10:54:14 OCA PAD INITIATION - PROJECT HEADER INFORMATION 02/19/96

Active

Project #: E-25-L09 Cost share #: Rev #: 0
Center # : 10/24-6-R8787-0A0 Center shr #: OCA file #:
Work type : RES
Contract#: AGMT DTD 960105 Mod #: Document : AGR
Prime #: Contract entity: GTRC

Subprojects ? : N CFDA: NA
Main project #: PE #: NA

Project unit: MECH ENGR Unit code: 02.010.126
Project director(s):
BAIR S S III MECH ENGR (404)894-3273

Sponsor/division names: LUBRIZOL CORP / WICKCLIFFE, OH
Sponsor/division codes: 211 / 029

Award period: 960116 to 970115 (performance) 970315 (reports)

Sponsor amount	New this change	Total to date
Contract value	63,476.00	63,476.00
Funded	63,476.00	63,476.00
Cost sharing amount		0.00

Does subcontracting plan apply ?: N

Title: CONCENTRATED CONTACT SIMULATOR

PROJECT ADMINISTRATION DATA

OCA contact: William F. Brown 894-4820

Sponsor technical contact	Sponsor issuing office
DR. HYUN HONG	DR. HYUN HONG
(216)943-1200	(216)943-1200
EXT. 2985	EXT. 2985
THE LUBRIZOL CORP.	THE LUBRIZOL CORP.
29400 LAKELAND BLVD.	29400 LAKELAND BLVD.
WICKLIFFE, OH 44092-2298	WICKLIFFE, OH 44092-2298

Security class (U,C,S,TS) : U
Defense priority rating : NA
Equipment title vests with: Sponsor

ONR resident rep. is ACO (Y/N): N
NA supplemental sheet
GIT X

Administrative comments -
INITIATION OF E-25-L09.

CA8120 Georgia Institute of Technology Page: 1
Office of Contract Administration 22-AUG-1997 15:56
PROJECT CLOSEOUT - NOTICE

U
(5)

Closeout Notice Date 22-AUG-1997

Project Number E-25-L09 Doch Id 37403

Center Number 10/24-6-R8787-0A0

Project Director BAIR, SS III

Project Unit MECH ENGR

Sponsor LUBRIZOL CORP/WICKCLIFFE, OH

Division Id 4269

Contract Number AGMT DTD 960105 Contract Entity GTRC

Prime Contract Number

Title CONCENTRATED CONTACT SIMULATOR

Effective Completion Date 16-JUL-1997 (Performance) 16-JUL-1997 (Reports)

Closeout Action:	Y/N	Date Submitted
Final Invoice or Copy of Final Invoice	Y	
Final Report of Inventions and/or Subcontracts	N	
Government Property Inventory and Related Certificate	Y	
Classified Material Certificate	N	
Release and Assignment	N	
Other	N	

Comments

Distribution Required:	
Project Director/Principal Investigator	Y
Research Administrative Network	Y
Accounting	Y
Research Security Department	N
Reports Coordinator	Y
Research Property Team	Y
Supply Services Department	Y
Georgia Tech Research Corporation	Y
Project File	Y

E-27-L09
#1
(New)

Georgia Institute of Technology

The George W. Woodruff School of Mechanical Engineering

MEMORANDUM

DATE: April 26. 1996

TO: Dr. Hyun-Soo Hong
Research Manager
The Lubrizol Corporation
29400 Lakeland Boulevard
Wickliffe. OH 44092-2298

FROM: Scott Bair
Principal Research Engineer
George W. Woodruff School of Mechanical Engineering
Georgia Institute of Technology
Atlanta. GA 30332-0405

SUBJECT: Progress on Concentrated Contact Simulation Since February 19. 1996

Components which fix and rotate the ball and disc test components have been designed (see attached drawings) and machined. The traction force transducer is on order. Nick Stadmyk has requested that the microscope be of the stereo type. We are searching for a supplier of components to assemble a stereo microscope with filter and beam splitter. Design work on the drive system will begin next week.

Attachment: 3 figures

Atlanta, Georgia 30332-0405 U.S.A.
Administration Office 404•894•3200
Finance Office 404•894•7400
Graduate Program 404•894•3204
Undergraduate Office 404•894•3203
Fax 404•894•8336 or
web site: http://www.me.gatech.edu/

E-25-L09
2

Georgia Tech

THE GEORGE W. WOODRUFF SCHOOL OF
MECHANICAL ENGINEERING

Georgia Institute of Technology
Atlanta, Georgia 30332-0405
USA

MEMORANDUM

DATE: July 17, 1996

TO: Dr. Hyun-Soo Hong
Research Manager
The Lubrizol Corporation
29400 Lakeland Boulevard
Wickliffe, OH 44092-2298

FROM: Scott Bair S.B.
Principal Research Engineer
George W. Woodruff School of Mechanical Engineering
Georgia Institute of Technology
Atlanta, GA 30332-0405

SUBJECT: Progress on Concentrated Contact Simulator

The tester housing and all related components are complete and assembled. A trinocular compound microscope has been received. This microscope allows binocular viewing with a third tube available for video. The incorporation of this microscope, however, has significantly altered the design of the supporting structure and drive system. Design changes are underway. We expect delays in obtaining materials and machine shop service during the Olympic period. Also, you should have received our report on 117616B oil.

Georgia Institute of Technology
The George W. Woodruff School of Mechanical Engineering

E-25-109
3

MEMORANDUM

DATE: October 14, 1996

TO: Dr. Hyun-Soo Hong
Research Manager
The Lubrizol Corporation
29400 Lakeland Boulevard
Wickliffe, OH 44092-2298

FROM: Scott Bair SB
Principal Research Engineer
George W. Woodruff School of Mechanical Engineering
Georgia Institute of Technology
Atlanta, GA 30332-0405

SUBJECT: Progress on Concentrated Contact Simulator

The Concentrated Contact Simulator has been completed. Training for Lubrizol personnel was accomplished earlier this month. A shipping box is under construction. Please advise regarding your preferred shipper as with previous testers.

Atlanta, Georgia 30332-0405 U.S.A.
Administration Office 404•894•3200
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Undergraduate Office 404•894•3203
Fax 404•894•8336 or
web site: http://www.me.gatech.edu/

E-25-L09
#5

Concentrated Contact Simulator

a Final Report to Lubrizol Corporation
29400 Lakeland Boulevard
Wickliffe, OH 44092-2298

by Scott Bair
Principal Research Engineer
G.W. Woodruff School of Mechanical Engineering
Georgia Institute of Technology
Atlanta, GA 30332-0405

Georgia Institute of Technology
The George W. Woodruff School of Mechanical Engineering

April 2, 1997

Dr. Hyun-Soo Hong
Research Manager
The Lubrizol Corporation
29400 Lakeland Boulevard
Wickliffe, OH 44092-2298

Dear Hyun:

Please find enclosed, the final report on our project, Concentrated Contact Simulator. The drawings contained in the Appendix represent the latest improvements.

Best regards,

Scott Bair
Principal Research Engineer

Atlanta, Georgia 30332-0405 U.S.A.
Administration Office 404•894•3200
Finance Office 404•894•7400
Graduate Program 404•894•3204
Undergraduate Office 404•894•3203
Fax 404•894•8336 or
web site: http://www.me.gatech.edu/

GEORGIA INSTITUTE OF TECHNOLOGY — OFFICE OF CONTRACT ADMINISTRATION

RESEARCH REPORT APPROVAL SHEET

(Please see Instructions on back)

Project No. E25-L09

Mechanical Engineering
Lab/School

I. GENERAL

A. Report Title Concentrated Contact Simulator

B. Author(s) and/or PD/PI. Scott Bair — Phone (404) 894-3273

C. Period Covered 96-01-16 to 97-03-17 — Due Date 97-07-16

II. REPORT IDENTIFICATION

A. Deliverable Line No. 5 (from Deliverable Schedule)

B. Type Report:

- ❑ Monthly
- ❑ Quarterly
- ❑ Semi-Annual
- ❑ Annual
- ❑ Progress
- ❑ Cost & Performance
- ❑ Contract Mgt.
- X Final
- ❑ Other ________ (Specify)

C. Draft Copy for Sponsor Approval ❑

D. Approval Copy for Distribution:

1. ❑ Send Copy to Sponsor
2. ❑ Send Master to Sponsor
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III. SECURITY CLASSIFICATION

- X Unclassified
- ❑ Secret
- ❑ In Confidence (Specified Industrial Contracts Only)
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- ❑ Other ________ (Specify)

IV. DATA RESTRICTIONS ❑ Yes X No

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VI. APPROVALS

		DATE
A.	PD/PI [signature]	4-2-97
B.	Div. Chief/Branch Head	
C.	Lab/School Director (Required on Finals)	
D.	Coordinator Log Entry:	

OCA Form 09-0593

Concentrated Contact Simulator

a Final Report to Lubrizol Corporation
29400 Lakeland Boulevard
Wickliffe, OH 44092-2298

by Scott Bair
Principal Research Engineer
G.W. Woodruff School of Mechanical Engineering
Georgia Institute of Technology
Atlanta, GA 30332-0405

Introduction

The Georgia Tech Tribology and Rheology Laboratory has constructed a new Concentrated Contact Simulator for Lubrizol Corporation. Concentrated contacts exist between non-conforming machine elements made of high modulus material and the dry Hertzian pressure may be between 0.5 to 3GPa. This new instrument can provide both film thickness and traction characteristics for liquid lubricants in concentrated contact while varying the kinematics from pure rolling to pure sliding. Velocities to 10 m/s and bulk oil temperatures to 150°C can be attained. The slide to roll ratio, Σ, can be varied step wize using interchangable geared pulley combinations or continuously variable by about 10% using the slide/roll micrometer.

Principles of Operation

The simulator utilizes a roller running against the flat face of a rotating disc. A single permanent magnet DC motor controls the rotational speed of both the roller, ω_r, and disc, ω_d, through a toothed belt system. The roller may consist of a ball mounted upon a shaft (producing a circular contact) or an integral roller/shaft element with a crown radius, r_y, selected to produce an elliptical contact of aspect ratio, k. See the component drawings in the Appendix for parts indentification and dimensions (in inches).

The radius of the path of the center of the contact on the disc face is r_d and is controlled by the slide-roll micrometer. This micrometer is equipped with a thrust ball where it contacts the roller or ball shaft and features a knurled locking cam to prevent loss of adjustment. The roller shaft runs within a spring energized lip seal (BAL Seal Co. 314 MB-106-G) where it exits the test housing to prevent sample loss. Likewise the disc shaft is equipped with a slinger and non-contacting labyrinth seal where it passes through the housing.

Load is applied to the disc shaft by dead weight through an angular contact ball bearing. Rotation of the bale is prevented by a hexagonal socket in the base plate. The load, W, on the contact is the sum of the weight of the disc, the disc shaft, all components which attach directly to the disc shaft, and the weights applied to the bale rod. The weight of the portion of the disc drive belt which acts on the thrust hub is neglected. The mass of the bale and disc shaft assembly is 129g and a typical sapphire disc is 24g; giving a typical contact load equal to the applied weights plus 1.5N.

The test housing requires a 4 to 5ml sample to fill from the dry condition and when hot can be drained to 1.5ml remaining liquid. As an alternative to disassembly and cleaning, a series of six hot fill-run-stop-drain procedures will leave 0.1% contamination form the previous sample. This is rheologically insignificant unless the previous sample was of exceptionally low viscosity compared to the present sample. Temperature control of the sample is provided by a 120V, 200W cartridge heater (Chromalox CIR 1023). This heater must be connected to AC power by a variable power supply (eg. a Variac). Temperature measurement is by a thermocouple of 1/16 inch diameter inserted in a hole in the test housing which places the bead directly under the sump from which the roller picks up liquid. The aluminum test housing is thermally isolated from the drive base by a steel isolator.

This instrument uses three toothed belts: 1). The roller drive belt connects the roller pulley (24 tooth) with the intermediate shaft with a quarter turn CCW twist. This belt is tensioned by sliding the intermediate shaft bearing housing. Only 140 tooth belts are used to drive the roller and pulleys no larger than 36 tooth may be used at the intermediate shaft to drive the roller. 2). The disc drive belt connects the disc with the intermediate shaft. It is tensioned by sliding an idler in a ¼ inch groove in the drive base. Note that the axial center of the disc shaft pulley (72 tooth) coincides with the axial center of the lower disc shaft bearing so that disc drive belt tension is completely reacted by the lower bearing without affecting the traction measurement. Belts with 180, 190 or 200 teeth may be used, depending on the number of the teeth on the disc pulley on the intermediate shaft. 3). A motor belt connects the motor pulley (24 or 96 tooth) to the intermediate shaft. Belts with 130 or 160 teeth are used depending on motor pulley. All belts and pulleys are 1/10 inch pitch and are available from Winfred M. Berg Inc.

Speed is measured at the intermediate shaft using a 10 tooth magnetic wheel and a Hall effect transducer. A tachometer displays the intermediate shaft rotational speed, ω_i, in revolutions per second with the last digit equal to 0.1 rps. The roller velocity is

$$V_r = 2\pi r_x \omega_i \frac{N_r}{24}$$

and where N_r is the number of teeth on the roller drive pulley at the intermediate shaft and r_x is one-half of the outside diameter of the roller or ball. The disc velocity is

$$V_d = 2\pi r_d \omega_i \frac{N_d}{72} .$$

The rolling or entrainment velocity is

$$u = (V_d + V_r)/2$$

and is the important velocity for film thickness. The sliding velocity which is important for traction and mechanical loss is

$$\Delta u = V_d - V_r$$

and the slide-roll ratio is

$$\Sigma = \Delta u / u .$$

Pure sliding (Σ=2 or -2) is achieved by fixing either the roller or disc. A rectangular toothless pulley is provided for fixing the roller by interfering with the insulator. Pure rolling is assured by setting $V_d = V_r$; however, it is acceptable to simply remove the disc drive belt and let the roller drive the disc when the load is high and the oil viscosity is low to assume pure rolling. Use caution for combinations of W<10N and oil ambient viscosity greater than 1000 cp. We have observed that the roller will not reliably drive the disc and both belts are required under these conditions.

Contact Pressure Calculation

An approximate method for calculating dry contact pressure and contact dimensions follows [1]. The roller crown radius is r_y. The ellipticity ratio is approximated by

$$\mathrm{k} = 1.034\left(\frac{r_y}{r_x}\right)^{0.636}$$

For the ball, $r_y = r_x$ and $\mathrm{k} = 1$.

$$\overline{\mathrm{E}} = 1.0003 + 0.5968\ {}^{r_x}\!/_{r_y}$$

For the ball $\overline{\mathrm{E}} = \pi/2$. The semi-major half width is

$$a = \left(\frac{6}{\pi}\frac{\mathrm{k}^2\overline{\mathrm{E}}\mathrm{W}}{\left(\frac{1}{r_y} + \frac{1}{r_x}\right)\mathrm{E}}\right)^{1/3}$$

and the semi-minor half width is

$$b = a/\mathrm{k},$$

Here, the equivalent modulus is

$$\mathrm{E} = 2\left(\frac{1-\nu_1^2}{\mathrm{E}_1} + \frac{1-\nu_2^2}{\mathrm{E}_2}\right)^{-1}$$

where E_i and ν_i; are elastic modulus and Poison's ratio respectively of material i. The average pressure and Hertz pressures are

$$\bar{p} = \frac{W}{\pi ab}$$

$$p_H = \frac{3}{2}\bar{p}$$

[1] A.B. Peterson and W.O Winer (1980), Wear Control Handbook, ASME.

Film Thickness Measurement

The verticle illumination binocular microscope is provided with interference filters having central wavelengths of $\lambda = 550$ and 589.6 nm. The 589.6 nm filter has a half transmittance band width of 10 nm and will give the sharpest fringe pattern. The sapphire disc may be coated with chromium or inconel to improve the fringe pattern. Coating should be applied until reflectivity reaches 20%. Uncoated sapphire has the advantage of being more durable at the expense of difficult measurements.

A measurement is begun under load with no motion. It is assumed, then, that the film thickness is zero throughout the Hertzian contact. The speed is increased continuously and the rolling velocity is noted for each dark and light fringe at the location of interest. The lubricant thickness is calculated by

$$h = \frac{\lambda}{2n}(N - \Delta\phi)$$

where n is the refractive index of the oil at wave length λ, and at the temperature and pressure existing in the lubricant film at the measurement location. For coated sapphire, the first observable fringe with non-zero velocity is dark and can be assigned the fringe order $N = \frac{1}{2}$. For uncoated discs the first fringe is bright. We arbitrarily assign dark fringes the orders $N = \frac{1}{2}$, $\frac{3}{2}$, $\frac{5}{2}$ ... and bright fringes $N =$ 1, 2, 3..... Now, $\Delta\phi$ is the phase change due to reflection and can be found from calibration with a Newtonian base oil and a regression of formula

$$C + 0.67 \text{ Log } (u_i) = \text{Log}\left[\frac{\lambda}{2n}(N_i - \Delta\phi)\right]$$

Where C is a parameter to be found along with $\Delta\phi$. we find $\Delta\phi$ to be about 0.1 for coated sapphire. For uncoated sapphire, if the first bright fringe is assigned $N = 1$, then $\Delta\phi$ is about 0.66.

Traction Measurement

The Concentrated Contact Simulator is equipped with a strain-guage type load cell to measure the portion of the traction force, F, reacted at the upper disc shaft bearing. The geometry gives us the relationship between F and traction, T, as

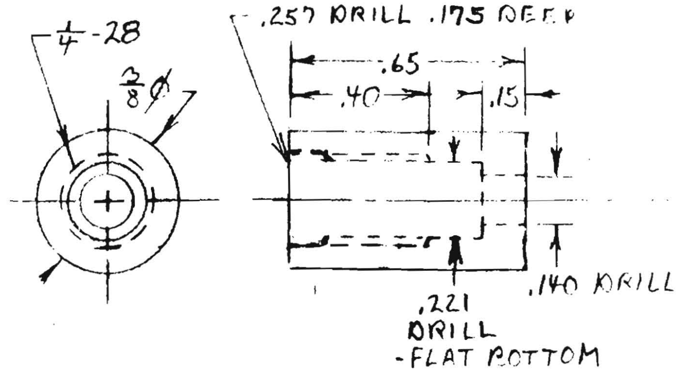
$$T = 1.297\ F$$

A weight equal to 1.0N is supplied with a pulley and string to calibrate the load cell, signal conditioner, and recorder as a system. Let V_c be the recorded change in voltage from the recorder when the calibration weight is applied and lifted. We find that the most reliable (repeatable) traction measurement is obtained by reversing the motor direction while the simulator is operating. The recorded change in voltage, ΔV, represents twice the traction and the load in Newtons is L. The traction coeficient is then

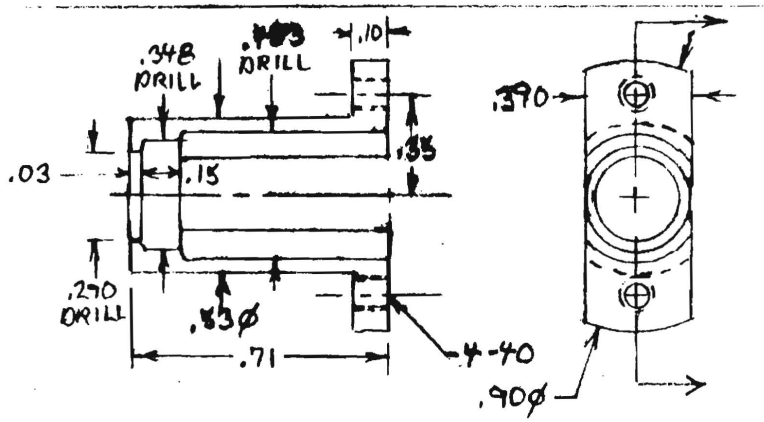
$$C_T = \frac{\Delta V}{2V_c}\frac{1.297}{L}$$

Appendix

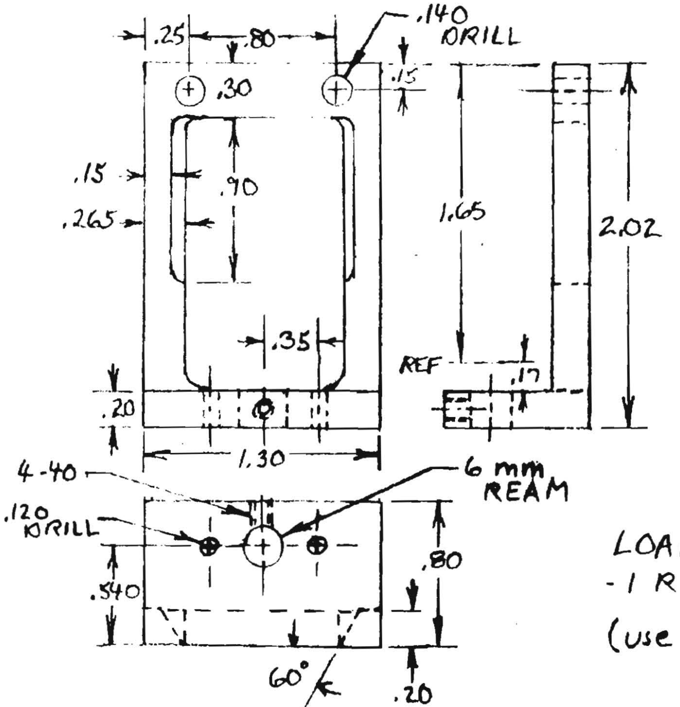
Component Drawings



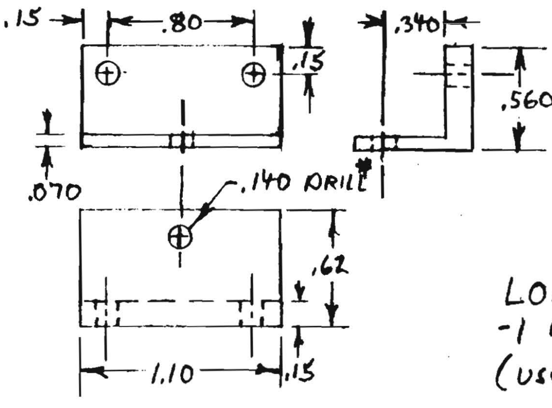
LOAD CELL ADAPTOR - 1 REQ'D
17-4 PH (use with ALD-MINI-UTC)



SPRING HOLDER - 1 REQ'D 2024 ALUM
(use with ALD-MINI-UTC)

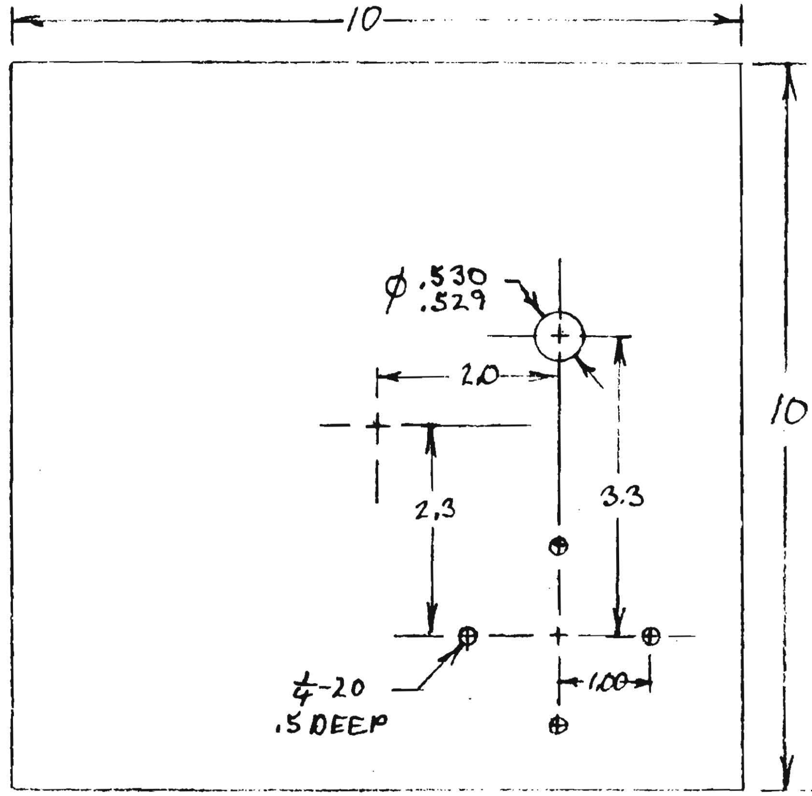


LOAD CELL BRACKET
- 1 REQ'D 2024 ALUM
(use with ALD-MINI-UTC)



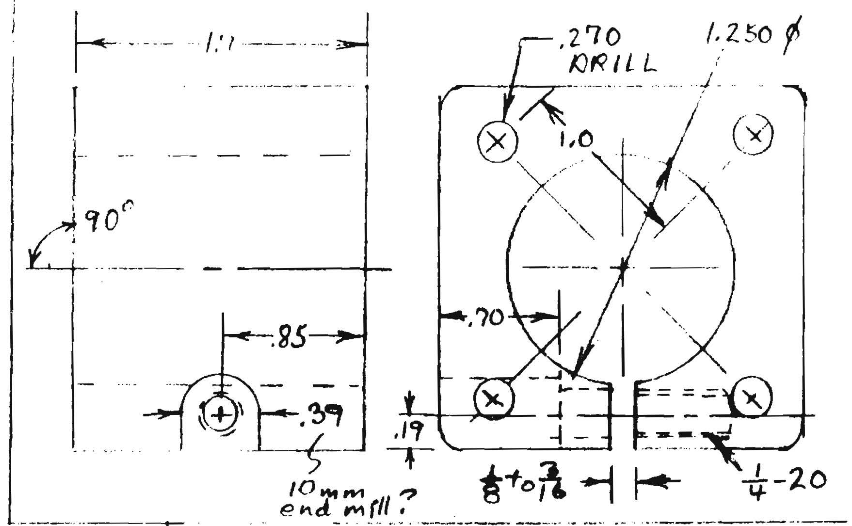
LOAD CELL BRACKET
- 1 REQ'D 2024 ALUM
(use with ALD-MINI-UTC-M)

* 3 PLACES

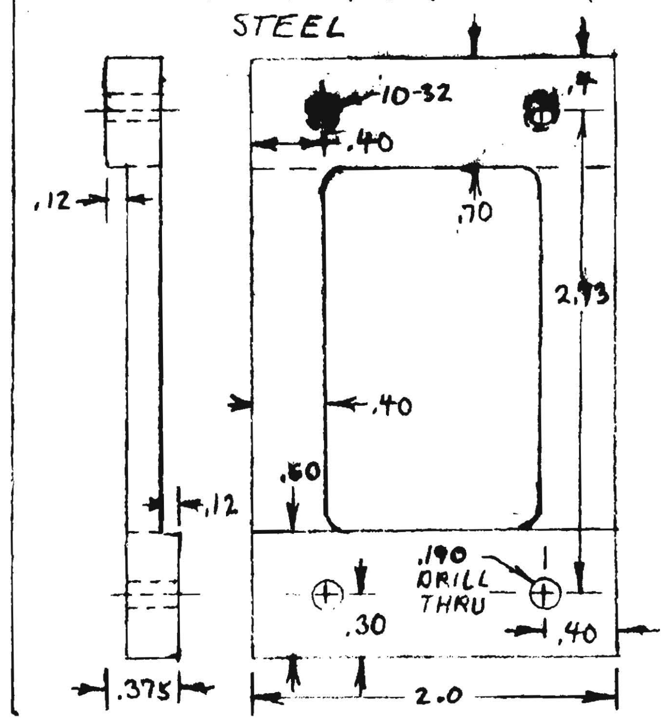


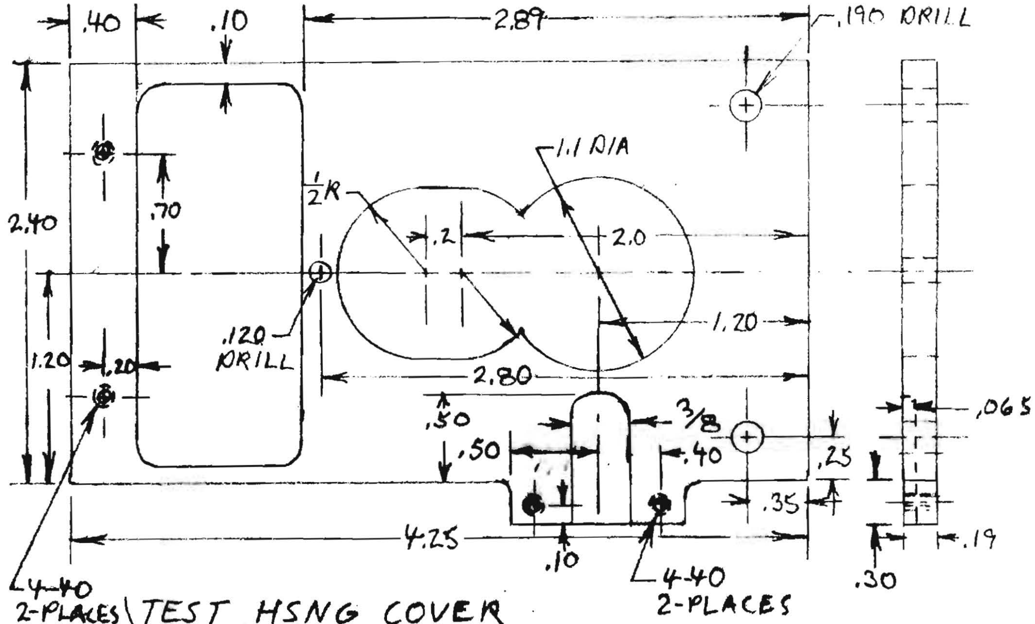
BASE PLATE- 2-REQ'D
¾ ALUM.

ADAPTOR BLOCK - 4 REQ'D
ALUM 2024 2" SQUARE

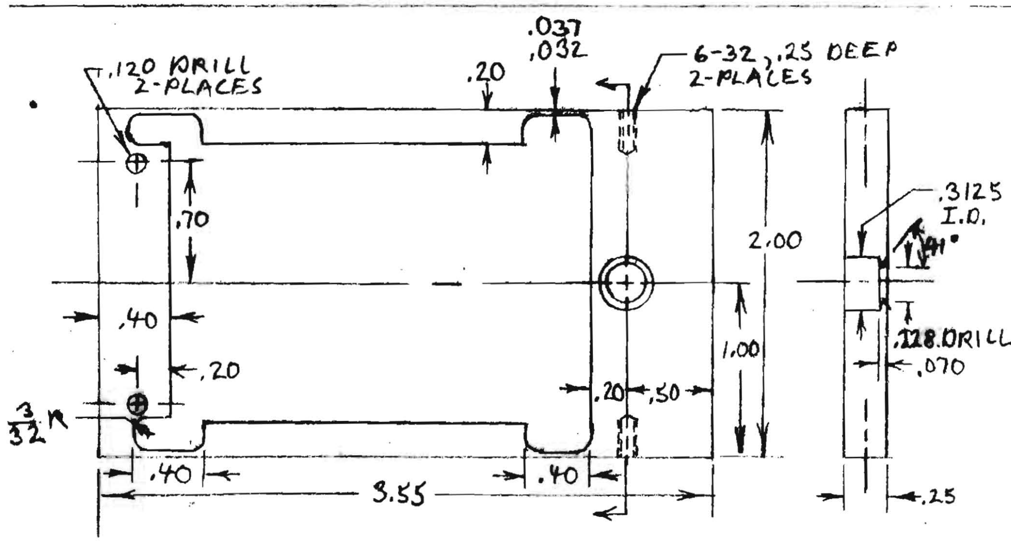


INSULATOR -2 REQ'D
STEEL

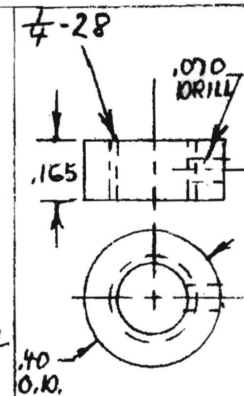




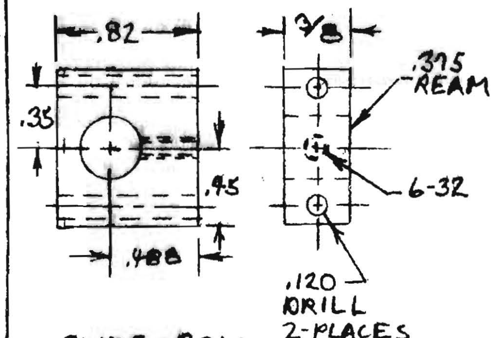
TEST HSNG COVER -2 REQ'D ALUM 2024



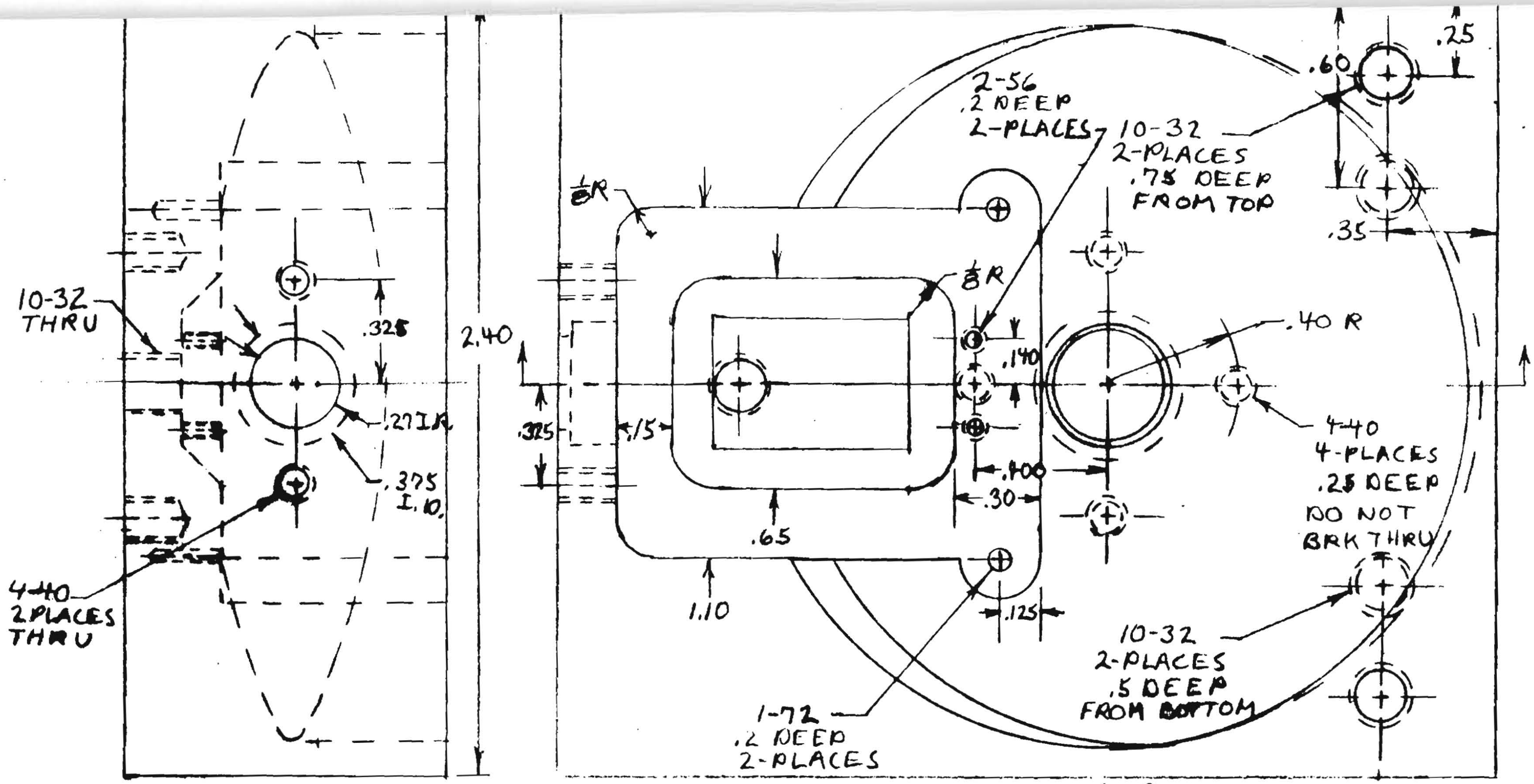
FLEXURE -2 REQ'D 2024 or 7075



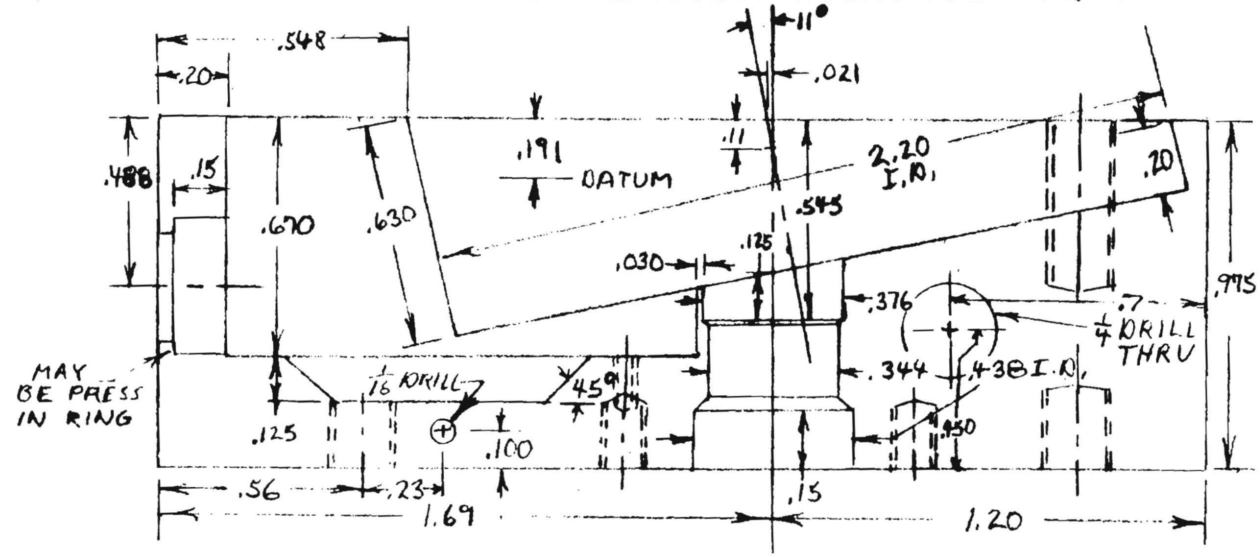
BALL NUT -2 REQ'D 17-4 PH

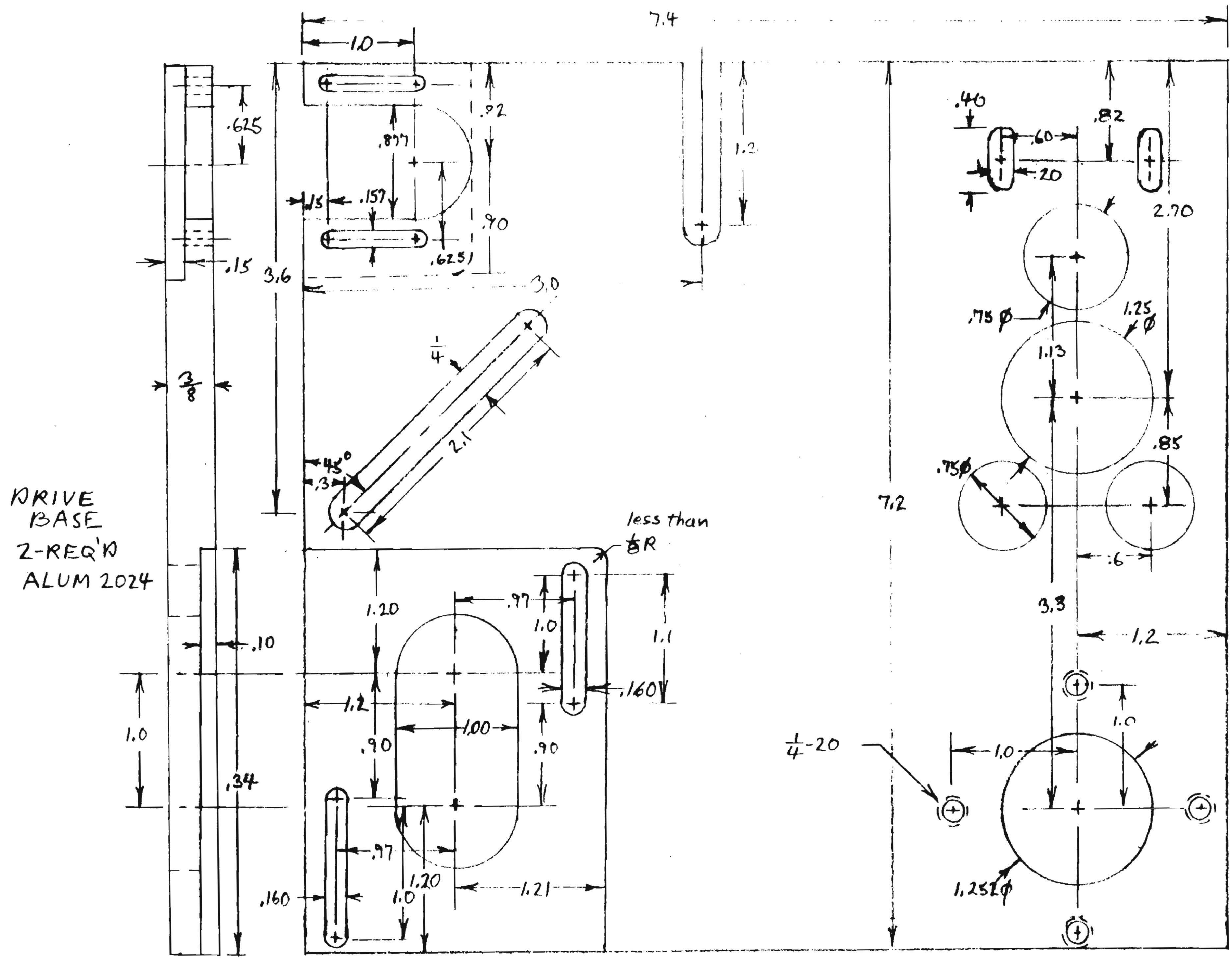


SLIDE-ROLL MICROMETER BLOCK 2-REQ'D 2024

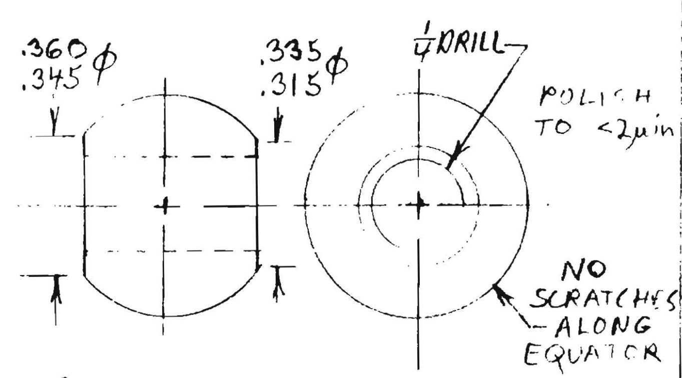


TEST HOUSING
-2 REQ'D - ALUM 2024

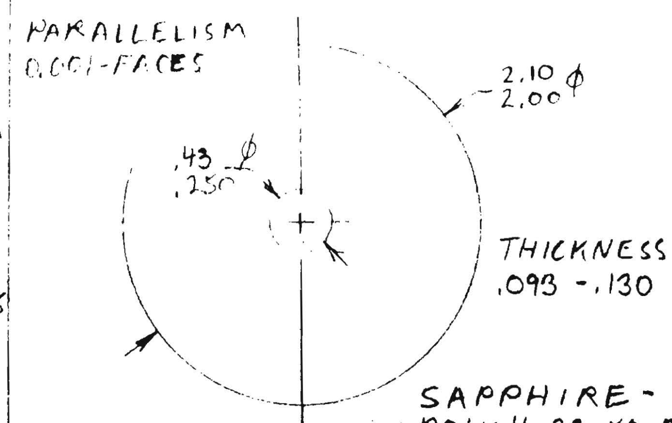




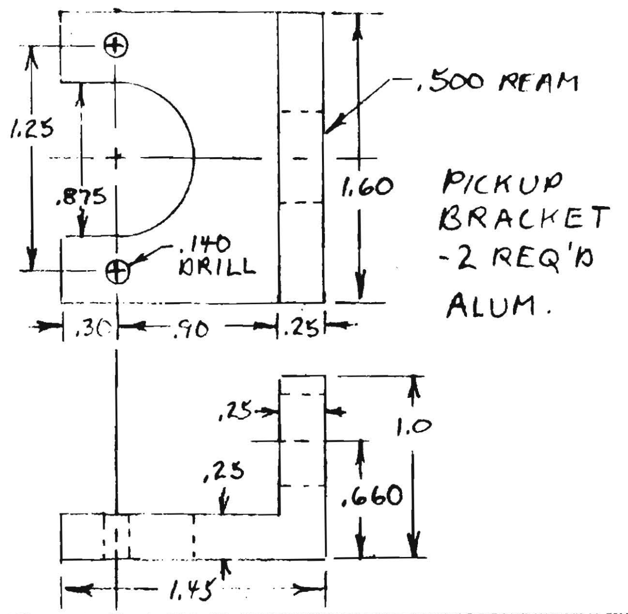
DRIVE
BASE
2-REQ'D
ALUM 2024
7.4
1.0
.625
.15
3/8
.10
1.0
.34
.877
.82
.15
.157
.90
.6251
3.6
3.0
1.2
1/4
2.1
45°
.3
less than
1/8 R
1.20
.97
1.0
1.1
.160
1.2
1.00
.90
.90
.97
1.20
1.0
.160
1.21
7.2
.40
.60
.82
.20
2.70
.75 ø
1.25 ø
1.13
.85
.75ø
.6
3.3
1.2
1.0
1/4-20
1.0
1.252ø



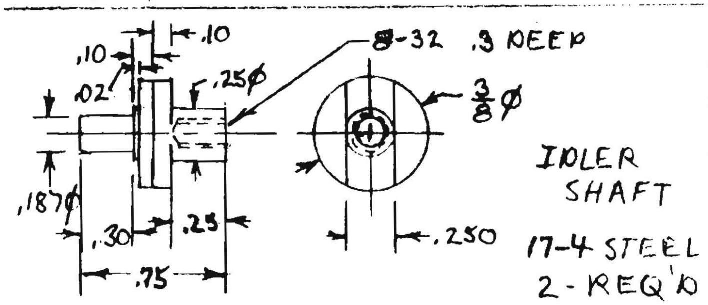
BALL ELEMENT-
MAKE FROM 19/32 BEARING



DISC ELEMENT
SAPPHIRE- POLISH 80-50 BOTH SIDES
STEEL- 52100 or O-1 or similar high carbon
POLISH TO < 2 μin FACES
≥ R_c 59 HARDNESS

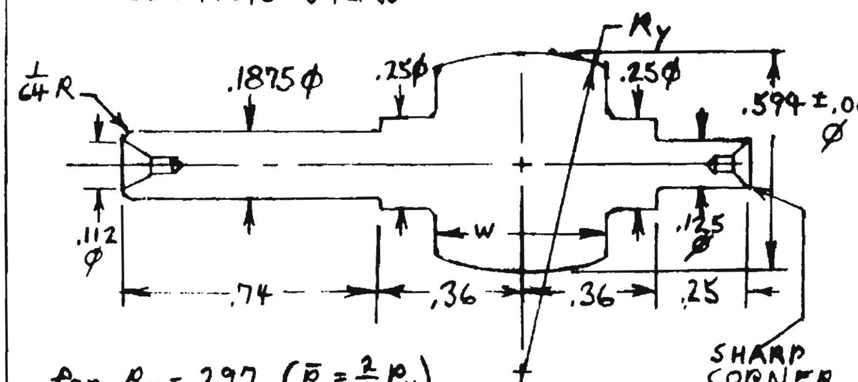


PICKUP BRACKET
-2 REQ'D
ALUM.



IDLER SHAFT
17-4 STEEL
2-REQ'D

SECTION VIEW



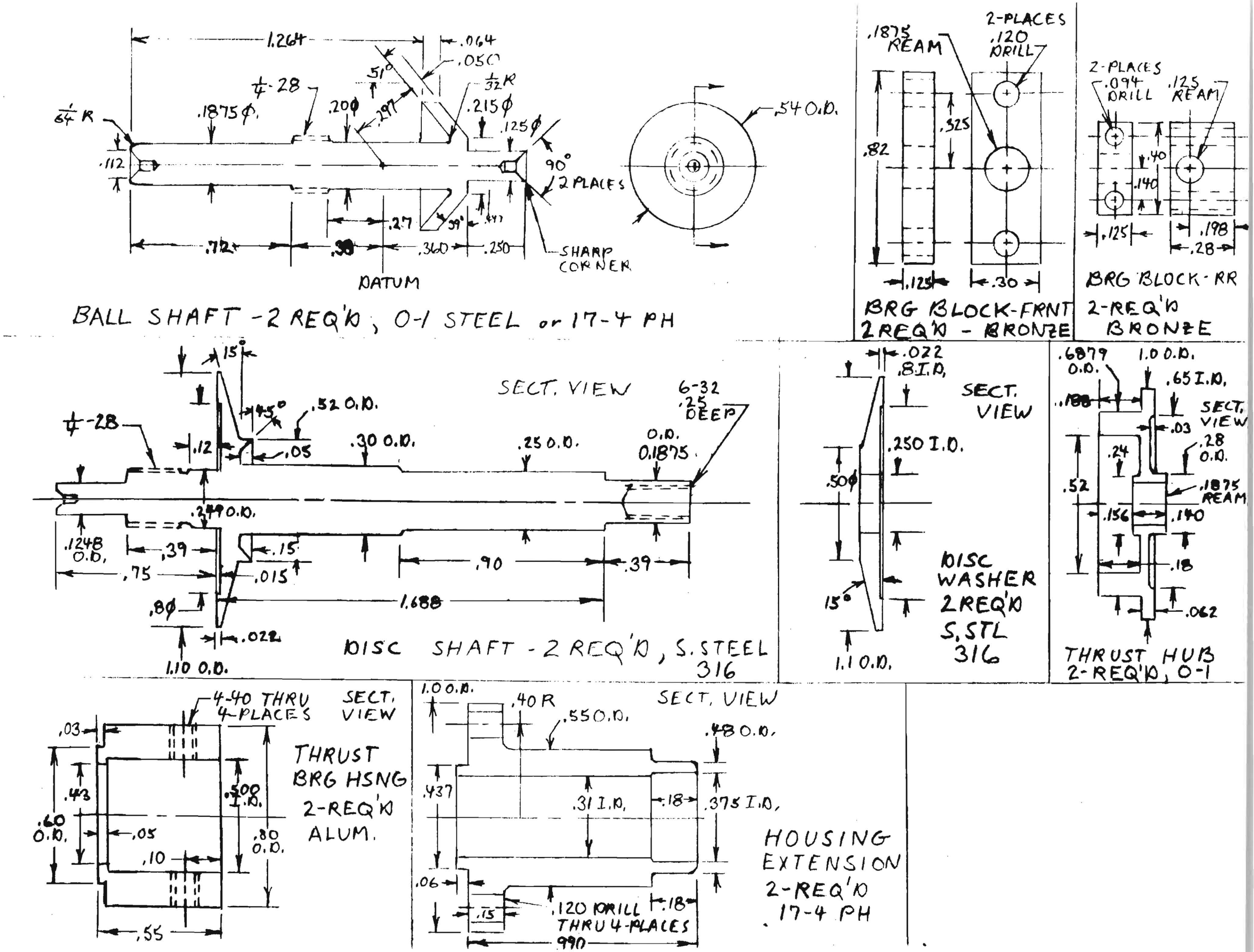
ROLLER ELEMENT-
STEEL-52100
or O-1 or
similar high carbon
≥ R_c 59
POLISH TO <2 μin SURFACE of R_y

For $R_x = .297$ $(\bar{P} = \frac{2}{3} P_H)$

R_y (in.) :	.050	.149	.297	.533	1.59	3.54
ellipticity ratio :	0.333	0.667	1	1.5	3	5
For 20N steel vs. sapphire						
P_H (GPa):	1.83	1.35	1.12	.93	.69	.57
a x b (μm):	42X125	69X103	92X92	124X83	203X68	289X58

contact
hand sanding to shape

w (in) :	.034	.070	.110	.165	.34	.58*


BALL SHAFT - 2 REQ'D, O-1 STEEL or 17-4 PH
1.264
.064
.050
51°
1/4-28
1/32 R
1/64 R
.1875 Ø
.200
.297
.215 Ø
.125 Ø
.112
90°
2 PLACES
.27
39°
.441
.72
.30
.360
.250
DATUM
SHARP CORNER
.540 O.D.
BRG BLOCK-FRNT
2 REQ'D - BRONZE
.1875 REAM
2-PLACES
.120 DRILL
.82
.325
.125
.30
BRG BLOCK-RR
2-REQ'D
BRONZE
2-PLACES
.094 DRILL
.125 REAM
.40
.140
.125
.198
.28
DISC SHAFT - 2 REQ'D, S. STEEL 316
SECT. VIEW
15°
45°
1/4-28
.52 O.D.
.12
.05
.30 O.D.
.25 O.D.
6-32
.25 DEEP
O.D.
0.1875
.249 O.D.
.1248 O.D.
.39
.15
.75
.015
.90
.39
.80
1.688
.022
1.10 O.D.
DISC WASHER
2 REQ'D
S. STL 316
SECT. VIEW
.022
.8 I.D.
.250 I.D.
.50 Ø
15°
1.1 O.D.
THRUST HUB
2-REQ'D, O-1
.6879 O.D.
1.00 O.D.
.65 I.D.
.188
SECT. VIEW
.03
.24
.28 O.D.
.52
.1875 REAM
.156
.140
.18
.062
THRUST BRG HSNG
2-REQ'D
ALUM.
SECT. VIEW
4-40 THRU
4-PLACES
.03
.43
.500 I.D.
.60 O.D.
.05
.80 O.D.
.10
.55
HOUSING EXTENSION
2-REQ'D
17-4 PH
SECT. VIEW
1.00 O.D.
.40 R
.550 O.D.
.480 O.D.
.437
.31 I.D.
.18
.375 I.D.
.06
.15
.120 DRILL
THRU 4-PLACES
.18
.990