THERMALLY ACTUATED VALVES

CONTRACT NO. 952762

FINAL REPORT NO. 14936-6001-R000 JULY 1970

Prepared for

THE JET PROPULSION LABORATORY
PASADENA, CALIFORNIA 91103

TRW SYSTEMS GROUP
ONE SPACE PARK · REDONDO BEACH, CALIFORNIA

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This work was performed for the Jet Propulsion Laboratory, California [illegible] Technology, sponsored by the National A[illegible]s and Space Administration under Contract NAS7-100.

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PASADENA, CALIFORNIA 91103
under Contract No. 952762

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TRW SYSTEMS GROUP

FOREWORD

This report was prepared by TRW Systems Group, Redondo Beach, California, and describes the results of a program to study, design, fabricate and evaluate two types of thermally actuated valves. The work described was accomplished between 15 December 1969 and 15 July 1970 for the Jet Propulsion Laboratory (JPL) of the California Institute of Technology, Pasadena, California, as a subcontract under National Aeronautics and Space Administration Contract NAS 7-100. The JPL Technical Manager was Mr. George Hotz.

The work performed on the program was accomplished by TRW Systems Group, Science and Technology Division. Mr. M. J. Makowski of the Applied Research Section of the Applied Technology Department was Program Manager. The technical efforts provided by several TRW Systems Group personnel are acknowledged:

Mr. C. E. Armstrong
Mr. N. J. Davenport
Mr. N. H. Doshi
Mr. O. O. Fiet

CONTENTS

1.0 BACKGROUND

Valving for use in the control of analytic instruments employed in planetary landers must be small, light and economical of power. This is due to the severe weight, size and power storage limitations on spacecraft being designed for landings on other planets - such as Mars. The valving must also be highly reliable, meet extremely stringent leakage requirements, and employ only materials which will not mask the analytic functions being performed.

Tight leakage requirements are more easily met if relatively large seat forces may be generated. High seat forces are difficult to obtain while maintaining small size and weight if conventional solenoid valve actuators are used. Thermal expansion actuators are capable of exerting very large forces in a relatively small sized package. The two valve types developed on this program utilize two different types of thermal expansion actuators, a polyimide rod actuator and a silicone rubber actuator. Both valves employ magnetic latching so they may be held open for long periods with no power drain. One of the valves is intended to control high pressure hydrogen gas while the other is a vacuum valve.

The program consisted of trade studies, design, fabrication and test of the two types of valves.

2.0 TRADE STUDIES AND CALCULATIONS

The trade studies were performed to identify the anticipated response times based on preliminary design data. The complete calculations are presented in Appendix I. The calculations show that the polyimide rod actuated high pressure valve would require approximately 23 watts to actuate the valve in 30 seconds from 50°C, and that the vacuum valve would require an actuation power of 35 watts for a 30 second actuation time. The power requirements are reduced drastically as allowable actuation times are increased and the allowable times between cycles are extended.

Appendix I also contains the magnetic design calculations for the latch and the design calculations for the silicone rubber thermal actuators.

3.0 DESIGN

The designs were based on minimizing size, weight and power within the performance parameters specified. These parameters or design goals are itemized in 3.1 below.

3.1 DESIGN GOALS

The size, weight, power and operational goals are:

- Weight - less than 15 grams
- Volume - less than 1/2 cubic inch
- Peak Power - less than 15 watts
- Voltage - approximately 28 volts dc
- Total Electrical Energy - to be minimized
- Maximum Time to Actuator (open or closed) - 30 seconds
- Maximum Dead Time (time between actuations) - 2 minutes
- Valve Internal Size (bore):
  - High pressure valve - .010 to .030 inch
  - Vacuum valve - approximately .060 inch
- Valve Poppet Stroke:
  - High pressure valve - .010 to .020 inch
  - Vacuum valve - approximately .080 inch
- Poppet Seating Forces - approximately 3 lbs for both valves
- Seat Design - substantially per JPL sketch 11-6-69
- Leakage Goals:
  - Internal leakage - 10^{-8} sccs He at one atmosphere pressure differential
  - External leakage - 10^{-6} sccs He at one atmosphere pressure differential
- Maximum Internal Operating Pressures:
  - High pressure valve - 3000 psi
  - Vacuum valve - 30 psi
- Valves are normally closed, i.e., closed for many months, but in operating will be opened a total of about 25 times for a period of one (1) hour each cycle; valves shall require no power when closed.

The expected environmental conditions are:

	High Pressure Valve	High Pressure Valve	Vacuum Valve	Vacuum Valve Actuator
Maximum Temperature	135°C[1]	135°C[1]	225°C[2]	135°C[1]
External Pressure	1,000 mb (earth)			
	520 mb (Mars)			
Maximum Shock	30 g 30 milliseconds			
Maximum Acceleration	25 g			

[1]Sterilization Temperature [2]Operating Temperature

3.2 HIGH PRESSURE VALVE DESIGN

Two approaches were considered to the high pressure valve; the first utilizing a silicone rubber thermal actuator, the second a polyimide rod actuator. Calculations defining actuator size are presented in Appendix I. The silicone rubber actuator is capable of higher strokes per degree actuator temperature rise, however, it would require a seal to isolate it from the hydrogen gas. This seal is required to prevent contamination of the gas supply and would preferably be a bellows or diaphragm. The polyimide actuator stroke per degree is lower, however, it does not outgas to a significant degree at the use temperature, therefore, it may be immersed in the hydrogen carrier gas. This capability of placing the actuator within the flow media completely eliminated the requirement for dynamic sealing in the high pressure valve. It was felt that this was a significant design simplification and a certain improvement in overall design reliability, therefore, the final design for the high pressure valve was based on the polyimide rod actuator.

The final high pressure valve design is shown in Figure 1. Detail drawings are presented in Appendix II. An alternate approach considered using a silicone rubber actuator is shown in Figure 2. Following initial design consideration a need was expressed for latching open with no power on the valve. The final design of Figure 1 indicates the magnetic latch utilized for this unit. A magnetic latch was chosen for its simplicity and reliability; and because it eliminated the need for dynamic seals in the latching device.

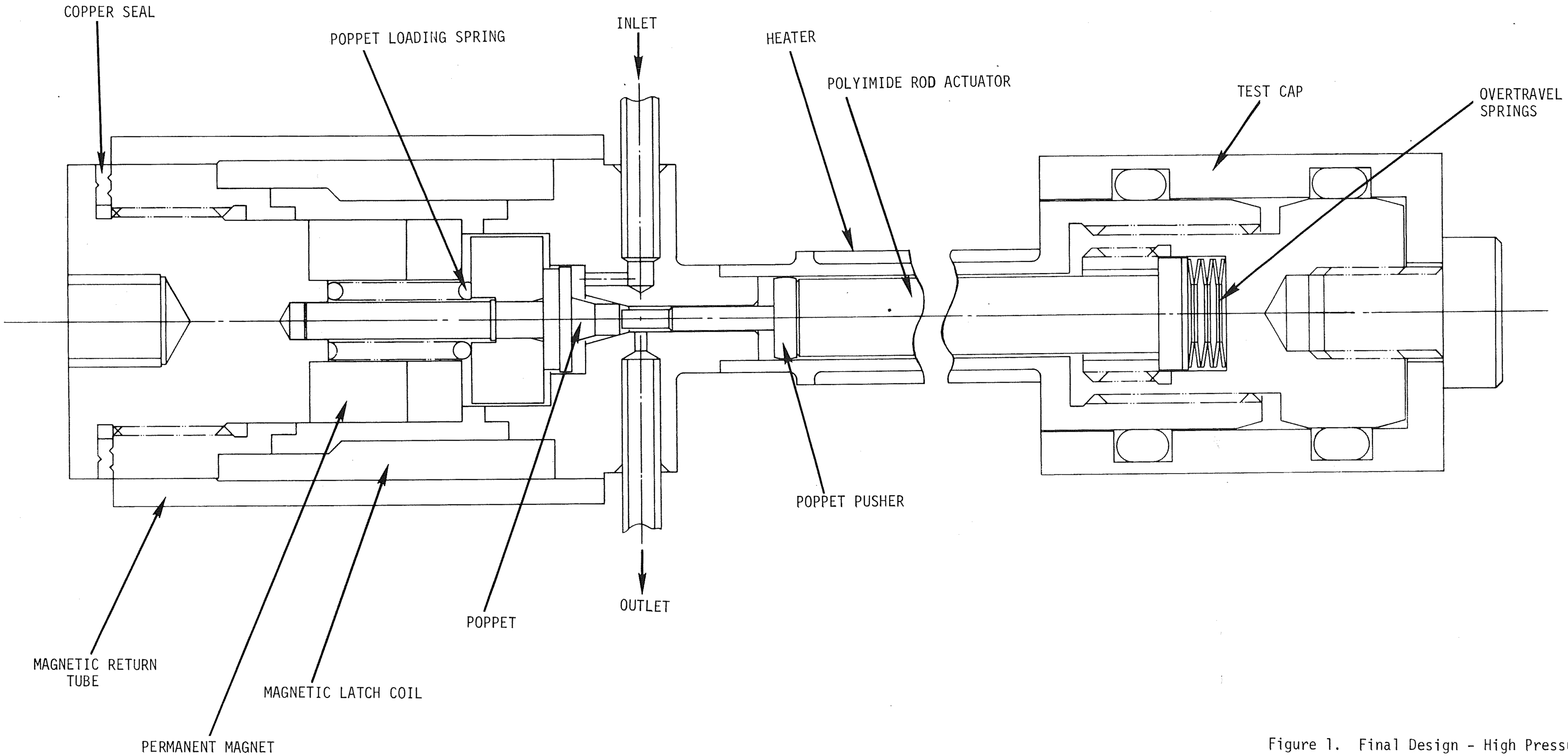


Figure 1. Final Design - High Pressure Valve

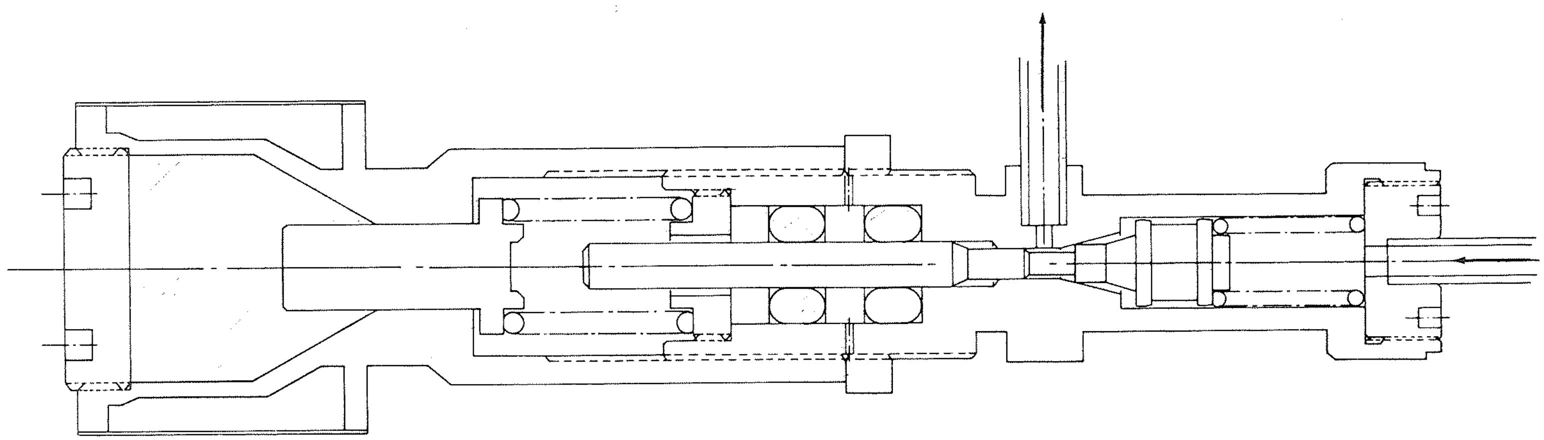


Figure 2. High Pressure Valve - Silicone Rubber Actuator

NOTE: Drawn 10X size, photo reduced 2.5X to 4X size.

The valve operates as follows: When power is applied to the heater it heats the polyimide rod actuator which expands pushing the poppet off its seat and opening the valve. The magnetic latch coil is then momentarily energized and the valve is latched open due to the magnetic forces generated by the permanent magnet. The heater is de-energized and the valve remains open until it is commanded to close with no power being dissipated. To close the valve the latch coil is momentarily energized with reverse polarity and at about one-third the voltage relative to latching open. This releases the poppet and allows the valve to snap shut. This technique results in a valve with a relatively slow opening time - with high opening force capabilities - and a short closing time.

3.3 VACUUM VALVE DESIGN

Two major approaches were considered for the vacuum valve. An approach incorporating the latch mechanism within the vacuum space and an approach wherein the latch is outside the vacuum space. In the former approach (see Figure 3), the actuator piston may push directly on the poppet to open the valve. Piston to valve housing sealing is provided by a bellows. In the latter approach, however, a method of pulling the valve open must be devised or two bellows seals must be used; one to seal the actuator piston and one to seal the latch. Two approaches minimizing mechanical parts exposed to the vacuum are shown in Figures 4 and 5. One approach utilizes a coaxial actuator concept where the silicone rubber expands against a differential piston, the other uses a direct acting piston and direction reversing mechanism. Evaluation testing indicated development problems existed in the application of the coaxial actuator (see Section 5.3), therefore the final design was based on the direct acting approach shown in Figure 5. Detail drawings of the valve are presented in Appendix III.

The valve operates as follows: When power is applied to the heater the silicone rubber actuator pellet is heated and expands pushing the piston against the housing. The actuator pulls the valve stem through the over-travel assembly opening the valve. When the valve is fully open a pulse of electrical energy is applied to the latch coil energizing the latch. The heater power is now turned off and the valve will remain open until commanded to close. Actuator retraction is assisted by the actuator return spring. Closure is commanded by applying a pulse of electrical energy of reverse polarity to the latch assembly, partially demagnetizing the magnet. The valve portion itself is bellows sealed and contains no organic materials other than the Vespel polyimide poppet. The housing has been grooved around the bellows to allow quick pumpout and eliminate trapped gas volumes.

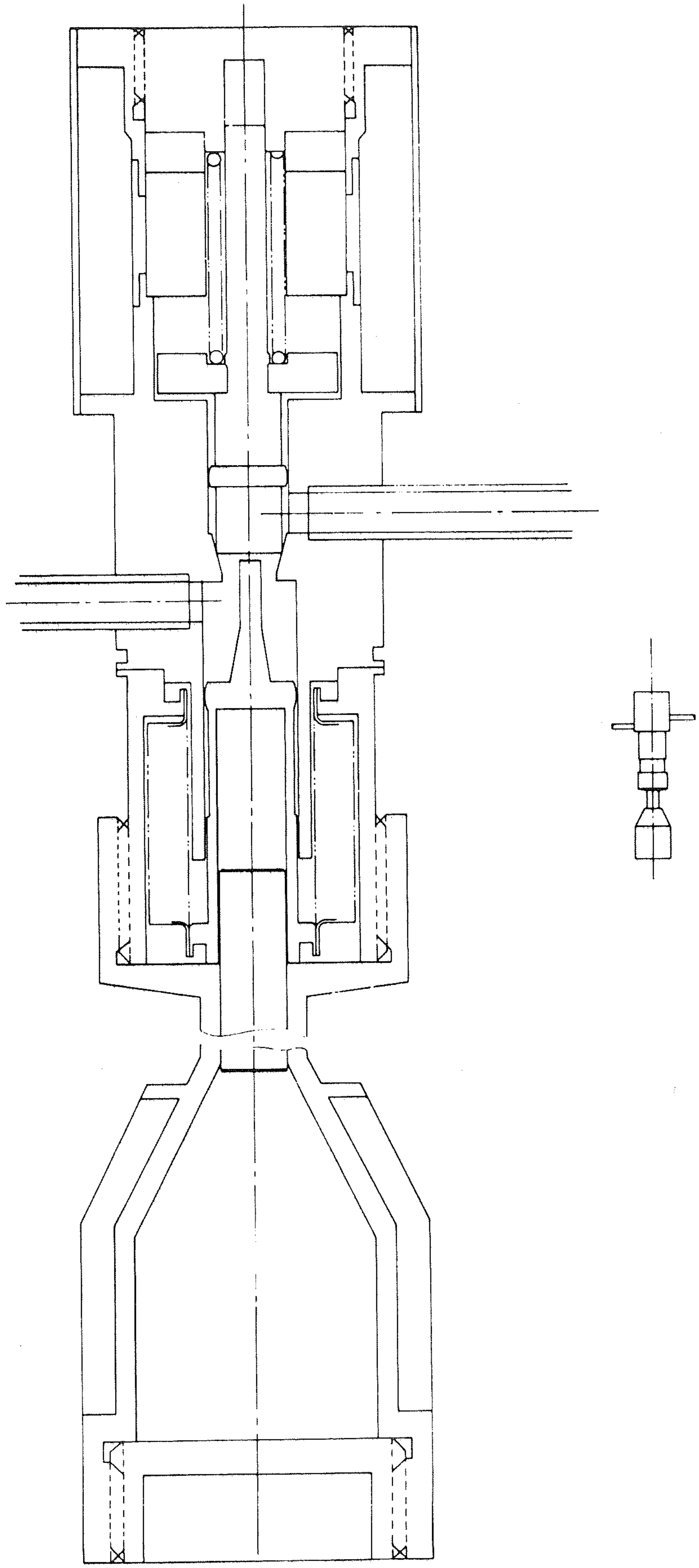
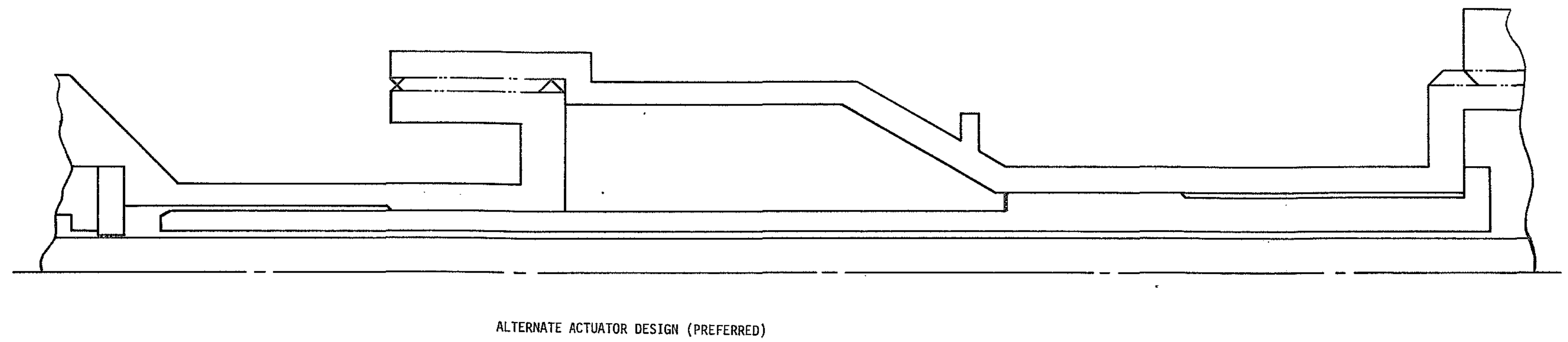


Figure 3. Vacuum Valve - Internal Latch



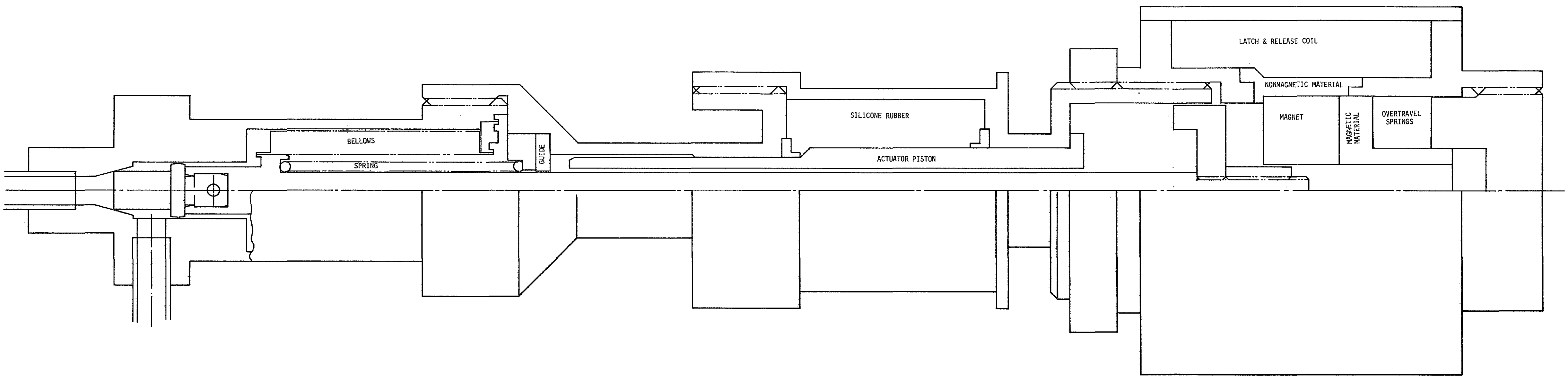


Figure 4. Vacuum Valve - Coaxial Actuator

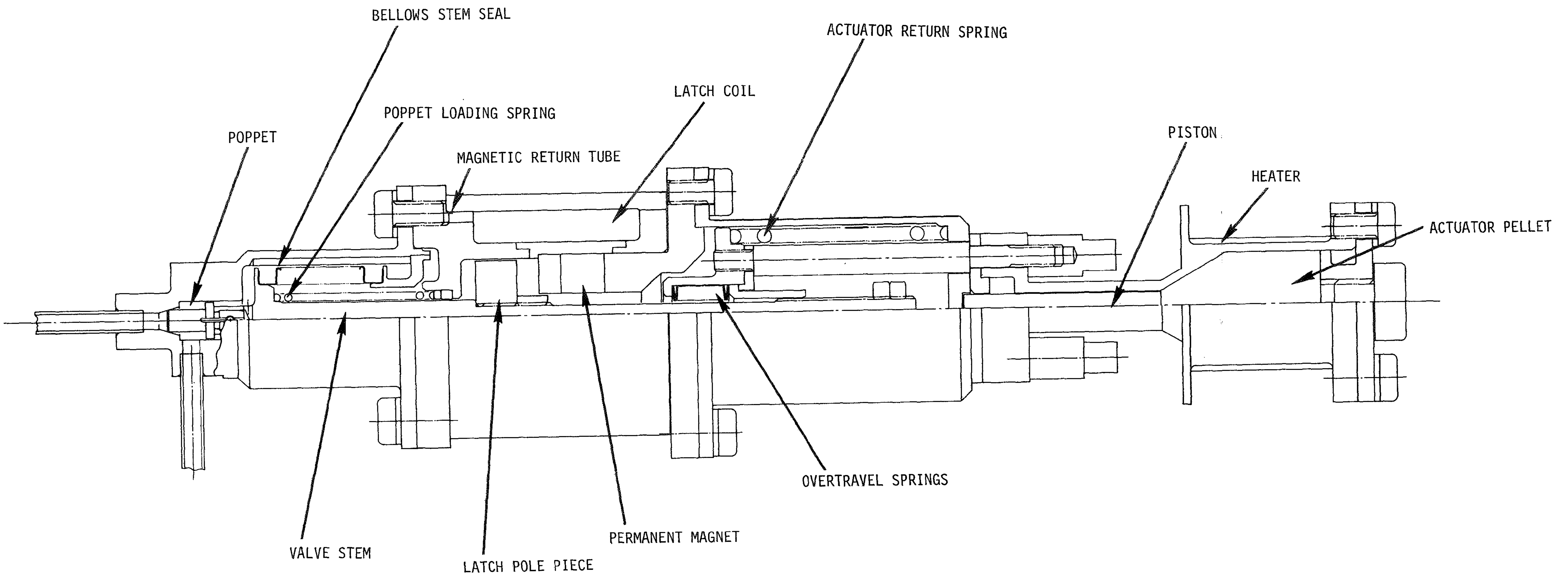


Figure 5. Final Design - Vacuum Valve
(Photo reduced to approx. 3.5X Size)

4.0 FABRICATION

Both valves were fabricated in the TRW Engineering Research Shop using conventional machinery and tooling. Brazing, where required, was performed in vacuum using NIORO (67 cu 23 AN) braze alloy. Welding was limited to TIG fusion welding without filler metal.

4.1 HIGH PRESSURE VALVE FABRICATION

High pressure valve fabrication was performed in the following stages:

a) The actuator housing was machined, the valve body and latch housing were rough machined.

b) The actuator housing, valve body and latch housing including the nonmagnetic separator were brazed together. An initial braze sample was pull tested to failure by applying a programmed linearly increasing load at a rate of 100 lbs per second. Failure occurred in the shear in the smallest braze joint, where the actuator housing attaches to the valve body, at a load of 1565 pounds. This corresponds to a joint shear stress of approximately 45,000 psi. The load applied exceeded the anticipated load due to the internal proof pressure of 4500 psi by a factor of 3.2. A photograph of the test sample showing the failure is presented in Figure 6. Following sample testing, the actual valve parts were brazed using the same alloy. Figure 7 shows the valve parts prior to brazing while Figure 8 shows the brazed high pressure valve housing assembly prior to application of the heater. Subsequent to brazing the valve housings were final machined and sent out for heater application.

   The heater consists of a layer of insulating ceramic fused to the surface of the actuator housing followed by a layer of conductive ceramic, which forms the heating element. The entire heater is then protected by an external silicone insulation compound. The heater installation was performed by Thermolab, Inc., of North Hollywood, Calif. A problem was initially encountered in finding a ceramic frit matching the expansion coefficient of the actuator housing,

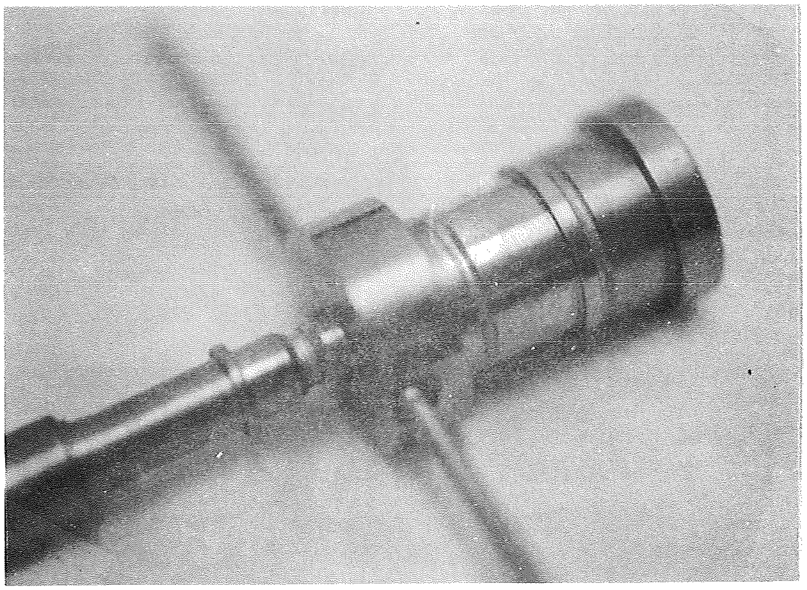


Figure 6. Braze Pull Test Sample
After Testing

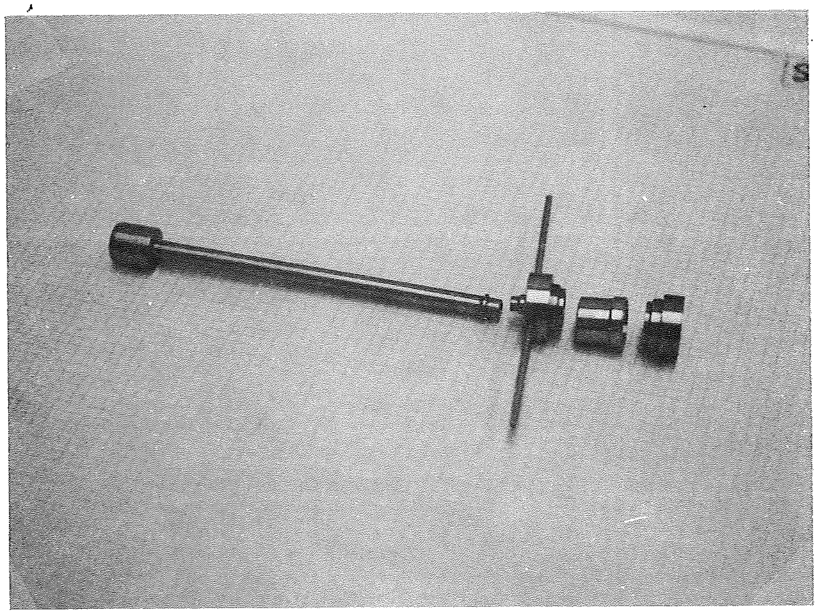


Figure 7. High Pressure Valve
Housing Parts

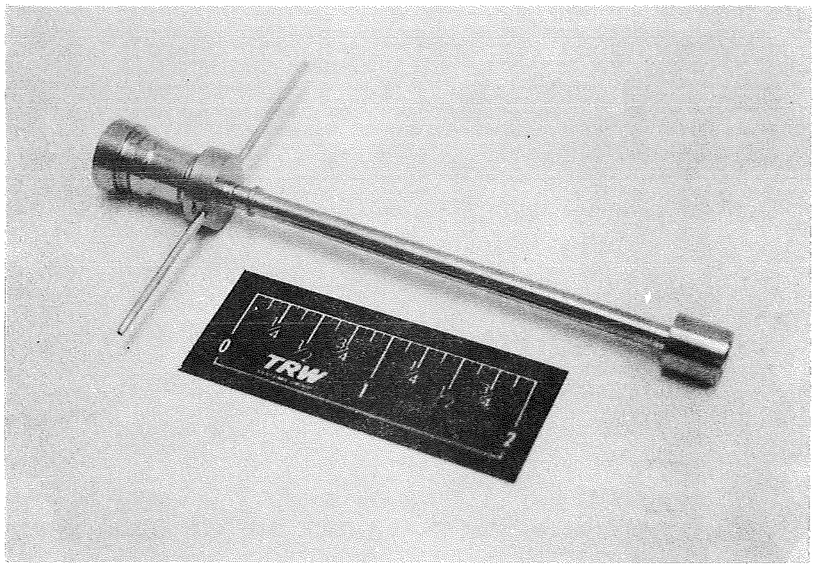


Figure 8. High Pressure Valve Housing
After Brazing

however, this was overcome by proper ceramic material selection. A more serious problem occurred due to the scaling and discoloration of the valve/ actuator housing occurring during the firing fusing the ceramic heater assemblies. This necessitated a considerable amount of cleanup and some remachining. It is recommended that on further valves, final internal machining be delayed until after heater application or that the firing to fuse the coating is done in an inert atmosphere.

4.2 VACUUM VALVE FABRICATION

Vacuum valve fabrication consisted of the following stages, some of which were carried on concurrently.

a) The valve body and other details were machined.

b) The tubes were brazed into the body and the body brazed together using NIORO (67% Cu, 23% Au) braze alloy.

c) The nickel stem seal bellows were fabricated and welded to the valve stem and bellows adaptor.

d) The poppets were assembled to the valve stems. The valve bodies were leak checked and seat leakage was measured.

e) The bellows adaptors were welded to the valve body.

f) Valve body, bellows, joint and seat leakage were checked.

g) The latch coils were wound and latch subassembly performed.

h) The total valve-latch-assembly was performed.

i) Actuator pellets were molded of Dow Corning MDX 4514 silicone rubber and heat cured.

j) The actuator housings were sent out for heater application. The heaters applied are single wire nichrome elements insulated with silicone rubber and molded directly to the actuator housing. The heater application was performed by Electrofilm, Inc., of North Hollywood, Calif.

k) The actuator pellets were installed into the actuators and the valves functionally tested.

5.0 TESTING

Testing consisted of functional and leak testing for both valves. The specific tests performed are itemized below. In addition, 5.3 summarizes testing performed on the coaxial silicone rubber valve actuator.

5.1 HIGH PRESSURE VALVE

The high pressure valve test sequence consisted of the following:

5.1.1 Proof Test

Each valve housing was hydrostatically proof tested to a pressure of 4750 psi and examined for any permanent structural deflections. No permanent deformation or structural damage was evident.

5.1.2 Housing Leakage

Each valve housing was leak checked after proof testing using a helium mass spectrometer leak detector. The leakage measurements were performed by pressurizing the inside of the valve housing to approximately 25 psig while set up in an evacuated bell jar which was hooked up to the leak detector. Thus, the leakage measured include all fitting leakages as well as the actual housing leakage. External valve leakages are shown on the attached data sheets, Tables 1 and 2.

5.1.3 Internal Leakage

Following external leakage testing the valves were assembled and checked for internal leakage in the same setup as described in 5.1.2. The inlet was pressurized to approximately 25 psig while the valve outlet was left open to the bell jar and, hence, the leak detector. The measurements made in this manner were actually a summation of internal, external and fitting leakages. The measured leakages are shown in Tables 1 and 2.

5.1.4 Functional Testing

Functional testing consisted of seating and latch load measurements followed by setting the actuator to open the valve at a temperature in excess of

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TABLE 1

HIGH PRESSURE THERMALLY ACTUATED VALVE

P/N SK 1190-040 S/N 2

PROOF PRESSURE 4750 PSIG

FORCE TO OPEN VALVE

LATCH UNMAGNETIZED	LATCH MAGNETIZED (NO POWER)
3.09 LBS	2.46 LBS

FORCE AT VALVE CLOSURE

LATCH UNMAGNETIZED	LATCH MAGNETIZED (NO POWER)
1.65 LBS	1.15 LBS

VALVE STROKE (LATCHED OPEN TO CLOSED) .010 IN

HEATER RESISTANCE 19.3 @ 26 °C
@ °C

LATCH COIL RESISTANCE 36.0 @ 26 °C
@ °C

SEAL THICKNESS .0205 IN. CAP TORQUE 60 IN-LBS

EXTERNAL LEAKAGE (TOTAL) 4.93×10^{-8} SCCS He @ 15 PSI

INTERNAL LEAKAGE (INCLUDES EXT. LEAKAGE)

4.93×10^{-8} SCCS He @ 15 PSI after pressurizing to 2000 PSI
1.0×10^{-4} SCCS He @ 25 PSI after pressurizing to ⊖ PSI
SCCS He @ PSI after pressurizing to PSI

ACTUATOR TEMPERATURE AT VALVE OPENING 149 °C @ 1000 PSI
165 °C @ 2000 PSI

TIME TO OPEN 28 SEC @ 28 VOLTS
1700 psi 68 SEC @ 20 VOLTS

TIME BETWEEN CYCLES 60 SEC

Szyplakowicz
4-9-70

4-6-70

TABLE 2

HIGH PRESSURE THERMALLY ACTUATED VALVE

P/N SK 1190-040 S/N 3

PROOF PRESSURE 4750 PSIG

FORCE TO OPEN VALVE

LATCH UNMAGNETIZED	LATCH MAGNETIZED (NO POWER)
3.25 LBS	2.95 LBS

FORCE AT VALVE CLOSURE

LATCH UNMAGNETIZED	LATCH MAGNETIZED (NO POWER)
1.35 LBS	.80 LBS

VALVE STROKE (LATCHED OPEN TO CLOSED) .010 IN

HEATER RESISTANCE 19.4 @ 30 °C

@ °C

LATCH COIL RESISTANCE 36.8 @ 30 °C

@ °C

SEAL THICKNESS .023 IN. CAP TORQUE 60 IN-LBS

EXTERNAL LEAKAGE (TOTAL) 3.5×10^{-9} SCCS He @ 25 PSI

INTERNAL LEAKAGE (INCLUDES EXT. LEAKAGE)

2.9×10^{-9} SCCS He @ 15 PSI after pressurizing to 2000 PSI

4.9×10^{-3} SCCS He @ 25 PSI after pressurizing to 0 PSI

SCCS He @ PSI after pressurizing to PSI

ACTUATOR TEMPERATURE AT VALVE OPENING 140 °C @ 1000 PSI

172 °C @ 2000 PSI

TIME TO OPEN 2000 PSI 32 SEC @ 28 VOLTS CLOSE TIME ~ 1 min.

85 SEC @ 20 VOLTS LATCH VOLTAGE 28V.

TIME BETWEEN CYCLES 60.0 SEC

[signature] 4-9-70

135°C and by performance tests to identify the opening time at rated voltages and the time between cycles (closing time for the thermal actuator). The opening temperatures were set between 165 and 175°C at 2000 psi inlet pressure. Opening times and times between cycles were 28 to 32 and 60 seconds, respectively. Complete performance data is presented in Tables 1 and 2.

Following functional testing the valves were packaged and transmitted to JPL.

5.2 VACUUM VALVE TESTING

The vacuum valves were tested as follows:

5.2.1 Body Leakage

The valve bodies were leak checked with a helium mass spectrometer leak detector. No leakage was found at a machine sensitivity of 2×10^{-10} sccs.

5.2.2 Seat Leakage

The valve seats were leak checked with only bellows load and pressure force holding the valve seated. This was used to screen for leakage before welding the bellows adaptor to the valve body.

5.2.3 Overall Leakage

After welding the bellows adaptor to the valve body another leakage series was run utilizing the mass spectrometer. This resulted in no detectable valve of housing leakage at a sensitivity of 2×10^{-10} sccs.

5.2.4 Functional Testing

Functional testing of the vacuum valve consisted of setting the actuator opening temperature to a valve above 135°C and actuation at rated voltage to define actuation time and time between cycles. Valve opening was set between 143 and 172°F by running the heater at reduced voltage. The valve actuator opening temperature, actuation times at 20 volts input and times between cycles are shown in Table 3. Valve opening was observed by applying

TABLE 3

Valve	Leakage* Sccs		Open Temp. °C	Actuation Time @ 20 Volts Sec.	Dead-Time Sec
	External	Internal			
001	0	0	149	90	100
002	0	0	153	80	100
004	0	0	143	80	100
005	0	0	172	105	120

*By He mass spectrometer at a sensitivity of 2.4×10^{-10} sccs.

low pressure (~1 psi) nitrogen to the outlet port and monitoring flow at the inlet port. A short duration electrical input of 28 volts was used to engage the latch when the valve had opened fully. A 5-6 volt input of opposite polarity was required to unlatch and close the valve.

Following functional testing the valves were packaged and shipped to JPL.

5.3 COAXIAL SILICONE RUBBER ACTUATOR TESTING

The coaxial valve actuator simplifies the construction of the vacuum valve, however, no test data was available on the coaxial silicone rubber actuator. An actuator test fixture was therefore designed and fabricated to investigate the performance characteristics of this unit. A cross-sectional view of the actuator test fixture is shown in SK 1190-001, which is attached. Figure 9 is a photograph showing the disassembled actuator test fixture. Rubber actuator pellets were molded from three candidate rubber compounds in a closed mold which is shown disassembled in Figure 10. Actuator pellets were molded from Dow Cornint RTV 3118, MDX 4514 and General Electric RTV 615.

Initial testing indicated a high level of friction between the piston rod and the rubber matrix resulting in excessive loads to return the piston after extension and high temperature requirements for extension. In addition, some of the rubber was lost by extrusion past the piston rod at the large

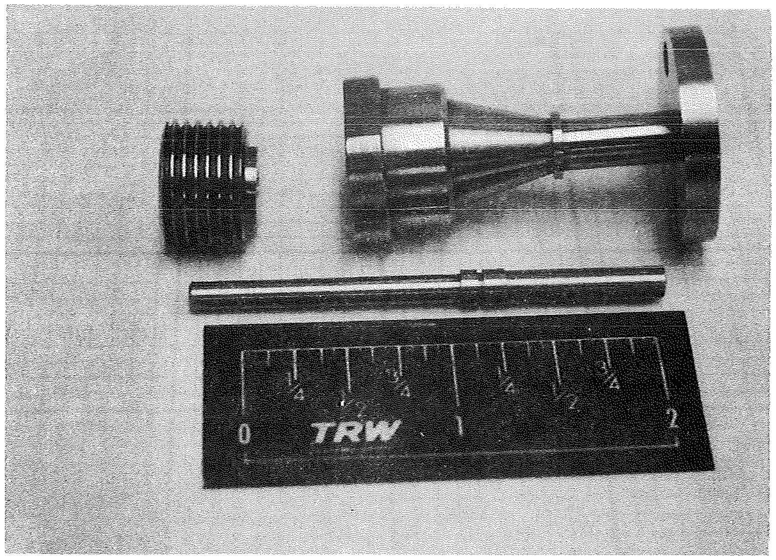


Figure 9. Coaxial Actuator Test
Fixture

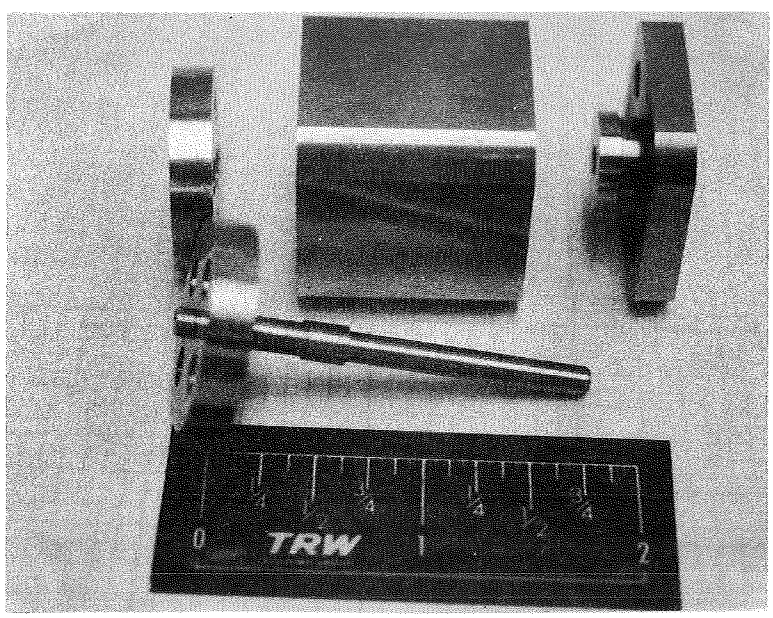


Figure 10. Silicone Rubber Actuator
Pellet Mold

end of the actuator. A sleeve attached to the actuator end plug was added to minimize the actuator friction. It was made a closer fit to the shaft than the original cap to shaft fit to minimize chances of extrusion. The sleeve was found to effectively reduce the frictional loads between the silicone rubber and the piston resulting in smoother extensions and lower initial return loads. However, some rubber did extrude into the clearance between the shaft and sleeve which prevented piston return. Figure 11 shows the piston, sleeve and an actuator pellet. Some silicone rubber is evident adhering to the shaft. This adhesion enhances the jamming tendency of the rubber.

Following the above tests the sleeve was turned to provide a .005 wall for approximately .050 at its end. This thin walled section was then squeezed down slightly to provide small interferences with the shaft. The result was a metal lip type seal between the sleeve and piston rod. The maximum force to move the piston rod with no rubber in place was found to be less than four pounds. A cycling test was performed using the modified sleeve and the MDX 4514 rubber actuator pellet. Thirty-one actuator cycles were performed at a maximum return load of 13.4 pounds. The actuator failed to return at the final cycle and showed a gradual increase in return load requirements with cycling. At this point the actuator was disassembled and examined. No sign of rubber extrusion was found. Extension gains with temperature were slightly higher than those predicted in the calculations presented in the proposal.

Due to the uncertain variations in return load experienced with this actuator, it is recommended that an inline piston actuator, as previously tested, be employed rather than the coaxial arrangement.

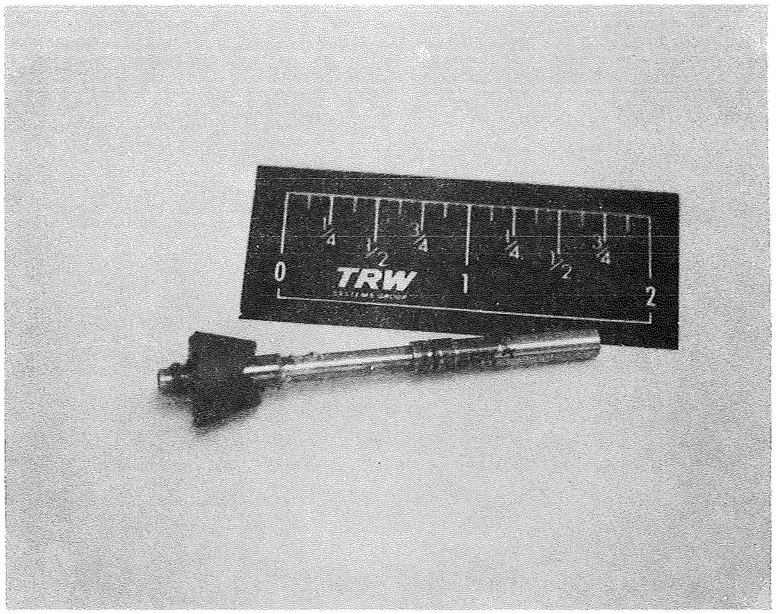
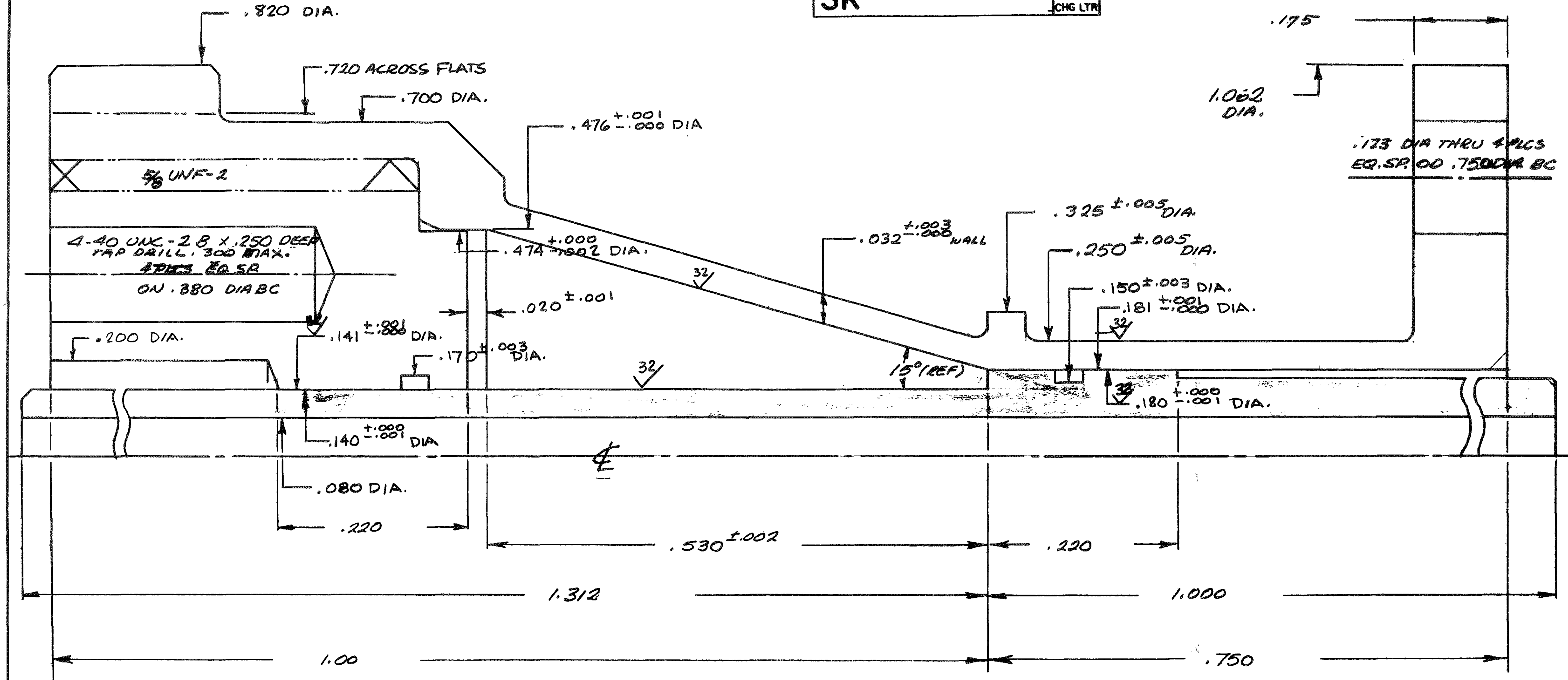


Figure 11. Actuator Piston and Sleeve After Test

SK | CHG LTR



4.

3. MATERIAL - 300 SERIES CRES (303, 304, 321, 347)

2. SCALE DIMENSIONS NOT SHOWN

1. SCALE 10/1

NOTE:

ORIGINATOR	DATE	TITLE
M. J. MAKOWSKI	1-25-70	FIXTURE - ACTUATOR TEST
MJO		

ENGINEERING SKETCH
TRW SYSTEMS GROUP
ONE SPACE PARK • REDONDO BEACH • CALIFORNIA

SK 1190-001

SHEET OF

SYSTEMS 3663 REV. 5-67

6.0 CONCLUSIONS AND RECOMMENDATIONS

The high pressure and vacuum valves developed on this program have shown promise for use in spacecraft instrumentation packages and other applications where a small zero leakage valve is required.

The high pressure and vacuum valves meet the leakage requirements set up in the design goals. They are somewhat larger than the original target size and weight goals, however, this is due in part to the addition of a latching requirement. The size and weight can be significantly reduced for spacecraft hardware. Power exceeded goals but this can be reduced at the expense of response time and deadtime between cycles. Response net goals on the high pressure valve and deadtime were improved. The response was somewhat in excess of the goals on the vacuum valve, however, the deadtime met its goals. Response was limited by maximum heater shell temperature constraints.

The following areas are recommended for further study:

Heater Design - The heater must be electrically isolated from, but thermally intimate to, the valve actuator surface. Ceramic designs require careful matching of expansion coefficients while organically insulated heaters are limited in maximum service temperature. Further work is required to optimize heaters for these valves.

Actuator Design - The basic actuator designs should be reexamined with a view to improving thermal response and actuator performance. Liquid expansion actuators are promising and should be investigated as an integral part of a valve design.

Long Term Testing - Long term cyclic and valve performance testing should be performed to identify any possible deterioration in valve/actuator performance over its lifetime.

APPENDIX IA

SILICONE RUBBER THERMAL ACTUATOR DESIGN ANALYSIS

The parameters pertinent to the design of silicone rubber thermal expansion actuators have been reviewed and design calculations are presented below.

SILICONE RUBBER ACTUATOR DESIGN CALCULATIONS

The following calculations apply to sizing the thermal expansion actuator planned for this application. The calculations apply to the use of silicone rubber as the heat sensitive medium.

1. Criteria:

   Force - 6-10

   Stroke - .03 HP Valve, .08 Vac. Valve

   Size - minimum

   Max. Hydrostatic Stress (in rubber) - 1000 psi

   ΔP for Stroke - 50°C (90°F)

   ΔT for no Actuation (overstroke) - 125°C (225°F)

2. Piston Area:

   Based on a maximum stress of 1000 psi and a load of 10 pounds. The piston area is:

$$a = \frac{F}{\sigma} = \frac{10 \text{ lbs}}{1000 \text{ lb/in}^2}$$

$$a = .01 \text{ in}^2$$

   For a simple round piston this is equivalent to a diameter of .113 inch.

3. Stroke: From Reference 1

$$(x - x_o) = \frac{V_c}{a} \left[\xi_m (T_m - T_o) - K_m (\sigma_m - \sigma_o)\right]$$

where: x = actuator piston position

x_o = initial piston position

V_c = rubber and cavity volume

a = piston area

ξ_m = rubber volume expansion with temperature

T_m = rubber temperature

T_o = initial temperature

K_m = the reciprocal of the rubber bulk modulus

σ_m = hydrostatic stress on the rubber

σ_o = initial hydrostatic stress on the rubber

The required stroke is known for both actuator cases. The operating temperatures are known. The maximum allowable stress is known. The ξ_m and K_m may be calculated from the data in References 1 and 2. The required volume V_c may be calculated from the above equation.

The ξ_m from Reference 1 was very close to the published value of 3.09×10^{-4} in^3/in^3 °F for temperature changes of 50°F.

Reference 2 indicates strokes of:

Material	Load Stress	Stroke	ΔT
318 RTV	356 lb/in^2	245×10^{-3} in	300°F/149°C
318 RTV	2140 lb/in^2	105×10^{-3} in	157°F/70°C
RTV 615	356 lb/in^2	222×10^{-3} in	283°F/142°C
RTV 615	2140 lb/in^2	213×10^{-3} in	300°F/149°C

The basic actuator volume V_c for the Reference 2 data is .0982 in^3. All actuator expansions will be based on this volume. The actual rubber volume equals V_c at approximately 80°F.

Then $\Delta V/V_c$ may be calculated from the stroke piston area and actuator volume according to $\Delta V/V_c = \Delta xa/V_c$.

These calculations are summarized as follows:

Material	Load Stress lb/in^2	$\frac{\Delta V}{V}$ in^3/in^3	ΔT °F	$\frac{\xi \Delta V}{V \Delta T}$ $\frac{in^3}{in^3\ °F}$
318 RTV	356	122.5×10^{-3}	300/149°C	$.408 \times 10^{-3}$
318 RTV	2140	52.5×10^{-3}	157/70°C	$.334 \times 10^{-3}$
615 RTV	356	111.0×10^{-3}	283/142°C	$.392 \times 10^{-3}$
615 RTV	2140	106.3×10^{-3}	300/149°C	$.353 \times 10^{-3}$

These data indicates a somewhat higher ξ than the $.309 \times 10^{-3}$ in^3/in^3 °F obtained from published data in Reference 1.

K_m may be calculated from the load-stroke data at constant temperature presented in Reference 2 and summarized below.

Material	Change in Load Stress $\Delta\sigma$	Change in Stroke Δx	Temperature
3118 RTV	947 psi	$31. \times 10^{-3}$ in	342°F/172°C
RTV 615	947 psi	$25. \times 10^{-3}$ in	227°F/109°C
RTV 615	947 psi	$15. \times 10^{-3}$ in	366°F/186°C

$$\text{Then } K_m = \frac{\Delta x a}{V_c \Delta\sigma} = \frac{\Delta V}{V_c \Delta C}$$

which for the above data yields:

Material	$\sigma\Delta psi$	$\Delta V/V_c$ $\frac{in^3}{in^3}$	$K_m = \frac{\Delta V}{V\Delta\sigma}$ $\frac{in^3/in^3}{psi}$	Temperature
3118 RTV	947	62×10^{-3}	$.645 \times 10^{-4}$	342°F/172°C
RTV 615	947	50×10^{-3}	$.528 \times 10^{-4}$	227°F/109°C
RTV 615	947	30×10^{-3}	$.317 \times 10^{-4}$	366°F/186°C

$$\frac{a(x-x_o)}{V_c} = \frac{\Delta V}{V_c} = [\xi_m (T_m - T_o) - K_m (\sigma_m - \sigma_o)]$$

From the above data, the RTV 615 seems stiffer and since there is no significant difference in ξ_m between 318 RTV and RTV 615, the RTV 615 will be used in calculating required actuator volume.

Using the data for RTV 615, K_m at 366°F (186°C) and ξ at 300°F (149°C)

$$\frac{\Delta V}{V_c} = [.353 \times 10^{-3} \frac{in^3}{in^{3\circ}F} (90°F) - .317 \times 10^{-4} \frac{in^3}{in^3\ psi} (1000\ psi)]$$

$$\frac{\Delta V}{V_c} = (.0318 \frac{in^3}{in^3} - .0317 \frac{in^3}{in^3}) = 10^{-4} \frac{in^3}{in^3}$$

$$\frac{a(x-x_o)}{V_c} = 10^{-4}$$

$$\frac{a(x-x_o)}{10^{-4}} = V_c$$

$$\frac{.01\ in^2 \times .03}{10^{-4}} = \frac{3 \times 10^{-4}\ in^3}{10^{-4} \frac{in^3}{in^3}} \qquad 3\ in^3 = V_c\ .$$

This is obviously unreasonable and indicates that some initial preload must occur between room temperature and the actuator start temperature if the actuator is to be efficient. If we assume actuator load range from 6 to 10 pounds, the $\Delta\sigma$ = 4 lbs/.01 in^2 = 400 psi.

$$(\frac{\Delta V}{V_c}) = (.0318 - [.317 \times 10^{-4}]\ 400) = .0191\ in^3/in^3$$

$$V_c = \frac{3 \times 10^{-4}\ in^3}{1.91 \times 10^{-2}\ in^3/in^3} = 1.57 \times 10^{-2}\ in^3$$

for a useful stroke of .030 in.

and if we maintain the load at 9 lbs = 100 psi at = 100 psi:

$$(\frac{\Delta V}{V_c}) = (.0318 - [.317 \times 10^{-4}]\ 100) = .0286\ in^3/in^3$$

$$V_c = \frac{3 \times 10^{-4}\ in^3}{2.86 \times 10^{-2}\ in^3/in^3} = 1.05 \times 10^{-2}\ in^3$$

for a useful stroke of .030 in.

Either of these are reasonable values. For a hollow cylinder .125 ID ~ .187 OD or an area of .0152 in^2, the length is: $1.57 \times 10^{-2}\ in^2/1.52 \times 10^{-2}\ in^2$ = 1.03 in. for the .030 stroke case.

It is desirable to examine the overstroke which must be allowed for from room temperature to the start temperature. Employing the same basic relation used for determining useful stroke-volume and assuming zero load at 77°F (25°C) and 6 lbs (600 psi) at 302°F (150°C):

$$(x-x_o) = \frac{1.57 \times 10^{-2}\ in^3}{1 \times 10^{-3}\ in^3}\left[.353 \times 10^{-3}\ \frac{in^3}{in^3\,°F}(225°F) - .317 \times 10^{-4}\ \frac{in^3}{in^3\ \frac{lb}{in^2}}(600)\right]$$

$$= 1.57\ [.0795 - .0190]$$

$$\underset{(n-302)}{(x-x_o)} = .095 \text{ in.}$$ initial free stroke for the .030 useful stroke case.

In the same manner as above, the rubber volume V_c, and the initial free stroke may be determined for the .080 stroke case. For the same load constraints as before the $\Delta V/V_c$ is the same or:

$$\frac{\Delta V}{V_c} = .0191\ in^3/in^3$$

for .080 stroke $\Delta V = .080\ in \times .01\ in^2 = 8 \times 10^{-4}\ in^3$.

Then: $$V_c = \frac{\Delta V}{.0191} = \frac{8 \times 10^{-4}\ in^3}{1.91 \times 10^{-2}\ in^3/in^3} = 4.19 \times 10^{-2}\ in^3$$

for a useful stroke of .080 in.

If a hollow cylinder .180 ID x .300 OD with a free area of .0453 in^2 is used, the length required is $4.19 \times 10^{-2}\ in^3/4.53 \times 10^{-2}\ in^2$ = .925 in.

REFERENCES

1. "Advanced Valve Technology," Final Report No. 06641-6023-R000, Contract NAS 7-436, January 1969.

2. "Advanced Spacecraft Valve Technology," Quarterly Report No. 12411-6003-R000, Contract NAS 7-717, September 1969.

APPENDIX IB

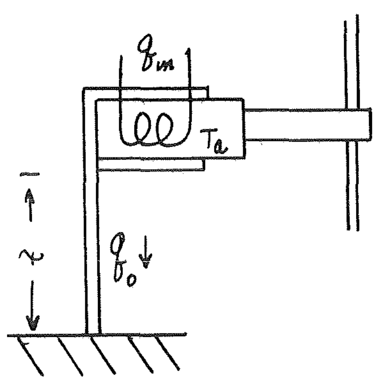
TRADE STUDIES - THERMAL BALANCE

To determine response and power requirements for thermal actuators we must define the steady state heat leak:

The target response - (time between actuations is 2 minutes). In this length of time the actuator must cool from its extended temperature to its maximum retracted temperature. (Actual opening or closing time desired is 30 seconds). We first make the following assumptions:

1. Material of Construction - stainless steel - including power windings
2. Actuator material - silicone rubber
3. Radiation and Convection - negligible - due to component stacking factor and other component temperatures.
4. Conduction - major and only significant heat transfer mechanism.
5. Temperatures - Sink temperature (50°C) 122°F unlimited capacity
   Maximum retracted temperature (150°C) 302°F
   Fully extended temperature (200°C) 392°F
   In addition - valve temperature for vacuum valve is 225°C.
   Heat leak must be low enough so actuator cannot self heat above 125/150°C 302°F (max.)

CASE 1: HIGH PRESSURE VALVE:



Assuming line conduction is negligible:

q_m = electrical power in

q_o = heat leakage according to the usual Fourier Relation

$$q_o = \frac{k\ a\ (T_a - T_s)}{x} \tag{1}$$

The heat which must be added to raise the actuator from its initial temperature T_a to any final temperature T_f is

$$Q_m = q_m \Delta t = C_{p_{act}} W_{act} \quad (T_a - T_f) \qquad (2)$$

The same quantity of heat must be removed in cooling it to the start temperature.

Using Figure 1 in Proposal 14936.000 as the model:
Assume the thermal mass to be heated (and cooled) includes 100% of the actuator section and 30% of the valve portion. Then the metal volume in the actuator is:

Tube	.438 OD x .431 ID x .381 long	=	1.83×10^{-3} in^3
Disc	.438 OD x .125 long	=	18.90×10^{-3} in^3
Tube	.338 OD x .300 X .25 long	=	4.75×10^{-3} in^3
Disc	.263 OD x .125 long	=	6.78×10^{-3} in^3
			32.26×10^{-3} in^3

for cres this results in a weight of: $V_{act_{(cres)}}$

$(\rho_{cres} = .29 \text{ lb/in}^3)$ $\underline{W_{act(cres)} = 9.40 \times 10^{-3} \text{ lbs}}$

The Si rubber volume is (from proposal 14936.000):

$V_{actR} = 1.57 \times 10^{-2}$ in^3

$(\rho_{siR} = .037 \text{ lb/in}^3)$
sq = 1.02

$\underline{W_{act(R)} = .58 \times 10^{-3} \text{ lbs}}$

Estimating Valve Metal Volume A:

Cyl. .181 dia x 1.30 long = .235 in^3

$$\underline{W_{valve(cres)} = 68.1 \times 10^{-3} \text{ lbs}}$$

$C_{p\ cres}$ = .12 Btu/lb°F (stainless steel handbook)

$C_{p\ SiR}$ = .4 Btu/lb°F (Est. no data available)

$$Q_{in} = \left\{ [W_{act_{(cres)}} + .3\ (W_{valve_{(cres)}})]\ C_{p_{cres}} + W_{act\ R}\ C_{p_R} \right\} (T_a - T_f) \qquad (3)$$

for the actual numbers above:

$$Q_{in} = \left\{ [9.4 \times 10^{-3} + .3\ (68.1 \times 10^{-3}]\ .12 + (.58 \times 10^{-3})\ .4 \right\} (T_a - T_f)$$

$$= \left\{ 4.02 \times 10^{-3} + .232 \times 10^{-3} \right\} (T_a - T_f)$$

$$Q_{in} = 4.252 \times 10^{-3}\ (T_a - T_f) \text{ Btu}$$

To actuate in 30 seconds from 50°C $\quad T_a$ = (50°C) 122°F

T_f = (200°C) 392°F

$$\therefore W_{in_{(122-392)}} = 4.252 \times 10^{-3}\ (122-392)$$

$$\underline{Q_{in_{(122-392)}} = -1.150 \text{ Btu}} \quad \text{(heat flow into the actuator)}$$

With no heat leakage the power over 30 seconds is:

$$q_{(122-392)_{30}} = \frac{1.150 \text{ Btu}}{30 \text{ sec}} = .0384 \text{ Btu/sec} \qquad q = \frac{Q}{t}$$

or 40.5 watts.

This is higher than the target value of 15 watts peak. It may be reduced by

- o extending the actuation time
- o lightening the heated structure and/or isolating the balance of the valve from the heater.

If the maximum target 15 watts was applied (with no heat leak), the actuation time from 50°C would be:

$$15 \text{ watts} = .0142 \text{ Btu/sec}$$

$$t_{(122-392)_{15.5}} = \frac{Q}{q} = \frac{1.150}{.0142} = 81.0 \text{ seconds}$$

In order to cool the actuator from the fully extended temperature of (200°C) 392°F to the maximum retracted temperaútre of (150°C) 302°F) (or vice versa)

$$Q = 4.252 \times 10^{-3} \ (90°F)$$

$$Q = .3825 \text{ Btu}$$

Over a 30 second period, this requires a heat flow of:

$$q = \frac{.3825}{30} = .01275 \text{ or } 13.46 \text{ watts}$$

into or out of the actuator for extension or retraction, respectively.

$$k_{cres} = 9.4 \frac{\text{Btu}}{\text{Hr Ft °F}} = 2.18 \times 10^{-4} \frac{\text{Btu}}{\text{sec in °F}} = .2295 \frac{\text{watts}}{\text{in °F}}$$

This 13.46 watt value dictates the value of the minimum steady state heat leak required to obtain 30 second deactuation times. If this heat leak is introduced it is an added load during actuation and an actuation power of 2(13.46) or 26.92 watts would be required to meet the 30 second actuation time (from 150-200°C).

Reassing the actual mass affected:

The heat leak from the actuator to the valve at 100°F ΔT (worst case) is

$$q_{hL} = \frac{kA\Delta T}{x} \quad \text{as in (1)} \qquad\qquad k_{cres} = 9.4 \text{ Btu/Hr Ft °F}$$

$$q = .2295 \frac{w}{in\,°F} \times \frac{.031 \text{ in}^2}{.25 \text{ in}} \times 100 \qquad\qquad = 2.18 \times 10^{-4} \frac{\text{Btu}}{\text{sec in°F}}$$

$$q_{hL} = 2.84 \text{ watts} = 2.69 \times 10^{-3} \frac{\text{Btu}}{\text{sec}} \qquad\qquad = .2295 \frac{\text{watts}}{\text{in °F}}$$

So if the above is added (or subtracted) from the heat in flow (or outflow) the effective mass may be reduced to the actuator mass only. Then:

$$Q_{in} = \left\{(9.40 \times 10^{-3} \text{ lbs}) \; .12 \frac{\text{Btu}}{\text{lb °F}} + (.58 \times 10^{-3} \text{ lbs}) \; .4 \frac{\text{Btu}}{\text{lb°F}}\right\} (T_a - T_f) + q_{hL}\, t$$

for short periods of time - long term the $q_{hL}t$ term disappears as the balance of the valve heats along with the actuator, its mass must then be once again considered.

Now:

$$Q_{in} = (1.13 \times 10^{-3} + .232 \times 10^{-3}) \frac{\text{Btu}}{\text{°F}} (T_a - T_f) - 2.69 \times 10^{-3} \frac{\text{Btu}}{\text{sec}} \; t$$

$$= 1.362 \times 10^{-3} (T_a - T_f) \text{ Btu} + 2.69 \times 10^{-3} \; t \text{ Btu}$$

And re-examining the (50$\rightarrow$200°C) 122$\rightarrow$392°F case for 30 seconds (assuming no heat leakage to ground)

(for heating)

$$Q_{\substack{in \\ (122-392)}} = (1.362 \times 10^{-3})(122-392) - (2.69 \times 10^{-3})\ (30)$$

$$Q_{in} = (-.368 - .0806) = -.449 \text{ Btu}$$

where heat flow into the valve/act is - .   over 30 seconds

$$q_{\substack{in \\ (122-392)_{30}}} = \frac{.449 \text{ Btu}}{30 \text{ sec}} = .01495 \text{ Btu/sec}$$

$$= \underline{15.8 \text{ watts}}$$

to close (or open) in 30 seconds requires the removal (or addition) of heat from (200-150°C) 392-302°F

$$Q_{\substack{act \\ (302-392)_{30}}} = (1.362 \times 10^{-3})(392-302) + \frac{(2.69 \times 10^{-3})}{2} \quad (30$$

{divide by 2 since mean ΔT is 45-50°F for this case}

$$Q = .123 + .0404$$

$$= .163 \text{ Btu}$$

or over a 30 second interval the heat flow out (or in) is:

$$q = \frac{.163 \text{ Btu}}{30 \text{ sec}} = .00543 \text{ Btu/sec} = 5.43 \times 10^{-3} \text{ Btu/sec}$$

$$= 5.73 \text{ watts}$$

This indicates that to meet the 30 second on/off time we will require a steady state heat leak to ground of 5.75 watts and a net input power over that of 5.75 watts for a total power of 11.5 watts if the actuator is at 150°C. If the actuator is at 50°C the power required to meet a 30 second actuation would be the 15.8 watts required to raise the temperature plus a mean heat leak to ground of .6(5.75) = 3.45 watts (since the mean ΔT for this case is ~88°C and for the 150 to 200°C case it is 175°C). This results in a total power for 30 sec (from 50 to 200°C) actuation of 15.8 + 3.45 watts = 19.25 watts. If only 11.5 watts were applied

$$11.5 \text{ watts} = .0109 \text{ BTU/sec}$$

$$t = \frac{.449 \text{ BTU}}{.0109 \frac{\text{BTU}}{\text{sec}}} = 41.2 \text{ seconds from } 50°\text{C}$$

This is only 11.2 seconds longer than the 30 seconds at 150°C and results in a peak power saving of 19.25-11.5 = 7.75 watts.

From this it is decided that the following heat and heat flow criteria should be used for the high pressure value: (no latching)

1. Actuator power - 11.5 watts
2. Actuation time
   at 50°C start - ~41.2 sec
   at 150°C start - ~30.0 sec
3. Hold (open) power - 5.75 watts
   (heat leak required)
4. Closing time - 30.0 sec
   (50°C ambient)
5. Actuation energy
   50°C start - 473 · Joules
   150°C start - 345 · Joules
6. Heat leak to ground - 5.75 watts
   (50°C required to meet above responses)

These numbers assume perfect conduction into the actuator. Times will be extended if this condition is not met.

Now if a latching design is considered, the 0 heat leak energy to open in 30 seconds is the same. But the time between actuations allowed is 2 minutes (120 sec) $\therefore$ the actuator retraction time is increased to 120 sec hence the steady-state heat leak may be reduced. This should result in a decrease in actuator power and energy. The heat which must be removed for retraction is .163 BTU (150-200°C) in 120 sec. This requires a heat flow of:

$$q = \frac{.163 \text{ BTU}}{120 \text{ sec}} = 1.36 \times 10^{-3} \text{ BTU/sec}$$

$$= 1.29 \text{ watts}$$

Thus the mean steady-state heat leak required from (150-200°C) to 50°C is 1.29 watts. The 30 second (150-200°C) actuation power is as before:

5.73 watts + heat leak

or 7.02 watts

The 30 second (50-200°C) actuation power is as before:

15.8 watts + mean heat leak is .6 x 1.29 = .774 watts

or a total of 16.574 watts

All not counting latch requirements. (50-200°C) actuation time at 15 watts would be $\simeq$ 33.2 sec.

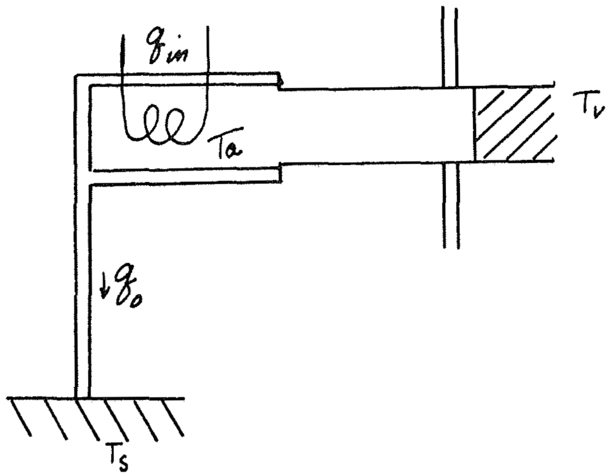
The latch will be considered as a separate item. Magnetic latching is receiving primary attention.

CASE 2: VACUUM VALVE:

The vacuum valve body is assumed to be maintained at (230°C) 446°F.

The actuator may not exceed 125°C steady state under this condition.

The calculation model for heat flow is the preliminary design presented in the proposal.



Line conductances are negligible.

Assume 100% of the actuator must be heated for actuation and 0% of this valve since it is spearately maintained hotter than the actuator.

The metal volumes in the actuator are:

Tube	.610 O.D.	x	.600 I.D.	x	.600 long	=	5.7×10^{-3} in^3
Disc	.610 O.D.	x	.150 long			=	43.8×10^{-3} in^3
Tube	.563 O.D.	x	.463 I.D.	x	.400 long	=	32.2×10^{-3} in^3
Disc	.200 O.D.	x	.250 long			=	7.86×10^{-3} in^3
					V_{act}	=	89.56×10^{-3} in^3

$\rho_{cres} = .29 \frac{lb}{in^3}$ $\quad$ $\underline{W_{act} = 89.56 \times 10^{-3} \times .29 = .026 \text{ lbs}}$

The Si Rubber volume from proposal 14956.000 is:

$$V_{act_R} = 4.19 \times 10^{-2} \text{ in}^3$$

$$\rho_{sir} = .037 \frac{lb}{in^3}$$

$$W_{act(R)} = 4.19 \times 10^{-2} \text{ in}^3 \times 3.7 \times 10^{-2} \frac{lb}{in^3}$$

$$\underline{W_{act(R)} = 1.55 \times 10^{-3} \text{ lbs}}$$

The connection between the valve and actuator consists of stainless steel cross-sectional area 11.53×10^{-3} in^2 and length .55 in.

as in (1) $q = \frac{k\Delta}{x} \; \Delta T$

k_{cres} = .2295 watts/in°F(2.18×10^{-4} BTU/sec in°F)

Therefore:

$$qh_{\ell} = .2295 \text{ w/m°F} \times \frac{11.53 \times 10^{-3} \text{ m}^2}{.55 \text{ in}} \; \left(\underset{446°F}{\overset{230°C}{T_v}} - \underset{257°F}{\overset{125°C}{T_{a\text{-closed}}}}\right)_{189}$$

= .91 watts

Therefore:

A heat leak of ~ .9 - 1.0 watts must be provided from 125°C to ground (50°C) to prevent inadvertent valve actuation.

The heat to be added to actuate the valve or removed to close the valve is:

$$Q_{in} = (W_{act_{cres}} C_{P_{cres}} + W_{act_R} C_{P_R}) \ (T_a - T_f)$$

or for the actuator above:

$$Q_{in} = (.026 \text{ lbs } .12 \frac{BTU}{lb°F} + 1.55 \times 10^{-3} \text{ lbs } .4 \frac{BTU}{lb°F}) \ (T_a - T_f)$$

$$= (3.12 \times 10^{-3} \frac{BTU}{°F} + .62 \times 10^{-3} \frac{BTU}{°F}) \ (T_a - T_f)$$

$$Q_m = (3.74 \times 10^{-3}) \ (T_a - T_f) \text{ BTU}$$

Raising the actuator from (150-200°C) 302-392°F requires:

$$Q_m = (3.74 \times 10^{-3}) \ (90)$$

$$Q_{\dot{m}} = .3365 \text{ BTU}$$

(302-392)

for a 30 second actuation time

$$q = \frac{.3365}{30} = .01122 \text{ BTU/sec}$$

$$= 11.84 \text{ watts}$$

This requires a 150-50°C heat leak of 11.84 watts for closing and a 23.68 watt power input for opening.

If this heat leak to ground is used the actuator temperature will not be maintained at 125°C but at the temperature where the heat flows balance, namely where:

$$q_o = q_{h\ell} \qquad\qquad q_o = \frac{k_oA_o}{X_o} \; (T_a - T_s)$$

$$A_{h\ell} = (\frac{kA}{X})_{h\ell} \; (T_v - T_a)$$

$$T_v \; (\frac{kA}{X})_{h\ell} - T_a \; (\frac{kA}{X})_{h\ell} = (\frac{kA}{X})_o \; T_a - (\frac{kA}{X_o})_o \; T_s$$

$$T_a \; (\frac{kA}{X})_o + T_a \; (\frac{kA}{x})_{h\ell} = T_v \; (\frac{kA}{X})_{h\ell} + T_s \; (\frac{kA}{X})_o$$

$$T_a \; [\; (\frac{kA}{X})_o + (\frac{kA}{X})_{h\ell} \;] = T_v \; (\quad)_{h\ell} + T_s \; (\quad)_o$$

$$T_a = \frac{T_v \; (\quad)_{h\ell} + T_s \; (\quad)_o}{(\frac{kA}{X})_o + (\frac{kA}{X})_{h\ell}}$$

$$T_a = \frac{T_v + T_s \; (\quad)_o / (\quad)_{h\ell}}{(\quad)_o / (\quad)_{h\ell} + 1}$$

In order to flow 11.84 watts at T_a = (150°C) 302°F and T_s = (50°C) 122°F. Since

$$q = \frac{kA}{X} \; (T_a - T_s)$$

$$(\frac{kA}{X})_o = \frac{11.84}{(302-122)} = .0658 \text{ BTU/°F}$$

$$(\frac{kA}{X})_{h\ell} = \frac{.2295 \times 11.53 \times 10^{-3}}{.55} = 4.8 \times 10^{-3}\ \text{BTU/}^\circ\text{F}$$

$$\frac{(\ )_o}{(\ )_{h\ell}} = \frac{.0658}{4.8 \times 10^{-3}} = 13.7$$

$$T_a = \frac{446 + 122\ (13.7)}{13.7 + 1}$$

$$T_a = 144^\circ\text{F or slightly higher than } 50^\circ\text{C ground}$$

$$\simeq 62^\circ\text{C}$$

If a two minute actuation time is allowed from 150-200°C,

$$a = \frac{.3365}{120} = 2.80 \times 10^{-3}\ \text{BTU/sec}$$

$$= 2.96\ \text{watts}$$

The heat leak to ground required for closing in two minues is 2.96 watts at a temperature drop of (150-50°) 302 → 122°F

Then:

$$(\frac{kA}{x})_o = \frac{2.96}{(302-122)} = 1.645 \times 10^{-2}$$

$$\frac{(\ )_o}{(\ )_{h\ell}} = \frac{.0165}{.0048} = 3.42$$

and

$$T_a = \frac{466 + 122\ (3.42)}{(3.42\ +11)} = 195.5^\circ\text{F}$$

$$\simeq 91^\circ\text{C}$$

For a start temperature of 195.5°F (91°C)

$$Q = (3.74 \times 10^{-3})\ (195-392) = .736\ \text{BTU}$$

and a two minute actuation time will require

$$q_{120} = \frac{.736\ \text{BTU}}{120\ \text{sec}} = 6.14 \times 10^{-3}\ \text{BTU/sec}$$
$$= 6.47\ \text{watts}$$

for a total actuation power $(q_o + q_{h\ell}) = (6.47 + 2.96) = 9.43$ watts.

A 30 second actuation would require:

$$q_{30} = \frac{.736}{30} = 24.6 \times 10^{-3}\ \text{BTU/sec}$$
$$= 25.9\ \text{watts}$$

For a total actuation power $(q_o + q_{h\ell}) = 25.9+2.96) =$ 28.86 watts.

From the above the following heat and heat flow criteria should be used for the vacuum value: (No latching)

1. Actuation power - 9.43 watts
2. Actuation time
   150°C start - 55 seconds
   91°C start - 120 seconds
3. Hold (open) power - 2.05 watts
   (heat leak required)

4. Closing time - 120 seconds
   (50°C ambient)

5. Actuation Energy
   150°C start - 518 joules
   91°C start - 1132 joules

6. Heat leak to ground - 2.96 watts

7. Heat flow in from valve - .91 watts

These numbers assume perfect conduction into the actuator times will be extended if this condition is not met.

The above apply to a latching design since 120 seconds between actuations is required. However, the hold open power is eliminated.

In order to clarify the interrelations above, tables and plots of power input q versus actuation time at various start temperatures have been prepared.

HP Value
(Fully actuated temperature = 200°C = 392°F)
(No thermal isolation from valve)

Actuation Time (sec)	T = 50°C 122°F		T = 100°C 212°F		T = 150°C 302°F	
	Q	Q/t = q	Q	Q/t = q	Q	Q/t = q
0	1.150 BTU	∞	.767 BTU	∞	.383 BTU	∞
5		.230 Btu/s 242 watts		.1532 Btu/s 161 watts		.0767 Btu/s 80.8 watts
10		.115 BTU/s 121 watts		.0767 BTU/s 80.8 watts		.0384 BTU/s 40.4 watts
20		.0575 BTU/s 61.6 watts		.0384 BTU/s 40.4 watts		.0192 BTU/s 20.2 watts
30		.0383 BTU/s 40.4 watts		.0256 BTU/s 27.0 watts		.0128 BTU/s 13.5 watts
60		.0192 BTU/s 20.2 watts		.0128 BTU/s 13.5 watts		.0064 BTU/s 6.75 watts
120		.00958 BTU/s 10.1 watts		.0064 BTU/s 6.75 watts		.0032 BTU/s 3.38
180		.00638 BTU/s 6.75 watts		.00426 BTU/s 4.49 watts		.00213 BTU/s 2.25 watts
240		.00479 BTU/s 5.05 watts		.0032 BTU/s 3.38 watts		.0016 BTU/s 1.69 watts

HP VALVE

WITH THERMAL ISOLATIONS FROM VALVE

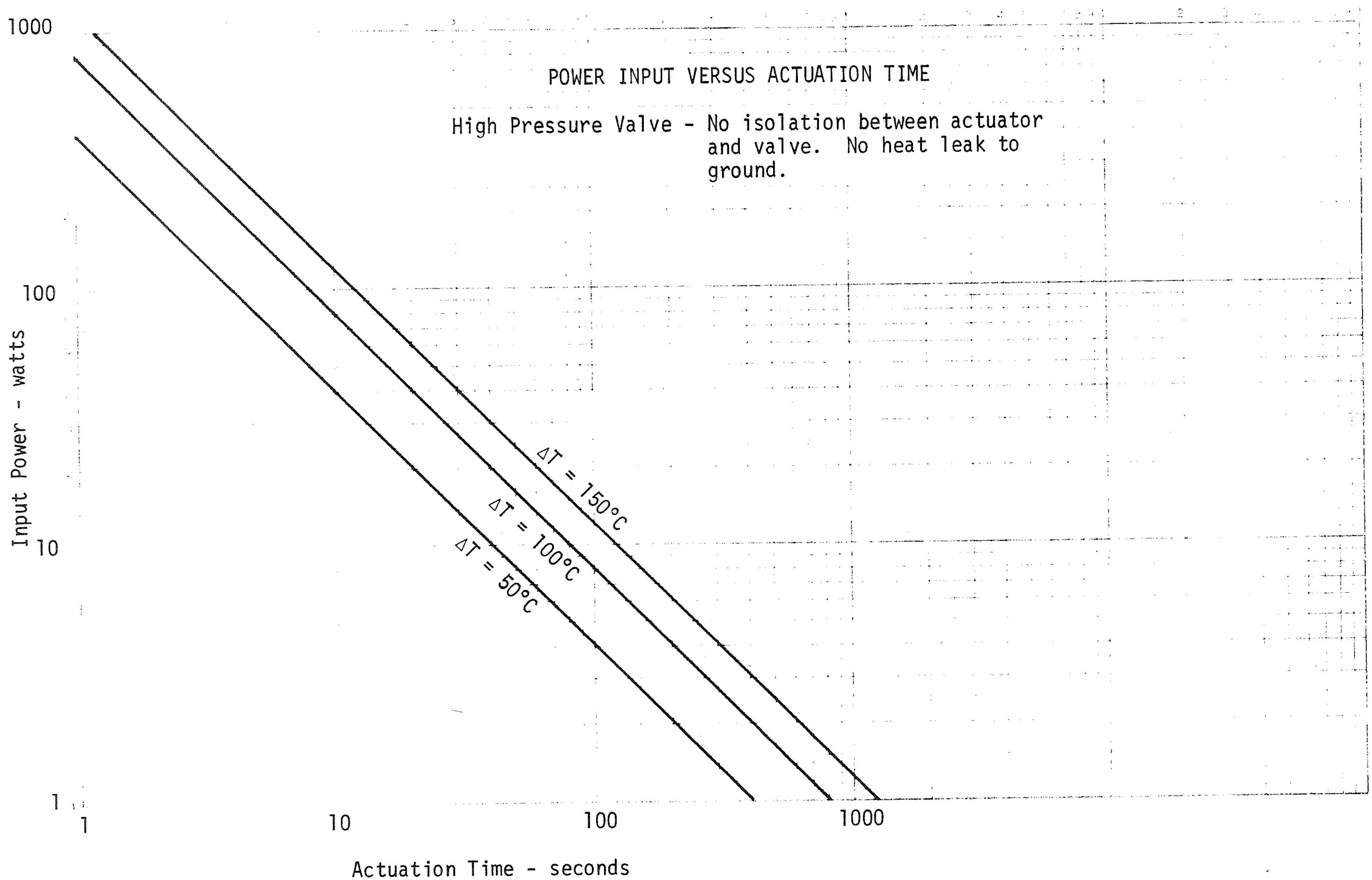
Actuation Time (t) (sec)	T=50°C (122°F) ΔT-150°C		T=100°C (212°F) ΔT-100°C		T=150°C (302°F) ΔT=50°C	
	Q	Q/t = q	Q	Q/t = q	Q	Q/t = q
0	.368 BTU	∞	.245 BTU	∞	.123 BTU	∞
5	.382 BTU	.07604 BTU/s 80.2 watts	.259 BTU	.0518 BTU/s 54.6 watts	.137 BTU	.0274 BTU/s 28.9 watts
10	.395 BTU	.0395 BTU/s 41.7 watts	.272 BTU	.0272 BTU/s 28.7 watts	.150 BTU	.0150 BTU/s 15.8 watts
20	.422 BTU	.0211 BTU/s 22.3 watts	.299 BTU	.0149 BTU/s 15.7 watts	.177 BTU	.00885 BTU/s 9.34 watts
30	.449 BTU	.0149 BTU/s 15.7 watts	.326 BTU	.0109 BTU/s 11.5 watts	.204 BTU	.00680 BTU/s 7.17 watts
60	.530 BTU	.00884 BTU/s 9.32 watts	.407 BTU	.00679 BTU/s 7.15 watts	.285 BTU	.00475 BTU/s 5.01 watts
120	.691 BTU	.00576 BTU/s 6.08 watts	.568 BTU	.00473 BTU/s 4.99 watts	.446 BTU	.00372 BTU/s 3.92 watts
180	.852 BTU	.00473 BTU/s 4.99 watts	.729 BTU	.00405 BTU/s 4.27 watts	.607 BTU	.00338 BTU/s 3.57 watts
240	1.013 BTU	.00422 BTU/s 4.45 watts	.890 BTU	.00371 BTU/s 3.92 watts	.778 BTU	.00324 BTU/s 3.42 watts

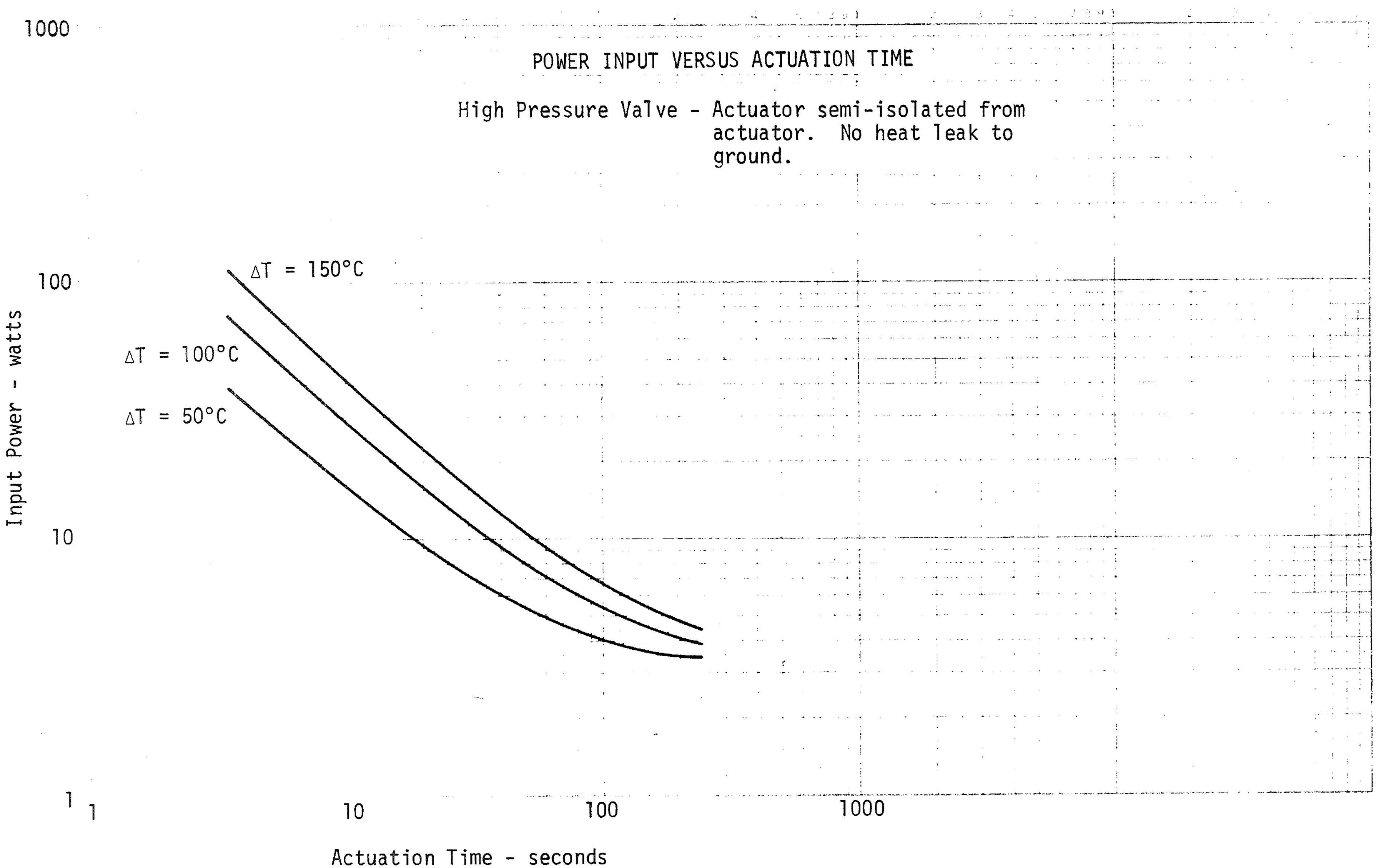
Now for the vacuum valve:

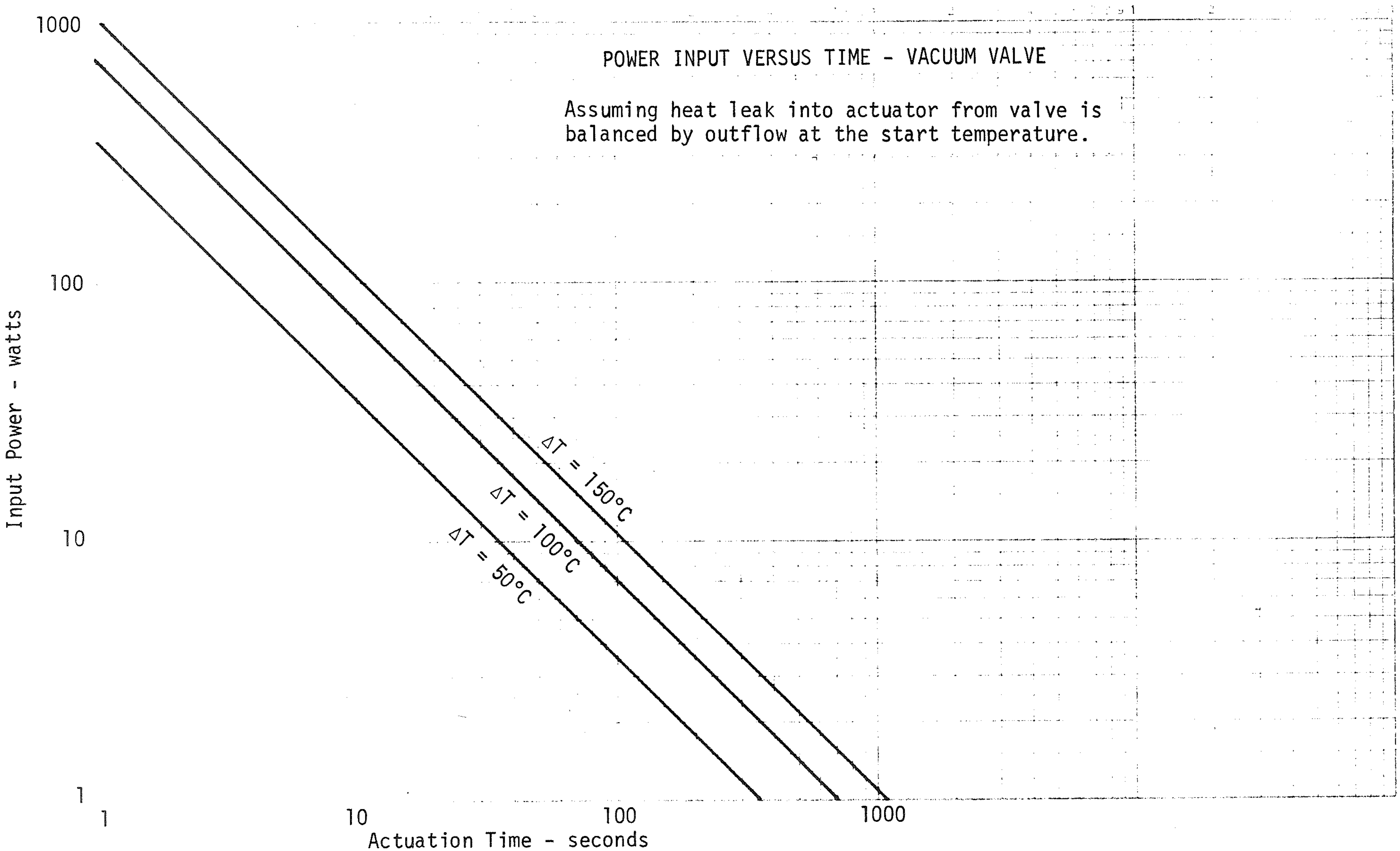
The total Q in each case is: $(C_p W\Delta T) = (3.74 \times 10^{-3})\ (\Delta T)$

Assuming the net heat leak into the act is balanced by a net outflow at the start temperature.

Actuation Time (t) (sec)	T=50°C (122°F ΔT=150°C		T=100°C (212°F ΔT=100°C		T=150°C (302°F) ΔT=50°C	
	Q	Q/t = q	Q	Q/t = q	Q	Q/t = q
0	1.012 BTU	∞	.673 BTU	∞	.337 BTU	∞
5		.202 BTU/s 213 watts		.135 BTU/s 143 watts		.0674 BTU/s 71 watts
10		.101 BTU/s 107 watts		.0674 BTU/s 71 watts		.0337 BTU/s 35.6 watts
20		.0506 BTU/s 53.4 watts		.0337 BTU/s 35.6 watts		.0168 BTU/s 17.7 watts
30		.0337 BTU/s 35.6 watts		.0224 BTU/s 23.6 watts		.0112 BTU/s 11.8 watts
60		.0169 BTU/s 17.8 watts		.0112 BTU/s 11.8 watts		.00562 BTU/s 5.93 watts
120		.00844 BTU/s 8.90 watts		.00560 BTU/s 5.91 watts		.00281 BTU/s 2.96 watts
180		.00562 BTU/s 5.92 watts		.00374 BTU/s 3.94 watts		.00187 BTU/s 1.97 watts
240		.00422 BTU/s 4.45 watts		.00280 BTU/s 2.96 watts		.00140 BTU/s 1.48 watts


POWER INPUT VERSUS ACTUATION TIME
High Pressure Valve - No isolation between actuator and valve. No heat leak to ground.
ΔT = 150°C
ΔT = 100°C
ΔT = 50°C
1000
100
10
1
Input Power - watts
1
10
100
1000
Actuation Time - seconds


POWER INPUT VERSUS ACTUATION TIME
High Pressure Valve - Actuator semi-isolated from actuator. No heat leak to ground.
ΔT = 150°C
ΔT = 100°C
ΔT = 50°C
Input Power - watts
1000
100
10
1
1
10
100
1000
Actuation Time - seconds


POWER INPUT VERSUS TIME - VACUUM VALVE
Assuming heat leak into actuator from valve is balanced by outflow at the start temperature.
ΔT = 150°C
ΔT = 100°C
ΔT = 50°C
Input Power - watts
1000
100
10
1
1
10
100
1000
Actuation Time - seconds

High Pressure Valve - Alternate Approach

There seems to be an advantage in using an all vespel actuator in the high pressure valve since all seals are eliminated. This simplifies construction and improves valve reliability.

Conservatively taken values of line expansion vespel from Data Book, Page 5, Figure 9 are:

	Base Resin	15% Graphite Filled
From 150°C (302°F) → (250°C) (482°F) =	7.00×10^{-3} in/in	6.00×10^{-3} in/in
→ (200°C) (3920°F) (400) =	4.00×10^{-3} in/in	3.25×10^{-3} in/in

For an actuator with an outer housing of cres, the housing exp. coefficient is:

17-4 PH (70 → 600)	6.2 → 6.6 $(10)^{-6}$	in/in°F
440 CRES	6.0 10^{-6}	in/in°F

at 6.2×10^{-6} in/in°F x 90°F = $.558 \times 10^{-3}$ in/in
x 180°F = 1.12×10^{-3} in/in

This indicates that an average relative expansion, over the temperature ranges noted, of:

	Base Resin	15% Graphite Filled
(150-250°C) -	5.88×10^{-3} in/in	4.88×10^{-3} in/in
(150-200°C) -	2.88×10^{-3} in/in	2.13×10^{-3} in/in

The modulus of the polyimide (Vespel) material is:

	Base Resin	15% Graphite Filled
at 392°F (200°C)	2.0×10^{5}	3.15×10^{5}

The deflection in a simple rod is $\sigma = E\varepsilon$; $\varepsilon = \frac{\sigma}{E}$

at 1000 psi $\varepsilon_{BR_{1000}} = \dfrac{1000}{2.1 \times 10^{5}} = 4.76 \times 10^{-3}$ in/in

$\varepsilon_{GF} = \dfrac{1000}{3.15 \times 10^{-5}} = 3.18 \times 10^{-3}$ in/in

and at 100 psi $\varepsilon_{BR} = 4.76 \times 10^{-4}$ in/in

$\varepsilon_{GF} = 3.18 \times 10^{-4}$ in/in

The basic actuator load output is approximately 3-4 lbs.

For the steel housing the modulus $E \simeq 30 \times 10^{6}$ (440 CRES)

$= 28.5 \times 10^{6}$ (17-4 PH)

At 10,000 psi $\varepsilon_{ST_{17-4}} = \dfrac{10^{4}}{28.5 \times 10^{6}} = 3.51 \times 10^{-4}$ in/in

$\varepsilon_{ST_{440}} = \dfrac{10^{4}}{30 \times 10^{6}} = 3.33 \times 10^{-4}$ in/in

at a load of 4 lbs the cross-sectional area for a 1000 psi actuator is

$\dfrac{4 \text{ lb}}{1000 \frac{\text{lb}}{\text{in}^2}} = 4 \times 10^{-3} \text{ in}^2 \simeq .071$ in diameter.

At 500 psi $\dfrac{4}{500} = 8 \times 10^{-3} \text{ in}^2 \simeq .101$ diameter

at 250 psi $\dfrac{4}{250} = 16 \times 10^{-3} \text{ in}^2 \simeq .143$ diameter

and at 100 psi $\dfrac{4}{100} = 40 \times 10^{-3} \text{ in}^2 \simeq .225$ diameter

The load stress versus diameter required are plotted on Page <u>25</u>. The optimum diameter from a stress-diameter trade-off seems to be .12-.15 in.

Standard cres. tubing is available: .160 O.D. x .006 wall = .148 I.D.

The tube metal area is: .02011 - .01720 = .00291

A load of 4 lbs (axial) will result in a stress

$$\sigma = \frac{4}{2.91 \times 10^{-3}} = 1375.0 \text{ psi}$$

A pressure of 3000 psi over the .0172 in^2 area gives a load of

$$F = 300 \times .01720 = 51.6 \text{ lbs}$$

$$\frac{51.6}{2.91 \times 10^{-3}} =$$

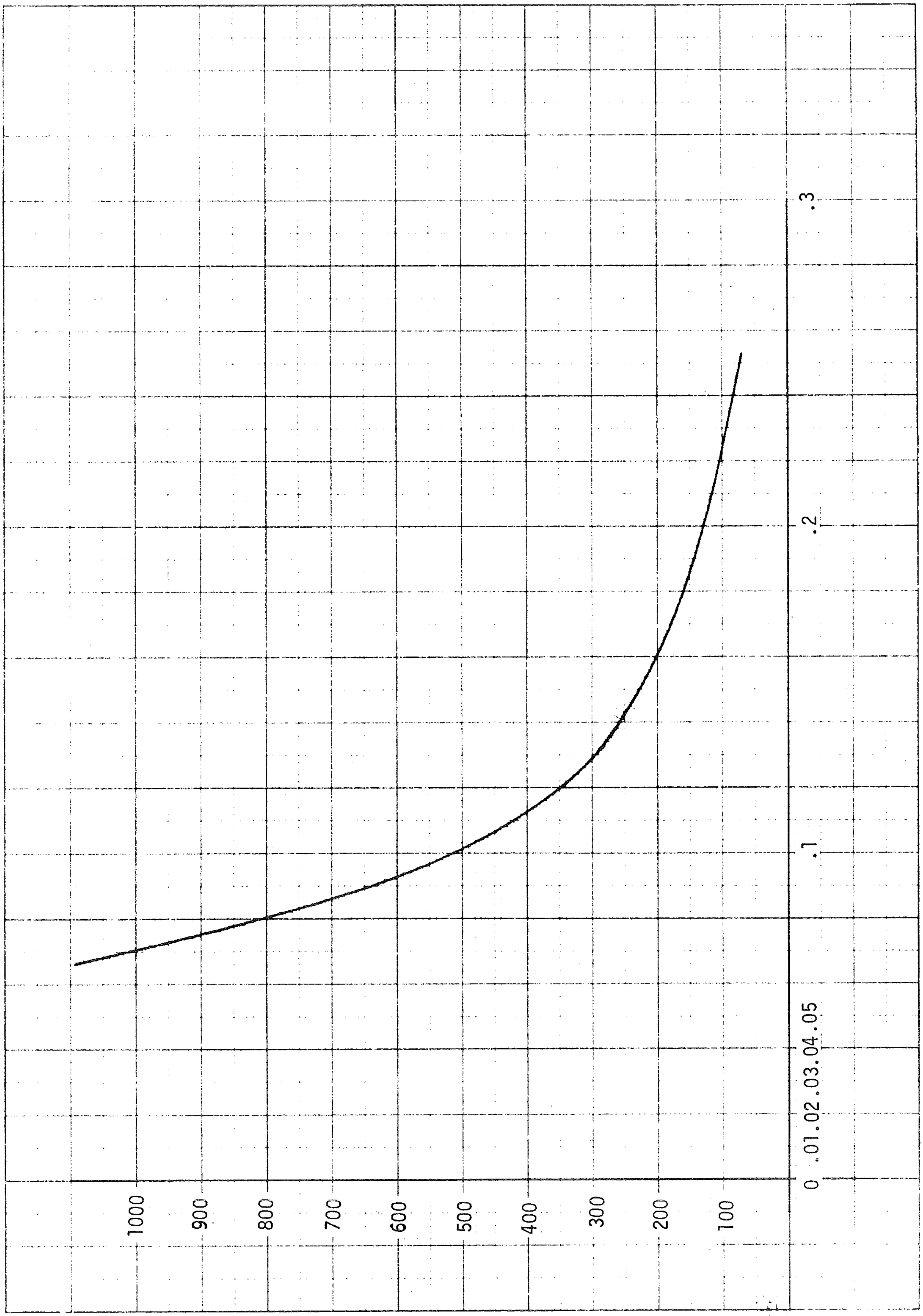
The hoop stress is:

$$\sigma = \frac{PD}{2t} \quad \text{or} \quad t = \frac{PD}{2\sigma}$$

At a design hoop stress of 20,000

$$t = \frac{3000 \times .148}{2 \times 20{,}000} = .0111$$

a wall thickness of .012 is available.


1000
900
800
700
600
500
400
300
200
100
0 .01.02.03.04.05
.1
.2
.3

At .012 wall .160 O.D. = .136 I.D.

Metal cross-sectionalarea = .02011 - .0145

= 5.58×10^{-3} in^2

The axial stress due to an actuator load of 4 lbs is:

$$= \frac{4 \text{ lb}}{5.58 \times 10^{-3} \text{ in}^2} = 717.0 \text{ psi}$$

and the axial pressure stress is:

$$\sigma = \frac{.0145 \text{ in}^2 \times 3000 \text{ lb/in}^2}{5.58 \times 10^{-3} \text{ in}^2} = 7{,}810 \text{ psi}$$

The combined actuator and pressure stress or

$$7810 + 717 = 8527 \text{ psi}$$

causes a deflection ε of

$$\varepsilon_{cres} = \frac{8527}{28.5 \times 10^6} = 2.99 \times 10^{-4} \text{ in/in}$$

For a .135 diameter Vespel actuator the σ at 4 lbs is:

$$\sigma = \frac{4 \text{ lb}}{.014314 \text{ in}^2}$$

$$\sigma = 279.5 \text{ lb/in}^2$$

This results in a stroke loss of

$$\varepsilon_{BR} = \frac{279.5}{2.1 \times 10^5} = 1.33 \times 10^{-3} \text{ in/in}$$

$$\varepsilon_{GF} = \frac{279.5}{3.15 \times 10^5} = .888 \times 10^{-3} \text{ in/in}$$

The total stroke loss is the sum of the Vespel compression, cres extension and cres thermal expansion or total stroke loss due to loads :

	Base Resin		Graphite Filled
ε_{BR}	1.33×10^{-3}	ε_{GF}	$.88 \times 10^{-3}$
ε_{CRES}	$.300 \times 10^{-3}$		$.30 \times 10^{-3}$
$\varepsilon_{LOAD_{BR}}$	1.63×10^{-3} in/in	$\varepsilon_{LOAD_{GF}}$	1.18×10^{-3} in/in

At 90°F (50°C)ΔT total loss is

	Base Resin		Graphite Filled
Load	1.63×10^{-3} in/in		1.18×10^{-3} in/in
Exp_{CRES}	0.55×10^{-3} in/in		0.56×10^{-3} in/in
$\varepsilon_{T_{90°BR}}$	2.19×10^{-3} in/in	$\varepsilon_{T_{90°GF}}$	1.74×10^{-3} in/in

At 180°F (100°C) ΔT total loss is:

	Base Resin	Graphite Filled
Load	1.63×10^{-3} in/in	1.18×10^{-3} in/in
Exp_{CRES}	1.12×10^{-3} in/in	1.12×10^{-3} in/in
$\varepsilon_{T180°BR}$	2.75×10^{-3} in/in	2.30×10^{-3} in/in

The gross available strokes at 90 and 180°F ΔT (from 19) are:

	Base Resin	Graphite Filled
ΔT = 90°F	4.00×10^{-3} in/in	3.25×10^{-3} in/in
ΔT = 180°F	7.00×10^{-3} in/in	6.00×10^{-3} in/in

This yields net available stokres as follows:

	Base Resin	Graphite Filled
ΔT = 90°F (50°C)	1.25×10^{-3} in/in	0.95×10^{-3} in/in
ΔT = 180°F (100°C)	4.25×10^{-3} in/in	3.70×10^{-3} in/in

For a design stroke of .012 in:

$$L_{BR_{(180)}} = \frac{12 \times 10^{-3} \text{ in}}{4.25 \times 10^{-3} \text{ in/in}} = 2.82 \text{ in}$$

$$L_{GF_{(180)}} = \frac{12 \times 10^{-3} \text{ in}}{3.70 \times 10^{-3} \text{ in/in}} = 3.24 \text{ in}$$

From this it appears that a 3.00 in Virgin Vespel actuator operating over a $100°C$ ($180°F$) ΔT will meet the system requirements. Preliminary design sketches will be made.

Reasses high pressure valve power/response characteristics in view of revised design - (12-1-69 40 vespel thermal actuator).

The actuator volumes are:

CRES:

Tube - .160 OD x .136 ID x 3.0 long - 17.34×10^{-3} in^3

Tube - .24 OD x 125 ID x .3 long - $\underline{9.87 \times 10^{-3} \text{ in}^3}$

Total CRES = 27.21×10^{-3} in^3

Vespel:

Rod - .135 OD x 3.00 long = 43.5×10^{-3} in^3

Weight:

CRES - 27.21×10^{-3} in^3 x .29 in^3 = 7.89×10^{-3} lbs

Vespel - 43.5×10^{-3} in^3 x .0515 = 2.24×10^{-3} lbs

(ρ_{vespel} = .0515 lb/in^3)

Assume that heat leak actual to valve is approximately as before - not over 3 watts worst case

($C_{p_{vespel}}$ = 27 Btu/lb°F)

Then

$$Q_{in} = \left\{(7.89 \times 10^{-3} \text{ lb} \times .12 \frac{\text{Btu}}{\text{lb°F}}) + (2.24 \times 10^{-3} \text{ lbs} \times .27 \frac{\text{Btu}}{\text{lb°F}})\right\} (T_a - T_f)$$

$$Q_{in} = (.945 \times 10^{-3} + .605 \times 10^{-3}) (T_a - T_f)$$

$$= 1.55 \times 10^{-3} (T_a - T_f) \text{ Btu}$$

or assuming a heat leak q_{h_ℓ} of 2.7×10^{-3} Btu/sec (~2.85 watts)

Re-examining the vacuum valve per the design sketch of 12-11-69

The actuator volumes are:

CRES:

Tube -	.420 OD x .360 ID x .30 long	=	$.0110\ in^3$
	.28 OD x .21 ID x .3 long	=	$.00808\ in^3$
Disc -	.52 OD x .090 long	=	$.0191\ in^3$
	Total		$.03818\ in^3$

$$W = .29 \times .03818 = .0111 \text{ lbs}$$

Si-Rubber - As Before

$$V = 4.19 \times 10^{-2}\ in^3$$

$$W = 1.55 \times 10^{-3} \text{ lbs}$$

The heat capacity is:

$$Q = \left\{ (.0110 \text{ lbs} \times .12 \frac{Btu}{lb°F}) + (1.55 \times 10^{-3} \text{ lbs} \times .4 \frac{Btu}{lb°F}) \right\} (T_a - T_f)$$

$$Q = (1.32 \times 10^{-3} \frac{Btu}{°F} + .62 \times 10^{-3} \frac{Btu}{°F}) (T_a - T_f)$$

$$Q = (1.94 \times 10^{-3}) (T_a - T_f) \text{ Btu}$$

Since the valve will be heated to above, the actuation temperature, we will assume no net heat flow into or out of the actuator due to the valve.

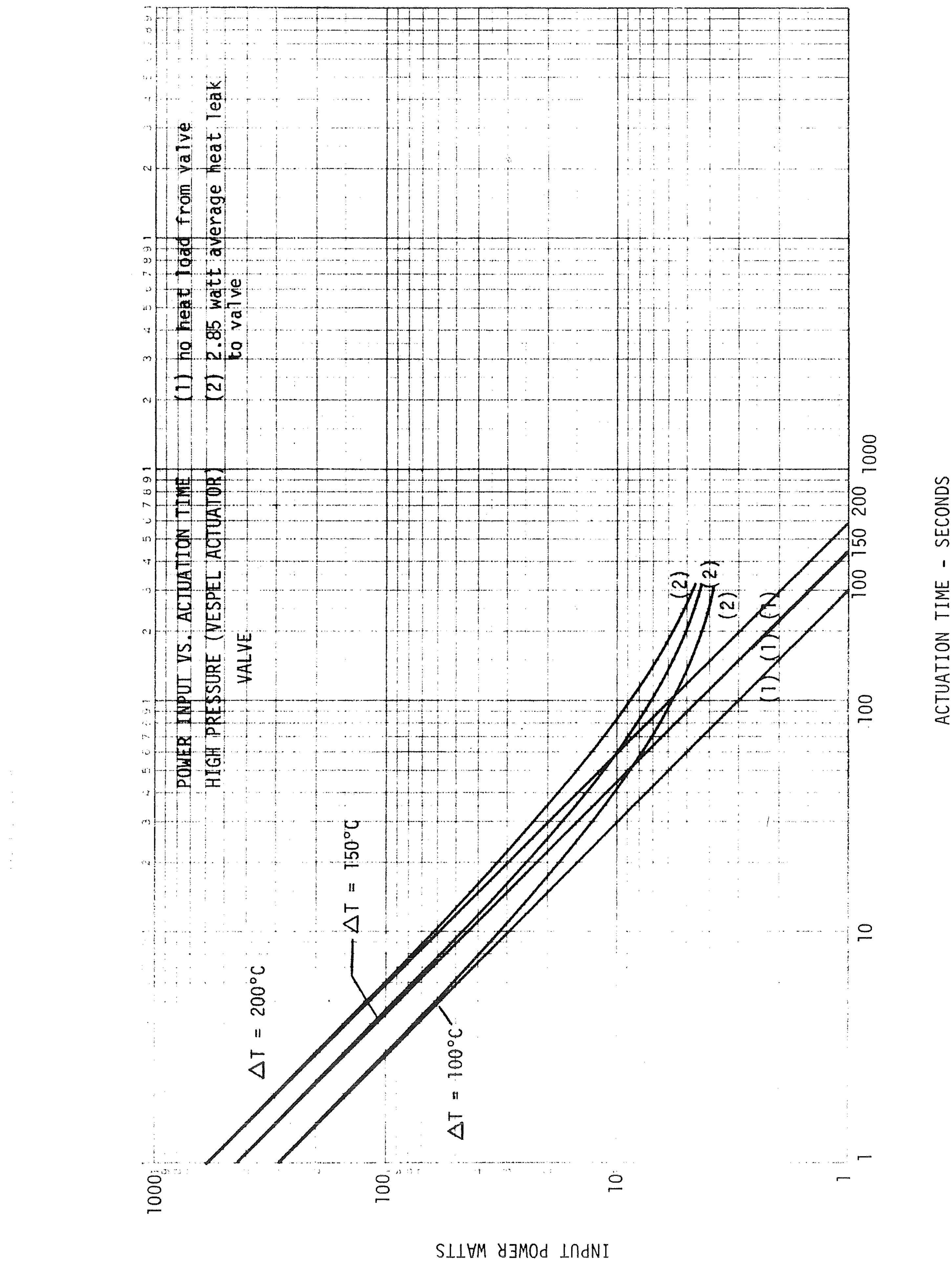
The actuation time vs. power may then be tabulated and plotted as follows:.

$$Q_{in} = [1.55 \times 10^{-3} (T_a - T_f) + 2.7 \times 10^{-3} t] \text{ Btu}$$

For a temperature rise of (100°C) 180°F for actuation, namely from (150-250°C) 302-482°F a table and plot similar to that for the first high pressure valve may be made:

Actuation time t (sec)	T = 50°C (122°F) ΔT = 200°C (360°F)		T = 100°C (212°F) ΔT = 150°C (270°F)		T = 150°C (302°F) ΔT = 100°C (180°F)	
	Q(BTU)	$\frac{Q}{t} = q \frac{\text{Btu}}{\text{sec}}$	Q	$\frac{Q}{E} = q$	Q	$\frac{Q}{t} = q$
0	.557	∞ Btu/sec watts	.418	∞	.279	∞
.5	.571	.114 Btu/sec 20.3 watts	.432	.0864 91.1	.292	.0584 61.6
10	.584	.0584 61.6	.445	.0445 47.0	.306	.0306 32.2
20	.611	.0306 32.3	.472	.0236 24.9	.333	.0166 17.5
30	.638	.0213 22.5	.499	.0166 17.5	.360	.0120 12.7
60	.719	.0120 12.65	.580	.00968 10.23	.441	.00735 7.75
120	.881	.00734 7.75	.742	.00618 6.52	.603	.00502 5.30
180	1.043	.00580 6.12	.904	.00502 5.30	.765	.00425 4.48
240	1.205	.00502 5.30	1.066	.00444 4.69	.927	.00386 4.07

These data are plotted in the following figure.

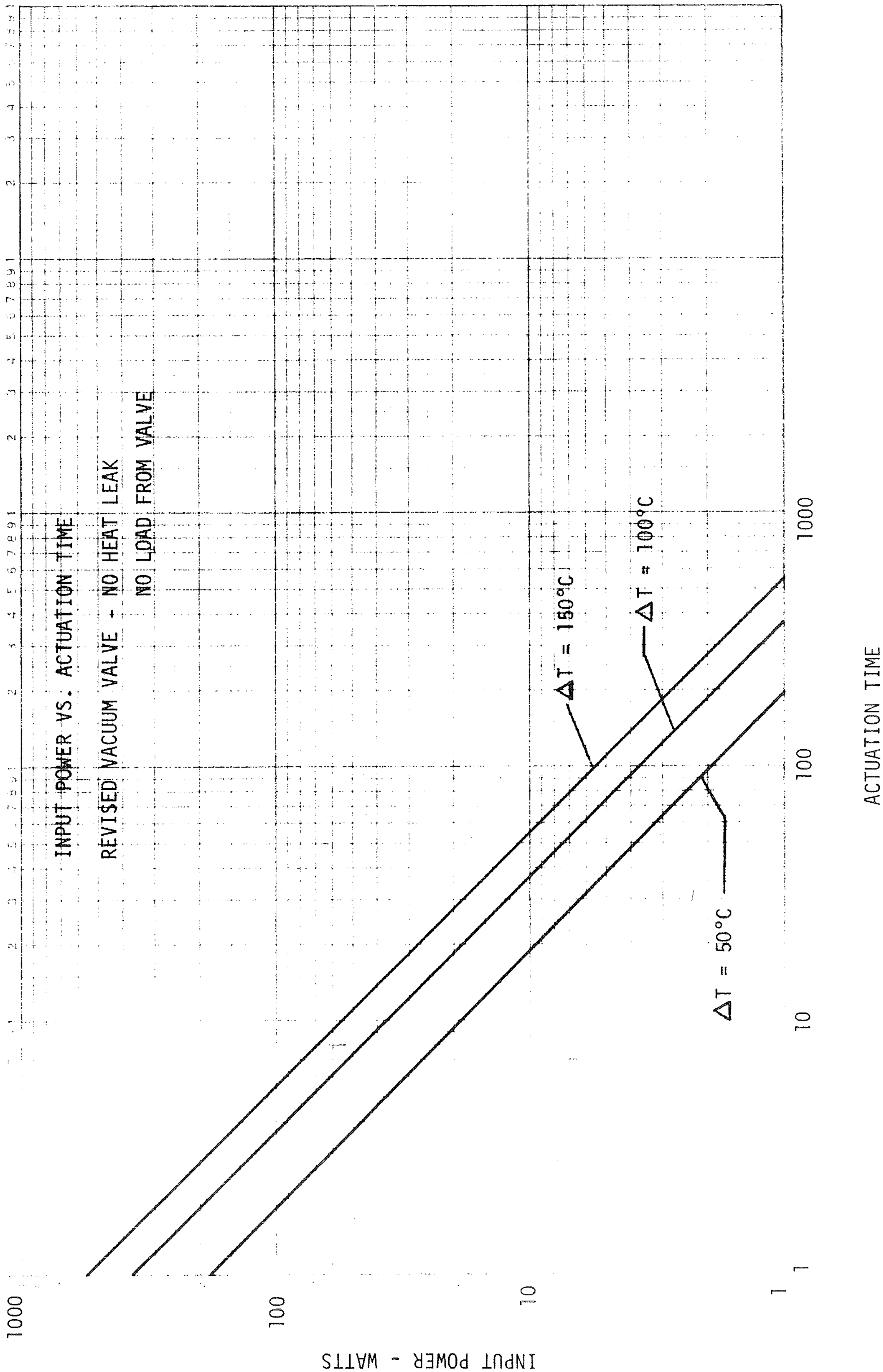

POWER INPUT VS. ACTUATION TIME
HIGH PRESSURE (VESPEL ACTUATOR)
VALVE
(1) no heat load from valve
(2) 2.85 watt average heat leak to valve
ΔT = 200°C
ΔT = 150°C
ΔT = 100°C
(1)
(2)
INPUT POWER WATTS
ACTUATION TIME - SECONDS
1000
100
10
1
150
200

ACTUATION TIME VS. POWER

REVISED VACUUM VALVE

$(Q = 1.94 \times 10^{-3} (T_a - T_f) \text{ Btu})$

Actuation Time (sec)	T = 50°C (122°F) ΔT = 150°C (270°F)		T = 100°C (212°F) ΔT = 100°C (180°F)		T = 150°C (302°F) ΔT = 50°C (90°F)	
	Q Btu	$\frac{Q}{t} = q \frac{\text{Btu}}{\text{sec}}$	Q	$\frac{Q}{t} = q$	Q	$\frac{Q}{t} = q$
0	.524	∞	.349	∞	.175	∞
5		.105 $\frac{\text{Btu}}{\text{sec}}$ 111 watts		.0698 73.6		.0350 36.9
10		.0524 55.3		.0349 36.8		.0175 18.5
20		.0262 27.6		.0175 18.5		.00875 9.23
30		.0172 18.0		.0116 12.1		.00584 6.15
60		.00873 9.20		.00582 6.13		.00292 3.08
120		.00436 4.60		.00291 3.07		.00146 1.54
180		.00291 3.07		.00194 2.05		.000972 1.03
240		.00218 2.3		.00145 1.53		.000730 .77


INPUT POWER VS. ACTUATION TIME
REVISED VACUUM VALVE - NO HEAT LEAK
NO LOAD FROM VALVE
ΔT = 150°C
ΔT = 100°C
ΔT = 50°C
1
10
100
1000
ACTUATION TIME
1000
100
10
1
INPUT POWER - WATTS

APPENDIX IC

MAGNETIC LATCH DESIGN

PRELIMINARY DESIGN

Requirements

Force: 4 lbs at a distance of 2 to 4 mils

Displacement: 0.01", 0.03", and 0.08"

The magnet size is to be minimized. The latching and unlatching operation is described by referring to Figure 1.

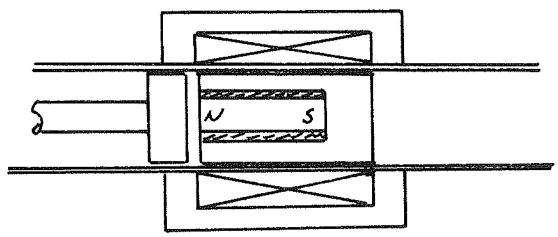


Fig 1.

For short distances (less than 0.004") the magnet pull is very high since the reluctance of the magnet gap is relatively small compared to the reluctance of the gap between poppet and magnet. For such an application a cup magnet assembly is quite efficient. When the poppet is pushed close to the magnet, it is pulled and latched to the magnet. Unlatching is performed by a bucking field generated by a solenoid coil.

Magnet Design

Large pull at short distances can be achieved by maximizing the flux density B. To guard against demagnetizing effect due to varying air gap and unlatching field, a reasonable coercive force is required. Residual induction B_r and coercive force H_c of superior magnetic materials are given in Table 1.

Table 1

Material	B_r Gauss	H_c Oerteds
Cast Alnico 5-7	13000	730
Cast Alnico 8A	8500	1600
Platinum Cobalt	6000	4200
Samarium-Cobalt	9000	9000

Alnico 5 appears to be most suitable for high force small gap magnet design. The force generated is given by the formula:

$$F = 5.77 \times 10^{-7} B^2 A$$

where: B = flux density in gauss

A = flux area

For F = 4 lbs and for maximum energy product, shear line slope = 18 which gives $B = 10^4$ gauss.

$$\text{Required } A = \frac{4}{5.77 \times 10^{-7} \times 10^8}$$

$$= 0.07 \text{ in}^2$$

$$\text{Required diameter} = \sqrt{\frac{4}{\pi} \times .07}$$

$$= 0.3''$$

Required magnet length = 0.3 x 4 for shear line slope of 18.

$L = 1.2''$

Assume cup gap width = 5 x .004 = 0.02". Then cup ID = 0.3 + 0.02 x 2 = 0.34".

Cup outer diameter is given by the following equation.

$$\frac{\pi}{4} D_o^2 = 0.07 + \frac{\pi}{4} D_i^2$$

$$D_o^2 = 0.07 \times \frac{4}{\pi} + 0.09$$

$$= 0.18$$

$$D_o = 0.42''$$

Total length of the assembly is:

$$L_o = 1.2 + 2 \times \text{wall thickness of the cup}$$
$$= 1.2 + .12 = 1.32''$$

Therefore overall magnet dimensions are:

$D_o = 0.42''$

$L_o = 1.32''$

It should be noted that there is a demagnetizing effect due to variable air gap and bucking magnetic field during the unlatching period.

The approximate field required to unlatch the poppet is:

$H_c = 100$ Oerteds

$$= \frac{1000}{4} \times 100 = 8{,}000 \text{ amp turns/meter}$$

$$\text{No of ampere turns} = \frac{80{,}000\ XL}{} = \frac{8000 \times 2}{} = 160 \text{ amp turns}$$

Since the current required is intermittent, less than 10% duty cycle, the solenoid dimension is reasonably small. For 8 mil wire diameter, 2 mil wire insulation, approximate solenoid dimensions are:

$$L = 1.2''$$

$$D_i = 0.45''$$

$$D_o = 0.50''$$

The design considered above is liable to degrade in latching force with time since demagnetizing of Alnico-5 due to the bucking field tends to reduce the magnet pull.

If Samarium-Cobalt magnet is used, the size of the magnet will be slightly larger with the advantage that the magnet flux density is essentially unchanged with time and repeated unlatchings. However, the size of the solenoid required to reduce the magnet pull to 60% of the latched valve will be quite large.

A latching magnetic circuit employing a different concept is shown in Figure 2.

Latching is achieved by magnetizing the permanent magnet to its full residual induction by activating the solenoid. Unlatching is performed by demagnetizing the magnet.

Latching force required = 4 lbs

Assume B = 10,000 gauss

Then the magnet face area required is:

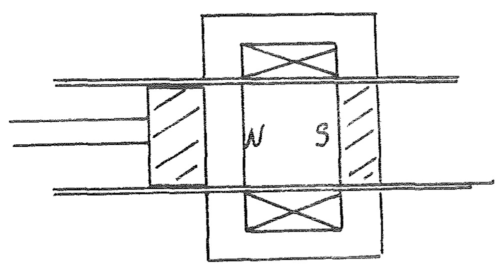


Fig. 2.

$$A = \frac{4}{5.77 \times 10^{-7} \times 10^{8}} = 0.07 \text{ in}^2$$

Inside diameter of the magnet = Outside diameter of the spring = 0.125".

Outside diameter D_o is:

$$D_o{}^2 = \frac{4}{\pi} D_i{}^2 + 0.07$$

$$= .02 + 0.07 = 0.09$$

$$D_o = 0.30"$$

Air gap dimensions are:

$$D_g = 0.3"$$

$$L_g = 0.005"$$

Required magnet length is:

$$L_m = \frac{B_g L_g}{H_d}$$

$B_g = 10^4$ gauss

H_d = magnetizing force corresponding to B operating point of 10^4 gauss.

For Alnico-5, H_d = 300 oersteds.

$$L_g = 0.005'' = 0.0125 \text{ cm}$$

$$L_m = \frac{10^4 \times 1.25}{300 \times 100} = 0.41 \text{ cm}$$

$$= 0.16 \text{ in.}$$

Solenoid Design

Following are the parameters during the latched position.

Latching force $F = 4$ lbs

Flux density $B = 10^4$ gauss.

To reduce the force to 75% of the latching force, B is required to be reduced to $10^4 \times \sqrt{.75}$. Therefore an unlatching B = 8600 gauss is required.

The required H for Alnico-5 is obtained from its B-H curve yielding:

$$H = 30 \text{ oersteds}$$

$$= 30 \times \frac{1000}{4} = 2400 \ \frac{\text{amp turns}}{\text{meter}}$$

Magnetic path length - 2 " = 5 cm (max)

No of amp turns required $= \frac{2400 \times 5}{100} = 120$ amp turns to unlatch and therefore release the poppet.

To remagnetize the magnet, approximately twice the value of magnetic field should be provided.

Number of amp turns required = 120 x 2

= 240 amp turns.

A solenoid consisting of 1900 turns and carrying 200 m amp will generate 1600 x 0.2 = 320 amp turns. The safety margin is 80 amp turns. Magnetization and demagnetization can be optimized by varying the forward and reverse solenoid current.

<u>Specifications of Solenoid</u>

No of turns = 1600

DC resistance = 150 ohms

Wire size = 40 gage

Space factor = 0.4

Solenoid length = 0.55"

Inside diameter = 0.34"

Outside diameter = 0.50"

In order to assess the latching forces available before the actuator has fully raised the poppet calculations of magnetic latching force were made at various air gaps. These are shown in the following table.

FORCE COMPUTATIONS FOR VARIOUS AIR GAPS

Magnet length - 0.16 inch

Magnet area = gap area = 0.07 in^2

Air gap L_g	$\frac{B_d}{H_d}$ Slope	Flux Density B gausses	Force lbs	Comment
0.005	32	10,000	4	Latching force after application of magnetic field
0.005	14	8,600	3	After application of demagnetizing field (-50 Oer)
0.01	7	4,500	0.8	Increased air gap length
0.01	-	5,000	1.0	Application of magnetizing field (100 oer)
0.03	2.3	2,000	0.16	Increased air gap length
0.03	-	2,500	0.25	Application of magnetizing field (100oer)
0.08	1	1,000	0.04	Increased air gap length

MAGNETIC LATCH DESIGN CALCULATIONS

Test Model Analysis

Required magneto motive force (MMF) for saturation condition is computed as follows:

For Alnico-5, required H around saturation is:

$$H = 700 \text{ oerteds } (B_r = 12{,}500 \text{ gauss})$$

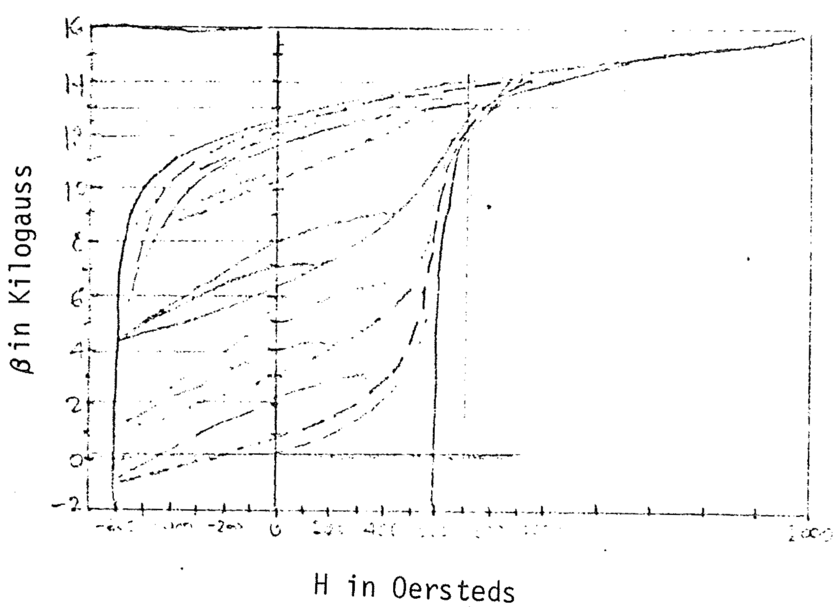
$$= 700 \times \frac{1000}{4\pi} \; \frac{\text{Amp-turns}}{\text{meter}}$$

$$= 5.6 \times 10^4 \; \frac{\text{Amp-turns}}{\text{meter}}$$

For $l_m = \frac{0.254}{100}$ meters

$$MMF = \frac{5.6 \times 10^4 \times 0.254}{100}$$

$$= 142 \text{ Amp turns}$$



Typical Interior Hysteresis Loop Data Taken on Alnico-5

Soft Iron Circuit

Assume μ_r for soft iron = 800

Magnet area A = constant

Soft Iron MMF = $R_{SI} B A_{SI}$

where RSI = reluctance of the soft iron circuit

B = saturation flux density

A_{SI} = Area of cross-section of the soft iron circuit

Approximate soft iron length l_{SI} = 2.54/100 meter

B = 12.5 k gauss = 1.25 Weber/in^2

$$RA = \frac{l_{SI}}{\mu} = \frac{2.54}{100} \times \frac{1}{800\,\mu_o} = \frac{3.15 \times 10^{-5}}{\mu_o}$$

$$\text{Soft iron MMF} = \frac{3.15 \times 10^{-5} \times 1.25 \times 10^{7}}{4}$$

$$= 32 \text{ amp turns}$$

Air-Gap MMF

Assume total gap length = 0.002" = 0.00508 cm

$$lg = 5.08 \times 10^{-5} \text{ meter}$$

$$\mu = \mu_0 ; \mu_2 = 1$$

$$\text{Air gap MMF} = \frac{Bl}{\mu} = \frac{5.08 \times 10^{-5} \times 10^{7} \times 1.25}{4\pi}$$

$$= 50 \text{ ampere turns}$$

Total of NI required

= 142 + 32 + 50

= 225

Parameters defined for the model:

Number of turns of the solenoid = 1900 $\pm$ 50

Minimum voltage across the coil = 26 volts

Coil resistance = 150 ohms

Requirmed minimum coil current $I_{min} = \frac{V_{min}}{R_{max}} = \frac{26}{150} = 0.174$

Minimum NI = $N_{min}\ I_{min} = 0.174 \times 1850 = 320$

Safety factor under worst condition $= \frac{320}{225} = 1.42$

Nominal V = 28 volts

" R = 150 ohms

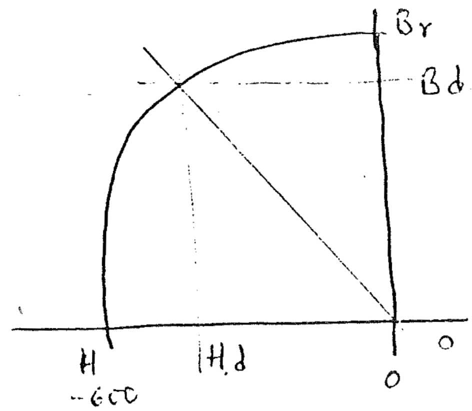
" N = 1900

" NI = $1900 \times \frac{28}{150} = 367$ amp turns

Nominal Safety Factor $= \dfrac{367}{225} = 1.64$

Therefore, at least 40% of the total ampere turns is supplied to account for leakage. Usually the leakage factor f is small for small air gaps.

<u>Latching Mode Calculation</u> (solenoid power removed)



Magnet length $= \dfrac{0.254}{100}$ meter = Lm

$$\text{Magnet MMF} = H_dL_m$$

$$= B_dA_{SI}R_{SI} + B_dA_gR_g$$

where suffix SI is for soft iron

g is for air gap

$$A_{SI}R_{SI} = \frac{l_{SI}}{\mu_{SI}} = \frac{3.15 \times 10^{-5} \times 10^{7}}{4\pi} = 25.5 \ \frac{\text{amp-turns}}{\text{per unit flux density}}$$

$$_gR_g = \frac{l_g}{\mu_o} = 40 \text{ amp turns per unit flux density}$$

$$\therefore \ H_dL_m = B_d[65.5]$$

$$\frac{B_d}{H_d} = \frac{0.254}{65.5 \times 100} \ \frac{\text{Weber/in}^2}{\text{amp/turn/meter}}$$

$$= \frac{0.254}{65.5} \times 10^4 \times \frac{10^3}{4}$$

$$= \frac{2540}{83} = 30.5$$

For $\dfrac{B_d}{H_d} = 30.5$ ratio

B_d = 11.4 K gauss for Alnico-5

and H_d = 400 Oerteds

$$H_d \text{ or Magnet MMF} = 400 \times \frac{10}{4\pi} \times 0.254$$

$$= \underline{81 \text{ amp turns}}$$

That 81 amp turns generating B_d = 11 kilogauss is sufficient to keep the magnet in latching position can be proved by computing holding force.

The holding force F_H generated is:

$$F_H = 5.77 \times B^2 A_m \times 10^{-7} \text{ lbs}$$

$$= 5.77 \times \frac{(11.4)^2}{10} \times A_m$$

where B is in kilograms and A_m in square inches.

$$A_m = \frac{\pi}{4} [(0.180)^2 - (0.050)^2]$$

$$= \frac{\pi}{4} \frac{3}{100} = \frac{2.35}{100}$$

$$F_H = 5.77 \times 14 \times \frac{2.35}{100} \text{ lbs}$$

$$= 1.75 \text{ lbs}$$

$$= \underline{\underline{28.0 \text{ oz}}}$$

<u>Demagnetizing MMF (NI_{demag}):</u>

Demagnetizing field required for Alnico-5 = 600 oerteds

Demagnetizing MMF = $600 \times \frac{10}{4\pi} \times 0.254$

Where magnet length $L_m = \frac{0.254}{100}$

Demagnetizing MMF is:

NI_{demag} = 120 ampere turns

$$\text{Max } I_{demag} = \frac{120}{N_{min}} = \frac{120}{1850}$$

$$= 0.065 \text{ amp}$$

$$\text{Required voltage } V = 0.065 \times 150$$

$$= 9.8 \text{ volts}$$

or approximately 140 % of the magnetizing voltage (26 volts) is required to demagnetize the magnet. In practice, 50% or half of the magnetizing voltage is applied.

Experimental Data

Valve Model No. 002; Coil R = 155 Ω, R series = 132 Ω

Scale Range: 0-5 lbs (1 oz increment)

Voltage (volts)	Force (oz)**
20	8
22	14, 14, 12, 15
26	21, 23, 22, 22.5
30	27.5, 27, 27
30*	27.5
40	31, 31.5
40*	31, 31
50	31, 31.5, 31, 31
50*	
60	30, 31, 31
70	32, 32, 31, 31.5, 32
80	29, 31, 31

*Reading is observed by demagnetizing first, then magnetizing.

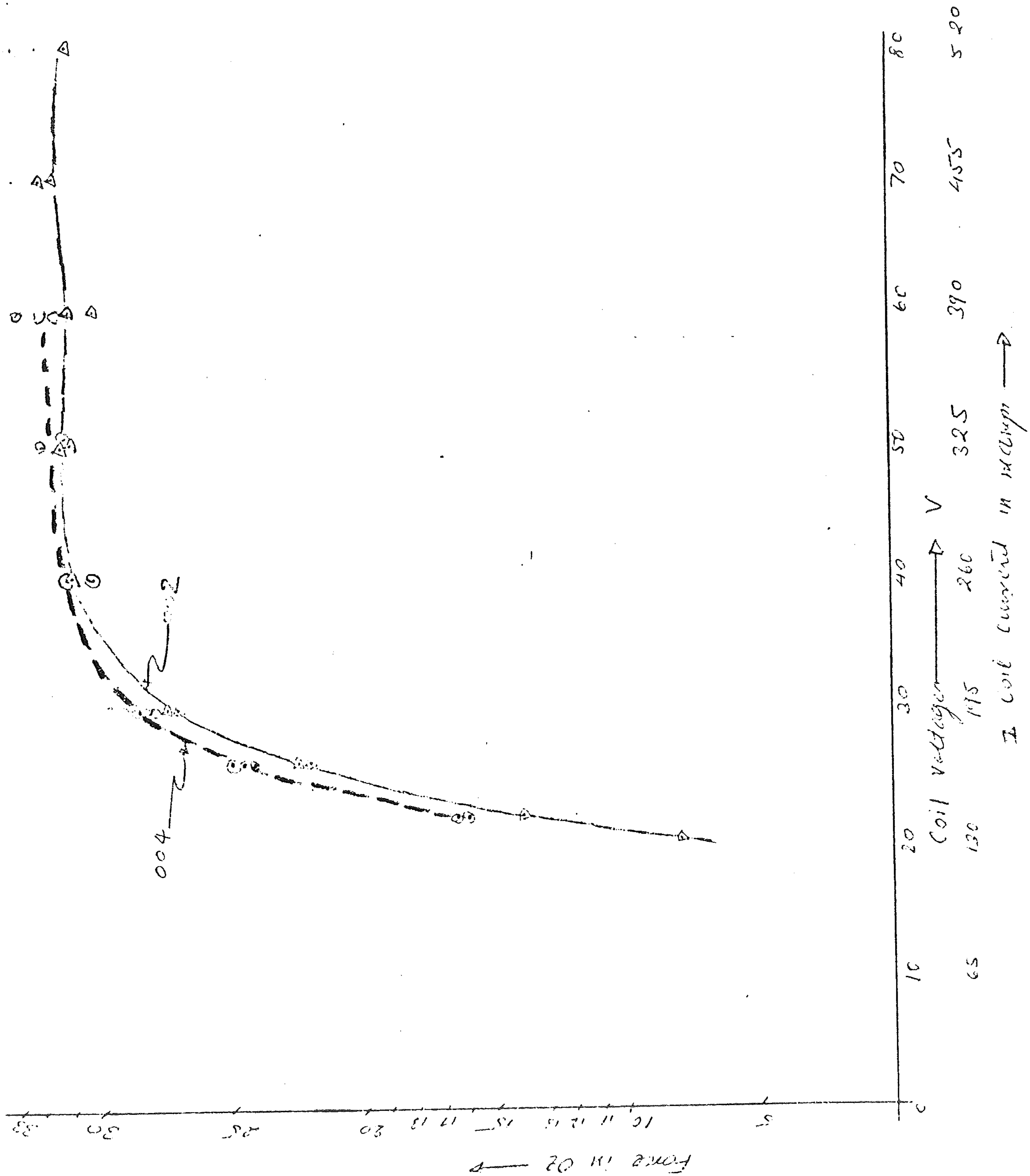
**Add spring force of at least 4 to 8 oz. in all measurements.

Valve No. 004

Scale: 0-2 lbs (with 0.5 oz increments)

Volts	Force **
22	16, 16.5, 16.5
26	24, 24.5
26*	25
30	28, 29, 29.5, 27.5, 26.5
30*	28.5, 26.5, 26.5
34	30, 28, 30, 29
34*	29, 29, 27.5, 29.5
40	28.5, 30, 31, 30.5, 31
40*	30.5, 30, 31
50	31, 32
50*	31, 32
60	33, 33
60*	32, 31.5

**Add spring force of at least 4 to 8 oz. in all measurements



Coil voltage V
I coil current in mAmp
Force in oz
.002
.004
10 20 30 40 50 60 70 80
65 130 195 260 325 390 455 520

FINAL MAGNET LATCH DESIGN

Utilizing the model tests, the final design is as follows:

Requirements

Force: 4 lbs

Air gap: 0-5 mils

Solenoid and magnet size: as small as possible

Magnet Area, A_m

Latching force required = 4

Assume Bd = 11 K gauss

Required magnet area A_m is obtained from the following equation

$$F = 5.77 \times 10^{-7} \times B^2 A_m$$

$$A_m = \frac{F}{5.77 \times 10^{-7} \times B^2} \text{ in}^2$$

$$= \frac{4}{5.77 \times 10^{-7} \times 121 \times 10^6}$$

$$= \frac{5.7}{100} \text{ in}^2$$

Take safety margin of 25%

Then area required $= \frac{5.7 \times 1.25}{100}$

$$= \frac{7.1}{100} \text{ in}^2$$

$$\frac{\pi}{4} D_o^2 = \frac{}{4} D_i^2 + \frac{7.1}{100}$$

$$\therefore D_o = [D_i^2 + 9/100]^{1/2}$$

$$= [\frac{1.56 + 9}{100}]^{1/2} = 0.315"$$

Magnet Length

Magnet MMF = Hd l_m

where l_m = magnet length

Hd = Field at which flux density Bd is produced in the circuit by the magnet.

Hdl_m = drop across air gap + drop across the magnet circuit

Assume soft iron $\mu_r = 1000$

Soft iron MMF = RB_dA_{SI}; R = reluctance

$$= l_{SI}/A_{SI}\mu$$

Area $A_{SI} = A_m$

$$R_{SI}A_{SI} = \left(\frac{l_{SI}}{\mu_o\mu_r}\right) = \left(\frac{3.8}{100}\text{ meter}\right)\frac{10^7}{1000 \times 471}$$

RA_{SI} = 30 mks units

Air gap lg = 0.005" = $\frac{12.6}{10^5}$ meter

$\mu_r = \mu_o = \frac{471}{10^7}$ henries/meter

$$\text{Air gap } R_gA_g = \frac{l_g}{\mu_o} = 12.6 \times \frac{10^2}{471}$$

$$= 100$$

$\therefore$ Hdl_m = Bd[130] = 130 x 1.1 = 143 amp-turns

Since Bd = 11 k gauss

= 1.1 weber/in^2

For Bd = 11 K gauss

Hd = 480 oerteds

$$= 480 \times \frac{1000}{4\pi} \text{ amp turns/meter}$$

$$l_m = \frac{143}{480 \times 10} \times 471 \times \text{cm}$$

$$= .356 \text{ cm} = 0.141''$$

10% safety margin gives

$$\underline{l_m = 0.155 \text{ to } 0.160 \text{ inch}}$$

Solenoid Design

For Alnico-5, required H around saturation is:

$$H_{sat} = 700 \text{ oerteds}$$

$$= 5.6 \times 10^4 \text{ amp-turns/meter}$$

For $l_m = 0.160'' = 0.407$ cm

$$l_m H_{sat} = \frac{0.407}{100} \times 5.6 \times 10^4$$

$$= 226 \text{ amp-turns}$$

$$B_{sat} = 13.0 \text{ K gauss}$$

$$= 1.3 \text{ weber/in}^2$$

$$NI_{soft\ iron} = 30 \times 1.3 = 39 \text{ amp turns}$$

$$NI_{air\ gap} = 100 \times 1.3 = 130 \text{ amp turns}$$

$\therefore$ Total NI required for saturation

$$= 226 + 130 + 39$$

$$= 395 \text{ amp turns}$$

Select minimum safety margin = 45%

Required amp turns = 395 x 1.45

= 572

Solenoid ID = 0.385"

Solenoid length = 0.55"

Minimum power supply voltage = 26 volts

Select No. 36 enamel wire.

Max wire dia = 0.0057

No. of turns/layer = $\frac{550}{5.7}$ = 96

Length of 1st layer = $96 \pi D_i$

= $96 \pi \times 0.392$

= 120 inches

= 10 feet

1st layer R_1 = 0.414 x 10 = 4.14 ohms

2nd layer R_2 = 4.14

3rd layer R_3 = 4.20

R_4 = 4.26

R_5 = 4.32

R_6 = 4.38

R_7 = 4.44

Total R = 29.88 ohms

$$\text{Minimum I} = \frac{V_{min}}{R} = \frac{26}{29.88} = 0.865$$

No. turns = 7 x 96 = 670

<u>No. NI = 670 x 0.865 = 580</u>

Solenoid OD = 0.385 + 7 x 0.0057 x 2

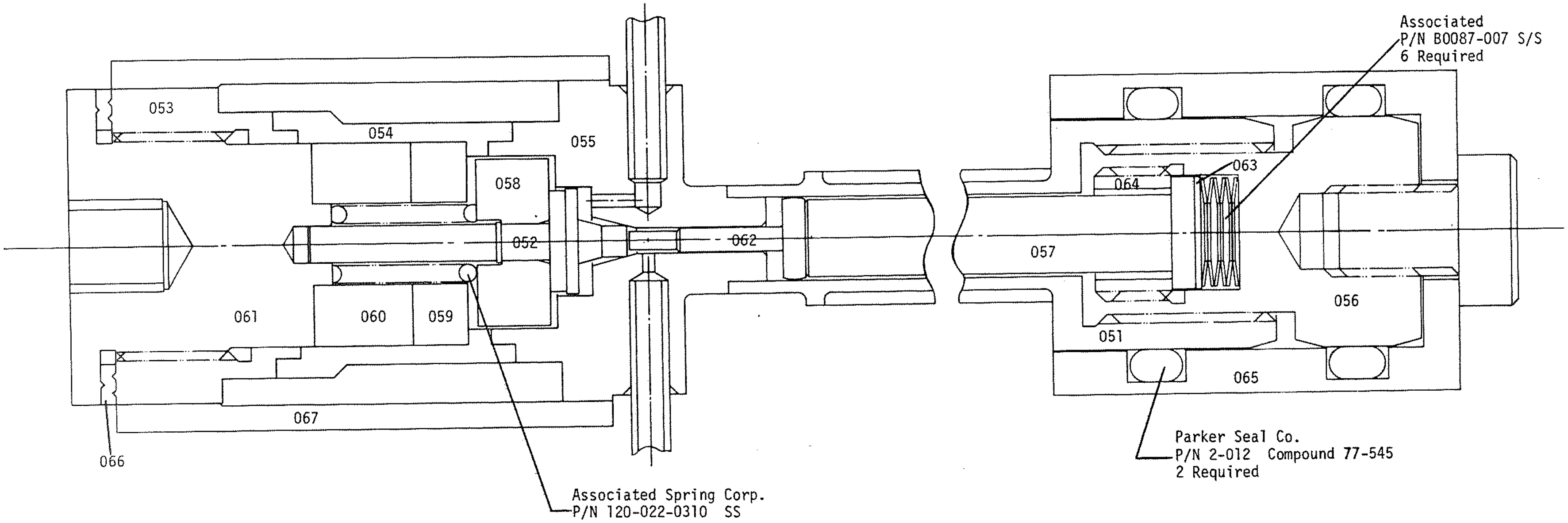
= 0.385 + 0.08

= 0.465

Selected solenoid OD = 0.5"

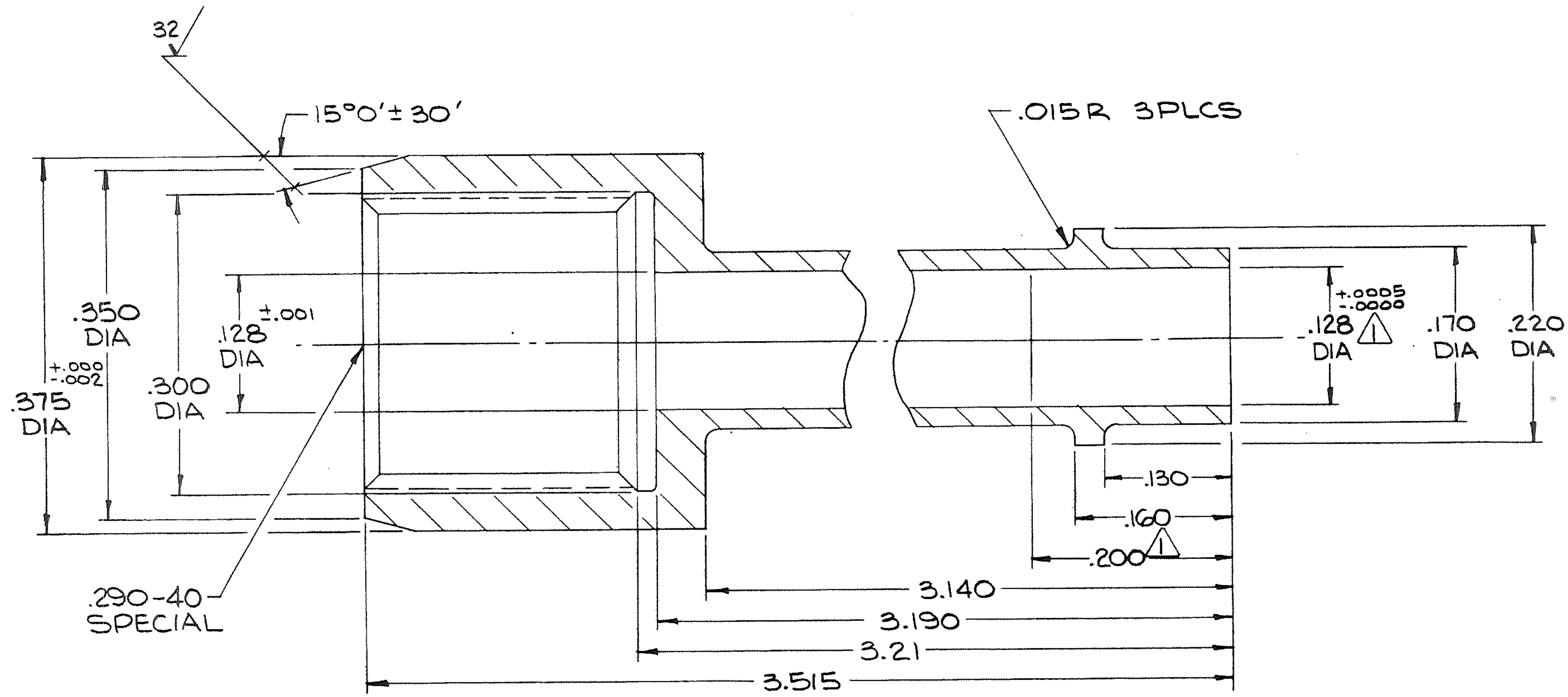
APPENDIX II

DETAIL DRAWINGS, HIGH PRESSURE VALVE



SK 1190-050
Final Design Drawing

SK | CHG LTR



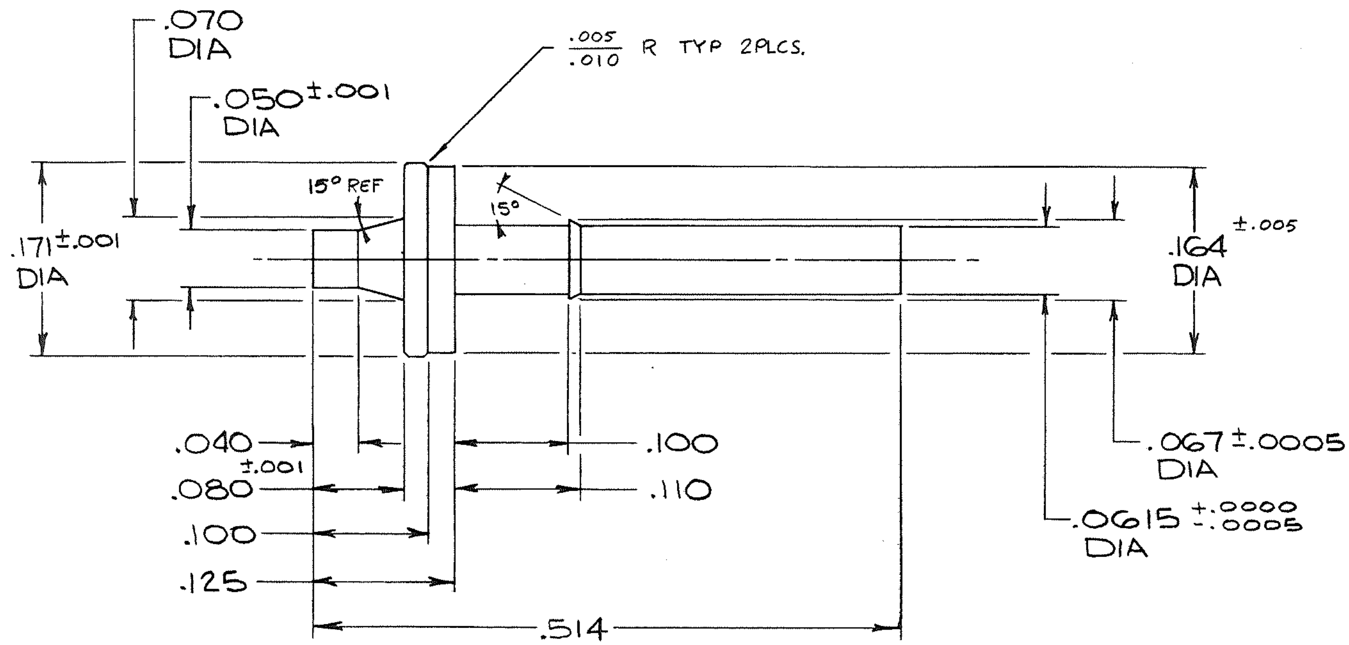
⚠1 .128 +.0005 -.0000 DIA APPLIES TO NOTED LENGTH.

TOL:
XX=±.010
XXX=±.005

MATL: CRES 410			
ORIGINATOR DAVENPORT	DATE	TITLE HOUSING - ACTUATOR	ENGINEERING SKETCH TRW SYSTEMS GROUP ONE SPACE PARK • REDONDO BEACH • CALIFORNIA
[signature]	7-6-70		SK 1190-051
MJO SCALE 10/1			SHEET 1 OF 1

SYSTEMS 3663 REV. 5-67

SK CHG LTR

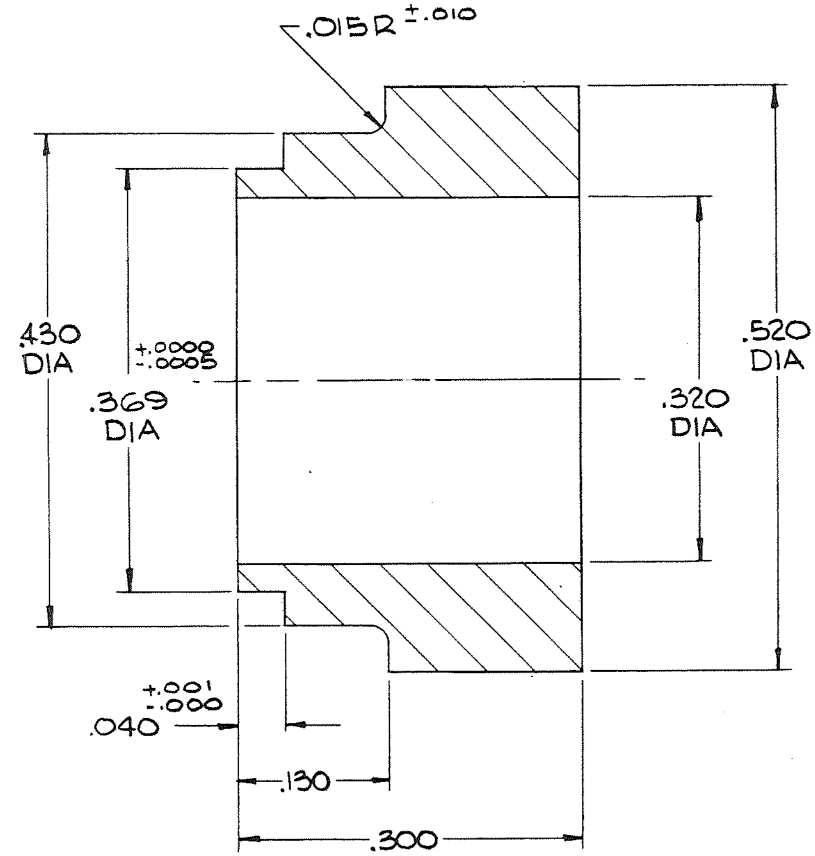


MATL: VESPEL

ORIGINATOR DAVENPORT	DATE	TITLE POPPET	ENGINEERING SKETCH TRW SYSTEMS GROUP ONE SPACE PARK • REDONDO BEACH • CALIFORNIA
	7-6-70		
MJO SCALE 10/1			SK 1190-052
			SHEET 1 OF 1

SYSTEMS 3663 REV. 5-67

SK | CHG LTR



TOL:
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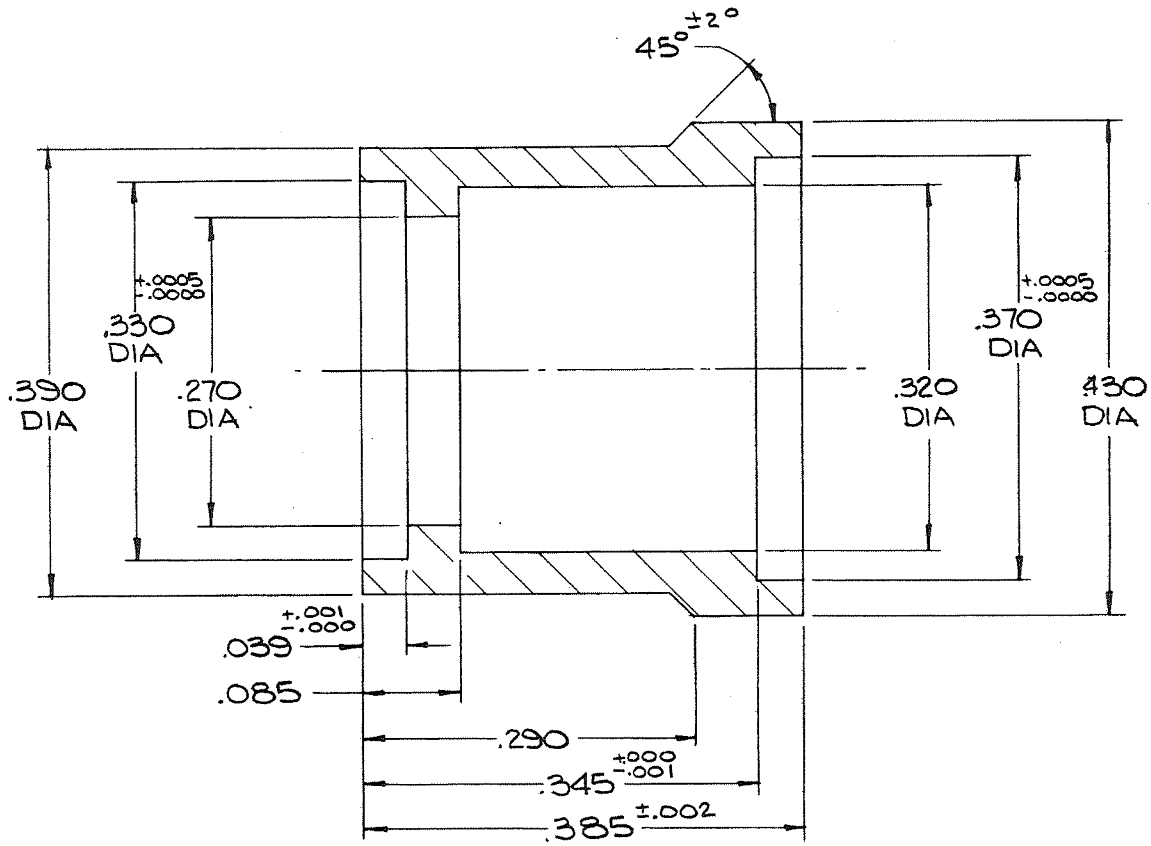
XXX=±.005

MATL: CRES 410

ORIGINATOR	DATE	TITLE	
DAVENPORT		HOUSING- REAR (ROUGH)	ENGINEERING SKETCH TRW SYSTEMS GROUP ONE SPACE PARK • REDONDO BEACH • CALIFORNIA
	7-6-70		SK 1190-053
MJO	SCALE: 10/1		SHEET 1 OF 1

SYSTEMS 3663 REV. 5-67

SK | CHG LTR



TOL:
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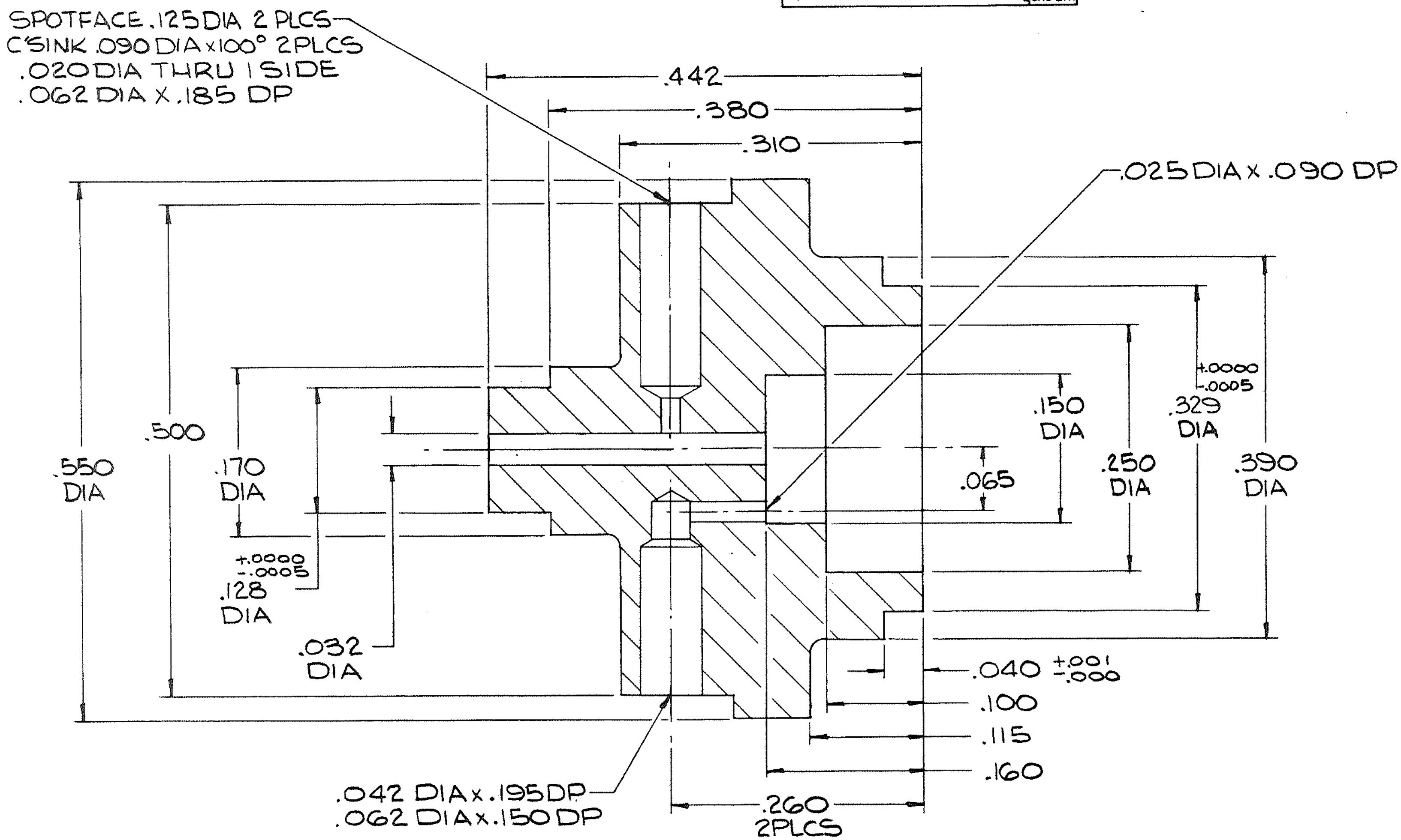
XXX = ±.005

MATL: CRES 316

ORIGINATOR	DATE	TITLE	ENGINEERING SKETCH
DAVENPORT		HOUSING - CENTER (ROUGH)	TRW SYSTEMS GROUP ONE SPACE PARK • REDONDO BEACH • CALIFORNIA
[signature]	7-6-70		SK 1190-054
MJO SCALE: 10/1			SHEET 1 OF 1

SYSTEMS 3693 REV. 5-67

SK CHG LTR



TOL:
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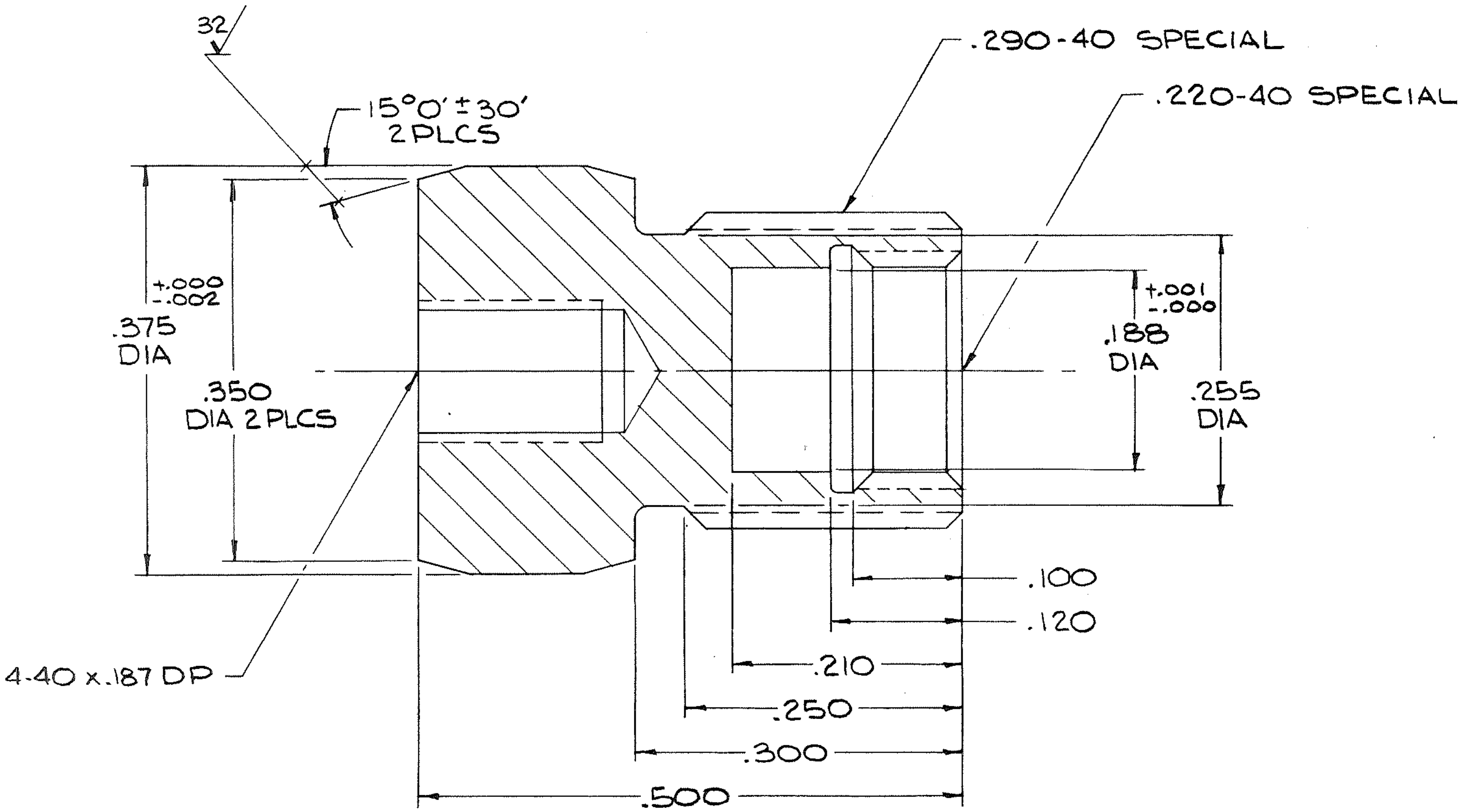
XXX = ±.005

MATL: CRES 410

ORIGINATOR	DATE	TITLE	
DAVENPORT		HOUSING - FRONT (ROUGH)	ENGINEERING SKETCH TRW SYSTEMS GROUP ONE SPACE PARK • REDONDO BEACH • CALIFORNIA
[signature]	7-6-70		SK 1190-055
MJO	SCALE: 10/1		SHEET OF

SYSTEMS 3663 REV. 5-67

SK | CHG LTR



TOL:
XX = ±.010
XXX = ±.005

MATL: CRES 410

ORIGINATOR	DATE	TITLE	ENGINEERING SKETCH
DAVENPORT		CAP- ACTUATOR	TRW SYSTEMS GROUP ONE SPACE PARK • REDONDO BEACH • CALIFORNIA
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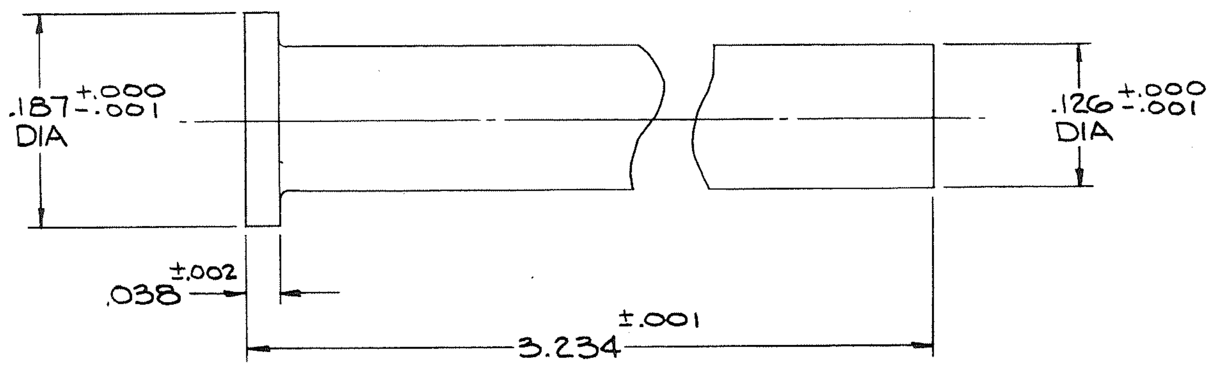
MJO SCALE 10/1			SHEET 1 OF 1

SYSTEMS 3063 REV. 5-67

SK | CHG LTR



MATL: VESPEL

ORIGINATOR	DATE	TITLE
DAVENPORT		ACTUATOR ROD
[signature]	7-6-70	
MJO SCALE 10/1		

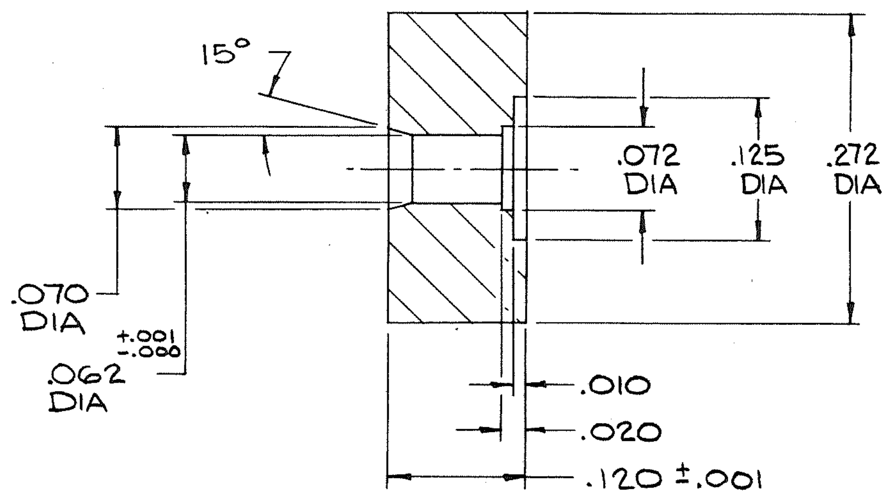
ENGINEERING SKETCH
TRW SYSTEMS GROUP
ONE SPACE PARK • REDONDO BEACH • CALIFORNIA

SK 1190-057

SHEET 1 OF 1

SYSTEMS 3603 REV. 5-67

SK | CHG LTR



TOL:
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XXX=±.005

MATL: VANADIUM PERMENDUR

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DAVENPORT		POLE PIECE - LATCH	TRW SYSTEMS GROUP ONE SPACE PARK • REDONDO BEACH • CALIFORNIA
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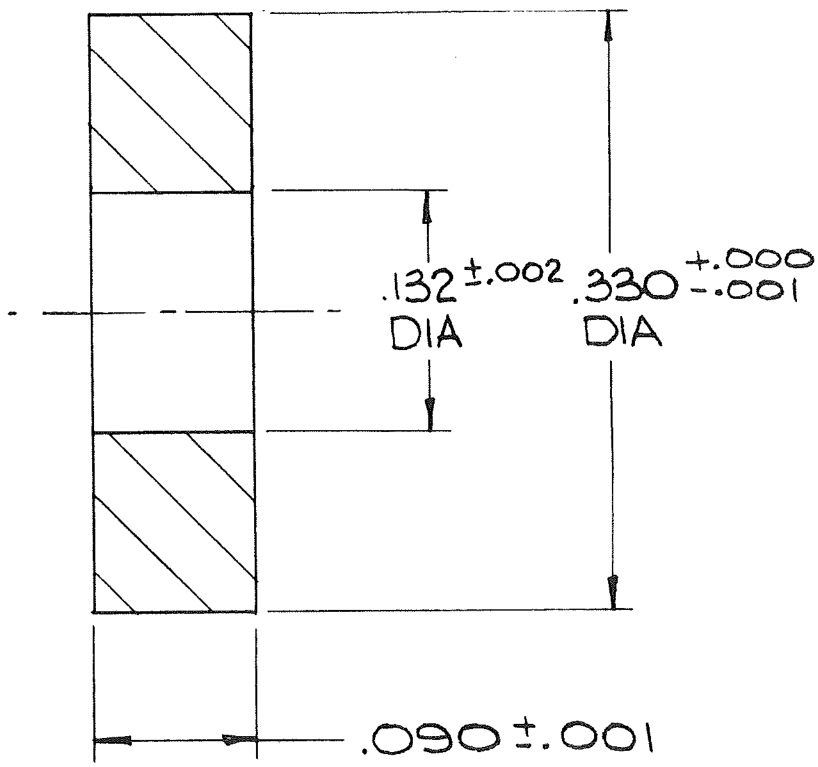
MJO SCALE 10/1			SHEET 1 OF 1

SYSTEMS 3003 REV. 5-67

CHG LTR

SK

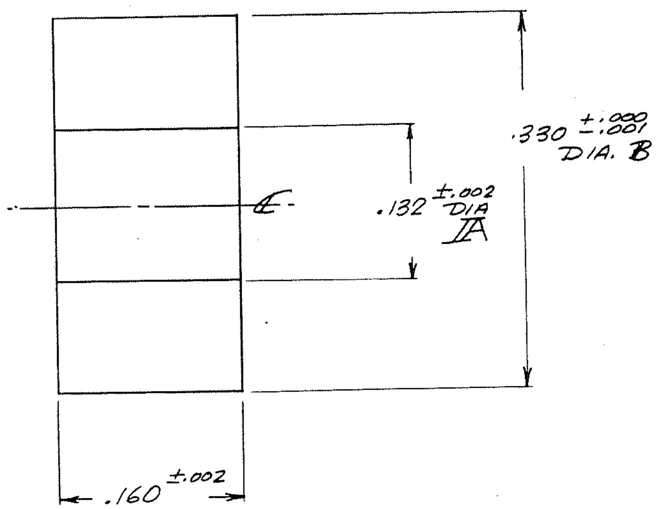


MATL: VANADIUM PERMENDUR

ORIGINATOR	DATE	TITLE	ENGINEERING SKETCH
DAVENPORT		SPACER-MAGNET	TRW SYSTEMS GROUP ONE SPACE PARK • REDONDO BEACH, CALIFORNIA
[illegible]	7-6-70		
			SK 1190-059
MJO SCALE 10/1			SHEET 1 OF 1

SYSTEMS 523A REV. 5-67

SK CHG LTR



3. FACES ⊥ AXIS ℄ .0005 T.I.R.

2. FACES // .0002 T.I.R.

1. DIA A CONCENTRIC WITH DIA B WITHIN .001 T.I.R.

MAT'L ALNICO V - ORIENTED // TO AXIS ℄

ORIGINATOR	DATE	TITLE
MAKOWSKI	7-6-70	MAGNET - LATCH
MJO	SCALE 10X	

ENGINEERING SKETCH

TRW SYSTEMS GROUP

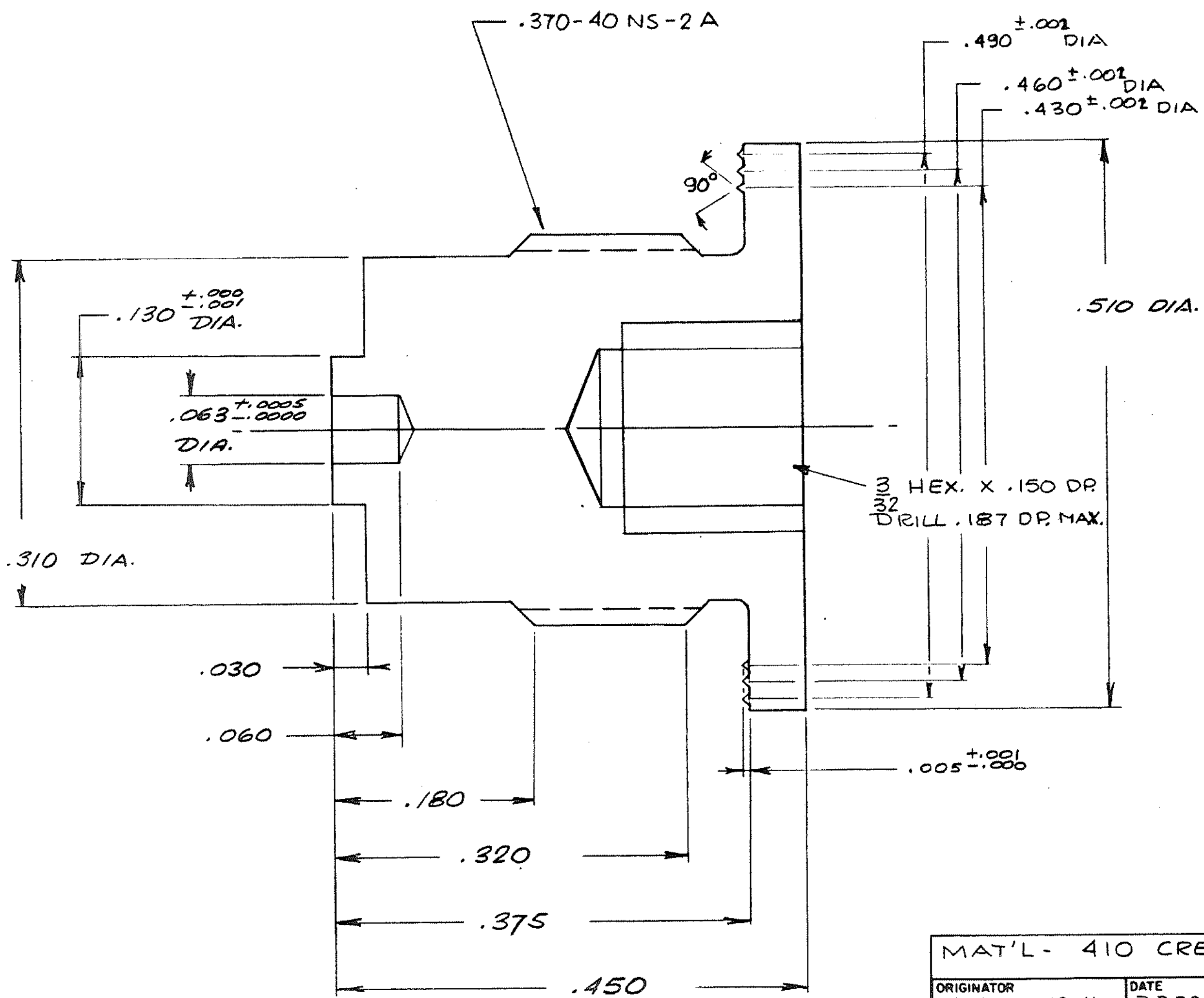
ONE SPACE PARK • REDONDO BEACH • CALIFORNIA

SK 1190-060

SHEET OF

SYSTEMS 3663 REV. 5-67

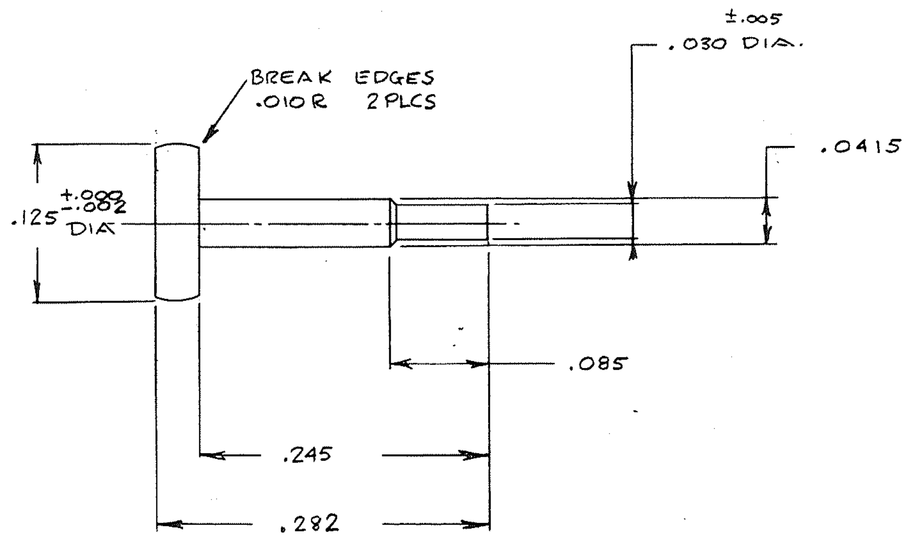
SK | CHG LTR



MAT'L - 410 CRES			
ORIGINATOR MAKOWSKI	DATE 7-7-70	TITLE PLUG - VALVE	ENGINEERING SKETCH TRW SYSTEMS GROUP ONE SPACE PARK · REDONDO BEACH · CALIFORNIA
			SK 1190-061
MJO SCALE - 10X			SHEET OF

SYSTEMS 3663 REV. 5-67

SK | CHG LTR



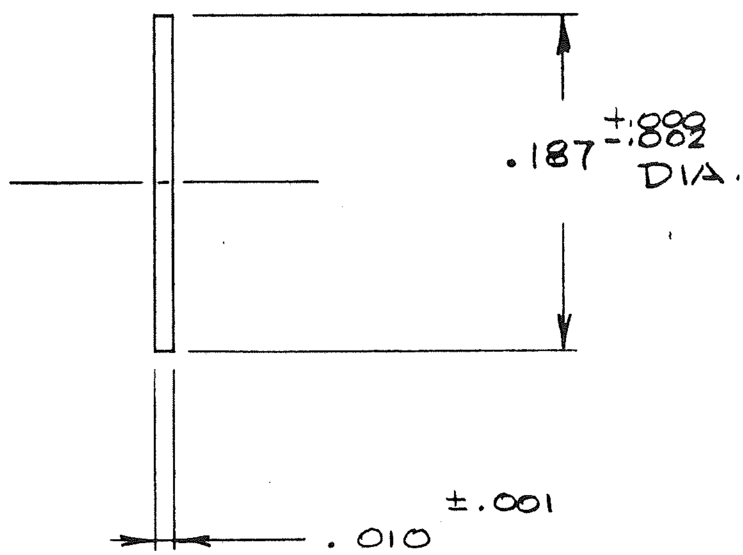
MAT'L - 17-4 PH H-1075

ORIGINATOR MAKOWSKI	DATE 7-6-70	TITLE PUSHER- POPPET	ENGINEERING SKETCH TRW SYSTEMS GROUP ONE SPACE PARK • REDONDO BEACH • CALIFORNIA
			SK 1190-062
MJO SCALE 10X			SHEET OF

SYSTEMS 3503 REV. 5-67

SK

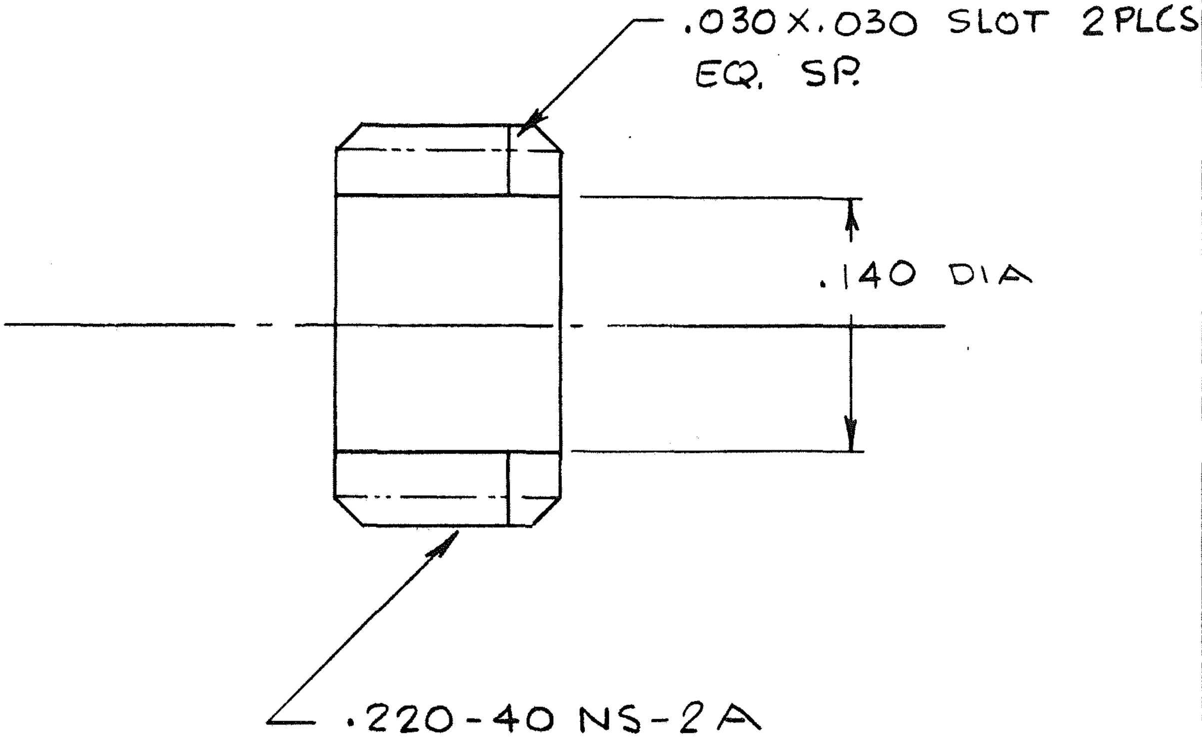
CHG LTR



MAT'L 300 SERIES CRES

ORIGINATOR	DATE	TITLE	ENGINEERING SKETCH
MAKOWSKI	7-10-70	SPACER - SPRING	TRW SYSTEMS
			SK 1190-063
MJO SCALE - 10 X			SHEET OF

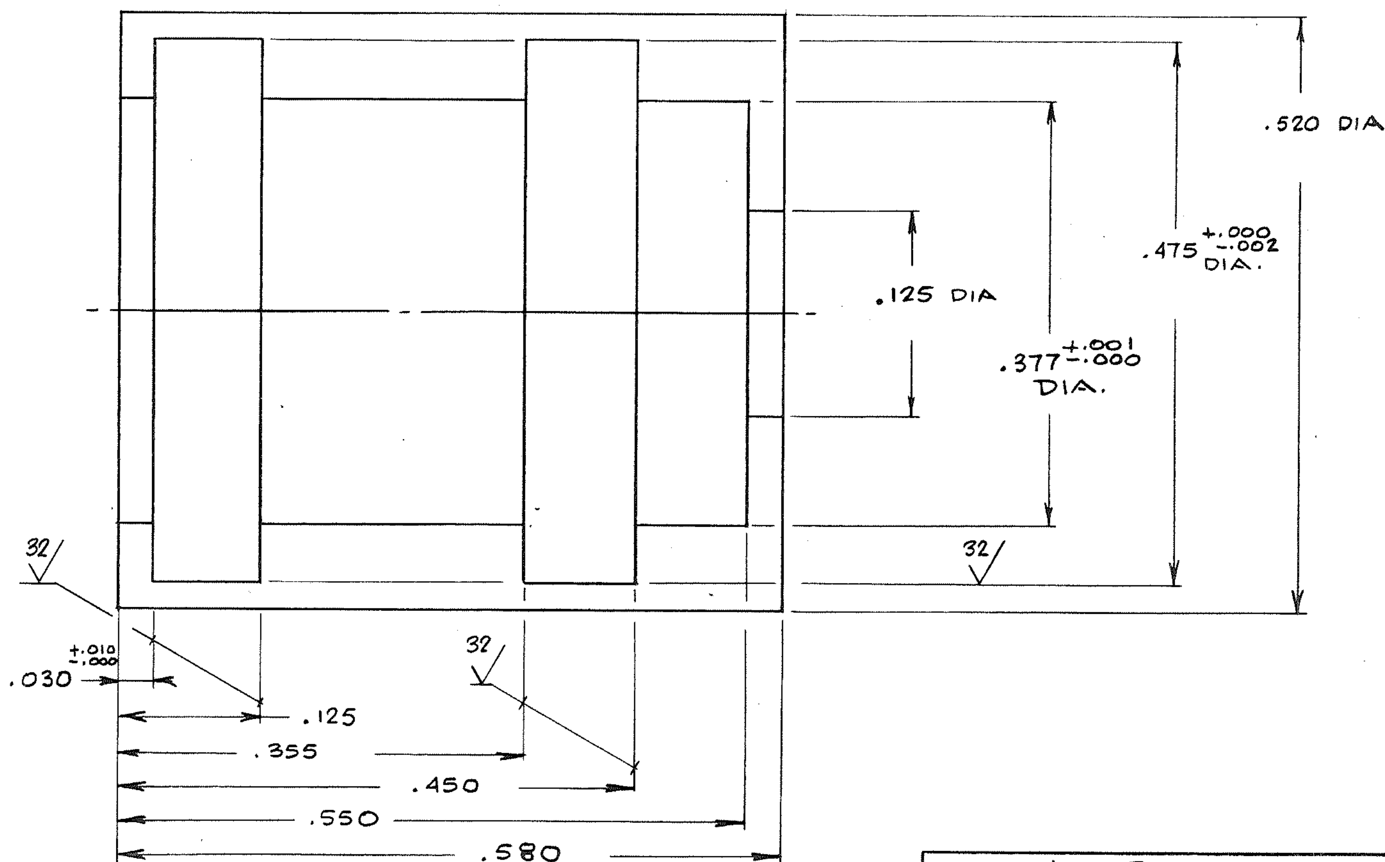
SYSTEMS 523A REV



MAT'L - 303 CRES

ORIGINATOR	DATE	TITLE	ENGINEERING SKETCH
MAKOWSKI	7-10-70	RETAINER - ACTUATOR	TRW SYSTEMS
			SK 1190-064
MJO SCALE 10X			SHEET OF

SK | CHG LTR



MAT'L - 303 CRES

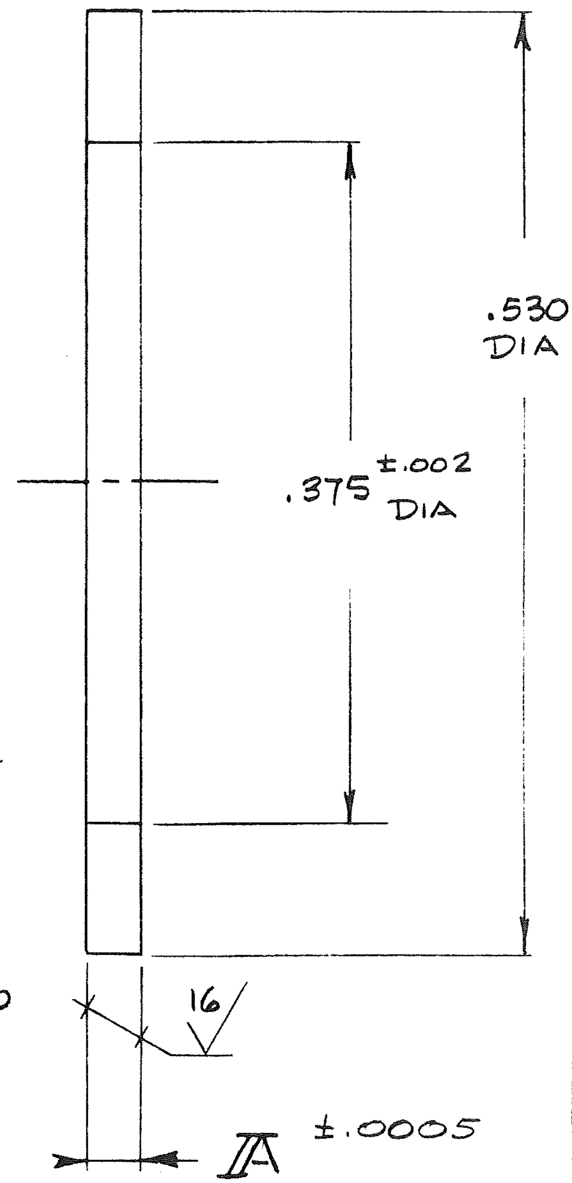
ORIGINATOR	DATE	TITLE	ENGINEERING SKETCH
MAKOWSKI	7-10-70	CAP - SEAL	TRW SYSTEMS GROUP ONE SPACE PARK • REDONDO BEACH • CALIFORNIA
			SK 1190-065
MJO SCALE - 10X			SHEET OF

SYSTEMS 3063 REV. 5-67

NOTE: USE WITH 2 "O" RINGS PARKE SEAL CO. No. 2-012
COMPOUND 77-545 (VITON A)

SK

CHG LTR



NOTE:

1) DETERMINE THICKNESS A REQ'D BY MEASURING GAP BETWEEN THE SERATIONS ON THE -061 PLUG AND 068 BODY AS FULLY ASSEMBLED & TORQUED WITHOUT -066 SEAL IN PLACE AND ADDING .005 TO THE MEASUREMENT

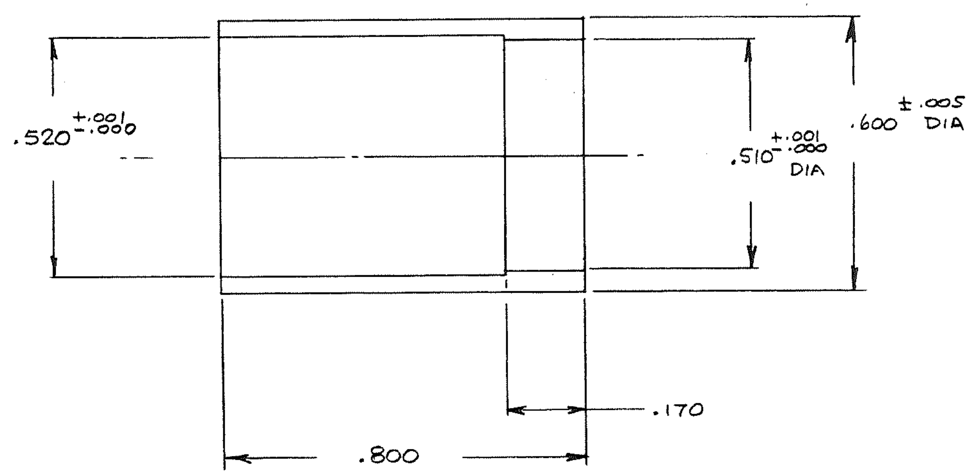
2) ANNEAL IN VACUUM AFTER FAB.

MAT'L - OFHC COPPER

ORIGINATOR	DATE	TITLE	ENGINEERING SKETCH
MAKOWSKI	7-10-70	SEAL - VALVE	TRW SYSTEMS
			SK 1190-066
MJO SCALE - 10X			SHEET OF

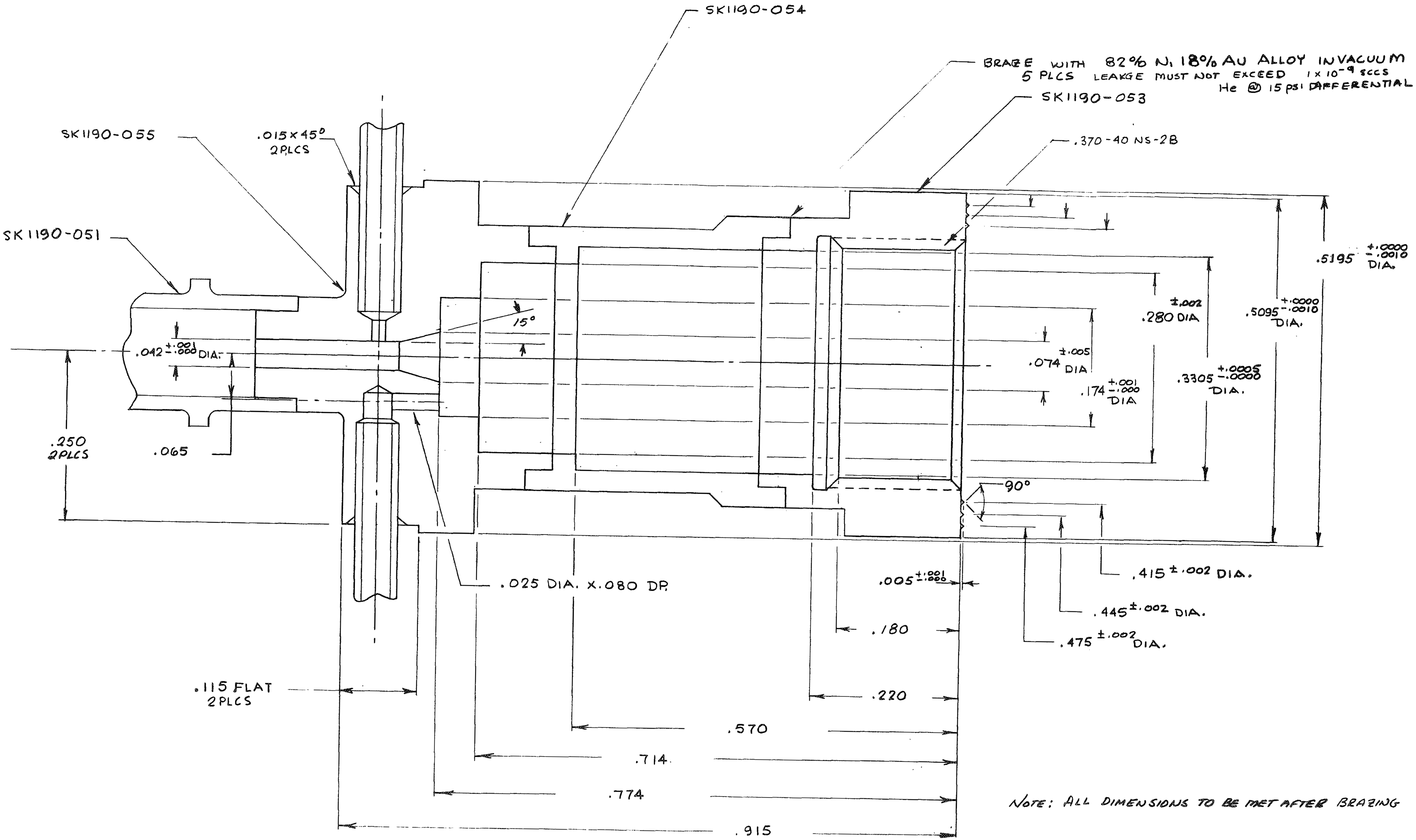
SYSTEMS 523A REV 9 65

SK | CHG LTR



MAT'L VANADIUM PERMADUR

ORIGINATOR	DATE	TITLE	ENGINEERING SKETCH
MAKOWSKI	7-7-70	TUBE- MAGNETIC RETURN	TRW SYSTEMS GROUP ONE SPACE PARK • REDONDO BEACH • CALIFORNIA
			SK 1190-067
MJO SCALE 4/1			SHEET OF



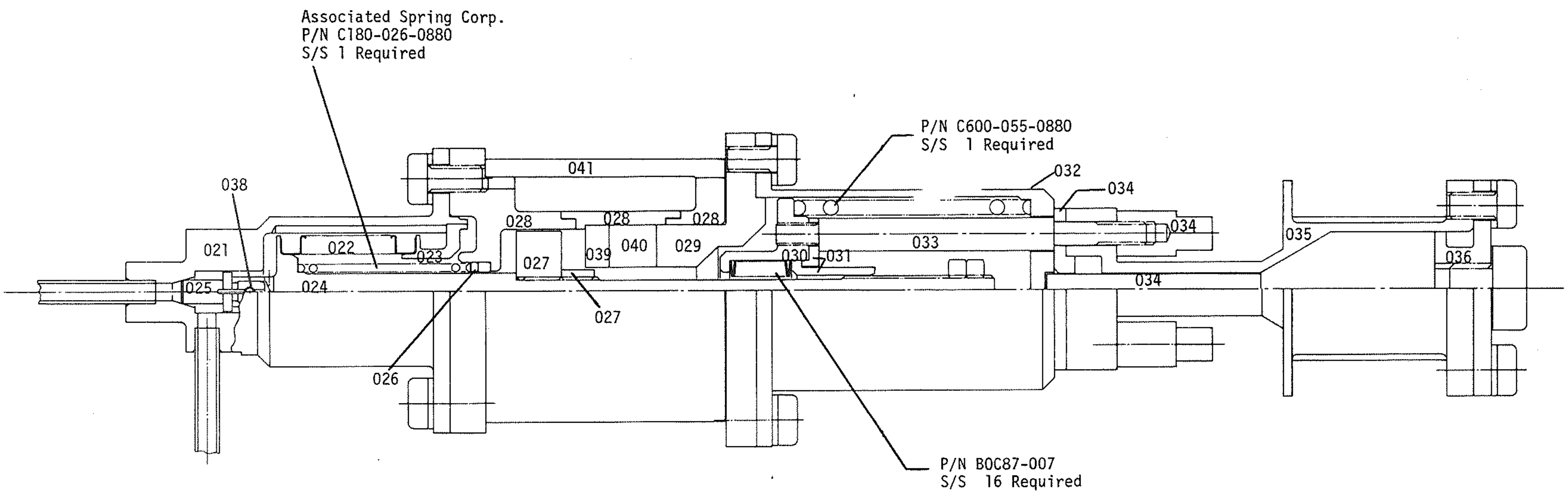
Note: All dimensions to be met after brazing

ORIGINATOR MAKOWSKI	DATE 7-10-70	TITLE Body- Brazement High Pressure Valve	ENGINEERING SKETCH TRW SYSTEMS GROUP ONE SPACE PARK · REDONDO BEACH · CALIFORNIA
MJO SCALE 10X			SK 1190-068 SHEET OF

SYSTEMS 1663 REV. 5-67

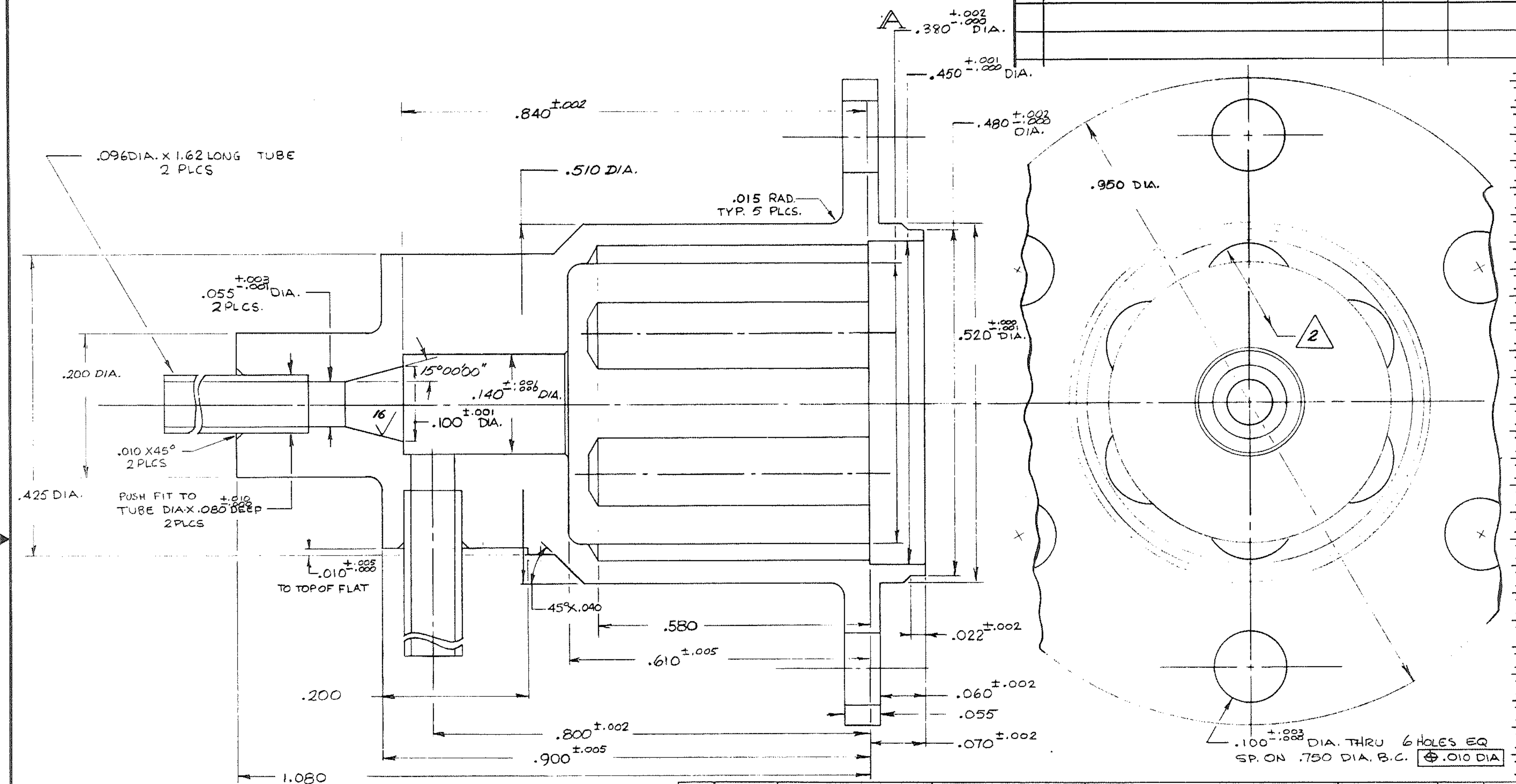
APPENDIX III

DETAIL DRAWINGS, VACUUM VALVE



SK 1190-020
Final Assembly Drawing

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED



				CODE IDENT NO.	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPEC.	REF DES	ITEM NO.

QTY REQD PER ASSY CONFIGURATION

PARTS LIST

FINISH

HEAT TREAT

2. SLOTS FAB'D BY DRILLING 6 .125 DIA HOLES EQ. SP. ON .340 DIA. B.C. ⊕ .005R BEFORE TURNING DIA A.

1. IDENTIFICATION MARKING PER PR 12-1

TYPE________ CLASS________

PART NUMBER________

NOTES: UNLESS OTHERWISE SPECIFIED

SK 1190-020			PR 12-1
USED ON	NEXT ASSY	NEXT ASSY QTY REQD	APPLICABLE SPECIFICATIONS
APPLICATION			THE ABOVE TRW SYSTEMS GROUP SPECS FORM A PART OF THIS DRAWING

UNLESS OTHERWISE SPECIFIED

1. INTERPRET PER MIL-STD-100.
2. DIMENSIONS ARE IN INCHES
3. SURFACE TEXTURE SHALL BE ✓
4. DIMENSIONS APPLY BEFORE PLATING OR CONVERSION COATING.
5. REMOVE BURRS & SHARP EDGES

TOLERANCES ON DECIMAL DIMENSIONS: .XXX ± .010, .XX ± .03, .X ± .1

TOLERANCES ON ANGULAR DIMENSIONS: MACHINED & LOCATING ± 0°30', FORMED ± 2°, CHAMFERS ± 5°

TOLERANCES - ALL HOLE DIA		
FROM	THRU	TOL.
UNDER	.0140	+.0020 -.0005
.0145	.125	+.004 -.001
.126	.250	+.005 -.001
.251	.500	+.006 -.001
.501	.750	+.008 -.001
.751	1.000	+.010 -.001
1.001	2.000	+.012 -.001
OVER	2.000	+.015 -.005

DO NOT SCALE DRAWING

CONTRACT NO.		
DRAWN	MAKOWSKI	2-3-70
CHECKED		
STRUCTURES		
MATL & PROCESS		
ENGR		
SUPERVISOR		
OTHER APPROVALS		

THE FOLLOWING EO'S HAVE BEEN ATTACHED TO THIS PRINT

TRW SYSTEMS GROUP
ONE SPACE PARK • REDONDO BEACH, CALIFORNIA

BODY - VALVE - VACUUM - THERMALLY ACTUATED

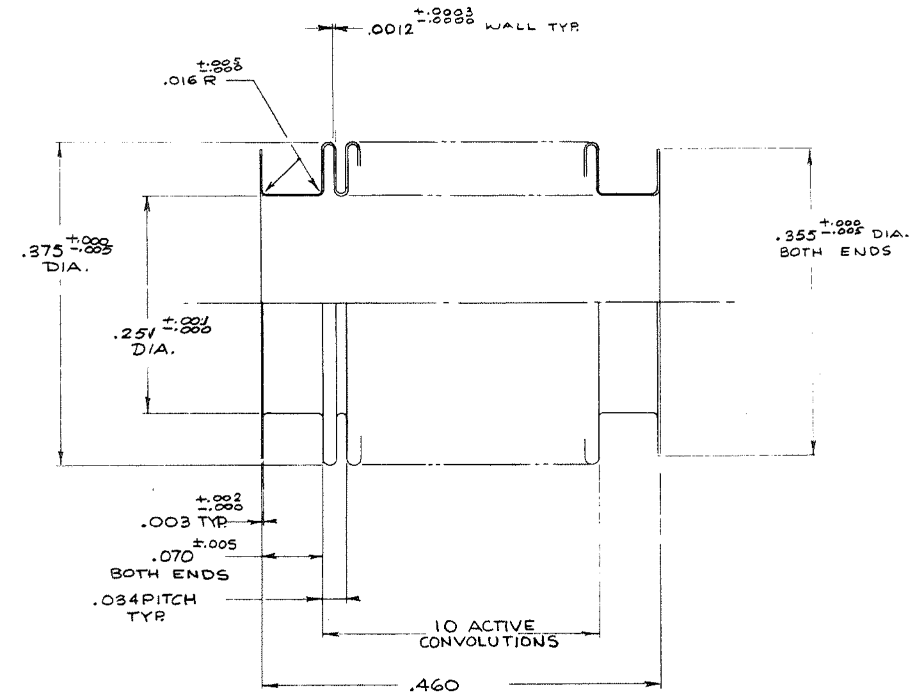
SIZE	CODE IDENT NO.	
C	11982	SK-1190-021

SCALE 10 X SHEET

11/61 DIETERICH-POST CLEARPRINT 1020

SYSTEMS 3486 REV. 12-60

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED



N/C SK1190-022

5. LEAKAGE - LESS THAN 10^{-9} sccs He by MASS SPECTROMETER
4. OPERATING TEMP. 250°C
3. WORKING PRESS. 30psig MAX. - INTERNAL
2. NOMINAL STROKE - .080 COMPRESSIVE
1. IDENTIFICATION MARKING PER PR 12-1
TYPE______ CLASS______
PART NUMBER______

NOTES: UNLESS OTHERWISE SPECIFIED

CODE IDENT NO.	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPEC.	REF DES	ITEM NO.
			SULFER FREE - WELDABLE NICKEL - ELECTRO DEPOSITED			

PARTS LIST

QTY REQD PER ASSY CONFIGURATION

FINISH ~

HEAT TREAT ~

SK1190-020	SK1190-037	1
USED ON	NEXT ASSY	NEXT ASSY QTY REQD
APPLICATION		

PR 12-1

APPLICABLE SPECIFICATIONS

THE ABOVE TRW SYSTEMS GROUP SPECS FORM A PART OF THIS DRAWING

UNLESS OTHERWISE SPECIFIED
1. INTERPRET PER MIL-STD-100.
2. DIMENSIONS ARE IN INCHES
3. SURFACE TEXTURE SHALL BE ✓
4. DIMENSIONS APPLY BEFORE PLATING OR CONVERSION COATING.
5. REMOVE BURRS & SHARP EDGES

TOLERANCES ON DECIMAL DIMENSIONS: .XXX ± .010, .XX ± .03, .X ± .1

TOLERANCES ON ANGULAR DIMENSIONS: MACHINED & LOCATING ± 0°30', FORMED ± 2°, CHAMFERS ± 5°

TOLERANCES - ALL HOLE DIA		
FROM	THRU	TOL.
UNDER	.0140	+.0020 -.0005
.0145	.125	+.004 -.001
.126	.250	+.005 -.001
.251	.500	+.006 -.001
.501	.750	+.008 -.001
.751	1.000	+.010 -.001
1.001	2.000	+.012 -.001
OVER	2.000	+.015 -.005

DO NOT SCALE DRAWING

CONTRACT NO.

DRAWN	MAKOWSKI	3-4-70
CHECKED		
STRUCTURES		
MATL & PROCESS		
ENGR		
SUPERVISOR		
OTHER APPROVALS		

THE FOLLOWING EO'S HAVE BEEN ATTACHED TO THIS PRINT

TRW SYSTEMS GROUP
ONE SPACE PARK • REDONDO BEACH, CALIFORNIA

BELLOWS - VALVE
VACUUM - THERMALLY ACTUATED

SIZE	CODE IDENT NO.	
C	11982	SK1190-022

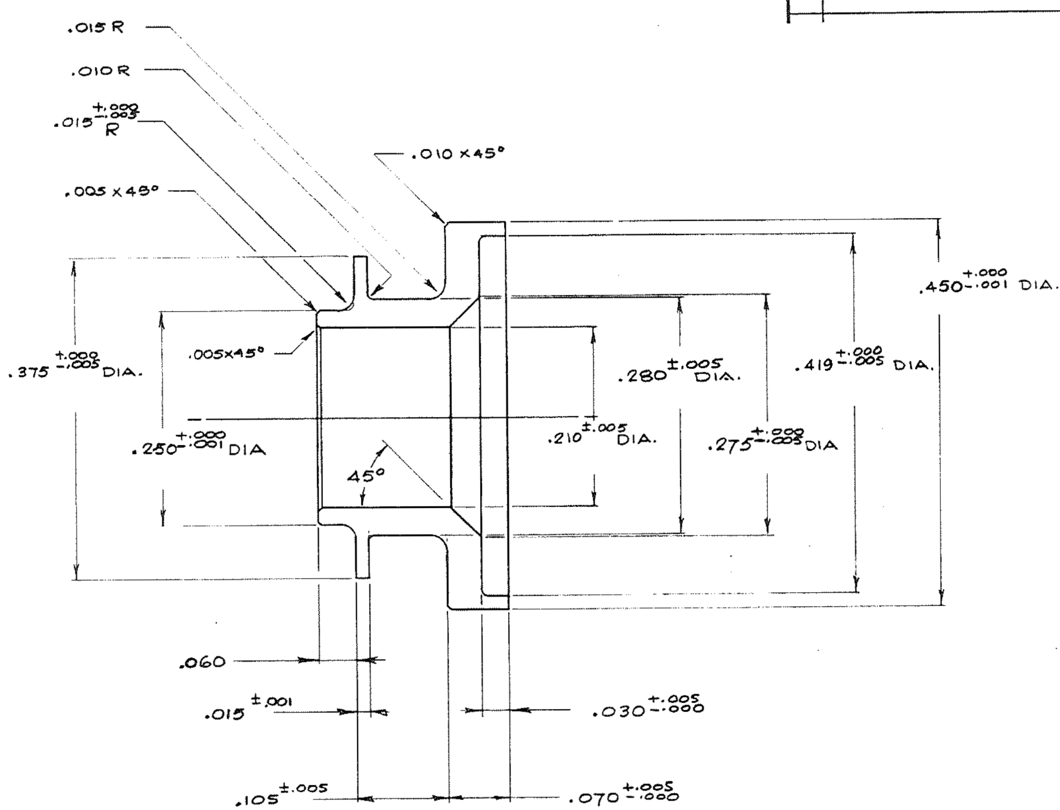
SCALE 10X SHEET

11/60 DIETZGEN-POST CLEARPRINT 1020

SYSTEMS 3486 REV. 12-60

REVISIONS

LTR	DESCRIPTION	DATE	APPROVED



SK1190-023 1/2

ITEM NO.	REF DES	SPEC.	MATERIAL	NOMENCLATURE OR DESCRIPTION	PART OR IDENTIFYING NO.	CODE IDENT NO.
			316 OR 304 L CRES.			

PARTS LIST

QTY REQD PER ASSY CONFIGURATION

FINISH ~

HEAT TREAT ~

PR 12-1

APPLICABLE SPECIFICATIONS

THE ABOVE TRW SYSTEMS GROUP SPECS FORM A PART OF THIS DRAWING

SK1190-020	SK1190-037	1
USED ON	NEXT ASSY	NEXT ASSY QTY REQD
APPLICATION		

1. IDENTIFICATION MARKING PER PR 12-1

TYPE________CLASS________

PART NUMBER________

NOTES: UNLESS OTHERWISE SPECIFIED

UNLESS OTHERWISE SPECIFIED

1. INTERPRET PER MIL-STD-100.
2. DIMENSIONS ARE IN INCHES
3. SURFACE TEXTURE SHALL BE ✓
4. DIMENSIONS APPLY BEFORE PLATING OR CONVERSION COATING.
5. REMOVE BURRS & SHARP EDGES

TOLERANCES ON DECIMAL DIMENSIONS: .XXX ± .010, .XX ± .03, .X ± .1

TOLERANCES ON ANGULAR DIMENSIONS: MACHINED & LOCATING ± 0°30', FORMED ± 2°, CHAMFERS ± 5°

TOLERANCES - ALL HOLE DIA		
FROM	THRU	TOL.
UNDER	.0140	+.0020 -.0005
.0145	.125	+.004 -.001
.126	.250	+.005 -.001
.251	.500	+.006 -.001
.501	.750	+.008 -.001
.751	1.000	+.010 -.001
1.001	2.000	+.012 -.001
OVER	2.000	+.015 -.005

DO NOT SCALE DRAWING

CONTRACT NO.

DRAWN MAKOWSKI 3-4-70

CHECKED

STRUCTURES

MATL & PROCESS ENGR

SUPERVISOR

OTHER APPROVALS

THE FOLLOWING EO'S HAVE BEEN ATTACHED TO THIS PRINT

TRW SYSTEMS GROUP

ONE SPACE PARK • REDONDO BEACH, CALIFORNIA

ADAPTER - BELLOWS

VALVE - VACUUM - THERMALLY ACTUATED

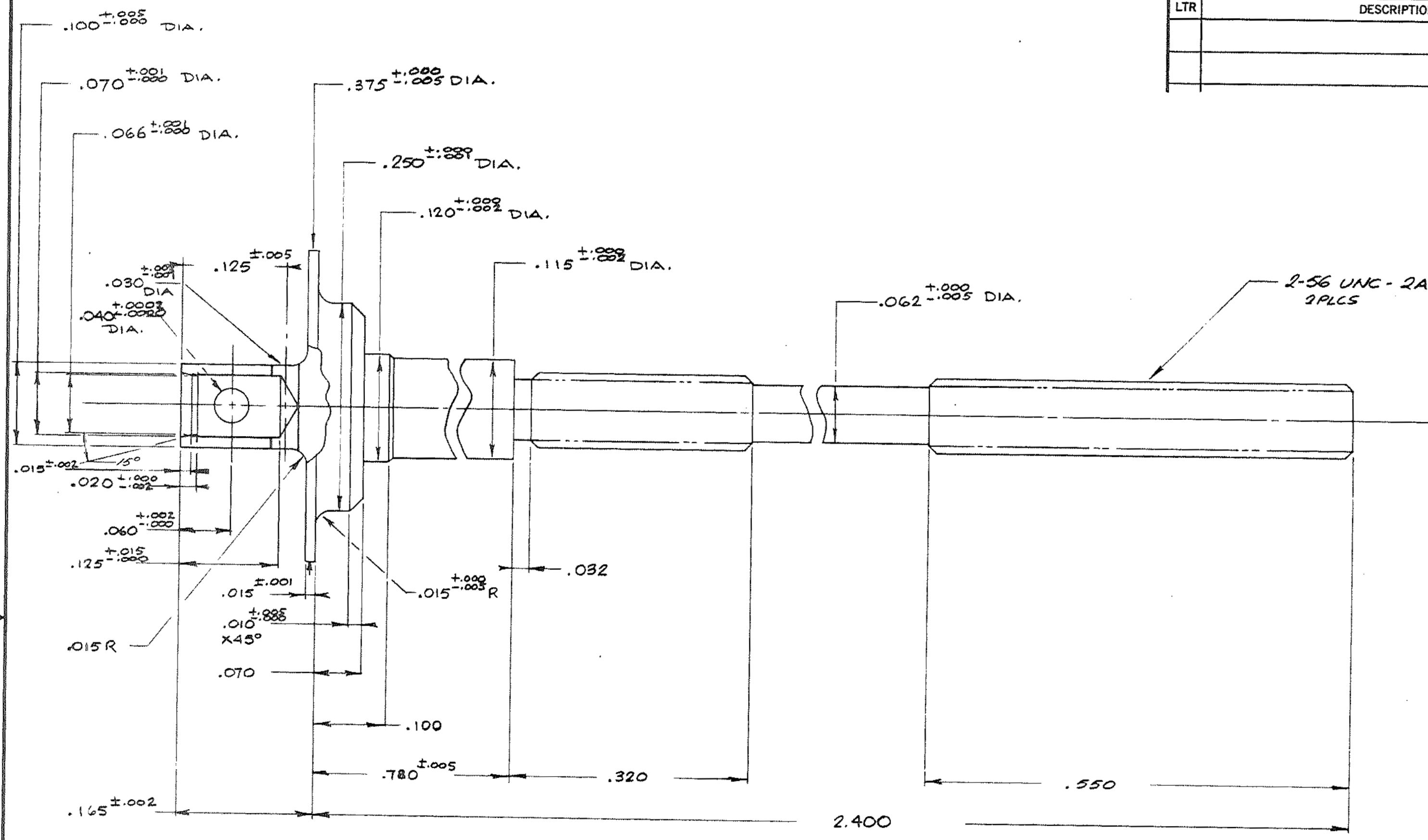
SIZE	CODE IDENT NO.	
C	11982	SK1190-023

SCALE 10 X SHEET

SYSTEMS 3486 REV. 12-68

11/69 DIETZGEN-POST CLEARPRINT 1020

LTR	REVISIONS DESCRIPTION	DATE	APPROVED



ITEM NO.	REF DES	SPEC.	MATERIAL	NOMENCLATURE OR DESCRIPTION	PART OR IDENTIFYING NO.	CODE IDENT NO.	QTY REQD PER ASSY CONFIGURATION
			316 OR 304L CRES				

PARTS LIST

FINISH ~

HEAT TREAT ~

UNLESS OTHERWISE SPECIFIED
1. INTERPRET PER MIL-STD-100.
2. DIMENSIONS ARE IN INCHES
3. SURFACE TEXTURE SHALL BE ✓
4. DIMENSIONS APPLY BEFORE PLATING OR CONVERSION COATING.
5. REMOVE BURRS & SHARP EDGES

TOLERANCES ON DECIMAL DIMENSIONS: .XXX ± .010; .XX ± .03; .X ± .1

TOLERANCES ON ANGULAR DIMENSIONS: MACHINED & LOCATING ± 0°30'; FORMED ± 2°; CHAMFERS ± 5°

TOLERANCES - ALL HOLE DIA FROM	THRU	TOL.
UNDER	.0140	+.0020 -.0005
.0145	.125	+.004 -.001
.126	.250	+.005 -.001
.251	.500	+.006 -.001
.501	.750	+.008 -.001
.751	1.000	+.010 -.001
1.001	2.000	+.012 -.001
OVER	2.000	+.015 -.005

DO NOT SCALE DRAWING

CONTRACT NO.		
DRAWN	MAKOWSKI	3-4-70
CHECKED		
STRUCTURES		
MATL & PROCESS ENGR		
SUPERVISOR		
OTHER APPROVALS		

THE FOLLOWING EO'S HAVE BEEN ATTACHED TO THIS PRINT

TRW SYSTEMS GROUP
ONE SPACE PARK • REDONDO BEACH, CALIFORNIA

STEM - VALVE
VACUUM THERMALLY ACTUATED

SIZE	CODE IDENT NO.	
C	11982	SK1190-024

SCALE 10 X SHEET

NEXT ASSY	USED ON	QTY REQD
SK1190-037	SK1190-020	1

APPLICATION

APPLICABLE SPECIFICATIONS: PR 12-1
THE ABOVE TRW SYSTEMS GROUP SPECS FORM A PART OF THIS DRAWING

1. IDENTIFICATION MARKING PER PR 12-1
TYPE______ CLASS______
PART NUMBER______

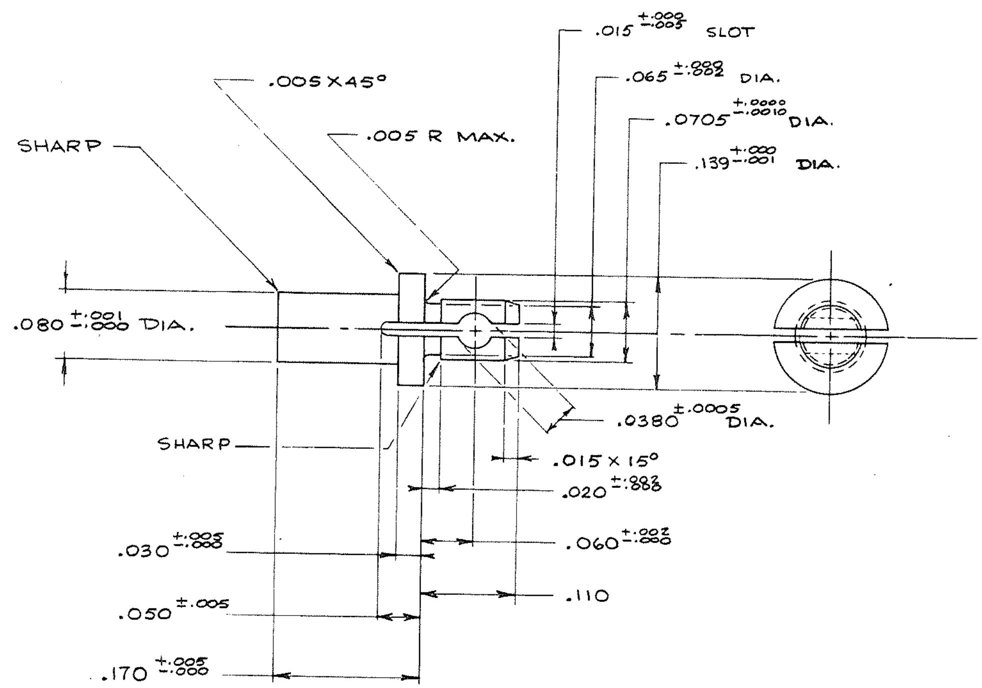
NOTES: UNLESS OTHERWISE SPECIFIED

N/C SK1190-024

11/69 DIETZGEN-POST CLEARPRINT 1020

SYSTEMS 3486 REV. 12-68

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED



			CODE IDENT NO.	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPEC.	REF DES	ITEM NO.
						VESPEL POLYIMIDE			

QTY REQD PER ASSY CONFIGURATION

PARTS LIST

FINISH ~

HEAT TREAT ~

UNLESS OTHERWISE SPECIFIED
1. INTERPRET PER MIL-STD-100.
2. DIMENSIONS ARE IN INCHES
3. SURFACE TEXTURE SHALL BE ✓
4. DIMENSIONS APPLY BEFORE PLATING OR CONVERSION COATING.
5. REMOVE BURRS & SHARP EDGES

TOLERANCES - ALL HOLE DIA		
FROM	THRU	TOL.
UNDER	.0140	+.0020 -.0005
.0145	.125	+.004 -.001
.126	.250	+.005 -.001
.251	.500	+.006 -.001
.501	.750	+.008 -.001
.751	1.000	+.010 -.001
1.001	2.000	+.012 -.001
OVER	2.000	+.015 -.005

TOLERANCES ON DECIMAL DIMENSIONS: .XXX ± .010, .XX ± .03, .X ± .1

TOLERANCES ON ANGULAR DIMENSIONS: MACHINED & LOCATING ± 0°30', FORMED ± 2°, CHAMFERS ± 5°

DO NOT SCALE DRAWING

CONTRACT NO.

DRAWN	MAKOWSKI	3-5-70
CHECKED		
STRUCTURES		
MATL & PROCESS		
ENGR		
SUPERVISOR		
OTHER APPROVALS		

THE FOLLOWING EO'S HAVE BEEN ATTACHED TO THIS PRINT

TRW SYSTEMS GROUP
ONE SPACE PARK • REDONDO BEACH, CALIFORNIA

POPPET - VALVE
VACUUM THERMALLY ACTUATED

SIZE	CODE IDENT NO.	
C	11982	SK1190-025

SCALE 10 X SHEET

NEXT ASSY	USED ON	NEXT ASSY QTY REQD
SK1190-020		

APPLICATION

PR 12-1

APPLICABLE SPECIFICATIONS
THE ABOVE TRW SYSTEMS GROUP SPECS FORM A PART OF THIS DRAWING

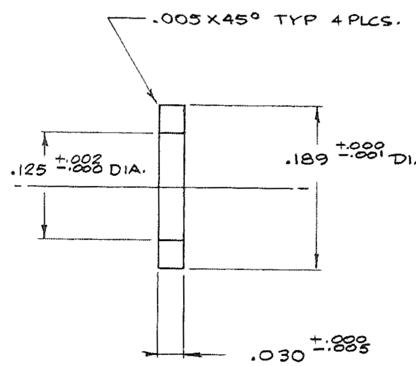
1. IDENTIFICATION MARKING PER PR 12-1
TYPE______ CLASS______
PART NUMBER______

NOTES: UNLESS OTHERWISE SPECIFIED

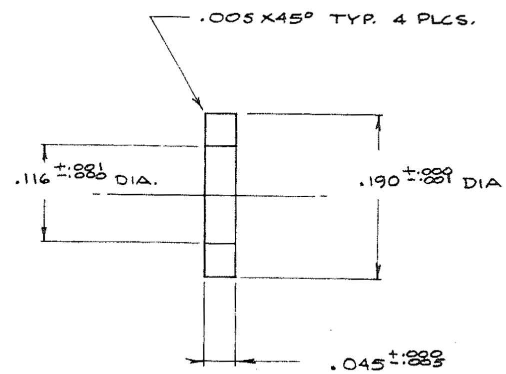
11/69 DIETZGEN-POST CLEARPRINT 1020

SYSTEMS 3486 REV. 12-68

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED



- 1 SPACER



-2 GUIDE

QTY REQ	CODE IDENT NO.	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPEC.	REF DES	ITEM NO.
1		SK1190-026-2	GUIDE	VESPEL POLYIMIDE			-2
1		SK1190-026-1	SPACER	303 CRES			-1

PARTS LIST

QTY REQD PER ASSY CONFIGURATION

FINISH ~

HEAT TREAT ~

UNLESS OTHERWISE SPECIFIED
1. INTERPRET PER MIL-STD-100.
2. DIMENSIONS ARE IN INCHES
3. SURFACE TEXTURE SHALL BE ✓
4. DIMENSIONS APPLY BEFORE PLATING OR CONVERSION COATING.
5. REMOVE BURRS & SHARP EDGES

TOLERANCES - ALL HOLE DIA		
FROM	THRU	TOL.
UNDER	.0140	+.0020 -.0005
.0145	.125	+.004 -.001
.126	.250	+.005 -.001
.251	.500	+.006 -.001
.501	.750	+.008 -.001
.751	1.000	+.010 -.001
1.001	2.000	+.012 -.001
OVER	2.000	+.015 -.005

TOLERANCES ON DECIMAL DIMENSIONS: .XXX ± .010, .XX ± .03, .X ± .1

TOLERANCES ON ANGULAR DIMENSIONS: MACHINED & LOCATING ± 0°30', FORMED ± 2°, CHAMFERS ± 5°

DO NOT SCALE DRAWING

CONTRACT NO.

DRAWN MAKOWSKI 4-5-70

CHECKED

STRUCTURES

MATL & PROCESS ENGR

SUPERVISOR

OTHER APPROVALS

THE FOLLOWING EO'S HAVE BEEN ATTACHED TO THIS PRINT

TRW SYSTEMS GROUP
ONE SPACE PARK • REDONDO BEACH, CALIFORNIA

GUIDE -VALVE
VACUUM - THERMALLY ACTUATED

SIZE C | CODE IDENT NO. 11982 | SK1190-026

SCALE 10X | SHEET

1. IDENTIFICATION MARKING PER PR 12-1
TYPE_____ CLASS_____
PART NUMBER_____

NOTES: UNLESS OTHERWISE SPECIFIED

NEXT ASSY	USED ON	QTY REQD
SK1190-020		

APPLICATION

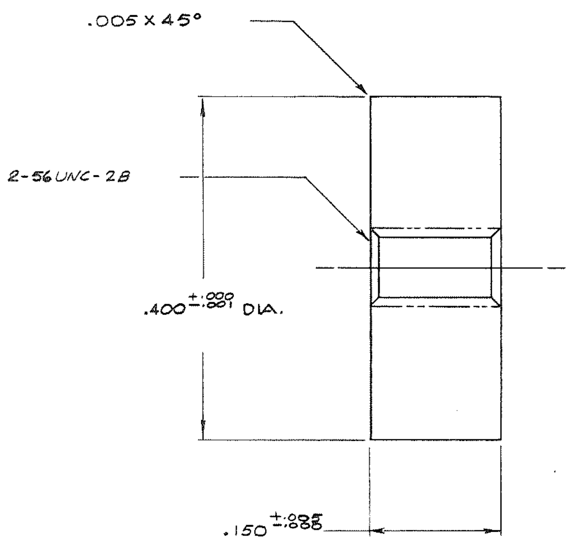
PR 12-1

APPLICABLE SPECIFICATIONS
THE ABOVE TRW SYSTEMS GROUP SPECS FORM A PART OF THIS DRAWING

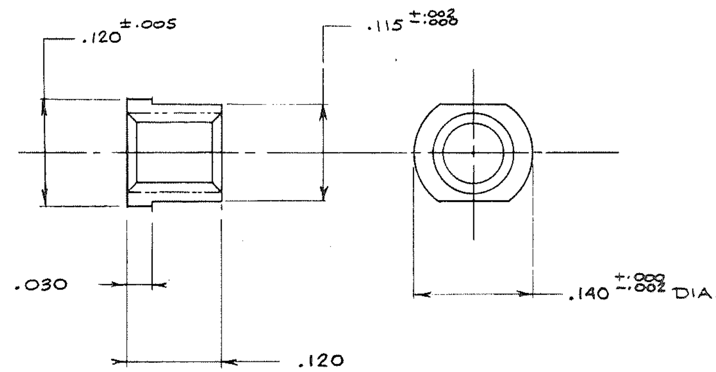
11410 DIETERICH-POST CLEARPRINT 1000

SYSTEMS 3486 REV. 12-68

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED



-1 POLE-LATCH



-2 LOCKNUT-LATCH

QTY. REQ.	CODE IDENT NO.	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPEC.	REF DES	ITEM NO.
1		SK1190-027-2	LOCKNUT	300 SERIES CRES (303)			-2
1		SK1190-027-1	POLE	ARMCO IRON OR PERMADUR			-1

PARTS LIST

QTY REQD PER ASSY CONFIGURATION

FINISH ~

HEAT TREAT ~

UNLESS OTHERWISE SPECIFIED

1. INTERPRET PER MIL-STD-100.
2. DIMENSIONS ARE IN INCHES
3. SURFACE TEXTURE SHALL BE ✓
4. DIMENSIONS APPLY BEFORE PLATING OR CONVERSION COATING.
5. REMOVE BURRS & SHARP EDGES

TOLERANCES ON DECIMAL DIMENSIONS: .XXX ± .010, .XX ± .03, .X ± .1

TOLERANCES ON ANGULAR DIMENSIONS: MACHINED & LOCATING ± 0°30', FORMED ± 2°, CHAMFERS ± 5°

TOLERANCES - ALL HOLE DIA		
FROM	THRU	TOL.
UNDER	.0140	+.0020 −.0005
.0145	.125	+.004 −.001
.126	.250	+.005 −.001
.251	.500	+.006 −.001
.501	.750	+.008 −.001
.751	1.000	+.010 −.001
1.001	2.000	+.012 −.001
OVER	2.000	+.015 −.005

DO NOT SCALE DRAWING

CONTRACT NO.		
DRAWN	MAKOWSKI	3-5-70
CHECKED		
STRUCTURES		
MATL & PROCESS		
ENGR		
SUPERVISOR		
OTHER APPROVALS		

THE FOLLOWING EO'S HAVE BEEN ATTACHED TO THIS PRINT

TRW SYSTEMS GROUP
ONE SPACE PARK • REDONDO BEACH, CALIFORNIA

POLE-LATCH-VALVE
VACUUM-THERMALLY ACTUATED

SIZE	CODE IDENT NO.	
C	11982	SK1190-027
SCALE 10X		SHEET

1. IDENTIFICATION MARKING PER PR 12-1
TYPE______ CLASS______
PART NUMBER______

NOTES: UNLESS OTHERWISE SPECIFIED

SK1190-020		
USED ON	NEXT ASSY	NEXT ASSY QTY REQD
APPLICATION		

PR 12-1

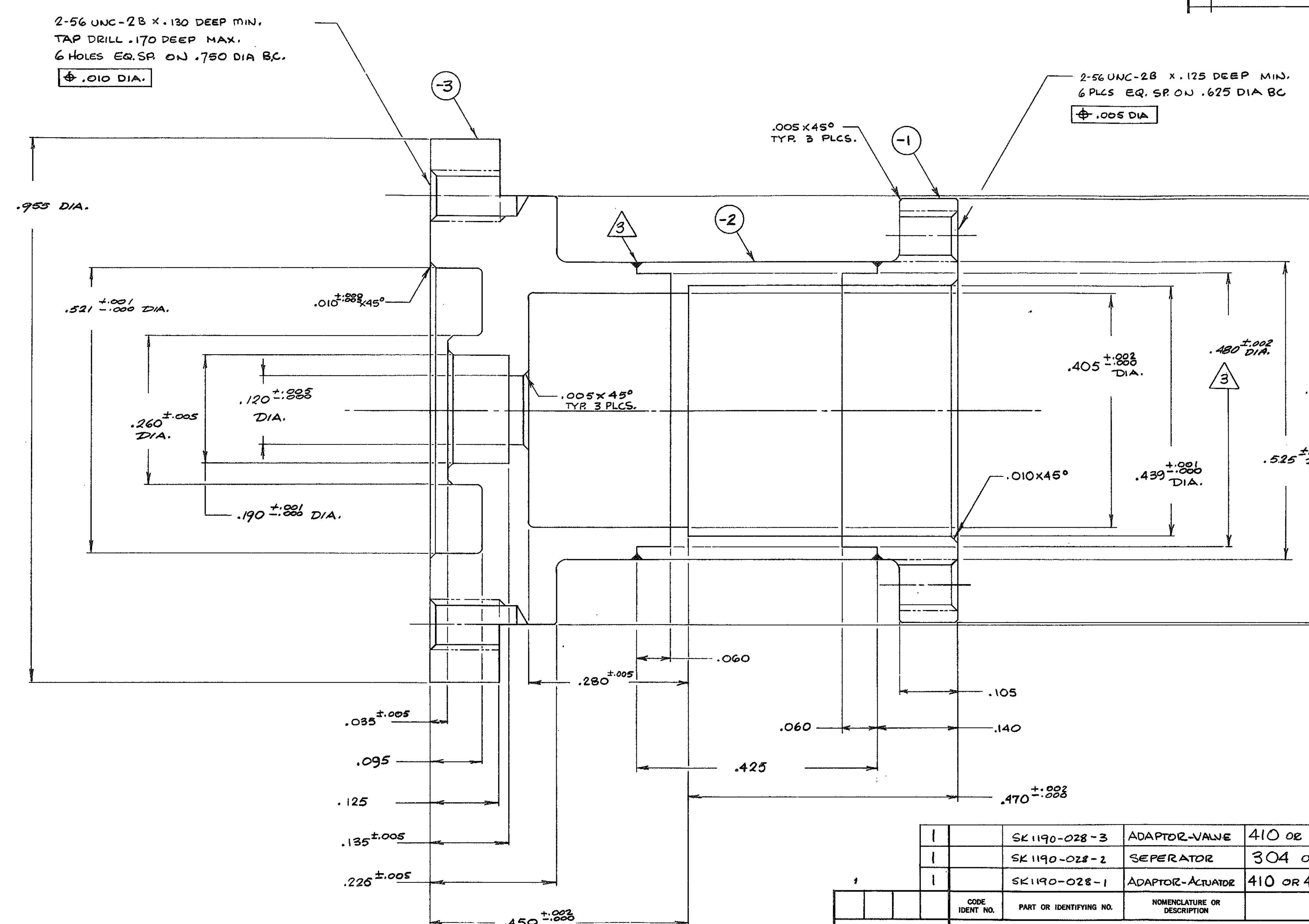
APPLICABLE SPECIFICATIONS

THE ABOVE TRW SYSTEMS GROUP SPECS FORM A PART OF THIS DRAWING

11/69 DIETZGEN-POST CLEARPRINT 1020

SYSTEMS 3405 REV. 12-68

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED



1		SK1190-028-3	ADAPTOR-VALVE	410 OR 416 CRES			-3
1		SK1190-028-2	SEPERATOR	304 OR 316 CRES			-2
1		SK1190-028-1	ADAPTOR-ACTUATOR	410 OR 416 CRES			-1
QTY REQD PER ASSY CONFIGURATION	CODE IDENT NO.	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPEC	REF DES	ITEM NO.

PARTS LIST

3 BRAZE -2 SEPERATOR TO -1 ADAPTOR & -2 ADAPTOR BEFORE FINAL MACHINING JOINT FIT FOR BRAZING .000 to .002 LOOSE.

2. ALL DIMENSIONS TO BE MET AFTER BRAZING

1. IDENTIFICATION MARKING PER PR 12-1
TYPE_____CLASS_____PART NUMBER_____

NOTES: UNLESS OTHERWISE SPECIFIED

SK1190-020		
USED ON	NEXT ASSY	NEXT ASSY QTY REQD
APPLICATION		

FINISH ~
HEAT TREAT ~

PR 12-1
APPLICABLE SPECIFICATIONS
THE ABOVE TRW SYSTEMS GROUP SPECS FORM A PART OF THIS DRAWING

UNLESS OTHERWISE SPECIFIED
1. INTERPRET PER MIL-STD-100.
2. DIMENSIONS ARE IN INCHES
3. SURFACE TEXTURE SHALL BE ✓
4. DIMENSIONS APPLY BEFORE PLATING OR CONVERSION COATING.
5. REMOVE BURRS & SHARP EDGES

TOLERANCES - ALL HOLE DIA		
FROM	THRU	TOL.
UNDER	.0140	+.0020 -.0005
.0145	.125	+.004 -.001
.126	.250	+.005 -.001
.251	.500	+.006 -.001
.501	.750	+.008 -.001
.751	1.000	+.010 -.001
1.001	2.000	+.012 -.001
OVER	2.000	+.015 -.001

TOLERANCES ON DECIMAL DIMENSIONS: .XXX ± .010, .XX ± .03, .X ± .1
TOLERANCES ON ANGULAR DIMENSIONS: MACHINED & LOCATING ± 0°30', FORMED ± 2°, CHAMFERS ± 5°

DO NOT SCALE DRAWING
CONTRACT NO.
DRAWN MAKOWSKI 3-6-70
CHECKED
STRUCTURES
MATL & PROCESS ENGR
SUPERVISOR
OTHER APPROVALS

THE FOLLOWING EO'S HAVE BEEN ATTACHED TO THIS PRINT

TRW SYSTEMS GROUP
ONE SPACE PARK • REDONDO BEACH, CALIFORNIA

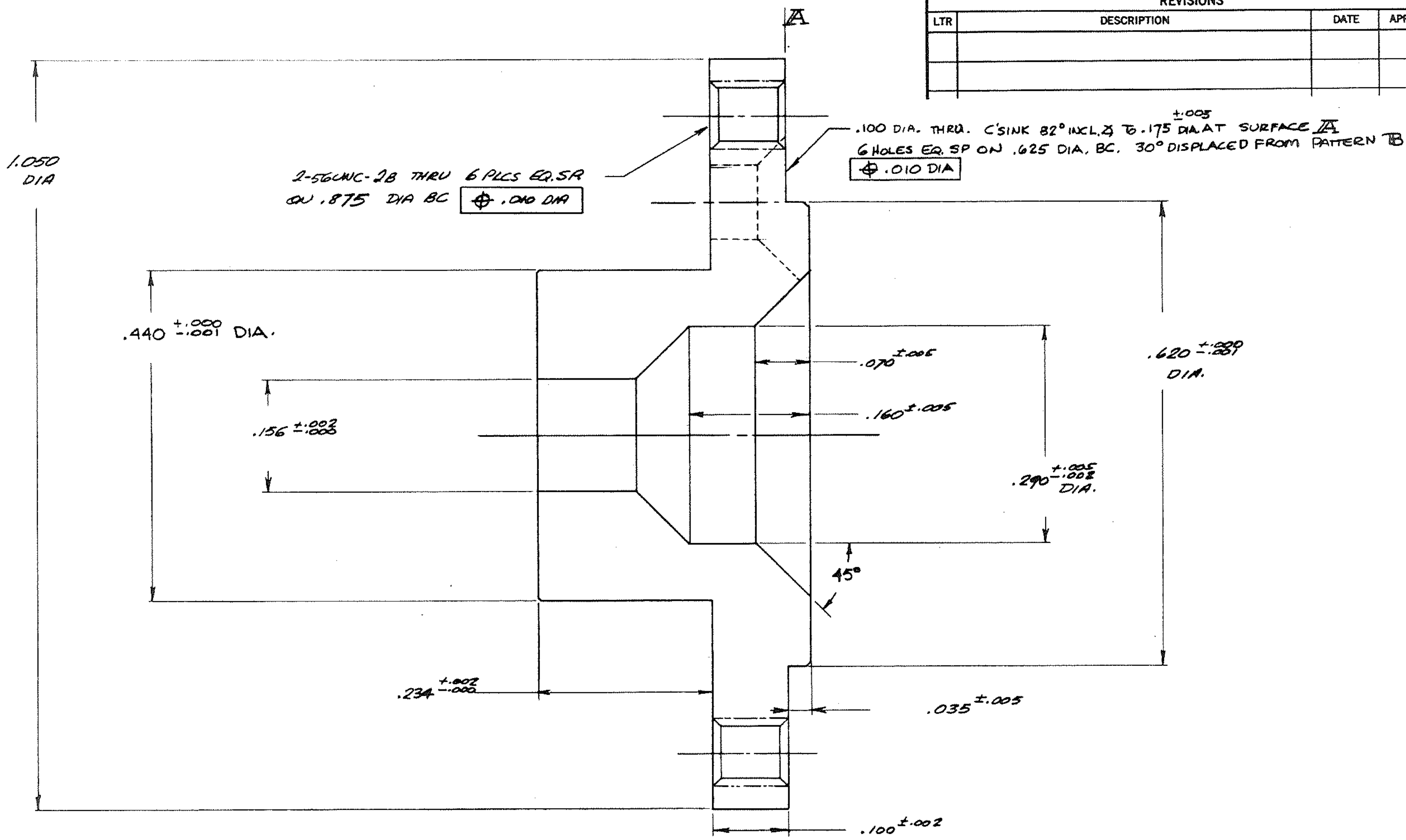
HOUSING - LATCH - VALVE
VACUUM - THERMALLY ACTUATED

SIZE	CODE IDENT NO.	
D	11982	SK1190-028

SCALE 10 X   SHEET

7/69 DIETZGEN-POST CLEARPRINT 1000   SYSTEMS 3427 REV. 4-69

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED



CODE IDENT NO.	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPEC.	REF DES	ITEM NO.
			ARMCO IRON OR PERMADUR			

QTY REQD PER ASSY CONFIGURATION

PARTS LIST

FINISH ~

HEAT TREAT ~

UNLESS OTHERWISE SPECIFIED
1. INTERPRET PER MIL-STD-100.
2. DIMENSIONS ARE IN INCHES
3. SURFACE TEXTURE SHALL BE ✓
4. DIMENSIONS APPLY BEFORE PLATING OR CONVERSION COATING.
5. REMOVE BURRS & SHARP EDGES

TOLERANCES ON DECIMAL DIMENSIONS: .XXX ± .010, .XX ± .03, .X ± .1

TOLERANCES ON ANGULAR DIMENSIONS: MACHINED & LOCATING ± 0°30', FORMED ± 2°, CHAMFERS ± 5°

TOLERANCES - ALL HOLE DIA		
FROM	THRU	TOL.
UNDER	.0140	+.0020 −.0005
.0145	.125	+.004 −.001
.126	.250	+.005 −.001
.251	.500	+.006 −.001
.501	.750	+.008 −.001
.751	1.000	+.010 −.001
1.001	2.000	+.012 −.001
OVER	2.000	+.015 −.005

DO NOT SCALE DRAWING

CONTRACT NO.

DRAWN	MAKOWSKI	3-9-70
CHECKED		
STRUCTURES		
MATL & PROCESS ENGR		
SUPERVISOR		

OTHER APPROVALS

THE FOLLOWING EO'S HAVE BEEN ATTACHED TO THIS PRINT

TRW SYSTEMS GROUP
ONE SPACE PARK • REDONDO BEACH, CALIFORNIA

ADAPTOR - ACTUATOR
VALVE-VACUUM - THERMALLY ACTUATED

SIZE	CODE IDENT NO.	
C	11982	SK1190-029

SCALE 10X SHEET

PR 12-1

APPLICABLE SPECIFICATIONS

THE ABOVE TRW SYSTEMS GROUP SPECS FORM A PART OF THIS DRAWING

NEXT ASSY	USED ON	NEXT ASSY QTY REQD
SK1190-020		

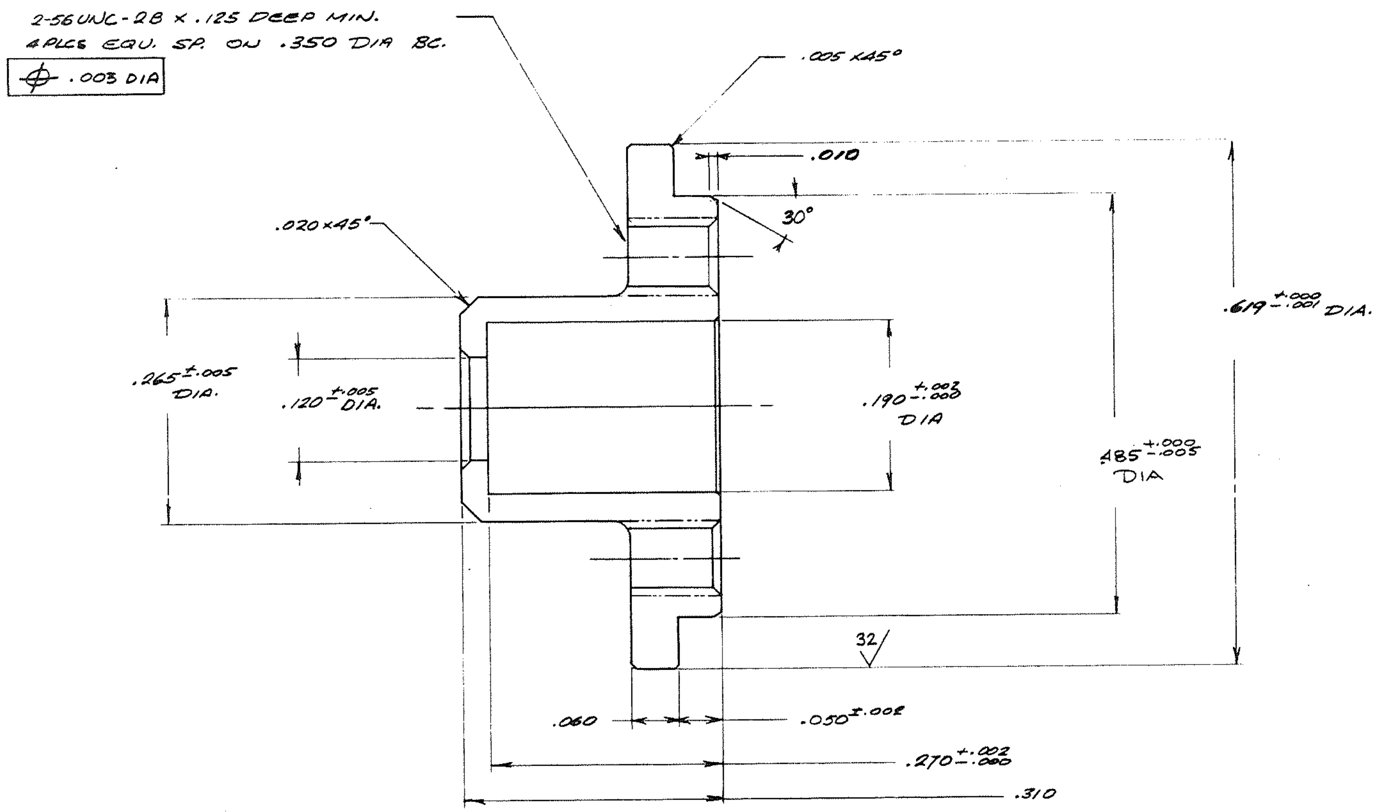
APPLICATION

1. IDENTIFICATION MARKING PER PR 12-1
TYPE ____ CLASS ____
PART NUMBER ____

NOTES: UNLESS OTHERWISE SPECIFIED

SYSTEMS 2455 REV. 12-68

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED



QTY REQD PER ASSY	CODE IDENT NO.	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPEC.	REF DES	ITEM NO.
1				303 OR 304 CRES			

PARTS LIST

QTY REQD PER ASSY CONFIGURATION

FINISH ~

HEAT TREAT ~

UNLESS OTHERWISE SPECIFIED
1. INTERPRET PER MIL-STD-100.
2. DIMENSIONS ARE IN INCHES
3. SURFACE TEXTURE SHALL BE ✓
4. DIMENSIONS APPLY BEFORE PLATING OR CONVERSION COATING.
5. REMOVE BURRS & SHARP EDGES

TOLERANCES - ALL HOLE DIA	FROM	THRU	TOL.
	UNDER	.0140	+.0020 −.0005
	.0145	.125	+.004 −.001
	.126	.250	+.005 −.001
	.251	.500	+.006 −.001
	.501	.750	+.008 −.001
	.751	1.000	+.010 −.001
	1.001	2.000	+.012 −.001
	OVER	2.000	+.015 −.005

TOLERANCES ON DECIMAL DIMENSIONS: .XXX ± .010, .XX ± .03, .X ± .1

TOLERANCES ON ANGULAR DIMENSIONS: MACHINED & LOCATING ± 0°30', FORMED ± 2°, CHAMFERS ± 5°

DO NOT SCALE DRAWING

CONTRACT NO.		
DRAWN	MAKOWSKI	3/9/70
CHECKED		
STRUCTURES		
MATL & PROCESS ENGR		
SUPERVISOR		
OTHER APPROVALS		

THE FOLLOWING EO'S HAVE BEEN ATTACHED TO THIS PRINT

TRW SYSTEMS GROUP
ONE SPACE PARK • REDONDO BEACH, CALIFORNIA

GUIDE - SPRING - ACTUATOR
VALVE - VACUUM - THERMALLY ACTUATED

SIZE	CODE IDENT NO.	
C	11982	SK1190-030

SCALE 10X SHEET

SYSTEMS 3406 REV. 12-68

PR 12-1

APPLICABLE SPECIFICATIONS

THE ABOVE TRW SYSTEMS GROUP SPECS FORM A PART OF THIS DRAWING

NEXT ASSY	USED ON	NEXT ASSY QTY REQD
SK1190-020		

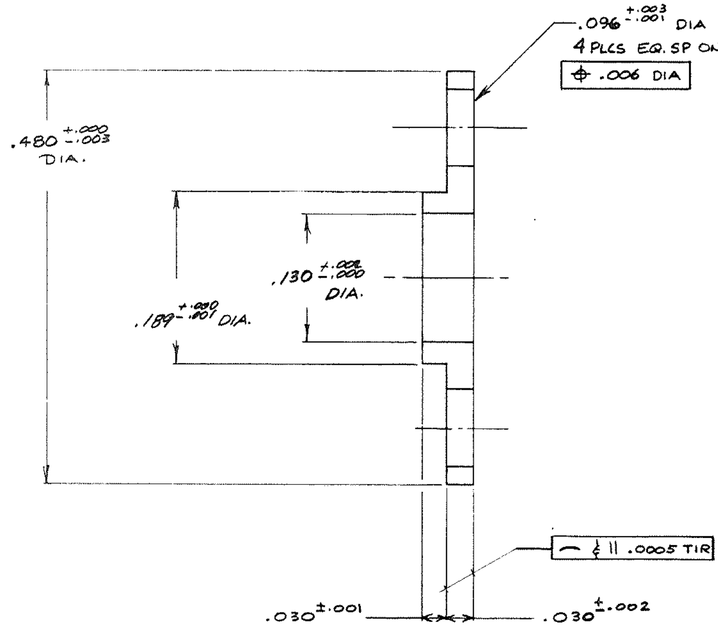
APPLICATION

1. IDENTIFICATION MARKING PER PR 12-1
TYPE ______ CLASS ______
PART NUMBER ______

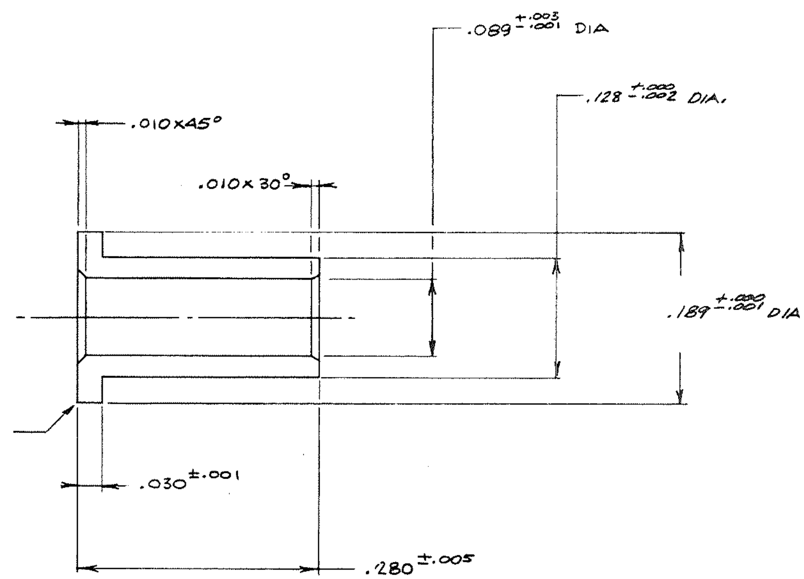
NOTES: UNLESS OTHERWISE SPECIFIED

11/69 DIETZGEN-POST CLEARPRINT 1020

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED



-1 RETAINER



-2 PLUNGER

QTY REQD PER ASSY CONFIGURATION	CODE IDENT NO.	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPEC.	REF DES	ITEM NO.
1		SK1190-031-2	PLUNGER	303 OR 304 CRES			-2
1		SK1190-031-1	RETAINER	303 OR 304 CRES			-1

PARTS LIST

FINISH: ~

HEAT TREAT: ~

UNLESS OTHERWISE SPECIFIED
1. INTERPRET PER MIL-STD-100.
2. DIMENSIONS ARE IN INCHES
3. SURFACE TEXTURE SHALL BE ✓
4. DIMENSIONS APPLY BEFORE PLATING OR CONVERSION COATING.
5. REMOVE BURRS & SHARP EDGES

TOLERANCES ON DECIMAL DIMENSIONS: .XXX ± .010; .XX ± .03; .X ± .1

TOLERANCES ON ANGULAR DIMENSIONS: MACHINED & LOCATING ± 0°30'; FORMED ± 2°; CHAMFERS ± 5°

TOLERANCES - ALL HOLE DIA		
FROM	THRU	TOL.
UNDER	.0140	+.0020 -.0005
.0145	.125	+.004 -.001
.126	.250	+.005 -.001
.251	.500	+.006 -.001
.501	.750	+.008 -.001
.751	1.000	+.010 -.001
1.001	2.000	+.012 -.001
OVER	2.000	+.015 -.005

DO NOT SCALE DRAWING

CONTRACT NO.

DRAWN: MAKOWSKI 3-10-70

CHECKED

STRUCTURES

MATL & PROCESS ENGR

SUPERVISOR

OTHER APPROVALS

THE FOLLOWING EO'S HAVE BEEN ATTACHED TO THIS PRINT

TRW SYSTEMS GROUP
ONE SPACE PARK • REDONDO BEACH, CALIFORNIA

RETAINER-SPRING-OVERTRAVEL - VALVE - VACUUM THERMALLY ACTUATED

SIZE: C | CODE IDENT NO.: 11982 | SK1190-031

SCALE: 10X | SHEET

SK1190-020		
USED ON	NEXT ASSY	NEXT ASSY QTY REQD
APPLICATION		

PR 12-1

APPLICABLE SPECIFICATIONS
THE ABOVE TRW SYSTEMS GROUP SPECS FORM A PART OF THIS DRAWING

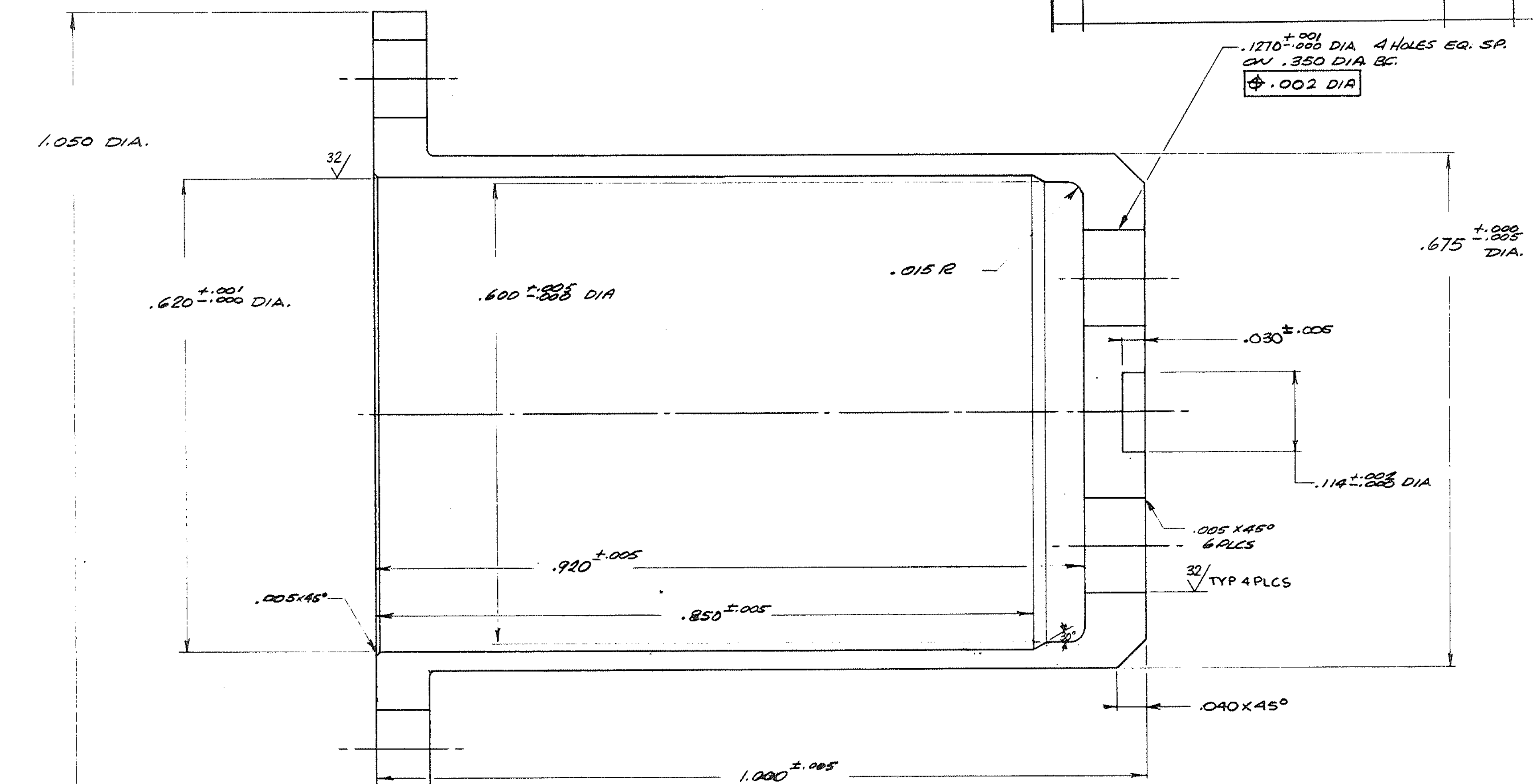
1. IDENTIFICATION MARKING PER PR 12-1
TYPE________CLASS________
PART NUMBER________

NOTES: UNLESS OTHERWISE SPECIFIED

11/69 DIETZGEN-POST CLEARPRINT 1020

SYSTEMS 3405 REV. 12-68

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED



1			303 OR 304 CRES			
CODE IDENT NO.	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPEC.	REF DES	ITEM NO.

PARTS LIST

QTY REQD PER ASSY CONFIGURATION

FINISH ~

HEAT TREAT ~

PR 12-1

APPLICABLE SPECIFICATIONS

THE ABOVE TRW SYSTEMS GROUP SPECS FORM A PART OF THIS DRAWING

UNLESS OTHERWISE SPECIFIED
1. INTERPRET PER MIL-STD-100.
2. DIMENSIONS ARE IN INCHES
3. SURFACE TEXTURE SHALL BE √
4. DIMENSIONS APPLY BEFORE PLATING OR CONVERSION COATING.
5. REMOVE BURRS & SHARP EDGES

TOLERANCES ON DECIMAL DIMENSIONS: .XXX ±.010, .XX ±.03, .X ±.1

TOLERANCES ON ANGULAR DIMENSIONS: MACHINED & LOCATING ±0°30', FORMED ±2°, CHAMFERS ±5°

TOLERANCES - ALL HOLE DIA		
FROM	THRU	TOL.
UNDER	.0140	+.0020 -.0005
.0145	.125	+.004 -.001
.126	.250	+.005 -.001
.251	.500	+.006 -.001
.501	.750	+.008 -.001
.751	1.000	+.010 -.001
1.001	2.000	+.012 -.001
OVER	2.000	+.015 -.005

DO NOT SCALE DRAWING

CONTRACT NO.

DRAWN MAKOWSKI 5-10-70

CHECKED

STRUCTURES

MATL & PROCESS

ENGR

SUPERVISOR

OTHER APPROVALS

THE FOLLOWING EO'S HAVE BEEN ATTACHED TO THIS PRINT

TRW SYSTEMS GROUP
ONE SPACE PARK • REDONDO BEACH, CALIFORNIA

GUIDE-ACTUATOR
VALVE-VACUUM-THERMALLY ACTUATED

SIZE	CODE IDENT NO.	
C	11982	SK1190-032

SCALE | SHEET

SK1190-020		
USED ON	NEXT ASSY	NEXT ASSY QTY REQD
APPLICATION		

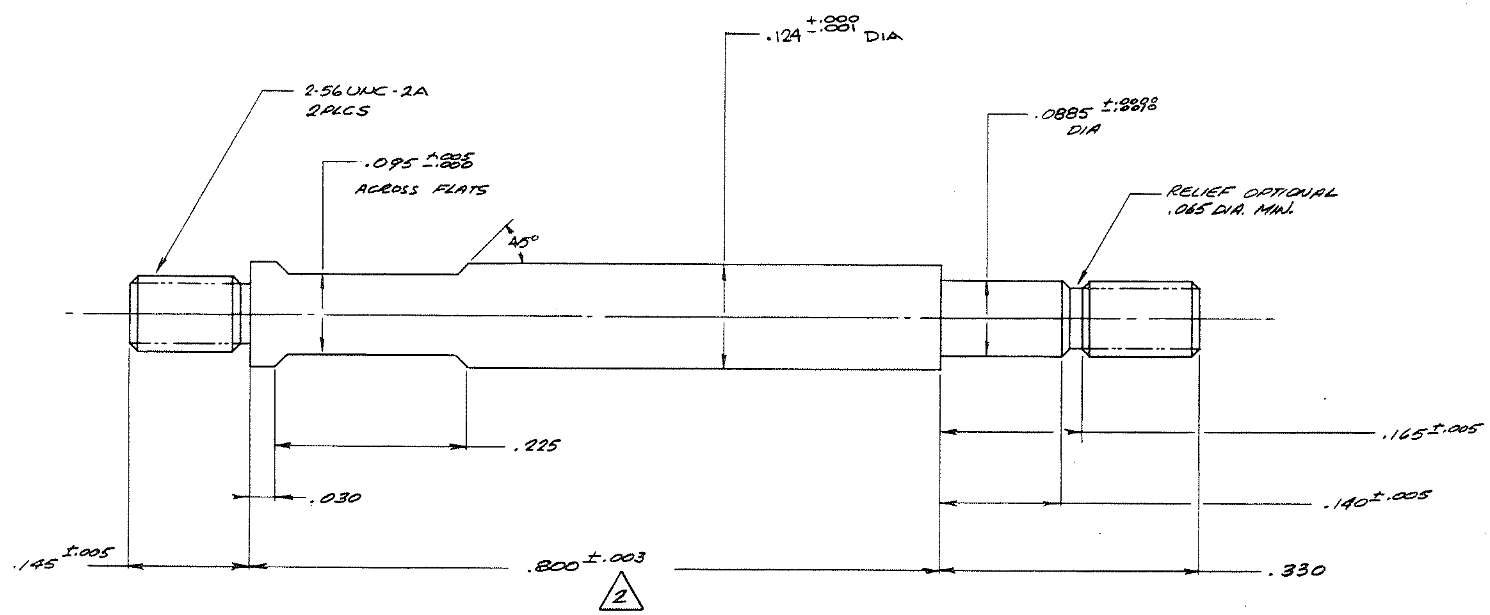
1. IDENTIFICATION MARKING PER PR 12-1
TYPE ________ CLASS ________
PART NUMBER ________

NOTES: UNLESS OTHERWISE SPECIFIED

SYSTEMS 3405 REV. 12-68

11/69 DIETZGEN-POST CLEARPRINT 1000

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED



4				303 OR 304 CRES				
Per Assy	CODE IDENT NO.	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPEC.	REF DES	ITEM NO.	

QTY REQD PER ASSY CONFIGURATION

PARTS LIST

FINISH ~

HEAT TREAT ~

UNLESS OTHERWISE SPECIFIED
1. INTERPRET PER MIL-STD-100.
2. DIMENSIONS ARE IN INCHES
3. SURFACE TEXTURE SHALL BE ✓
4. DIMENSIONS APPLY BEFORE PLATING OR CONVERSION COATING.
5. REMOVE BURRS & SHARP EDGES

TOLERANCES ON DECIMAL DIMENSIONS: .XXX ± .010, .XX ± .03, .X ± .1

TOLERANCES ON ANGULAR DIMENSIONS: MACHINED & LOCATING ± 0°30', FORMED ± 2°, CHAMFERS ± 5°

TOLERANCES - ALL HOLE DIA		
FROM	THRU	TOL.
UNDER	.0140	+.0020 −.0005
.0145	.125	+.004 −.001
.126	.250	+.005 −.001
.251	.500	+.006 −.001
.501	.750	+.008 −.001
.751	1.000	+.010 −.001
1.001	2.000	+.012 −.001
OVER	2.000	+.015 −.005

DO NOT SCALE DRAWING

CONTRACT NO.

DRAWN MAKOWSKI 3-10-70

CHECKED

STRUCTURES

MATL & PROCESS ENGR

SUPERVISOR

OTHER APPROVALS

THE FOLLOWING EO'S HAVE BEEN ATTACHED TO THIS PRINT

TRW SYSTEMS GROUP
ONE SPACE PARK • REDONDO BEACH, CALIFORNIA

ROD - ACTUATOR - PULL
VALVE-VACUUM-THERMALLY ACTUATED

SIZE C | CODE IDENT NO. 11982 | SK1190-033

SCALE | SHEET

SK1190-020	
USED ON	NEXT ASSY
APPLICATION	

NEXT ASSY QTY REQD

PR 12-1

APPLICABLE SPECIFICATIONS

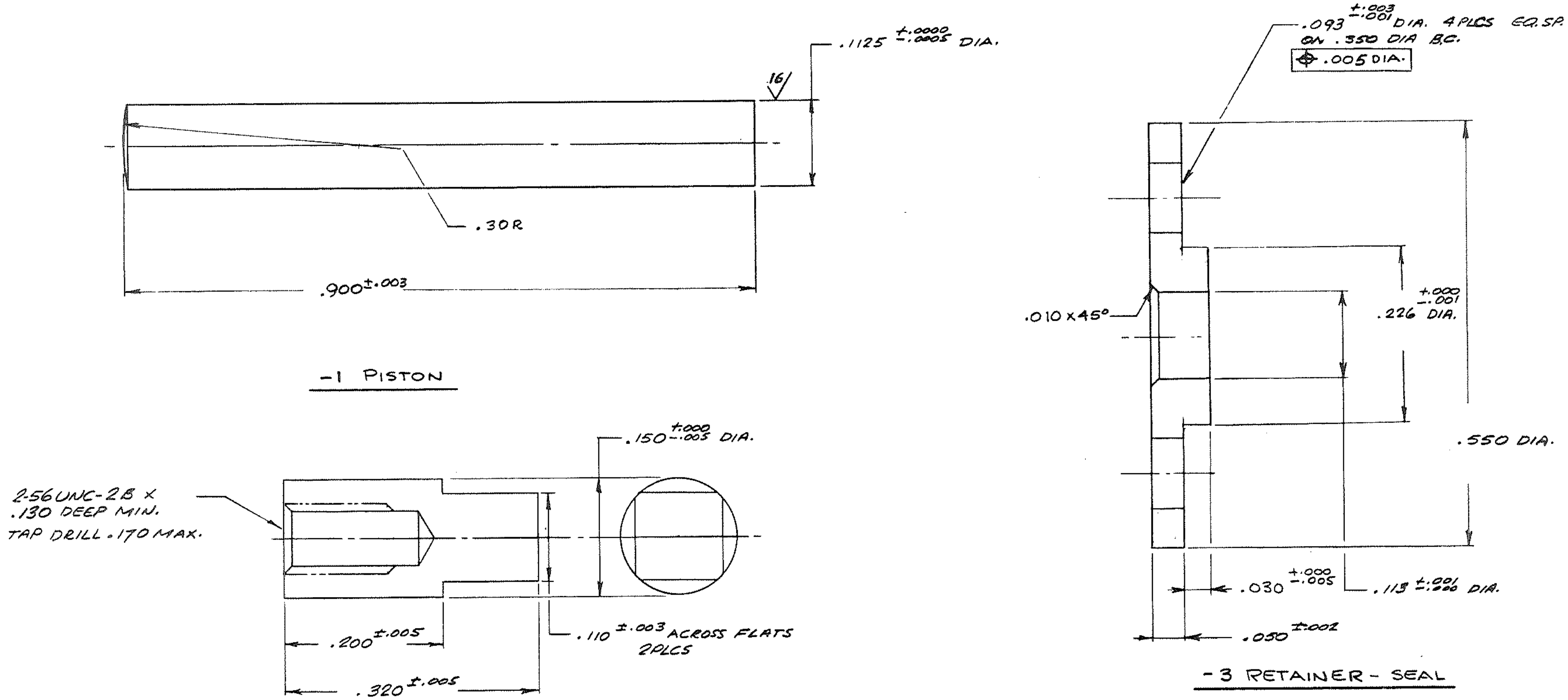
THE ABOVE TRW SYSTEMS GROUP SPECS FORM A PART OF THIS DRAWING

2. EACH ROD, IN EACH SET OF 4 RODS, MUST MATCH IN LENGTH WITHIN .0005.

1. IDENTIFICATION MARKING PER PR 12-1
TYPE______ CLASS______
PART NUMBER______

NOTES: UNLESS OTHERWISE SPECIFIED

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED



QTY REQD PER ASSY	CODE IDENT NO.	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPEC.	REF DES	ITEM NO.
1		SK 1190-034-3	RETAINER	303 or 304 CRES			-3
4		SK1190-034-2	NUT	303 or 304 CRES			-2
1		SK1190-034-1	PISTON	303 or 304 CRES			-1

Per Assy

QTY REQD PER ASSY CONFIGURATION

PARTS LIST

FINISH

HEAT TREAT

UNLESS OTHERWISE SPECIFIED
1. INTERPRET PER MIL-STD-100.
2. DIMENSIONS ARE IN INCHES
3. SURFACE TEXTURE SHALL BE ✓
4. DIMENSIONS APPLY BEFORE PLATING OR CONVERSION COATING.
5. REMOVE BURRS & SHARP EDGES

TOLERANCES ON DECIMAL DIMENSIONS: .XXX ± .010, .XX ± .03, .X ± .1

TOLERANCES ON ANGULAR DIMENSIONS: MACHINED & LOCATING ± 0°30', FORMED ± 2°, CHAMFERS ± 5°

TOLERANCES - ALL HOLE DIA		
FROM	THRU	TOL.
UNDER	.0140	+.0020 -.0005
.0145	.125	+.004 -.001
.126	.250	+.005 -.001
.251	.500	+.006 -.001
.501	.750	+.008 -.001
.751	1.000	+.010 -.001
1.001	2.000	+.012 -.001
OVER	2.000	+.015 -.005

DO NOT SCALE DRAWING

CONTRACT NO.		
DRAWN	MAKOWSKI	3-10-70
CHECKED		
STRUCTURES		
MATL & PROCESS		
ENGR		
SUPERVISOR		
OTHER APPROVALS		

THE FOLLOWING EO'S HAVE BEEN ATTACHED TO THIS PRINT

TRW SYSTEMS GROUP
ONE SPACE PARK • REDONDO BEACH, CALIFORNIA

PISTON - ACTUATOR
VALVE - THERMALLY ACTUATED

SIZE	CODE IDENT NO.	
C	11982	SK1190-034

SCALE 10X | SHEET

1. IDENTIFICATION MARKING PER PR 12-1
TYPE_______ CLASS_______
PART NUMBER_______

NOTES: UNLESS OTHERWISE SPECIFIED

NEXT ASSY	USED ON	NEXT ASSY QTY REQD
SK1190-020		
APPLICATION		

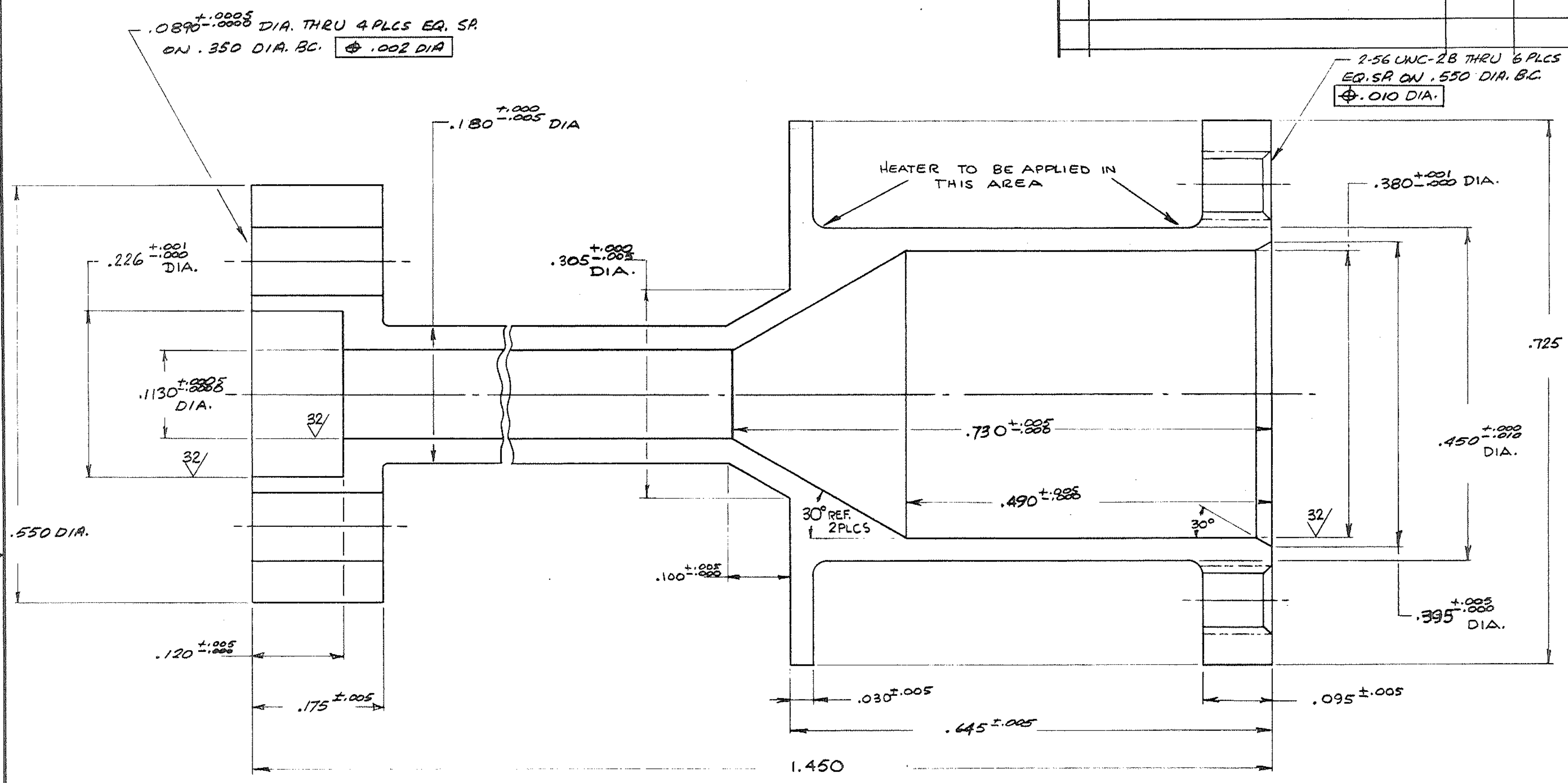
PR 12-1

APPLICABLE SPECIFICATIONS
THE ABOVE TRW SYSTEMS GROUP SPECS FORM A PART OF THIS DRAWING

11/69 DIETZGEN-POST CLEARPRINT 1000

SYSTEMS 3485 REV. 12-68

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED



2. HEATER DATA:
NOMINAL VOLTAGE - 28 VOLTS
POWER - 30 WATTS @ 28 VOLTS & 200°C
OPERATING TEMP. - NOMINAL 200°C, MAXIMUM 250°C
LEAD LENGTH - 12 IN. LOCATION OPTIONAL
MFTR. - ELECRTOFILM INC., N. HOLLYWOOD, CA.
P/N-111893

1. IDENTIFICATION MARKING PER PR 12-1
TYPE_____CLASS_____
PART NUMBER_____

NOTES: UNLESS OTHERWISE SPECIFIED

CODE IDENT NO.	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPEC.	REF DES	ITEM NO.
			303 OR 304 CRES			

PARTS LIST

QTY REQD PER ASSY CONFIGURATION

FINISH

HEAT TREAT

NEXT ASSY	USED ON	QTY REQD
SK1190-020	SK1190-020	1

APPLICATION

PR 12-1

APPLICABLE SPECIFICATIONS
THE ABOVE TRW SYSTEMS GROUP SPECS FORM A PART OF THIS DRAWING

UNLESS OTHERWISE SPECIFIED
1. INTERPRET PER MIL-STD-100.
2. DIMENSIONS ARE IN INCHES
3. SURFACE TEXTURE SHALL BE ✓
4. DIMENSIONS APPLY BEFORE PLATING OR CONVERSION COATING.
5. REMOVE BURRS & SHARP EDGES

TOLERANCES ON DECIMAL DIMENSIONS: .XXX ± .010, .XX ± .03, .X ± .1
TOLERANCES ON ANGULAR DIMENSIONS: MACHINED & LOCATING ± 0°30', FORMED ± 2°, CHAMFERS ± 5°

TOLERANCES - ALL HOLE DIA		
FROM	THRU	TOL.
UNDER	.0140	+.0020 -.0005
.0145	.125	+.004 -.001
.126	.250	+.005 -.001
.251	.500	+.006 -.001
.501	.750	+.008 -.001
.751	1.000	+.010 -.001
1.001	2.000	+.012 -.001
OVER	2.000	+.015 -.005

DO NOT SCALE DRAWING
CONTRACT NO.
DRAWN MAKOWSKI 3-11-70
CHECKED
STRUCTURES
MATL & PROCESS
ENGR
SUPERVISOR
OTHER APPROVALS

THE FOLLOWING EO'S HAVE BEEN ATTACHED TO THIS PRINT

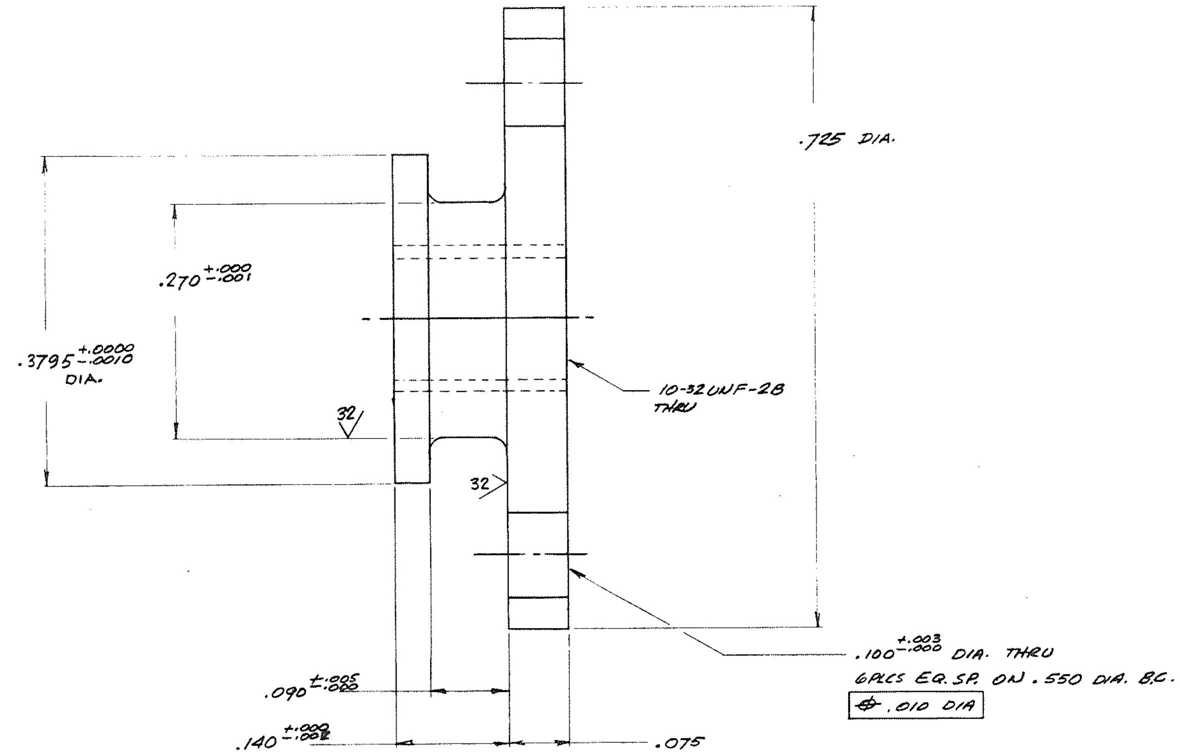
TRW SYSTEMS GROUP
ONE SPACE PARK • REDONDO BEACH, CALIFORNIA

BODY-ACTUATOR
VALVE-VACUUM-THERMALLY ACTUATED

SIZE C | CODE IDENT NO. 11982 | SK1190-035
SCALE 10X | SHEET

11/69 DIETZGEN-POST CLEARPRINT 1020
SYSTEMS 3486 REV. 12-68

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED



ITEM NO.	REF DES	SPEC.	MATERIAL	NOMENCLATURE OR DESCRIPTION	PART OR IDENTIFYING NO.	CODE IDENT NO.
			303 OR 304 CRES			

PARTS LIST

QTY REQD PER ASSY CONFIGURATION

FINISH ~

HEAT TREAT ~

UNLESS OTHERWISE SPECIFIED
1. INTERPRET PER MIL-STD-100.
2. DIMENSIONS ARE IN INCHES
3. SURFACE TEXTURE SHALL BE ✓
4. DIMENSIONS APPLY BEFORE PLATING OR CONVERSION COATING.
5. REMOVE BURRS & SHARP EDGES

TOLERANCES ON DECIMAL DIMENSIONS	TOLERANCES - ALL HOLE DIA FROM	THRU	TOL.
.XXX ± .010	UNDER	.0140	+.0020 -.0005
.XX ± .03	.0145	.125	+.004 -.001
.X ± .1	.126	.250	+.005 -.001
	.251	.500	+.006 -.001
TOLERANCES ON ANGULAR DIMENSIONS:	.501	.750	+.008 -.001
MACHINED & LOCATING ± 0°30'	.751	1.000	+.010 -.001
FORMED ± 2°	1.001	2.000	+.012 -.001
CHAMFERS ± 5°	OVER	2.000	+.015 -.005

DO NOT SCALE DRAWING

CONTRACT NO.

DRAWN	MAKOWSKI	3-11-70
CHECKED		
STRUCTURES		
MATL & PROCESS ENGR		
SUPERVISOR		
OTHER APPROVALS		

THE FOLLOWING EO'S HAVE BEEN ATTACHED TO THIS PRINT

TRW SYSTEMS GROUP
ONE SPACE PARK • REDONDO BEACH, CALIFORNIA

CAP - ACTUATOR
VALVE - THERMALLY ACTUATED

SIZE	CODE IDENT NO.	
C	11982	SK1190-036

SCALE 10X SHEET

PR 12-1
APPLICABLE SPECIFICATIONS
THE ABOVE TRW SYSTEMS GROUP SPECS FORM A PART OF THIS DRAWING

NEXT ASSY	USED ON
	SK1190-020

APPLICATION

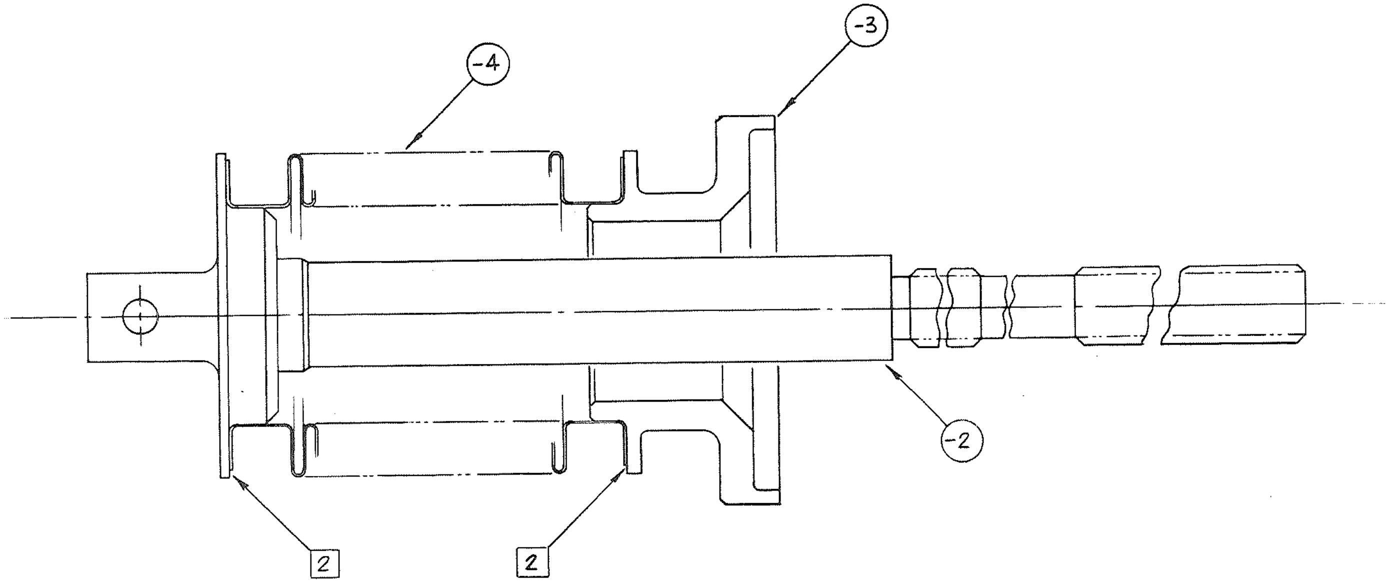
NEXT ASSY QTY REQD

1. IDENTIFICATION MARKING PER PR 12-1
TYPE ______ CLASS ______
PART NUMBER ______

NOTES: UNLESS OTHERWISE SPECIFIED

11/69 DIETZGEN-POST CLEARPRINT 1000

SYSTEMS 3496 REV. 12-68



SK1190-037 N/C

REVISIONS

LTR	DESCRIPTION	DATE	APPROVED

PARTS LIST

QTY REQD PER ASSY CONFIGURATION	CODE IDENT NO.	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPEC.	REF DES	ITEM NO.
1		SK1190-022	BELLOWS				-4
1		SK1190-023	ADAPTER				-3
1		SK1190-024	STEM				-2
1		-1	STEM ASS'Y				-1

3. TOTAL ASS'Y LEAKAGE WITH 15 psia HELIUM (INTERNAL) TO VACUUM (EXTERNAL) 1×10^{-9} SCCS MAX. PER HELIUM MASS SPECTROMETER

$\boxed{2}$ FUSION WELD

1. IDENTIFICATION MARKING PER PR 12-1
TYPE______CLASS______
PART NUMBER______

NOTES: UNLESS OTHERWISE SPECIFIED

USED ON	NEXT ASSY	NEXT ASSY QTY REQD
SK190-020		1

APPLICATION

FINISH ~

HEAT TREAT ~

PR 12-1

APPLICABLE SPECIFICATIONS
THE ABOVE TRW SYSTEMS GROUP SPECS FORM A PART OF THIS DRAWING

UNLESS OTHERWISE SPECIFIED
1. INTERPRET PER MIL-STD-100.
2. DIMENSIONS ARE IN INCHES
3. SURFACE TEXTURE SHALL BE ✓
4. DIMENSIONS APPLY BEFORE PLATING OR CONVERSION COATING.
5. REMOVE BURRS & SHARP EDGES

TOLERANCES ON DECIMAL DIMENSIONS: .XXX ± .010, .XX ± .03, .X ± .1

TOLERANCES ON ANGULAR DIMENSIONS: MACHINED & LOCATING ± 0°30', FORMED ± 2°, CHAMFERS ± 5°

TOLERANCES - ALL HOLE DIA

FROM	THRU	TOL.
UNDER	.0140	+.0020 −.0005
.0145	.125	+.004 −.001
.126	.250	+.005 −.001
.251	.500	+.006 −.001
.501	.750	+.008 −.001
.751	1.000	+.010 −.001
1.001	2.000	+.012 −.001
OVER	2.000	+.015 −.005

DO NOT SCALE DRAWING

CONTRACT NO.

DRAWN	MAKOWSKI	3/20/70
CHECKED		
STRUCTURES		
MATL & PROCESS		
ENGR		
SUPERVISOR		
OTHER APPROVALS		

THE FOLLOWING EO'S HAVE BEEN ATTACHED TO THIS PRINT

TRW SYSTEMS GROUP
ONE SPACE PARK • REDONDO BEACH, CALIFORNIA

STEM ASS'Y - VALVE - VACUUM - THERMALLY ACTUATED

SIZE	CODE IDENT NO.	
C	11982	SK1190-037

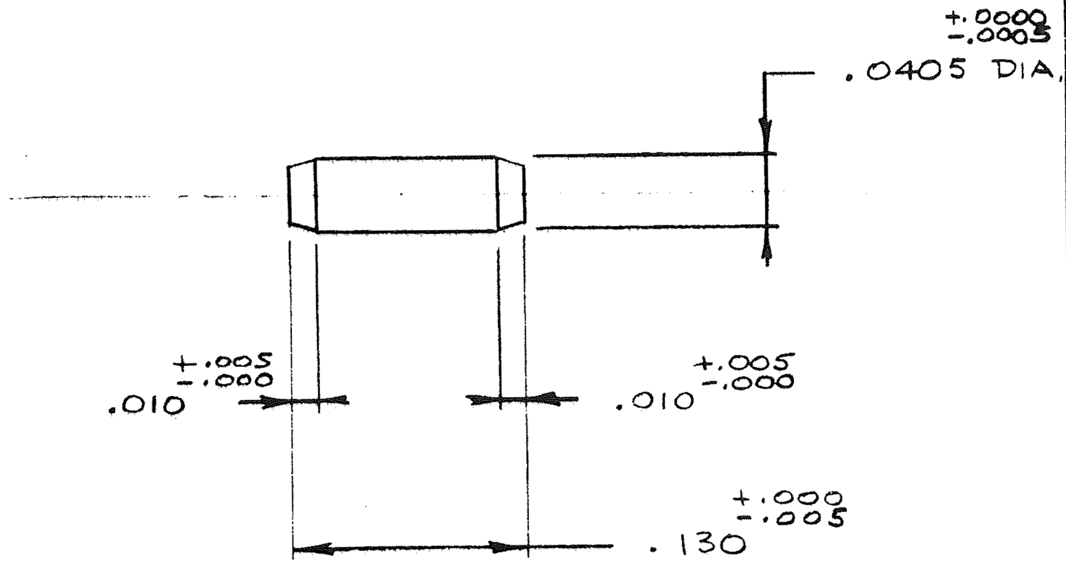
SCALE 10X SHEET

SYSTEMS 3406 REV. 12-69

11/69 DIETZGEN-POST CLEARPRINT 1020

SK

CHG LTR

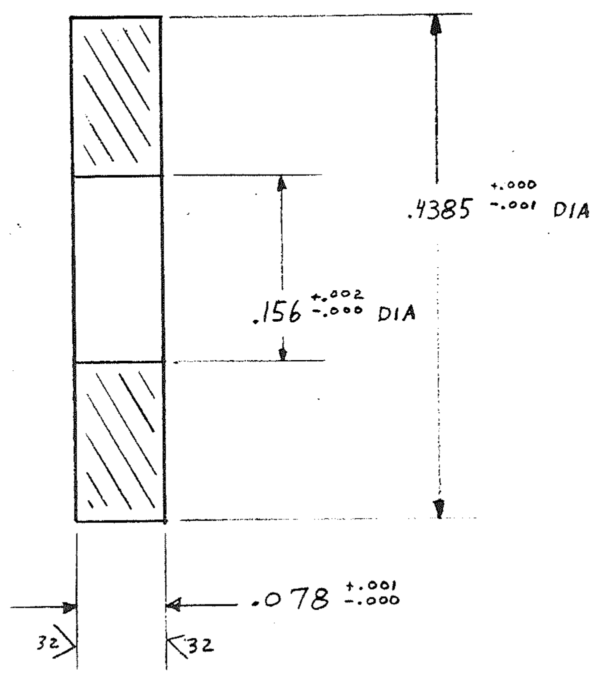


MATERIAL - VESPEL POLYIMIDE
10X SIZE

ORIGINATOR	DATE	TITLE	ENGINEERING SKETCH
M.J. MAKOWSKI	5-15-70	PIN- RETAINING	TRW SYSTEMS
			SK 1190-038
MJO			SHEET OF

SYSTEMS 523 A REV 9-65

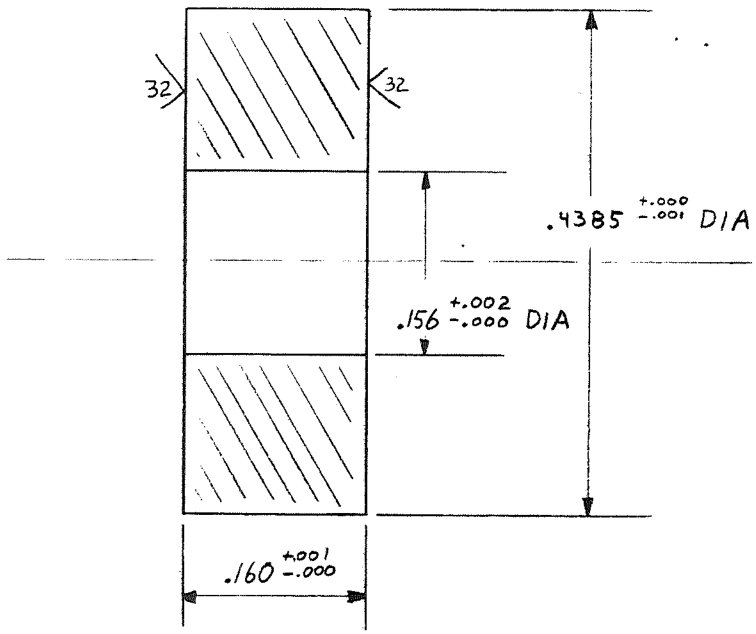
SK	CHG LTR



MAT'L- ARMCO MAGNETIC INGOT IRON

ORIGINATOR	DATE	TITLE	ENGINEERING SKETCH
ARMSTRONG	4-15-70	SPACER-LATCH	TRW SYSTEMS GROUP
	5-11-70		ONE SPACE PARK • REDONDO BEACH • CALIFORNIA
			SK 1190-039
MJO SCALE- 10X			SHEET OF

SK CHG LTR

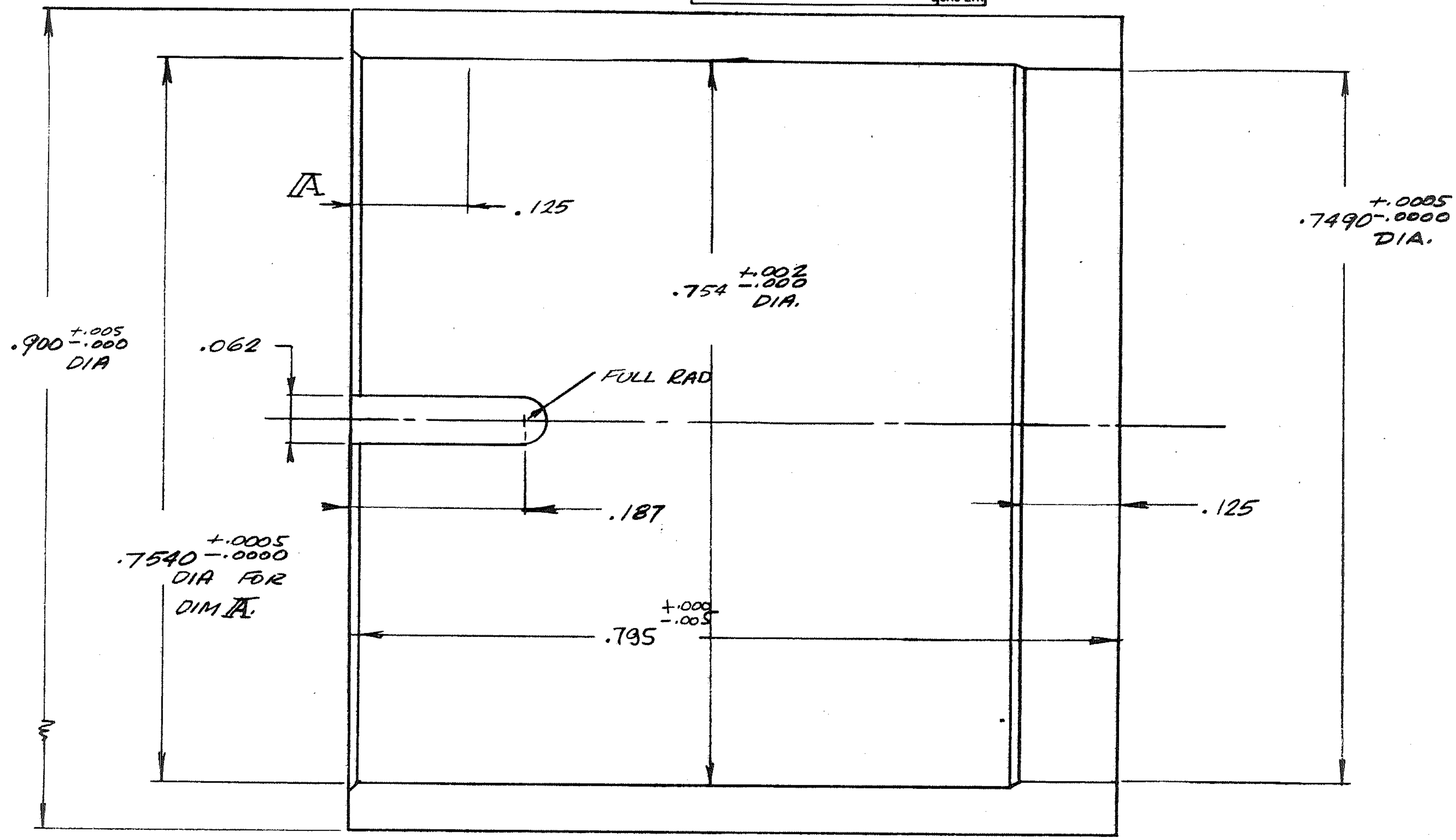


MAT'L- ALNICO V ORIENTED // TO AXIS

ORIGINATOR	DATE	TITLE	ENGINEERING SKETCH
ARMSTRONG	4-15-70	MAGNET-LATCH	TRW SYSTEMS GROUP ONE SPACE PARK • REDONDO BEACH • CALIFORNIA
	5-11-70		SK 1190-040
MJO SCALE-10X			SHEET OF

SYSTEMS 3003 REV. 5-67

SK | CHG LTR



MAT'L ARMCO IRON OR PERMADUR

ORIGINATOR	DATE	TITLE	
MAKOWSKI	4-7-70	TUBE - MAGNETIC RETURN	ENGINEERING SKETCH TRW SYSTEMS GROUP ONE SPACE PARK • REDONDO BEACH • CALIFORNIA
			SK1190-041
MJO			SHEET OF

SYSTEMS 3003 REV. 5-67