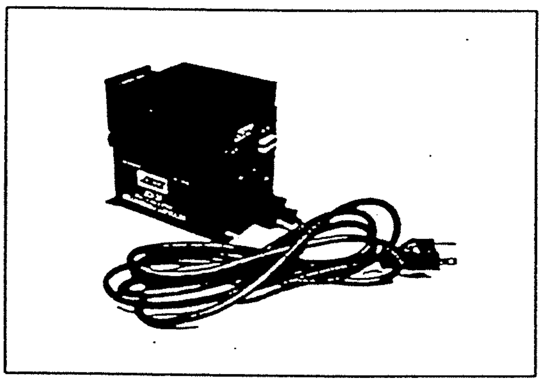
42S2-12

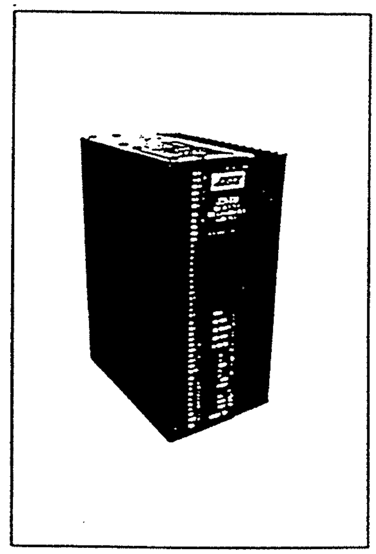


Note: Percentages under curve represent motor duty cycle (assuming proper drive and cooling systems are used).

"JDI" Series Step Motor Controls

- Includes a powerful built-in indexer, driver, and power supply
- Optically coupled step and direction inputs for reliable operation
- Easy to learn English-like instructions
- Built-in editor allows creation of up to 88 different motion programs
- RS-232 communications allows daisy chaining of multiple devices
- Home, extend & retract limits, and multiple programmable inputs and outputs
- Encoder feedback capabilities (JDI-6M & 8M only)
- Short circuit and over temperature protected





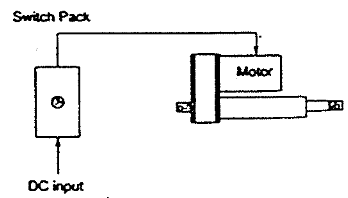
General
The "JDI" series step motor controls are fully compatible with all Jasta-Dynact actuator series, utilizing the step motor as the driving motor. These units are of the highest quality and finest workmanship and are designed to deliver optimum performance to all Jasta-Dynact actuators.

"JDI" Series Specifications

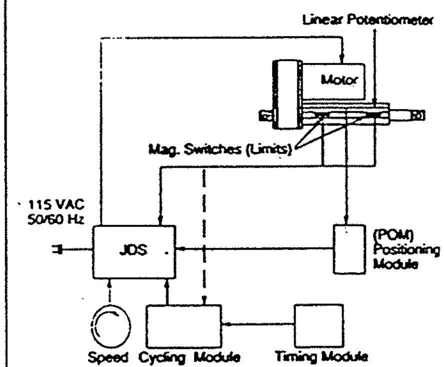
Common Specifications	JDI-3F	JDI-6M & JDI-8M
Drive Type	2 phase, bipolar, constant current, MOSFET chopper, 20 KHz fixed	
Resolutions	200, 400.	200, 400, 1000, 2000, 5000, 10000, 18000, 20000, 21600, 25000, 25400, 25600, 36000, 50000, 50800
Power (Inputs)	115-230V, 50/60Hz, 50VA.	90-135VAC, 50/60Hz, +5VDC logic
Power (Outputs)	0.2-2.8 amp/phase programmable.	JDI-6M=0.2 to 6 amps JDI-8M=2 to 8 amps.
Protection (Short circuit)	Phase to phase, phase to ground	
Protection (Over Temperature)	Internal air temperature exceeds 140° F (60° C)	
Automatic Current Limit	50% of running current when motor is stationary	
Fault Output	Sinking output to OUTCOM, 5-24VDC, 60mA maximum. Disable LED on	
Low Power Mode (Auto reduce)	Programmable "Hold" current 1% resolution.	DIP switch enabled. Current drops to 50% of selected value if no step pulses are received in one second
Environmental (Temperature)	Drive max. 130° F (55° C), storage -50° F to 185° F (-45° to 85° C).	Drive heatsink max. 140° F (60° C); Motor case max. 212° F (100° C); Storage -40° F to 185° F (-40° C to 85° C)
Environmental (Humidity)	0-95% non-condensing	
Additional Specifications		
Operational		
Acceleration	Programmable ramps.	Opimal non-linear mathematical function or programmable
Step Accuracy	±0 steps	
Position Range	±17 million steps.	±2.1 billion steps
Speed Range	0 to 23,000 pulses/second.	0 to 750,000 pulses/sec. ±1% max. speed
Communications		
Type	RS-232 serial or RS-422.	RS-232C serial, 3 wire implementation (Tx, Rx, Ground)
Baud Rates	300, 1200, 2400, 4800, 9600, 19200.	1200, 2400, 4800, 9600, 19200
Mode	Full duplex	
Format	8 data bits; 1 stop bit, no parity; ASCII characters	
Multi-Axis	Daisy chain 32 indexers on RS-422.	Daisy chain up to 36 indexers from a single host RS-232C port
Inputs		
Type	Optically isolated, 5VDC.	Optically isolated. TTL or 5-15VDC
Limits	CW, CCW, HOME	
Programmable	Five.	Thirteen
Interrupts	One.	Inputs 12 & 13. Software selectable
Jog, Hold, Stop	Three.	Software assignable to programmable inputs
Active State	High on Power Up I/O ports TTL logic low.	High or low. Software selectable
Outputs		
Type	Open collector with pull-up resistors.	Optically isolated. Open collector 5-15VDC, 25 milliamp maximum
Fault	N/A.	Overtemp, under-voltage or under-current.
Programmable	Two. TTL logic low level-On.	Eight. Active high or low. Software selectable
Encoder		
Channels	None.	Complimentary A & B channel in quadrature with index channel. Maximum input frequency rate of 256 kHz on A & B channel (prequadrature)
Dimensions	4" W x 4" H x 4-1/4" L	JDI-6M = 3" W x 9-1/2" H x 6-7/8" L JDI-8M* = 4-9/16" W x 9-1/2" H x 6-7/8" L *Heatsink added

Control Block Diagrams & Accessories

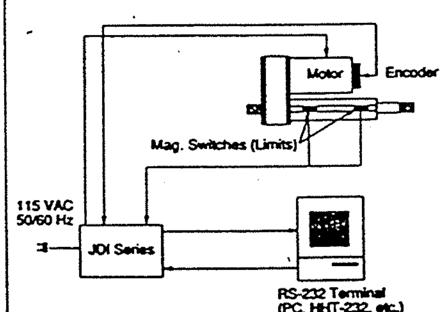
SP01 Switch Pack



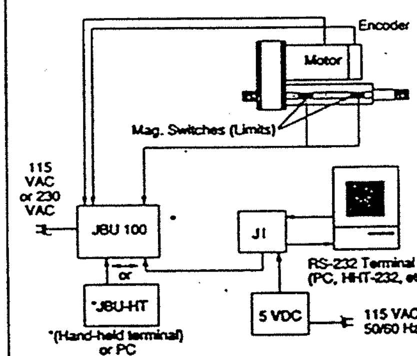
JDS Series

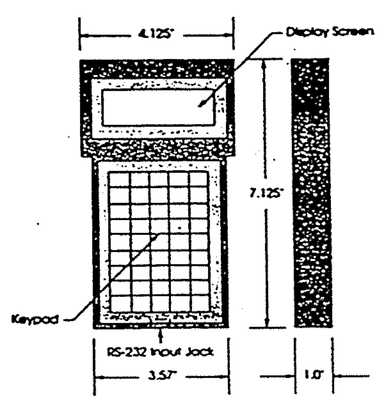


JDI Series

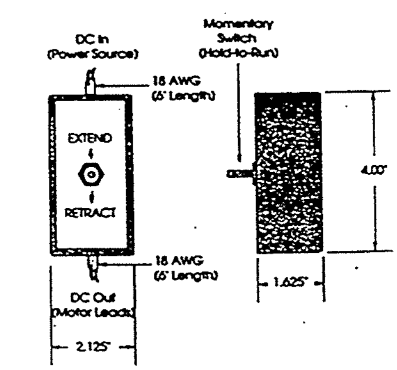


JBU Series





HHT-232 (Hand-held programmable terminal)



SP01 & *SP01R Switch Pack

*For driving 90 VDC motors from a 115 VAC input.

Actuator and Linear Positioner Series Options

General

Jasta offers the following as options for the actuators and positioners. These items enhance overall performance, protect operating components, and increase longevity.

Overload Protection

Jasta actuators and positioners should not be continually operated against the end stops, thereby putting the motor in "stall". Overload protection devices such as mechanical limit switches, magnetic reed switches, and linear potentiometers are some of the options which should be incorporated into the actuator or positioner to prevent overload.

Description:

BR - Electromechanical Brake: Required on all units with a ball screw nut combination or an acme lead of .5 inch or over in applications where load is acting opposite to drive force, tending to "back-drive" the system when stopped.

ES - Environmentally Sealed: A special sealing on the actuator or positioner to guard against very tough environmental conditions; i.e., snow, heavy rain, washdowns, sandstorm, etc.

MSR - Magnetic Switch Relay: The MSR is an add on package which converts the magnetic reed switch signal into a stand alone limit switch package. It can be wired directly in line with the motor and is capable of switching up to 15 amps - enough to handle full motor current on most of Jasta's actuators.

MS - Magnetic Reed Switches: Reed switches can be adjusted at any position along the actuator or positioner's switch track. A magnet within the drive nut of the actuator "trips" the switch as it passes. A magnet on the LP carriage "trips" the switch as it passes. Rated: 0.15 amp maximum at 100 VDC. Rated life: 5 million cycles. Refer to page 55 for more information regarding dimensions.

ZN - Antibacklash Acme Nut: Removes backlash from the plastic drive nut and is used in precise positioning applications where lost motion cannot be tolerated. Please refer to page 5 for more info.

LZ - Low Backlash Ballnut: The ballnut is individually fitted to the screw, giving maximum backlash of 0.002" or less.

GSR - Guide Rail Supports: Used only for the Linear Positioner series LP100 and LP150. These support rails serve in accomodating higher loads (See page 48).

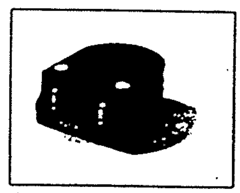
EN - Optical Encoder: An encoder is fitted to the actuator or positioner for servo or step motor closed-loop systems. Refer to page 55 for more information regarding dimensions.

***LPO - Linear Potentiometer:** Position of the actuator stroke can be determined by resistance output proportional to the actuator stroke position. The LPO is linear to ± 1% of total stroke. LPO output is 1500 ohms per inch of stroke length. Stroke availibility of 2,3,6,9,and 12.

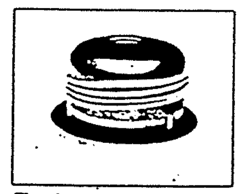
*LPO is not available with Jasta's "Linear Positioners".

CN - Encoder or Brake Canister: A protective canister which houses an encoder or brake option and conveniently includes quick connect/disconnect terminals for all wiring associated with the encoder or brake option. Refer to page 55 for more information regarding dimensions.

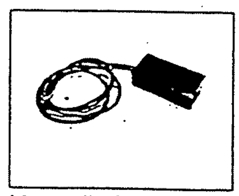
CND - Encoder and Brake Canister: Same function as the "CN" option but designed to house both the encoder and brake options. Refer to page 55 for more information regarding dimensions.



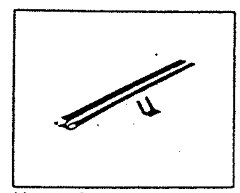
Optical Encoder



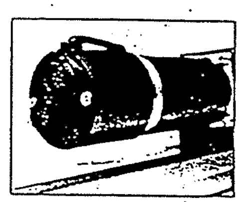
Electromechanical Brake



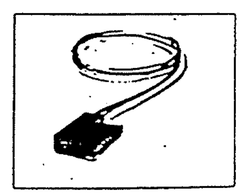
Magnetic Switch Relay



Linear Potentiometer



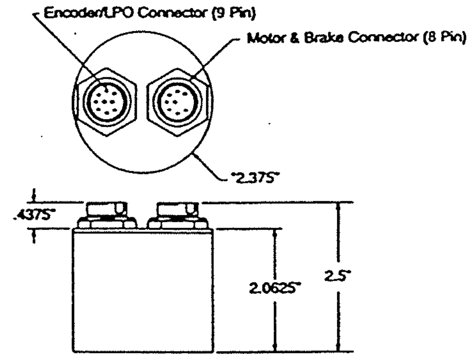
Brake or Encoder Canister



Magnetic Reed Switch

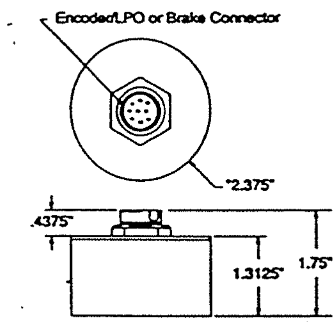
Actuator and Linear Positioner Option Dimensions

Motor, Brake and Encoder Canister Dimensions (CND)



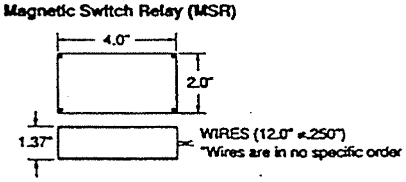
*This dimension changes to 3.00" for a size 2

Motor, Brake or Encoder Canister Dimensions (CN)

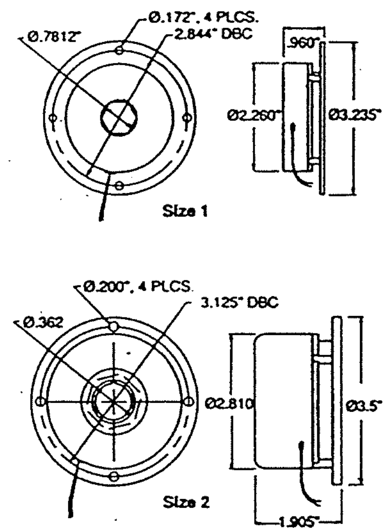


*This dimension changes to 3.00" for a size 2

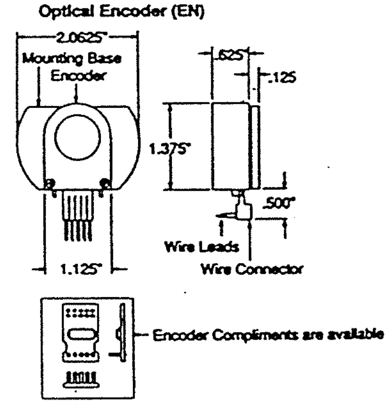
Magnetic Switch Relay (MSR)



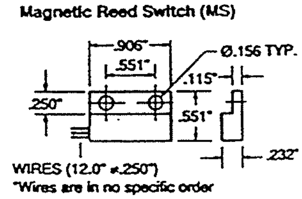
Electromechanical Fail-safe Brake (BR)



Optical Encoder (EN)

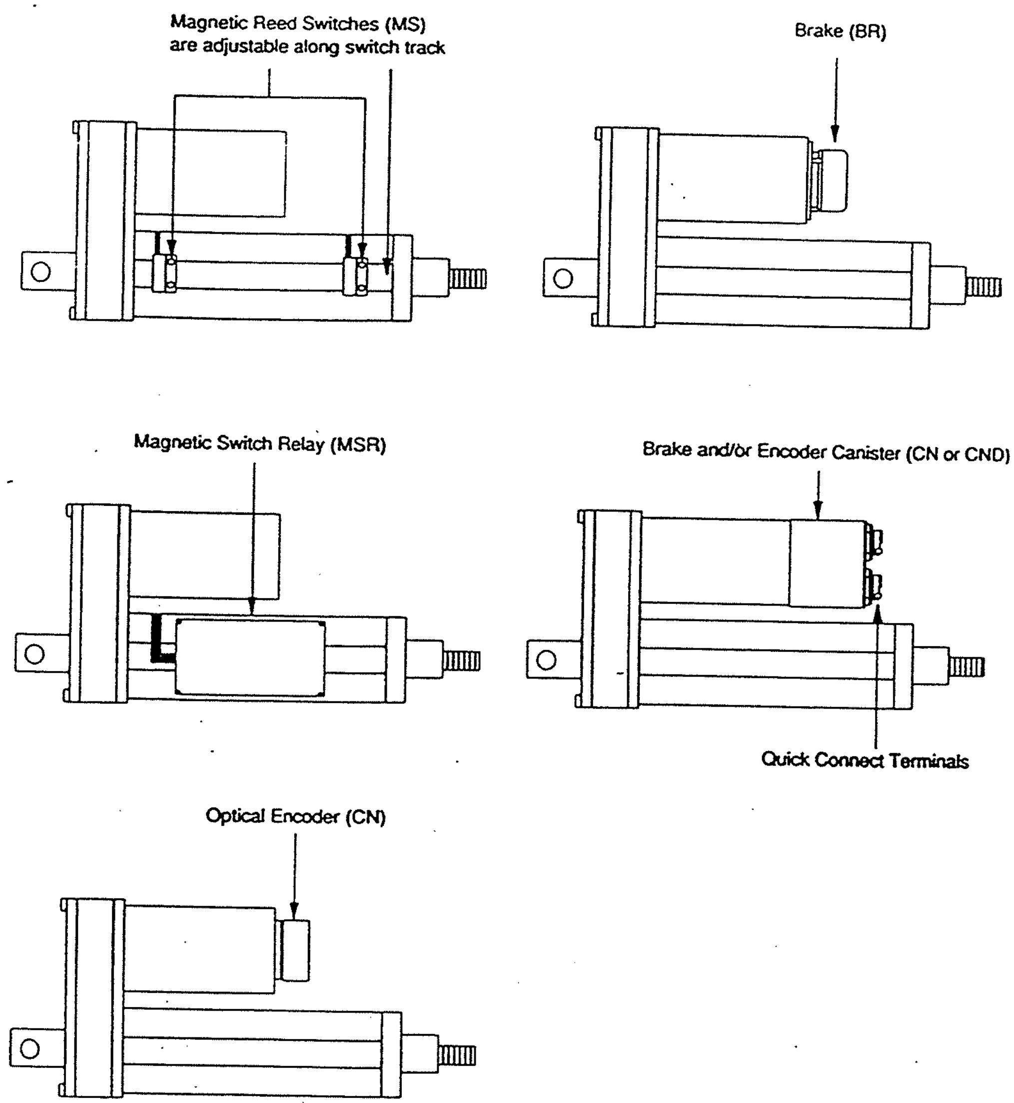


Magnetic Reed Switch (MS)



Note: For more information regarding option specifications contact Jasta.

Option Locations



All of the option mounting locations as shown in these configurations for the linear actuator are the same for the linear positioner series.

US DIGITAL

E2 Series

Quick Assembly Optical Encoder

Technical Data, Rev. 1.28, Feb. 1995

The E2 optical incremental shaft encoder is a noncontacting rotary to digital position feedback device designed to easily mount to an existing shaft.

The internal monolithic electronic module converts the realtime shaft angle, speed and direction into TTL-compatible outputs. Simplicity and low cost make the E2 ideal for both high and low volume motion control applications.

The E2 consists of four parts: base, cover, code wheel and encoder module. The encoder module incorporates a lensed LED light source and monolithic photodetector array with signal shaping electronics to produce the two channel bounceless TTL outputs.

The hub diameter is specified when ordering to adapt to any shaft diameter up to 3/8". Standard diameters are stocked. Quick turn around time is also offered for any special order diameter.

The cover is available in three configurations: The standard is a solid flush back which can accommodate a shaft length up to .57". Option 'H' specifies a .375" diameter hole in the flush back for the shaft to pass through. This hole diameter is .500" when the 3/8" diameter hub is specified. Option 'E' provides a cylindrical extension making room for a 3/4" shaft length.

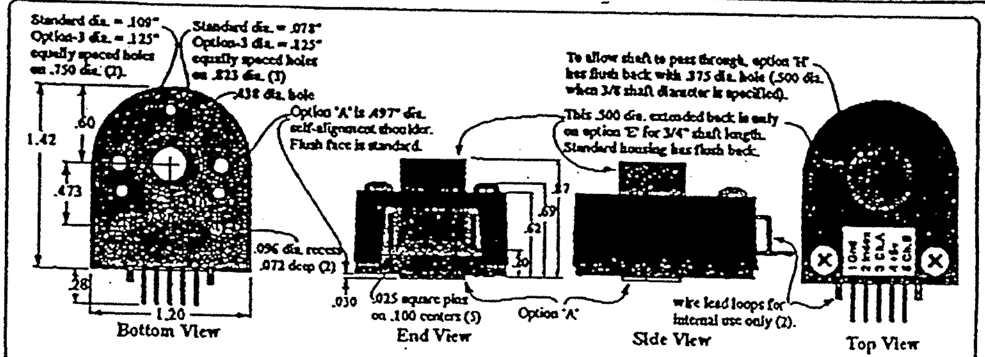
The base provides mounting holes for 2 (2-56 or 4-40) screws in a .750" bolt circle or 3 (0-80) screws in a .823" bolt circle. Option-3 makes all five of these hole diameters .125". If desired, the two .096" diameter recesses will mate with matching aligning pins. The .438" diameter center hole can also mate with a motor boss. The standard base is flat. Option 'A' adds a .497" diameter alignment shoulder designed to slip into a .500" diameter recess centered around the shaft.

Features

- Quick and simple assembly & dis-assembly
- Rugged screw-together housing
- Low cost
- Accepts ±.010" axial shaft play
- Small size
- Tracks from 0 to 100,000 cycles/sec
- 96 to 1024 cycles/rev.
- 384 to 4096 codes per revolution
- 2 channel quadrature TTL squarewave outputs
- Optional index (3rd channel)
- -40 to +100°C operating temperature
- Compatible with HP HEDS-5500
- Fits shaft diameters to 2mm to 3/8"
- Single +5v supply
- Flush back, through shaft hole, or extended back
- Flat or self-aligning base
- Also adapts to 1.812" bolt circle (2 or 3 holes)

Electrical Specifications:

See our HEDS Optical Encoder Module data sheet.



Mechanical Specifications

Parameter	Dimension	Units
Moment of Inertia	8.0×10^{-6}	oz-in-s^2
Hub Set Screw Size	3-48	inches
Hex Wrench Size	.050	inches
Encoder Base Plate Thickness	.135	inches
3 Mounting Screw Size	0-80	inches
2 Mounting Screw Size	2-56 or 4-40	inches

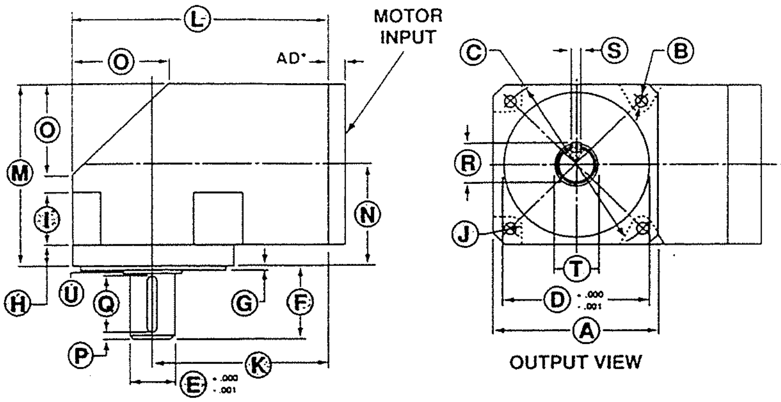
Mechanical Specifications

Parameter	Dimension	Units
3 Screw Bolt Circle Diameter	.823±.005	inches
2 Screw Bolt Circle Diameter	.750±.005	inches
Required Shaft Length	.445 to .570*	inches
with 'E' Option	.445 to .800*	inches
with 'H' Option	>.445*	inches

* Add .125" to the required shaft length when using the P-option or R-option adapter plates.

Phone (360) 696-2468 Sales (800) 736-0194 Fax (360) 696-2469
For Product Information call our automated Fax Service at (360) 696-3836 from your fax machine.
U.S. Digital Corp. • 3800 N.E. 68th St., Suite A3 • Vancouver, WA 98661-1353

DIMENSIONS



Model No.	(A) Square Flange in	(mm)	(B) Bolt Hole in	(mm)	(C) Bolt Circle in	(mm)	(D) Pilot Diameter in	(mm)	(E) Output Shaft Diameter in	(mm)	(F) Output Shaft Length in	(mm)	(G) Pilot Thickness in	(mm)	(H) Flange Thickness in	(mm)	(I) Recess Length in	(mm)	(J) Radius in	(mm)
RA 60	2.36	(60)	.197	(5.0)	2.756	(70)	1.969	(50)	0.630	(16)	0.98	(25)	.098	(2.5)	0.51	(13)	1.06	(27)	R.187	(5)
RA 90	3.54	(90)	.256	(6.5)	3.937	(100)	3.150	(80)	0.787	(20)	1.57	(40)	.118	(3.0)	0.47	(12)	1.25	(32)	R.263	(7)
RA 115	4.53	(115)	.335	(8.5)	5.118	(130)	4.331	(110)	0.945	(24)	1.97	(50)	.138	(3.5)	0.55	(14)	1.55	(39)	R.296	(8)
RA 142	5.59	(142)	.433	(11.0)	6.496	(165)	5.118	(130)	1.575	(40)	3.15	(80)	.138	(3.5)	0.79	(20)	3.00	(76)	R.410	(10)
RA 180	7.17	(182)	.512	(13.0)	8.465	(215)	6.299	(160)	1.969	(50)	3.74	(95)	.394	(10.0)	0.98	(25)	3.12	(79)	R.500	(13)
RA 220	8.66	(220)	.669	(17.0)	9.843	(250)	7.087	(180)	2.953	(75)	6.10	(155)	.591	(15.0)	1.38	(35)	3.50	(89)	R.625	(16)
RA300	11.81	(300)	.827	(21.0)	13.780	(350)	9.843	(250)	3.937	(100)	7.09	(180)	.787	(20.0)	1.97	(50)	4.33	(110)	R.787	(20)

Model No.	(K) Dist. to Output Centerline in	(mm)	(L) Length in	(mm)	(M) Width in	(mm)	(N) Dist. to Input Centerline in	(mm)	(O) Taper Dist. in	(mm)	(P) Dist. From Shaft End in	(mm)	(Q) Keyway Length in	(mm)	(R) Keyway Height in	(mm)	(S) Keyway Thickness in	(mm)	(T) Shoulder Height in	(mm)	(U) Shoulder Diameter in	(mm)
RA 60	2.83	(72)	4.02	(102)	2.87	(73)	1.69	(43)	1.50	(38)	.118	(3)	0.630	(16)	0.71	(18.0)	0.197	(5)	.04	(1)	0.87	(22)
RA 90	3.58	(91)	5.35	(136)	3.94	(100)	2.17	(55)	2.03	(52)	.197	(5)	1.102	(28)	0.89	(22.5)	0.236	(6)	.04	(1)	1.42	(36)
RA 115	4.61	(117)	6.85	(174)	5.08	(129)	2.83	(72)	2.83	(72)	.276	(7)	1.260	(32)	1.06	(27.0)	0.315	(8)	.06	(1.5)	1.57	(40)
RA 142	6.57	(167)	9.47	(241)	6.38	(162)	3.58	(91)	3.31	(84)	.315	(8)	2.480	(63)	1.69	(43.0)	0.472	(12)	.06	(1.5)	1.97	(50)
RA 180	8.39	(213)	11.97	(304)	8.15	(207)	4.57	(116)	4.49	(114)	.236	(6)	2.756	(70)	2.11	(53.5)	0.551	(14)	.08	(2)	2.56	(65)
RA 220	10.12	(257)	14.45	(367)	9.92	(252)	5.59	(142)	4.82	(123)	.315	(8)	3.937	(100)	3.15	(80.0)	0.787	(20)	.08	(2)	3.54	(90)
RA 300	12.60	(320)	18.50	(470)	13.78	(350)	7.87	(200)	5.91	(150)	.591	(15)	4.331	(110)	4.331	(110.0)	1.102	(28)	.12	(3)	4.92	(125)

*AD = Adapter Length. Adapter will vary, depending on motor. Consult appropriate motor sizing chart for details.

BAYSIDE RIGHT ANGLE PLANETARY GEARHEADS PERFORMANCE SPECIFICATIONS

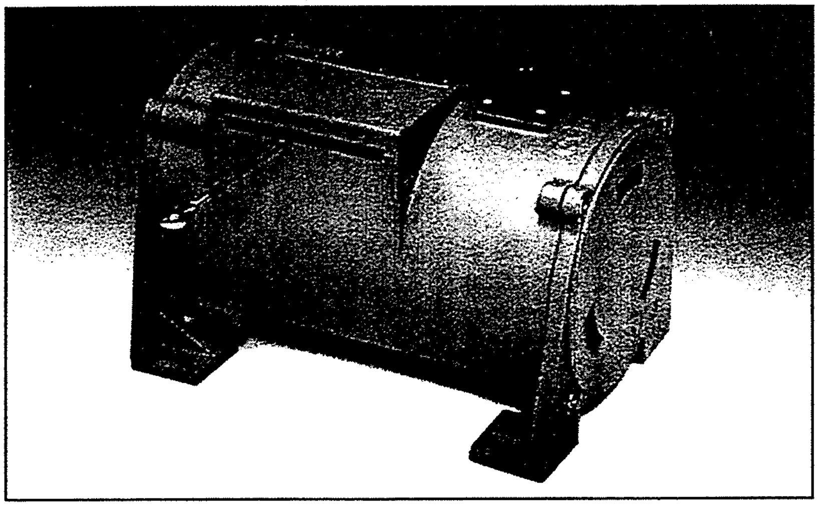
Model No.	Rated Output Torque in-lbs	(Nm)	Peak Output Torque in-lbs	(Nm)	Maximum Input Speed (RPM)	Standard Backlash (minutes)	Low Backlash (minutes)	Efficiency (%)
RA 60	300	(33.9)	498	(56.3)	5000	10	5	90%
RA 90	800	(90.4)	1328	(150.1)	5000	10	5	90%
RA 115	1600	(180.8)	2656	(300.1)	5000	10	5	90%
RA 142	4600	(519.8)	7636	(862.9)	4000	10	5	90%
RA 180	8000	(904.0)	15000	(1695.0)	4000	10	5	90%
RA 220	12000	(1356.0)	20000	(2260.0)	4000	10	5	90%
RA 300	24000	(2711.9)	36000	(4067.8)	2500	10	5	90%

Model No.	Moment of Inertia Oz-in-sec^2	(kg m^2)	Torsional Stiffness in-lbs/min	(Nm/min)	Maximum Weight lbs	(kg)	Radial Load (1) lbs	(N)	Axial Load lbs	(N)
RA 60	$6x10^{-4}$	$(4x10^{-6})$	50	(5.7)	5	(2.3)	400	(1779.4)	400	(1779.4)
RA 90	$3x10^{-3}$	$(2x10^{-5})$	80	(9.0)	9	(4.1)	600	(2669.0)	600	(2669.0)
RA 115	$7x10^{-3}$	$(5x10^{-5})$	140	(15.8)	20	(9.1)	1100	(4893.2)	1100	(4893.2)
RA 142	$5x10^{-2}$	$(4x10^{-4})$	360	(40.7)	43	(19.5)	1800	(8007.1)	1800	(8007.1)
RA 180	$9x10^{-2}$	$(6x10^{-4})$	640	(72.3)	85	(38.6)	2800	(12455.5)	2800	(12455.5)
RA 220	$3x10^{-1}$	$(2x10^{-3})$	960	(108.5)	160	(72.6)	10000	(44484.0)	10000	(44484.0)
RA 300	$1x10^{-1}$	$(7x10^{-2})$	1200	(135.6)	340	(154.5)	12000	(53380.8)	12000	(53380.8)

(1) Radial loads are at 1.00 inches (25.4mm) from the face of the gearhead.

Cable-Extension Position Transducer

- Medium to Long Range / Industrial Grade
- Incremental-Encoder Output



PT9150

The PT9150 is for long range measurement applications that require a digital incremental encoder position feedback signal. Available in extended ranges up to 1750", the PT9150 comes in a variety of resolutions and output stages that will fit almost any requirement.

Like other members of Celesco's innovative family of NEMA 4 rated cable-extension transducers, the PT9150 can be installed in minutes, function properly without perfect parallel alignment, and fit into areas unsuitable for rod-type measurement devices. When its stainless-steel cable is retracted, the PT9150 is only 6" long. Its small-size-and-low-cost-to-measurement ratio offers remarkable flexibility and value.

Standard Specifications:

GENERAL

Range	0-75, -100, -150, -200, -250, -300, -400, -450, -500, -550 inches
Extended Ranges to 1750 inches	please consult factory
Weight	7 lb. typical
Housing Material	Powder-Painted Aluminum
Optional	Stainless Steel
Sensor	Incremental Optical Encoder
Electrical Connector	MS3102E-14S-6P
Mating Connector (included)	MS3106E-14S-6S

ELECTRICAL

Input Voltage	4.5 - 13.2 VDC
Options	see fig. 4
Input Current	50 mA max.
Output Stage	see fig. 4, option 1
Output Channels	A, B (see fig. 1)
Optional Channels	Index and compliments of A, B, & Index

PERFORMANCE

Accuracy	0.04% of Full Stroke +/- 1 pulse
Repeatibility	0.02% of Full Stroke
Resolution:	
English	100 pulses per inch nominal**
Metric	5 pulses per mm nominal**

MECHANICAL

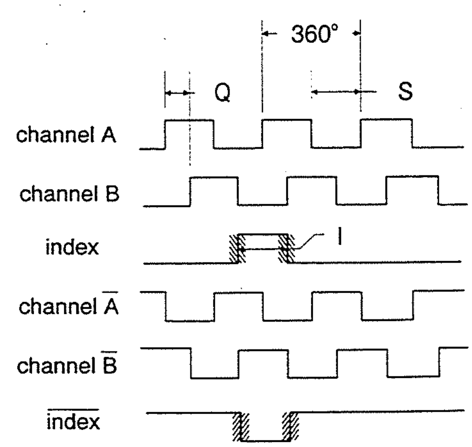
Cable Tension	see fig. 3
Cable Diameter	0.024 in. **
Cable Fitting	MS20668 Stainless Steel Eye Fitting

ENVIRONMENTAL

Operating Temperature	0° to 160°F
Environmental Suitability	Indoor/Outdoor
Oprerating-Humidity, Splash	NEMA 4, IP 67
Vibration	up to 10 G's to 2000 Hz

***See order code for more options*

fig. 1 Output Waveforms



Q: quadrature 90° +/- 30° S: symmetry 180° +/- 10°
I: index 90° to 270°

celesco

Celesco Transducer Products, Inc. 7800 Deering Avenue Canoga Park, CA 91309 Tel: (800) 423-5483 Fax: (818) 340-1175

fig 2 Cable Exit

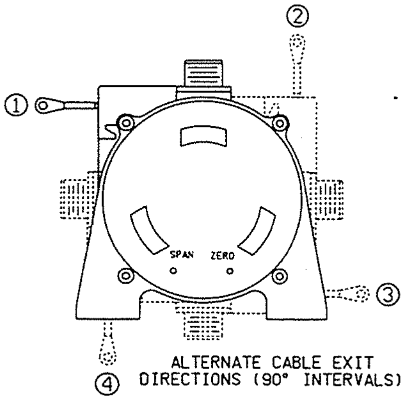
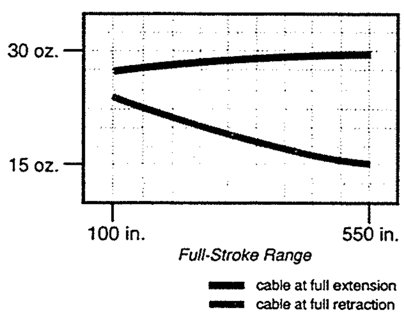


fig 3 Cable Tension

Standard Cable Tension



Increased Cable Tension

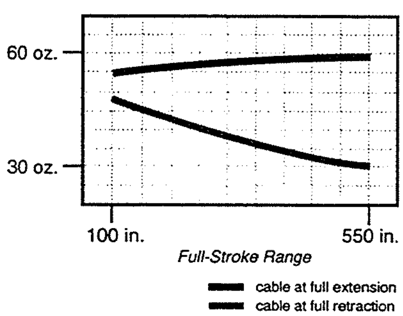
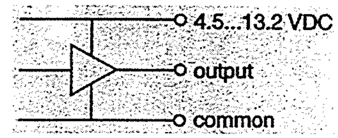


fig 4 Output Stage

1 CMOS / TTL

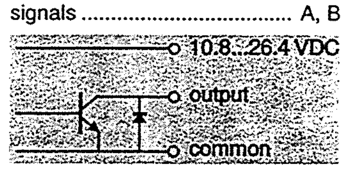
signals .... A, B



Pin	Signal
A	4.5...13.2 VDC
B	common
C	channel B
D	channel A
E	n/c
F	n/c

2 Open Collector

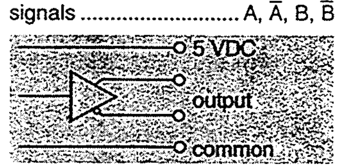
signals .... A, B



Pin	Signal
A	10.8...26.4 VDC
B	common
C	channel B
D	channel A
E	n/c
F	n/c

3 Line Driver

signals .... A, $\bar{A}$, B, $\bar{B}$

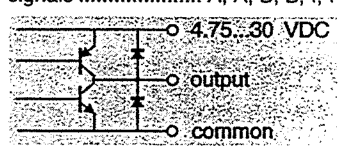


Pin	Signal
A	5 VDC
B	common
C	channel B
D	channel A
E	channel B'
F	channel A'

Repeat infant mortality problems.

4 Universal Line Driver

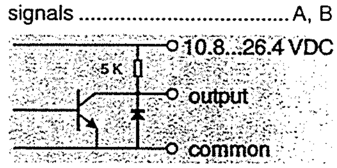
signals .... A, $\bar{A}$, B, $\bar{B}$, I, $\bar{I}$



Pin	Signal
1	4.75...30 VDC
2	common
3	channel B
6	channel A
7	index
11	channel B'
12	channel A'
15	index'

5 Open Coll. w/ 5K pullup

signals .... A, B

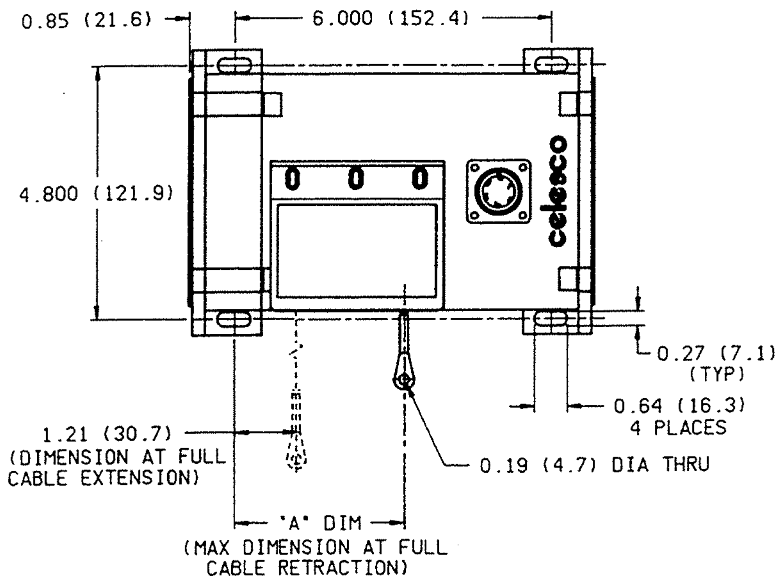


PIN	SIGNAL
A	10.8...26.4 VDC
B	common
C	channel B
D	channel A
E	n/c
F	n/c

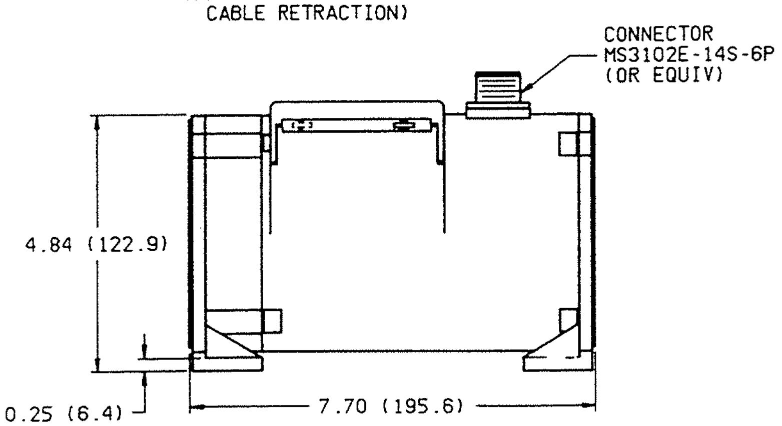
2713

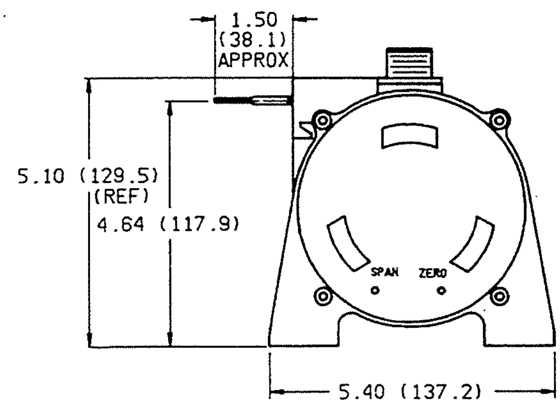
celesco

fig. 5 Outline Drawing



Dimension "A"					
English			Metric		
Range (in.)	0.024" dia. cable	0.047" dia. cable	Range (mm)	0.61mm dia. cable	1.19mm dia. cable
75	1.36"	1.50"	2500	34.5mm	38.2mm
100	1.40"	1.60"	3750	35.7mm	40.7mm
150	1.50"	1.80"	5000	38.2mm	45.6mm
200	1.60"	1.99"	6250	40.6mm	50.5mm
250	1.70"	2.19"	7500	43.2mm	55.6mm
300	1.80"	2.38"	8750	45.7mm	60.5mm
350	1.90"	2.58"	10000	48.2mm	65.5mm
400	2.00"	n/a	11250	50.8mm	n/a
450	2.10"	n/a	12500	53.3mm	n/a
500	2.20"	n/a	13750	55.9mm	n/a
550	2.30"	n/a	15000	58.4mm	n/a

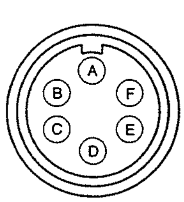




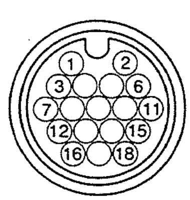
ALL DIMENSIONS ARE IN INCHES(MM)

fig. 6 Mating Connectors

1 6-pin



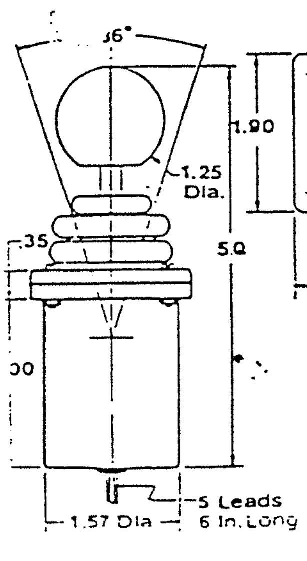
3 18-pin

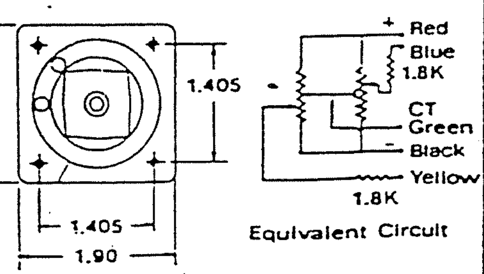


DURING INSTALLATION
REFERENCE WIRING INFO.
SUPPLIED WITH TRANSDUCER

celesco

Celesco Transducer Products, Inc. 7800 Deering Avenue Canoga Park, CA 91309 Tel: (800) 423-5483 Fax: (818) 340-1175





Maurey

INDUCTION TYPE JOYSTICK CONTROL

Operating Voltage:	4.5 to 15.0 Volts, D.C.
Current:	15 ma at 10 Volts, D.C.
Output Impedance:	1800 Ω (Signals)
Center Tap Impedance:	340 Ω
Equivalent Noise Resistance:	NONE
Temperature Range:	-30° to 105° C
Center Tap Voltage:	50% of Input Voltage
··solution:	Infinite
:	20.000.000 cycles
.ads	6 inch standard lengt··
	color coded

Knob has spring return to center.

Voltage Swing: **+/— 10% of Operating Voltage**

General

The 7500 series computer chassis from Industrial Computer Source provide the ruggedness and durability required for industrial applications. There are several models, i.e. mounting configurations, of chassis available in this series, all with essentially the same construction but slightly different features.

MODEL	MOUNT	BACKPLANE
7515-33H	RACK	PASSIVE, 15 SLOT
7508-33H	RACK	MOTHERBOARD MOUNT
7615-33H	BENCH TOP	PASSIVE, 15 SLOT
7608-33H	BENCH TOP	MOTHERBOARD MOUNT
7915-33H	FLOOR	PASSIVE, 15 SLOT
7918-33H	FLOOR	MOTHERBOARD MOUNT
7815-33H	RACK, KEYBD DRAWER	PASSIVE, 15 SLOT
7818-33H	RACK, KEYBD DRAWER	MOTHERBOARD MOUNT
7500-XC	RACK, EXPANSION	PASSIVE, 15 SLOT
7600-XC	BENCH TOP, EXPANSION	PASSIVE, 15 SLOT

The passive backplane chassis are designed and built for the most demanding of industrial needs. These units have a 15 slot, all AT, passive backplane which accepts your selection from a wide range of available CPU cards. These CPUs plug into the backplane as any other adapter card would. The backplane itself has very few components. The components it does have are the necessary sockets to accept up to fifteen adapter cards and LED indicating circuitry, Industrial Computer Source's Bus Power Check™ circuitry, for each power supply output, ±5VDC and ±12VDC.

The difference between the chassis is the mounting configurations, i.e. whether they rack mount in 19" equipment cabinets, set on a bench top, or set on the floor with or without optional shock mount stands. The motherboard mounting chassis appear identical to the passive backplane units from the outside. Inside they have provisions for mounting typical XT or AT compatible motherboards rather than a passive backplane. These chassis offer you the capability to take your choice of motherboards from "office" systems and ruggedize them for use in factory floor environments. The hole pattern for acceptable mother boards, such as full size and "Baby AT" boards, is found in the installation section of this manual.

Power Supply

The power supply in this series of chassis provides more than adequate power for even the most rigorous requirements. A switching type power supply is incorporated to provide large amounts of power without the heat and weight associated with transformer, linear power supplies. The total output of the supply is 315 Watts with up to 35 Amps available from the +5VDC supply and up to 10 Amps at +12VDC.

Disk Drives

The chassis, except for the expansion chassis, will accept up to three half-height disk drive devices or a full-height and a half-height. The mounting configuration for drives utilizes shock mounts to permit use in high vibration and shock applications. The expansion chassis, the 7500 and 7600, can accept fixed disk drives in a drive cage but provide no front panel access.

Cooling and Filtration

The chassis are designed for use in industrial areas. Positive pressurization of the chassis is accomplished through the use of heavy duty fans. Two 106 CFM fans are included in the card cage area with an additional 24CFM fan mounted in the power supply module. These three fans, with their filtered intakes, provide protection for the full system, including the disk drives, from environmental dirt and grit.

Specifications

Power Suppply:

35 Amps @ +5 VDC
1 Amp @ -5 VDC
10 Amps @ +12 VDC
1 Amp @ -12 VDC

Fuse:

5 Amp, 250V, 3AG, Fast Blow

Power Requirements:

120VAC +10%/-25% or 220VAC +10%/-25% , 49-61Hz
The power supply switches automatically
The supply will operate normally at 400Hz input power frequency - however, the system is NOT UL/CSA Recognized in that mode of operation.

Operating Temperature:

+5 to +50°C, 5 - 95% R. H. Non-condensing

Storage Temperature:

-5 to +75°C, 5 - 95% R. H. Non-condensing

Shock Tolerance:

5g, Half sine, 15mSeconds duration

FCC Classification:

Meets FCC Part 15, Class A Emission Limits

UL Ratings:

UL 478, UL Recognized

nstruction:

Chassis:	0.055" Aluminum Alloy, Gold Zinc finish
Front Panel:	0.125" Aluminum Alloy, Medium Texture Sherwin Williams Paint #F63-A-3080

ns, Filtration:

Card Cage Area:	2, 106 CFM, 4.68" Fans, filtered to 45 ppi
Power Supply Module:	1, 24 CFM, 3.15" Fan, filtered to 45 ppi

nnectors, External:

Keyboard 5 pin DIN connector, front and rear
Accessory power outlet plug, rear

itches:

Power on, CPU reset, front panel
(Keylock power on/reset switch optional)

ive Capacity:

Three half-height on shock mounts or one half-height and one full-height on shock mounts. 3.5" devices will require an adapter mounting bracket for 5.25" device mounts.

eight:

35 Lbs (16.0 Kg)
(Shipping - 45 Lbs (20.5 Kg))

mensions:

Rack Mount:	23"(58.42cm) D x 7.0"(17.78cm) H x 19"(48.26cm) W, Front Panel, 17"(43.18cm) W chassis
Bench Top:	23"(58.42cm) D x 7.0"(17.78cm) H x 17"(43.18cm) W
Floor Mount:	25"(63.50cm) D x 17"(43.18cm) H x 7.0"(17.78cm) W

ssive Backplane:

15 slot, 4 layer, low capacitance backplane standard configuration, all AT (16 bit) slots. Rear panel has 15 slot access. Different configurations available on special request.

otherboard:

Mother Board CPU, 8 slot rear panel with DIN keyboard connector cutout. Hole patterns in floor of chassis to accept most standard AT and "Baby AT" mother boards.

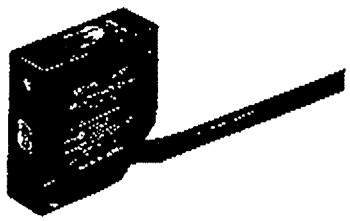
Aromat

SUBMINIATURE MARK SENSOR

Components for advanced technology

MQ Mark Sensor

Subminiature with built in amplifier, with detection speed of 1,000 times per second achieved.



MQ-VD2AR Mark Sensor
(diffused reflection type)
Sensing distance: 2 cm approx. 0.8 inches

- **High speed detection: 1,000 times/second**
- **Subminiature with built-in amplifier**
- **Mark sensing or bar code (UPC code)**
- **Detection of 0.5 mm 0.02 inch width's possible**
- **Light ON or OFF output detection is selectable**
- **Wide range operation 12/24 V DC**
- **Environmental resistance (IEC IP67)**
- **Horizontal or vertical mounting**
- **Simple sensitivity adjustment**

ORDERING INFORMATION

Detection method	Product name	Part No.	Operating condition	Setting distance	Packing q'ty.	
					Inner carton	Outer carton
Diffused reflection	MQ-VD2AR Mark Sensor	MQ-VD2AR-DC12-24V	Light ON, Dark ON selection	2 cm approx. 0.8 inches	1	10

Note: A special mounting bracket is provided as accessory.

RATINGS AND PERFORMANCE SUMMARY

1. Ratings

Item		Description
Operating side	Rated operating voltage	DC 12/24 V
	Rated current consumption	Less than 35 mA (excluding load)
Load side	Output current capacity	100 mA max.

2. Performance summary

Item \ Type		Diffuse reflective
Item		MQ-VD2AR
Light source		Red light emitting diode*
Standard target		2.0 mm .079 inch mark on white field
Minimum mark detection width		0.5 mm .020 inch (at rated setting distance)
Operating voltage range		9.6 to 30 V DC including ripple (P-P)
Max. sensing distance		2±0.2 cm
Hysteresis		Less than 20 % (at rated setting distance)
Detection speed		1,000 times/second (at 2 mm .079 inch black and 1 mm .039 inch white mark width)
Insulation resistance (Initial)		Between I/O terminal and outer case 20 MΩ (with 500 V DC megger)
Dielectric strength (Initial)		Between I/O terminal and outer case 500 V AC for 1 minute
Vibration endurance Malfunction vibration		10 to 55 Hz (1 min cycle) amplitude 1.5 mm .059 inch 2 h on 3 axes
Shock endurance Malfunction shock		100 G 6 times in each direction
Protective construction		Diecast case immersion proof form (Equivalent to IEC IP67)
Usable ambient conditions	Usable ambient light	Incandescent lamp: less than 3,000 lux; Sunlight: less than 10,000 lux.
	Detection object	Translucent, opaque body and mark
	Usable ambient temperature	25°C to +55°C 13°F to +131°F
	Usable ambient humidity	Less than 85%
Indicator		Indicator lights with light input (red), surplus indicator (red)

Notes: 1. Undesignated measurement conditions are at rated operating voltage, storage battery power source, ambient temperature +20°C −68°F standard detection object, light receiving surface light intensity less than 200 lux.
2. Because the rated setting distance and response difference distance for the diffused reflection type are measured with the standard detection object, the distance will vary depending upon the material, color, and size of the object.