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TWO POSITION FAIL SAFE SWITCH. (U)

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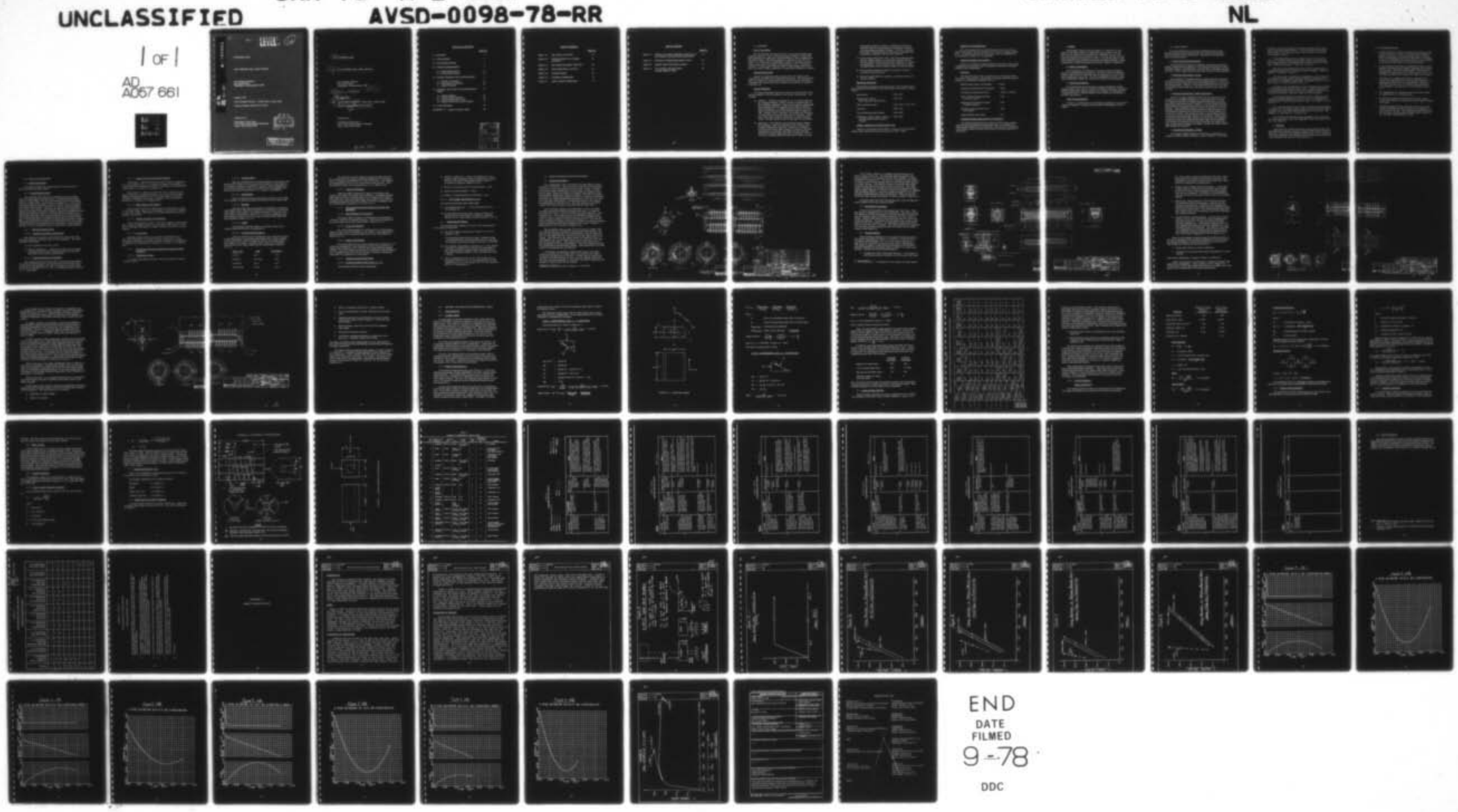

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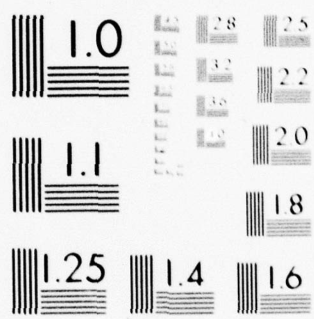
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AVSD-0098-78-RR

TWO POSITION FAIL SAFE SWITCH

Avco Systems Division
201 Lowell Street
Wilmington, Massachusetts 01887

January 1978

Final Technical Report -- CDRL A004 & CDRL A006

Contract Number DAAA21-76-C-0218

Prepared for:

Department of the Army
U.S. Army Armament R&D Command
Dover, New Jersey 07801

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(6) TWO POSITION FAIL SAFE SWITCH.

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(11) January 1978

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 SUMMARY

Device Description

The Two Position Fail Safe Switch is a strong link normally open (unarmed position), rotary switch specifically designed to safely withstand abnormal environments of high temperature, static crushing load, and impact shock. The design approach is depicted in LA23527 (see Figure 3-1). This switch configuration contains 14 normally open functional circuits and one normally closed monitor circuit. It basically consists of a strong outer structure made of high strength steel and an inner core made of high compressive strength/high temperature ceramic.

Design Requirements

Section 4.0 states the design requirements and changes to the requirements developed as the program progressed. The switch mechanism was required to function under normal environments and behave predictably and remain safe under abnormal environments as specified in Section 4.0.

Design Philosophy

The design philosophy stated in the scope of work was used as the primary guidance in the development of the design configuration. Specifically:

(a) Isolation -- Separate terminations, one containing input and one containing outputs, shall be located on opposite sides of the switching mechanism. Each circuit input and output shall have maximum internal separation and isolation within the switch mechanism. A complete physical dielectric barrier shall be provided between each adjacent input to output circuit. Internal voids or openings, which allow any movement of loose metal or dielectric parts are not desirable. Maximum effort shall be made to minimize or reduce voids entirely. Internal cabling or hard wiring shall not be allowed.

(b) Materials -- The behavior of all materials used, metallic and insulating, shall be predictable in the normal and abnormal environments specified. Selection of conductors and other metal parts shall consider the effects of elevated temperatures on melting, vaporizing and other physical properties including impact and shock resistance. The use of solder and plating materials that melt or vaporize at low temperatures shall be avoided. Insulating and dielectric materials shall be non-flammable, temperature resistant, non-carbonizing and shall not outgas. Ceramics, silicones and similar materials shall be considered in obtaining high temperature resistance and electrical isolation.

(c) Stored energy shall not be used. The only exceptions allowable are spring contacts or compression springs used to provide contact pressure upon normal activation of a switching mechanism. The movement of any contact as a result of spring failure in the off position shall not degrade safety.

(d) The switching mechanism shall be designed to require a minimum of driving torque.

(e) Size and weight shall be a minimum consistent with the protection required.

Significant Documents

The following documents generated as part of this program have been prepared and submitted in full conformance with contract requirements:

Specification	CDRL A002
Engineering Drawings (All details plus top assembly)	CDRL A003
Final Technical Report	CDRL A004, CDRL A006
Test Plan	CDRL A007
Test and Demonstration Report	CDRL A008
Reliability, Failure Modes, Effects, and Criticality Analysis Report (FMEA)	CDRL A009

Studies, Analyses and Experimental Tests

Section 6.0 describes all the studies, analyses and experimental impact tests conducted during the program and their results.

Significant Accomplishments

All of the requirements of the Statement of Work were accomplished successfully with the exception of the abnormal impact requirement. A detailed statement and description of the accomplishments are contained in Section 2.0, Conclusions.

Design Description and Evolution

Section 5.0 contains a complete detailed description of the design configuration and discusses the development evolution and rationales leading to that configuration.

Hardware

The following major items of hardware were fabricated during the course of the program. All hardware including expended units was submitted to ARRADCOM (DRDAR-LCN-F):

Experimental Impact Test Samples	20 units
Complete Functional Switch Assembly	6 units
Prototype Demonstration Model	1 unit w/4 contacts
Rotor Contact Forming and Heat Treatment Fixture	1 unit
Retaining Clip Forming and Heat Treatment Fixture	1 unit
Vibration, Shock and Life Cycle Test Fixture	1 unit
Representative Piece Parts	1 set

Additional Design Requirements Consideration

The following discusses the treatment of those design requirements considered attainable through application of established and demonstrated feasible design techniques. This allowed concentration of the limited resources on the more difficult and undemonstrated requirements.

- <u>Sealing</u>

The baseline design, reference Figure 3-1, includes "O" ring seals for the stator contacts in conjunction with ceramic adhesives. Sealing of the shaft drive end would be accomplished by an "O" ring face seal when mated to the switch driver. The seal concepts were not further developed in this program in order to concentrate effort on the more difficult design problems associated with impact strength, contact configuration, electrical isolation and thermal response of materials.

- <u>Contact Termination</u>

The development of a design for the stator contact termination was not a requirement of the program. The stator contact termination method could readily be tailored to specific applications such as weld, braze, spade lug, crimp, etc. The nut configuration was used to allow interchangeability of leads for various test methods for this program.

- <u>Corrosion Resistance</u>

The switch body and the electrical contact assemblies will ultimately require some form of corrosion resistance treatment. Numerous standard plating and coating techniques are available for satisfying this requirement such as cadmium plating of the housing and gold plating of the BeCu piece parts.

<u>Final Recommendations</u>

Section 3.0 contains the recommendations applicable to any planned further development. Specific areas of further investigation are described.

2.0 CONCLUSIONS

It was demonstrated by test and/or analysis that an 8 ounce fail safe switch could be designed within all of the specified requirements except that of abnormal impact. Specifically, the following have been demonstrated:

- <u>Normal Operating Requirements</u>

The feasibility of meeting the functional operating requirements before, during and after exposure to the normal environments of transportation vibration, handling shock, thermal shock, operating vibration, life cycle, static voltage discharge and surge current was demonstrated.

- <u>Abnormal Requirement - Crush</u>

The feasibility of meeting isolation requirements after exposure to abnormal crush environment of 50,000 pounds applied to at least 70 percent of switch surface area along each octagonal axis for one minute was demonstrated. Further, it was demonstrated that the switch met all frictional requirements after exposure to the abnormal crush environment.

- <u>Abnormal Requirement - High Temperature</u>

Based on the high temperature abnormal environment test and analysis of all candidate materials, it is concluded that the switch, as configured with BeCu or Paliney M contact materials, can meet an abnormal temperature level of 1850°F. Testing conducted in this high temperature environment resulted in lower insulation resistance than the 10,000 megohms required, with one circuit as low as 0.52 megohm. Subsequent failure analysis indicated that the cause of the low insulation resistance was the presence of an epoxy adhesive internal to the switch. This epoxy was used as an assembly aid where a ceramic, non-carbonizing, adhesive was intended. In those areas of the switch where the epoxy residue was not present, the insulation resistance values were measured at greater than 50,000 megohms. It is felt that in the absence of the epoxy material, the design would fully comply with the insulation resistance requirement after abnormal high temperature exposure.

- <u>Abnormal Requirement - Impact</u>

The 8 ounce weight limitation and functional requirements (i.e., number of switch circuits, isolation, contact resistance, and voltage breakdown) precludes meeting the original abnormal impact requirement of surviving without fracture - a 100 foot drop of a 100 pound steel weight on any of the three switch major surfaces (80 feet per second impact velocity).

It was demonstrated, by test, that an 8 ounce test specimen with a 1/2 inch high compressive strength ceramic rotor could survive without fracture. The specimen did not have any stator contact holes. (Reference Table 6-2, Test Nos. 11 and 14.)

The stress concentration due to the 30 stator contact holes is a significant contributor to reduction in impact strength. (Reference Table 6-2, Test Nos. 15 and 17.)

The small rotor (.28 diameter) configuration with 30 stator contact holes has a higher impact capability than an equivalent weight large rotor (.44 diameter) configuration. (Reference Table 6-2, Test Nos. 10 and 13 versus Test Nos. 19 and 20.)

The large rotor configuration is a more feasible design because of the limitations inherent in a small rotor. A small rotor leads to an impractical contact design in terms of acceptable resistance, current carrying capacity, stresses, deflection and tolerancing.

It was demonstrated by test that the baseline configuration has an impact strength capability of a 50 foot drop of a 100 pound steel weight without fracture along the lateral y axis. (See Table 6-2, Test No. 18.)

It is concluded that the x axis impact strength is approximately a 30 foot drop of a 100 pound weight, based on an analysis of the relative strength of the y and x axes and the impact test in y direction. (See Section 6.1.2 and Table 6-2, Test No. 18.)

It is felt that the abnormal impact capability in the z direction is at least equivalent to the y axis capability, based on results of Test No. 13 of Table 6-2.

- <u>Bearings</u>

The ceramic to ceramic main rotor bearing surfaces have been demonstrated as adequate, based on measured mid-rotation torque of less than 1 inch ounce and maximum closure torque of 12.4 inch ounce after being subjected to the required environmental tests including the 2,000 operation life cycle test (see Reference 3).

3.0 RECOMMENDATIONS

1. A study should be conducted to estimate the increased weight required to allow the switch to meet the stated abnormal impact environment. This study should include considerations of surrounding the switch with materials for absorbing or otherwise mitigating the impact energy as well as designs which increase the amount of switch body material.

2. A study should be performed to establish the scope of a test program to characterize the impact capability of the existing switch design. This study should include consideration of additional instrumentation of the impact event as well as establishing the number and sequence of impact tests required.

3. The impact test configuration should be standardized to reflect the configuration used in the reported program, i.e., impacting the switch with a 6 inch diameter, 100 pound, 1018 steel slug at R_B 72 to 73 with the switch bonded to a 6 inch diameter, one inch thick, 1018 steel plate at R_B 72 to 73.

4. The requirement for operating torque of the switch should be established at 12 to 14 inch-ounces.

5. A steel band around the slotted drive end of the ceramic switch rotor should be incorporated to better support unusual drive loads.

6. If additional impact testing, using the Avco air gun is anticipated, consideration should be given to decreasing the set-up time for the gun. One significant improvement would be to provide a reusable optical velocity sensor in place of the "one shot" switch probes now used.

4.0 DESIGN REQUIREMENTS

4.1 Initial Requirements

The following details the requirements as initially stated for the Two Position Fail Safe Switch.

4.1.1 General Requirements

The switching action shall be accomplished by rotary motion from a normally open to closed position. The switching mechanism shall be of a type that can be driven mechanically by various methods such as a stepper motor, inertial mass or manual force. The switch mechanism shall be developed, initially to switch 14 circuits from the open to the closed position. However, the concept must be adaptable to as many as 28 circuits. Monitoring the open contact position after normal or abnormal environment response shall be accomplished without utilizing the functional contacts. Electrical monitoring shall be provided on the input side of the switch mechanism only. Monitoring contact requirements shall be in addition to the basic 14 functional contact pairs. The weight of the switching mechanism shall not exceed 8 ounces. Any detent action shall be assumed to be provided by the driver mechanism and shall not be considered a part of this effort. Proper functioning after a 20 year storage life shall be considered a design objective.

4.1.2 Electrical Requirements

4.1.2.1 Insulation Resistance (Off Position)

When tested in accordance with Method 302 of MIL-STD-202E, minimum insulation resistance shall be 10,000 megohms. The following details shall apply:

(a) Test Condition B (500 VDC ± 10%)

(b) Points of Application -- between each input and each output termination and all other termination points and case with the switch in the normally open position.

4.1.2.2 Contact Resistance (On Position)

After testing each switch contact pair in accordance with Method 307 of MIL-STD-202E using a test current of 100 ma maximum and a voltage of 28 VDC maximum, the contact resistance of any pair shall not exceed 30 milliohms at $73^{\circ} \pm 3^{\circ}F$. The additional details in Section 4.1.5.1 shall apply.

4.1.2.3 Contact Current Capacity (On Position)

Steady State -- After each and every set of contacts is subjected to 5 ± 0.25 amperes D.C. for 5 minutes minimum, there shall be no visual indication of damage to the switch. In addition, the requirements of Sections 4.1.2.1 and 4.1.2.2 shall be met.

Surge Current -- After each and every a set of contacts is subjected to four 20 ± 1 ampere DC pulses, each with a minimum pulse-width of 20 milliseconds at the 50% level, there shall be no visible indication of damage of the switch. In addition, the requirements of Sections 4.1.2.1 and 4.1.2.2 shall be met.

4.1.2.4 Static Voltage (Off Position)

When each and every set of open contacts is subjected to 20,000 ± 1,000 volts surge, obtained by discharging a 500 pf capacitor through a 5,000 ohm resistor, there shall be no visible indication of arcing or damage to the switch.

4.1.2.5 Voltage Breakdown (Off Position)

When a DC potential of 2,000 ± 100 volts is applied to each mating pair of input and output terminals for one minute, there shall be no evidence of disruptive discharge or leakage current in excess of 1.0 milliampere.

4.1.2.6 Life Cycling

When the switch is tested in accordance with Method 206 of MIL-STD-202E using Test Condition B and a cycle rate of 10 cpm, examination shall show no broken, deformed, displaced, or loose parts. In addition, the requirements of Sections 4.1.2.1 and 4.1.2.2 shall be met.

4.1.3 Normal Environmental Requirements (Operable After Exposure)

4.1.3.1 Temperature Range

The switch shall function properly over the temperature range of $-65^{o}F$ to $+160^{o}F$.

4.1.3.2 Thermal Shock

After the switch has been thermally shocked in accordance with Method 107D of MIL-STD-202E using Test Condition A, there shall be no evidence of damage or loosening of its parts, and the maximum contact resistance change of each set of contacts from that initially measured in accordance with Section 4.1.5.1 shall be 10 milliohms.

4.1.3.3 Seal Integrity

After the switch has been subjected to a pressure of 13.5 psig for 30 minutes, its interior pressure rise shall be no more than 4 psi.

4.1.3.4 Humidity

After the switch has been subjected to humidity in accordance with Method 103B of MIL-STD-202E using Test Condition B and the specified "after drying period", the contact resistance of each set of contacts shall be as specified in Section 4.1.2.2 and the insulation resistance between each and every set of open terminals shall comply with that specified in Section 4.1.2.1.

4.1.3.5 Fungus

All insulation materials shall be non-fungus nutrient in accordance with MIL-STD-454, Requirement 4.

4.1.3.6 Vibration (Both Positions)

After the switch in the off position has been subjected to vibration in three planes in accordance with Method 204C of Test Condition A, MIL-STD-202E, with the exceptions listed in the schedule below, there shall be no evidence of broken, loose, deformed or displaced parts and the switch shall comply with the requirements of Section 2.1.2.1.

Range (H_z)	Input	Time (Min.)
6-20-6	2 g's	15.0
20-60-20	.06" D.A.	10.0
60-300-60	10 g's	25.0
300-500-300	10 g's	25.0

The vibration test above shall be repeated with the switch in the on position and its contacts continuously monitored for discontinuities in accordance with Method 310 of MIL-STD-202E. There shall be no discontinuity in excess of 10 microseconds during the test. After the vibration testing, the requirements of 4.1.2.2 shall be met.

4.1.3.7 Shock (Off Position)

When the switch is subjected to shock in accordance with Method 213B of MIL-STD-202E, Test Condition I, monitoring measurement shall be made to verify that there is no closing of open contacts during the test. After the shock testing, there shall be no evidence of mechanical damage and the switch shall be tested for compliance with the requirements of Sections 4.1.2.1 and 4.1.2.2.

4.1.4 Abnormal Environment Requirements (Safe After Exposure)

4.1.4.1 Heat Resistance (Off Position)

The switch shall be capable of withstanding a temperature of 1,850°F ± 100°F for 60 minutes minimum. After this heat application, the switch shall meet all the requirements of Section 4.1.2.1.

4.1.4.2 Crush (Off Position)

The switch shall withstand a crushing force of 50,000 pounds applied in each of three directions for one minute. After application of these crushing forces, the switch shall meet all the requirements of Section 4.1.2.1.

4.1.4.3 Impact (Off Position)

The switch shall meet all of the requirements of Section 4.1.2.1 except the termination to case requirement, after being exposed to an impact from the flat face of a 100 pound steel weight which is dropped 100 feet. The switch shall meet the above requirements when the impact force is applied to any one of each of its three mutually perpendicular axes while it is positioned on a steel plate.

4.1.5 Additional Test Method Details

4.1.5.1 Contact Resistance (See Section 4.1.2.2)

The following additional details shall apply:

(a) Method of connection -- between each input and corresponding output termination using a suitable jig on clamps. The four wire kelvin measurement method would be preferable to minimize equipment error.

(b) Number of activations prior to measurement -- none.

(c) Number of test activations -- three.

(d) Number of measurements per activations -- one.

4.1.5.2 Life Cycling (See Section 4.1.2.6)

The following additional details shall apply:

(a) Test potential and load -- 20 VDC maximum and 0.5 ± .025 ampere DC.

(b) Measurements and testing after cycling to verify compliance with the requirements of insulation resistance (Section 4.1.2.1) and contact resistance (Section 4.1.2.2).

4.2 Requirements Changes

The following detail changes were made to the requirements as the program progressed.

(a) The static voltage requirement of Section 4.1.2.4 was changed to read:

"A preferential path between the input terminals and the case and between the output terminals and the case shall be provided to discharge voltages in excess of 2,500 VDC."

(b) The vibration requirements of Section 4.1.3.6 was changed to provide for testing of the switch in the on position to the following Random Vibration input. Random noise at a flat power spectral density of $.06\ g^2/H_z$ between 10 and 2,000 H_z.

(c) The test potential and load for the Life Cycling Test requirements of Section 4.1.5.2 was changed from 20 VDC maximum and 0.5 ± 0.025 ampere DC to 20 VDC maximum and 10 to 15 milliamperes.

5.0 DESIGN APPROACH AND DEVELOPMENT

5.1 Detailed Description

The configuration of the Two Position Fail Safe Switch is shown in Figure 5-1 (LA23527). The switch has 14 normally open functional circuit contacts and one normally closed monitor circuit. The input and monitor contact connections are on two faces, 60 degrees apart, and the output contact connections are diametrically opposite to maintain maximum separation of inputs and outputs. The unit is basically comprised of a strong outer housing structure (1)* made from hardened 4340 steel, and a high strength/high temperature inner rotor (2) made from aluminum oxide (Al_2O_3). An important feature of the design is the minimization of internal voids. The total amount of void volume consist of the slots and grooves machined into the solid rotor.

The 15 movable contact brush assemblies (3 and 4) are shown as Paliney M which is a high temperature noble alloy. It should be noted that BeCu 145/175 is also a candidate for this application (refer to Section 6.2). Each contact brush is mechanically retained in the ceramic rotor by a clip (5) which fits into two slots machined into the rotor, as shown in Sections D-D and H-H (Figure 5-1). The clip and brush combination is under spring load for positive mechanical retention. Each brush assembly fits into a machined rotor cavity, as shown in Sections B-B, C-C, D-D and E-E (Figure 5-1).

The machining of the ceramic rotor to accept the contact brush and retaining clip was accomplished by diamond wheel grinding. The slots for the retaining clips were machined with a .062 inch diameter and .012 inch thick wheel at a speed of 30,000 rpm with a water spray coolant. The grooves for the contact brush were machined with a 1.0 inch diameter and .046 inch thick wheel also at a speed of 30,000 rpm and with the water spray. The tooling used for these operations is part of standard Avco in-house facilities. The brush contacts and clips were fabricated by standard photo etching. These fabrication processes proved to be practical and cost effective.

The brushes are angularly oriented with respect to the stator contact assemblies (8) by a button which is swaged onto the contact brush and a matching hole in the rotor. A steel shim (6) controls the end play of the rotor and also serves as the rotor angular limit stop. The rotor and shim assembly is secured to the unit by a hardened 4340 bushing (7) which threads into the housing.

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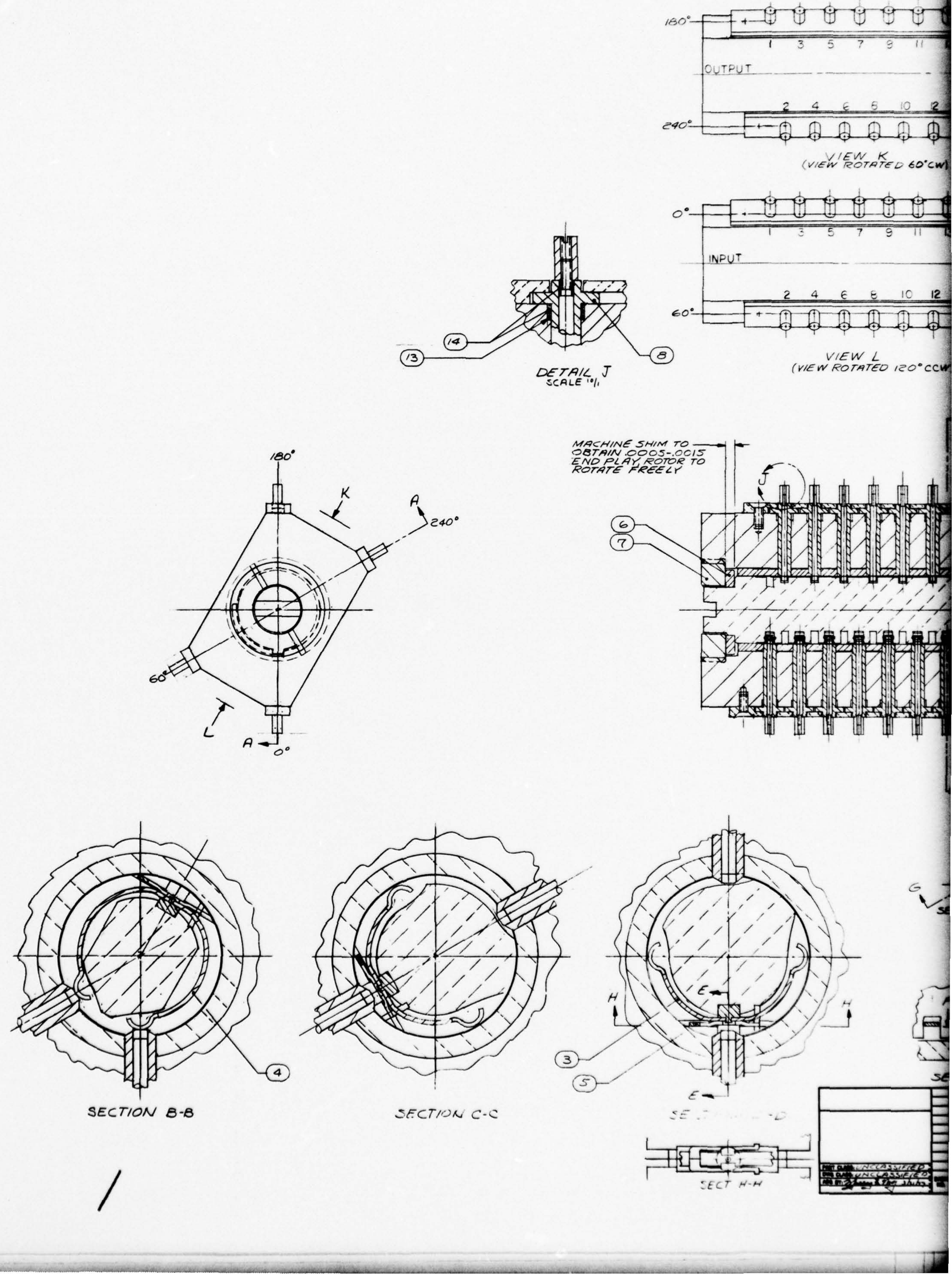
*Numbers in parenthesis refer to Figure 5-1 (LA23527).



180°
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OUTPUT
2 4 6 8 10 12
240°
VIEW K
(VIEW ROTATED 60°CW)
0°
1 3 5 7 9 11
INPUT
2 4 6 8 10 12
60°
VIEW L
(VIEW ROTATED 120°CCW)
14
13
8
DETAIL J
SCALE 10/1
MACHINE SHIM TO
OBTAIN .0005-.0015
END PLAY ROTOR TO
ROTATE FREELY
J
6
7
180°
K
A
240°
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L
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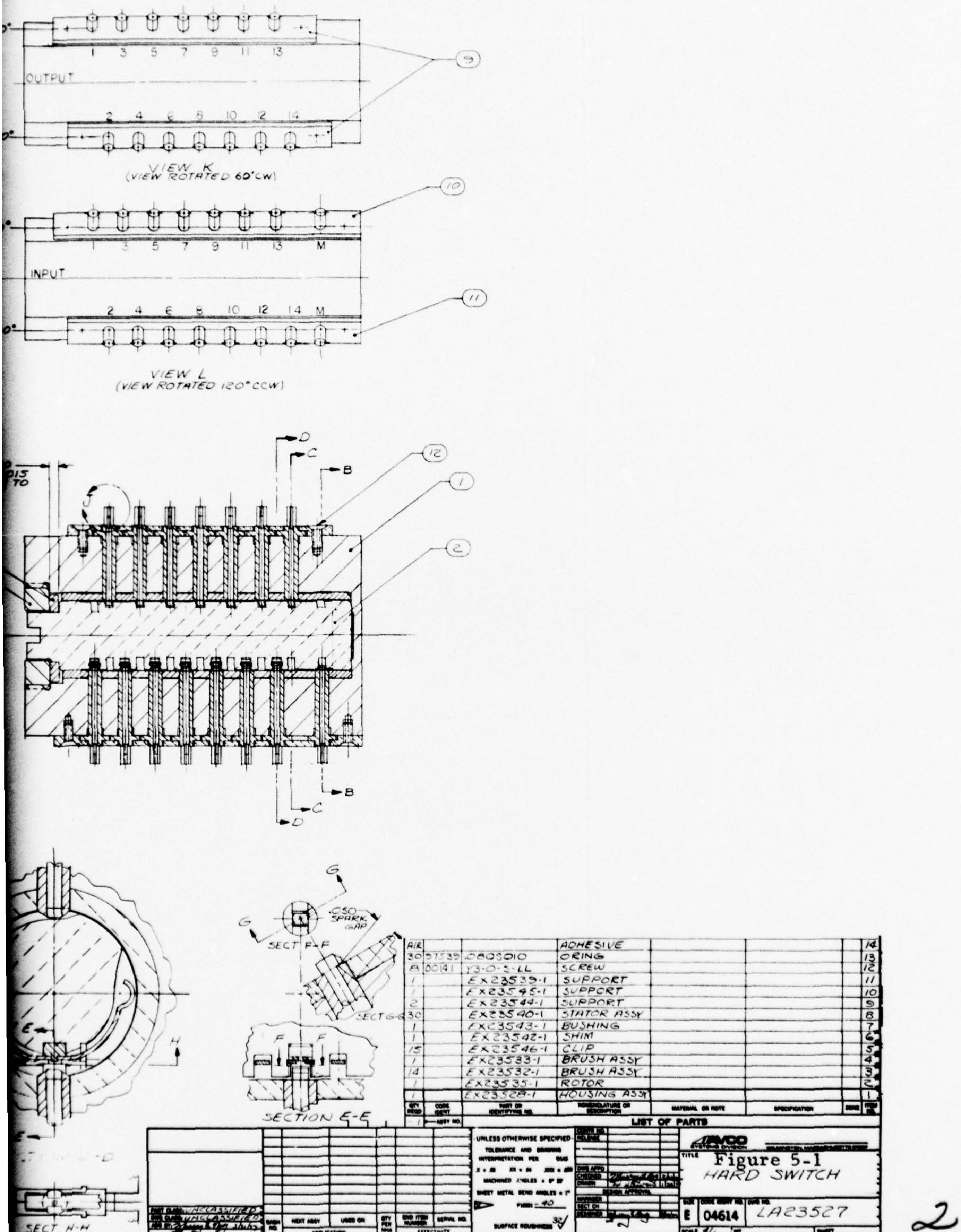


QTY REQD	CODE IDENT	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL OR NOTE	SPECIFICATION	ZONE	ITEM NO.
AIR			ADHESIVE				14
30	57539	.080S010	ORING				13
8	00141	Y3-O-3-LL	SCREW				12
1		EX23539-1	SUPPORT				11
1		EX23545-1	SUPPORT				10
2		EX23544-1	SUPPORT				9
30		EX23540-1	STATOR ASSY				8
1		EX23543-1	BUSHING				7
1		EX23542-1	SHIM				6
15		EX23546-1	CLIP				5
1		EX23533-1	BRUSH ASSY				4
14		EX23532-1	BRUSH ASSY				3
1		EX23535-1	ROTOR				2
1		EX23528-1	HOUSING ASSY				1

LIST OF PARTS

Figure 5-1
HARD SWITCH

The 30 stator contacts are insulated from the housing by an Al_2O_3 ceramic sleeve (8). The insulating characteristics are purposely limited by a slot machined into the stator insulator, as shown in Section G-G (Figure 5-1). This slot is a controlled air gap between the stator contact and the housing which is less than any other internal or external air gap. This feature provides a controlled high voltage breakdown path between the stator contact and the case. The stator contact assemblies are mechanically secured to the housing by Al_2O_3 channel shaped supports (9, 10 and 11) which are fastened to the housing with self locking screws. Electrical contact terminations are made through nut lugs fabricated from a nickel alloy. These nut lugs also secure the stator contact assemblies, as shown in Detail J (Figure 5-1).

An Al_2O_3 sleeve fits inside the housing base to provide high electrical isolation of the rotor contact brushes.

5.2 Description of Operation

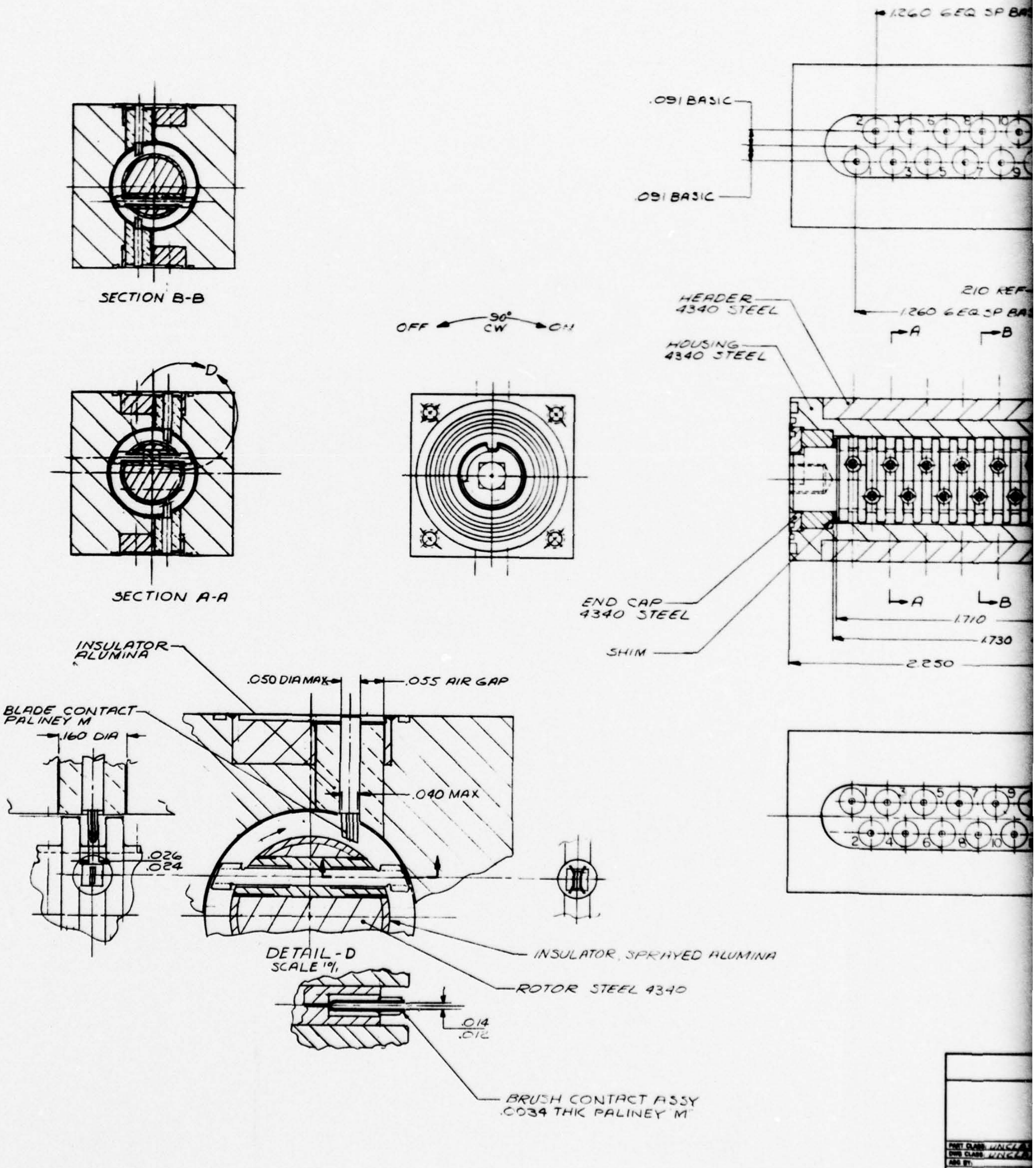
A drive slot is provided at the exposed end of the rotor. This slot allows for engagement of a drive mechanism. The rotor is driven 90° clockwise from the off position to close the functional circuits and open the monitor contacts requiring a maximum of 14 inch ounce of torque. Positive limit stops are provided in the switch to control the on and off positions. The monitor circuit changes from closed to open within the first 10° of rotation. The functional circuits change from open to closed after 80° of rotation. The contact pressure is calculated to be 28 grams nominal using BeCu alloy 175 contacts and 30 grams nominal using Paliney M.

5.3 Design Evolution

Several design configurations were studied during this program. The initial design shown in Figure 5-2 (LA23159 -- 5/20/76) was a rectangular parallellepiped .95 x .95 x 2.25 inches long with a 1/2 inch steel core rotor and a bifurcated brush contact configuration. This design is similar to that which was presented in the proposal.[1] Detailed examination of the design shown in Figure 5-2, early in the program, indicated the following disadvantages:

- Complex and Costly Fabrication Required -- The design required flame sprayed ceramic on the steel body of the rotor.

1. AVSD-B446-AA1 -- A Proposal for Two Position Fail Safe Switch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SECTION A-A
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CW
ON
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.091 BASIC
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1.260 6 EQ SP BAS
HEADER
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HOUSING
4340 STEEL
A
B
END CAP
4340 STEEL
SHIM
1.710
1.730
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INSULATOR
ALUMINA
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BLADE CONTACT
PALINEY M
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DETAIL - D
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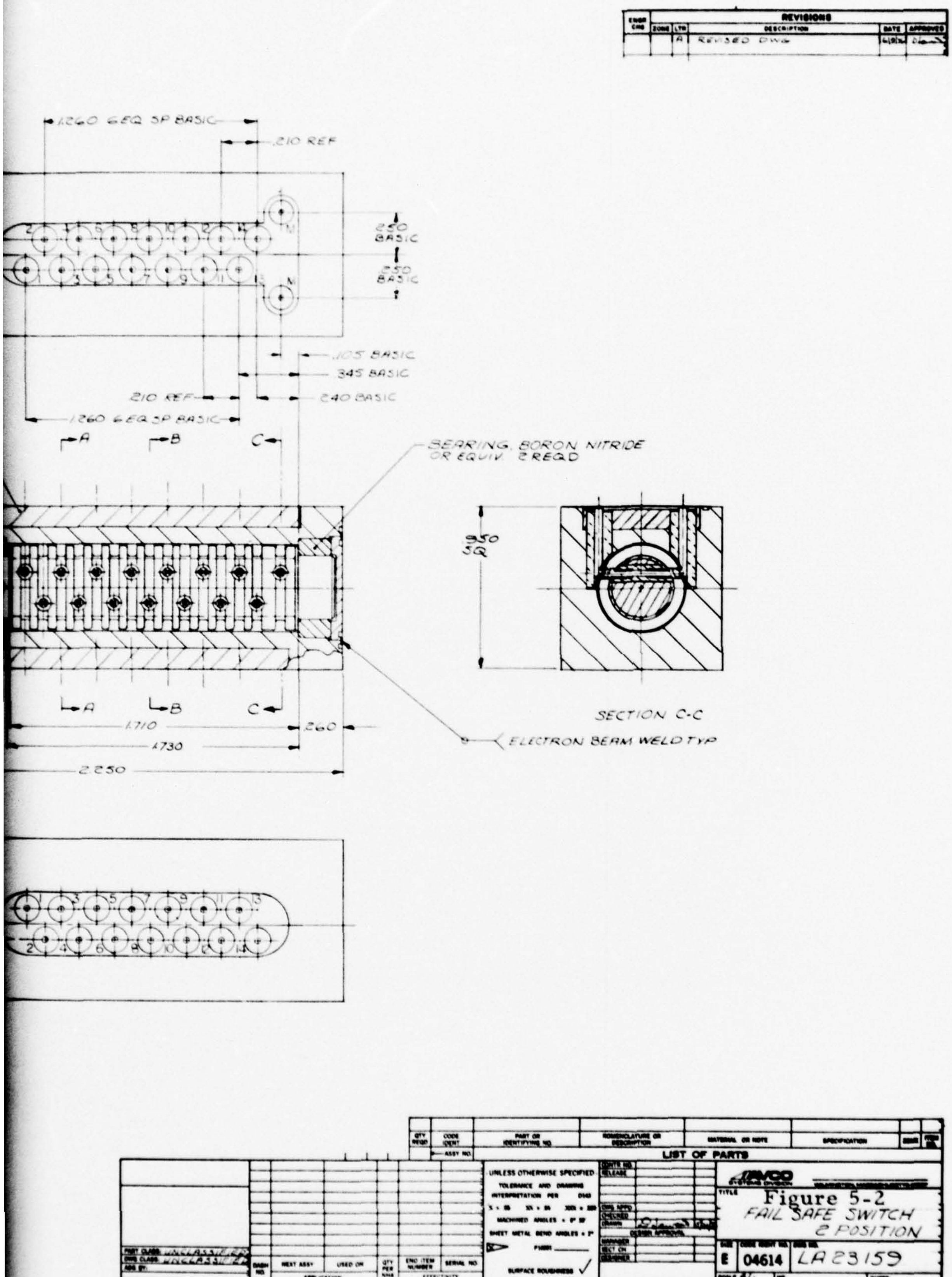
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LIST OF PARTS
UNLESS OTHERWISE SPECIFIED
SURFACE ROUGHNESS
UNCLASSIFIED
AVCO
Figure 5-2
FAIL SAFE SWITCH
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04614
LA 23159
SCALE 4/1

2

The rotor contacts required metallizing of the rotor's insulator followed by brazing of the electrical elements. The attachment of the stator's contacts also required this metallizing and subsequent brazing operation.

- Minimal Input to Output Electrical Isolation -- A thin layer of flame sprayed ceramic onto the hardened high strength steel rotor is used to obtain maximum structural support from the rotor assembly. This thin layer represented the only barrier between the input contact, rotor core and output contact.

- High Stress, Small Deflection of the Electrical Contacts -- The bifurcated contact configuration, constrained by the switch size requirements, resulted in short cantilevered members which have very little deflection capabitilies before they become overstressed. This small deflection characteristic would require close tolerancing, thus costly fabrication and assembly of parts.

- Unequal Relative Lateral Strength -- All the stator contact holes are on one of the lateral axes which significantly reduces the stress area. A trade-off analysis of impact strength capability (i.e., structurally supporting rotor) or less complex fabrication and increased isolation (i.e., nonstructural rotor) was conducted. The analysis of the effect of a nonstructural rotor indicated that the lateral axis impact capability would be decreased approximately 60% for the 1/2 inch rotor configuration (refer to Section 6.2.1).

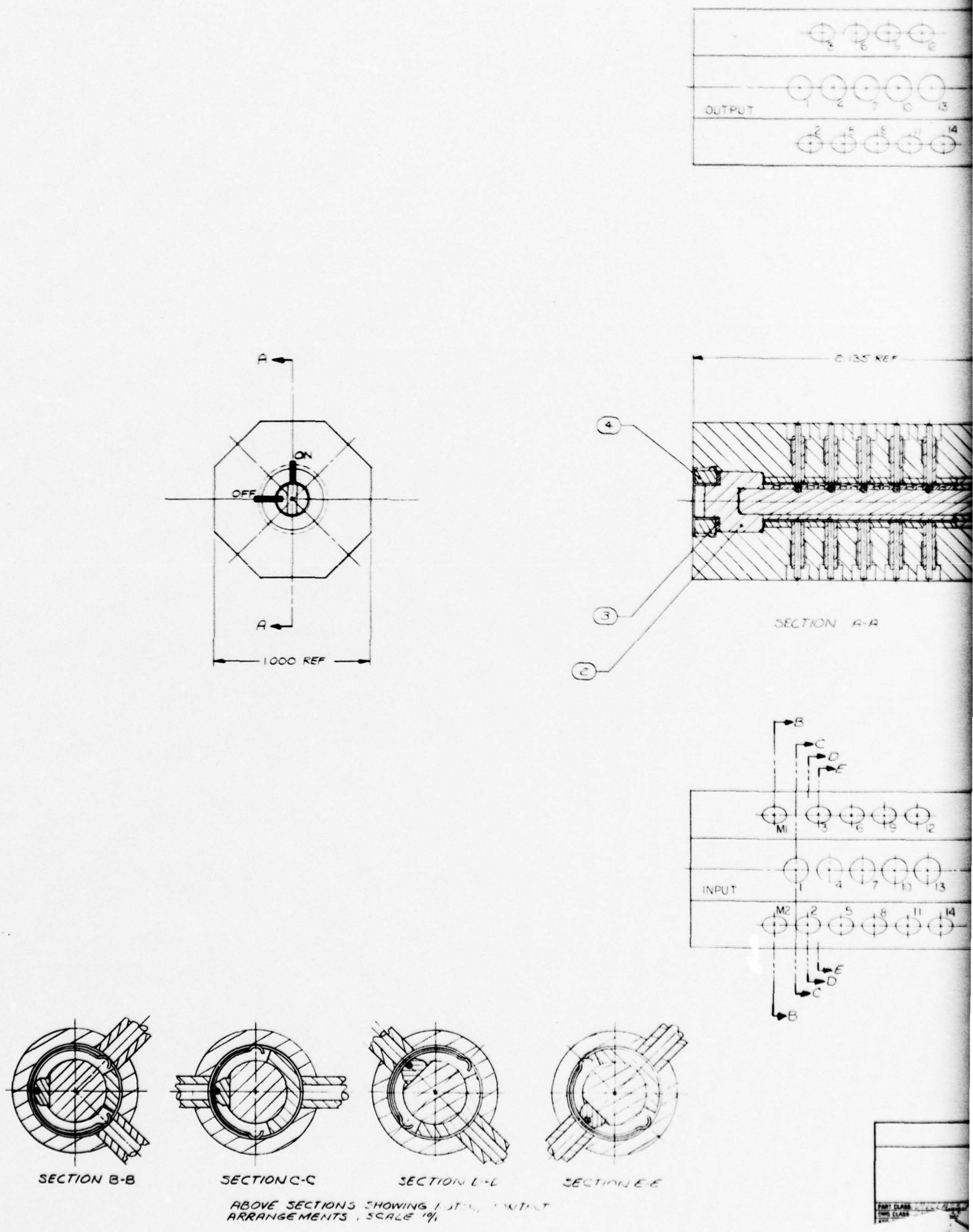
Based on the excessive predicted impact capability decrease, a design was generated which minimized dependency on rotor structure by reducing the diameter, thus increasing the body wall thickness. This design also included the following features:

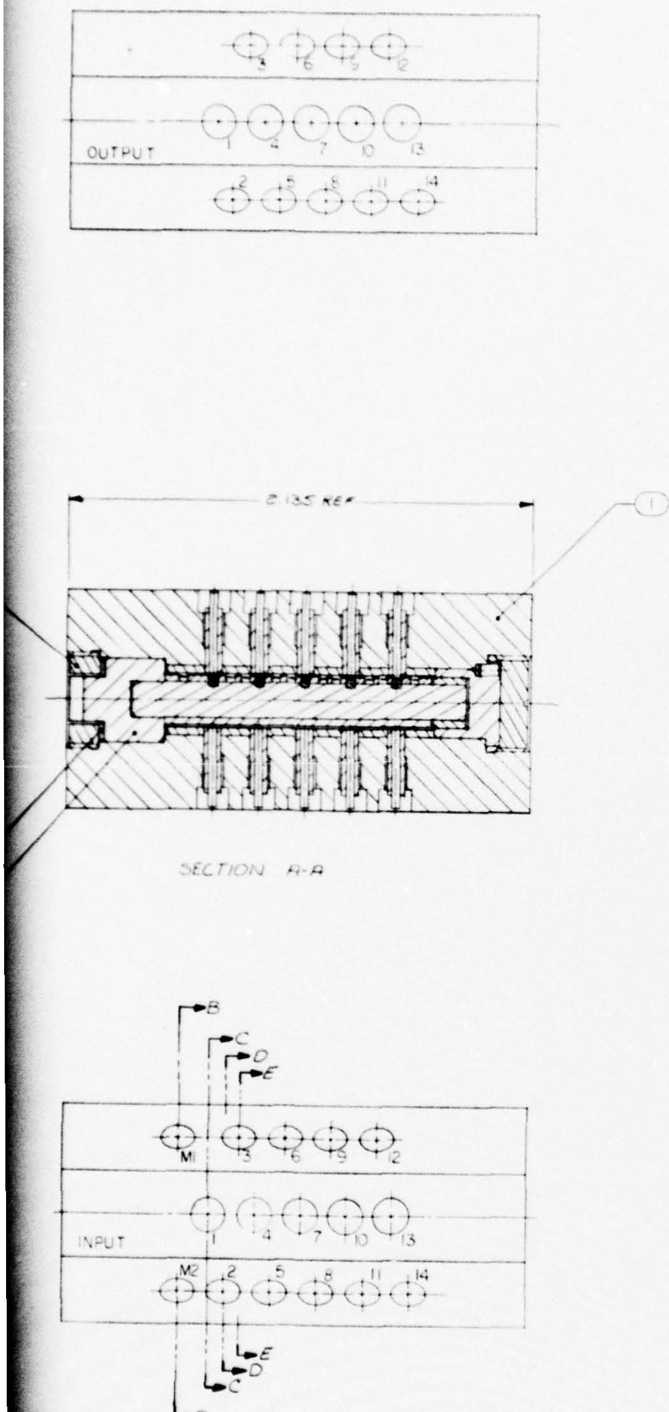
- Brush type contacts to increase deflection.

- Octagonal cross section with contacts distributed on 6 of the 8 faces.

This design configuration is shown in Figure 5-3 (EX23220).

Impact test samples were fabricated to evaluate the impact capability of this configuration. These samples (refer to Figure 6-2) included stator contact holes filled with epoxy (low strength) and molded epoxy rotor to approximate the material configuration.


OUTPUT
INPUT
M1
M2
ON
OFF
A
2.135 REF
1.000 REF
SECTION A-A
SECTION B-B
SECTION C-C
SECTION D-D
SECTION E-E
ABOVE SECTIONS SHOWING ROTOR CONTACT ARRANGEMENTS, SCALE 10/1
PART CLASS
DWG CLASS



QTY REQD	CODE IDENT	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL OR NOTE	SPECIFICATION	ZONE	ITEM NO.
1		EX23217-1	NUT, RETAINER				4
1		EX23218-1	SHIM				3
1		EX23225-1	ROTOR ASSY				2
1		EX23221-1	STATOR ASSY				1
1	← ASSY NO.						

LIST OF PARTS

UNLESS OTHERWISE SPECIFIED TOLERANCE AND DRAWING INTERPRETATION PER

MACHINED ANGLES

SHEET METAL BEND ANGLES

SURFACE ROUGHNESS √

AVCO SYSTEMS DIVISION

TITLE Figure 5-3 HARD SWITCH ASSY

SIZE	CODE IDENT NO.	DWG NO.
E	04614	EX23220

2

Test results (refer to Section 6.4) indicated a capability of approximately 60% of required impact strength as opposed to the approximately 40% predicted. It then appeared that only small structural benefit is gained by increasing body wall thickness at the expense of a relatively complicated rotor/contact assembly (due to small rotor diameter).

In addition, isolation considerations, namely susceptibility to shorting input to output terminal with the adjacent switch brush in a postulated longitudinal crush, showed the 3 row configuration to be unacceptable. This can be seen in the adjacent section views D-D and E-E of Figure 5-3. A postulated crush could drive the brush at D-D into the plane of the E-E stator contacts thus shorting the E-E input to output.

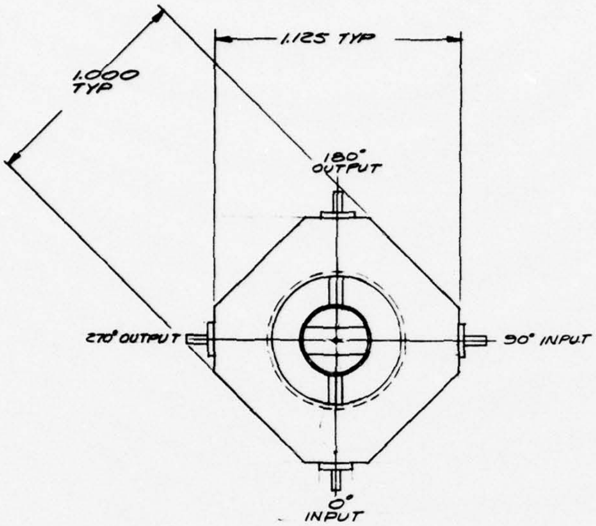
A study was made of high compression strength ceramic materials for use as the switch rotor. This could allow increasing the rotor diameter and obtaining good isolation while supplying structural support for the switch body. Samples were fabricated and tested using a one inch square cross section with a 1/2 inch rotor bore (Test 14). The sample bodies were of 4340 steel at 53 R_c with 350,000 psi compressive strength ceramic rotors. The samples did not include the stator contact holes and thus could be compared to the scale tests conducted as part of the proposal effort (Ref. 1). These tests showed that the selected ceramic provided approximately as much support as the high strength steel rotor (refer to Section 6.4) (Test Nos. 11 and 14).

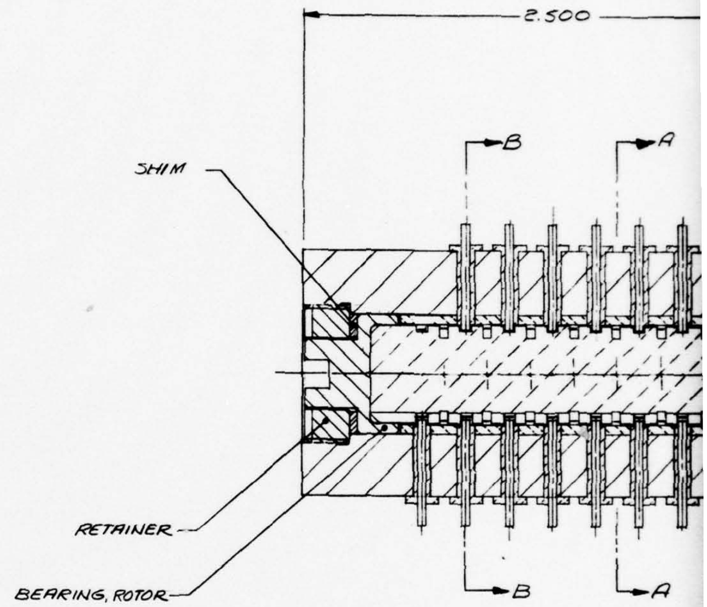
Based on the above, the design configuration shown in Figure 5-4 (LA23397) was generated. Concurrently, another series of test specimens was fabricated to determine the effect of the stator holes and the effect of a reduction in housing hardness. None of the samples tested as strongly as the previous octagonal shaped units (refer to Section 6.4) (Test Nos. 15, 16 and 17).

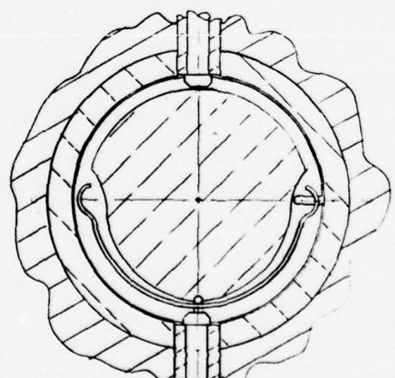
Based on the above, it now appeared that the stress concentration due to the 30 stator holes has a significant detrimental effect on the impact strength.

At this point, it was decided to develop a configuration which incorporated the most desirable features derived from the previous designs, tests and analyses. The main features are as follows:

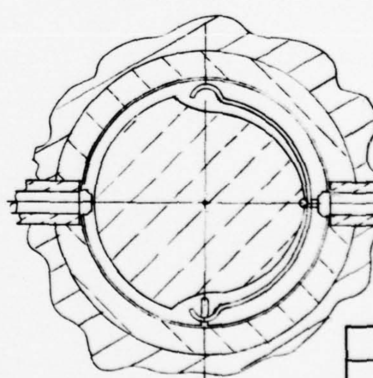
- Retain the .50 pound weight.
- Retain 2 in^3 volume.







SECTION B-B
SCALE 10/1



SECTION A-A
SCALE 10/1

PART CLASS: UNCLASSIFIED
DWG CLASS: UNCLASSIFIED
ASG BY:

1

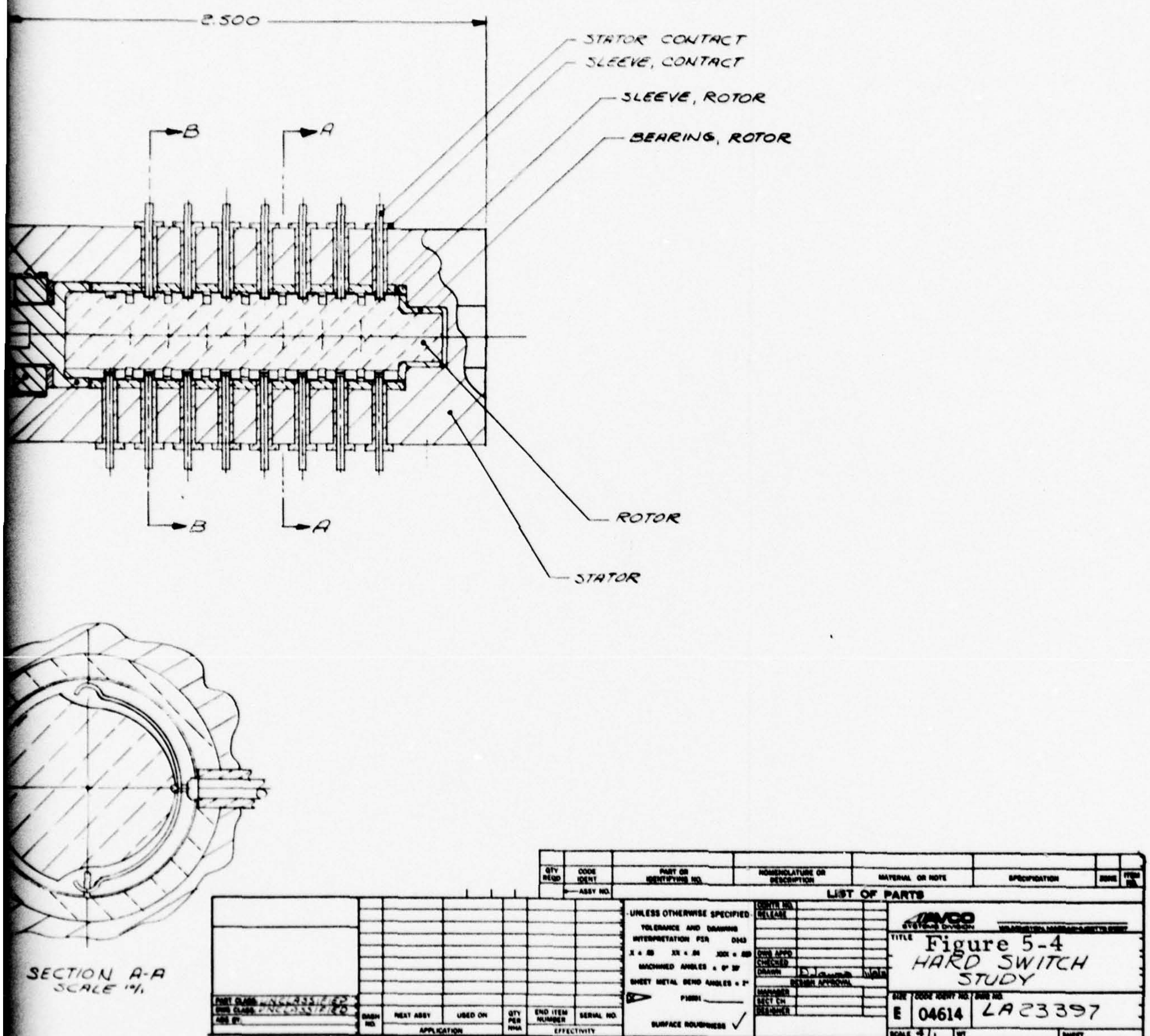


Figure 5-4
HARD SWITCH STUDY

- Retain 14 functional contacts and 1 monitor contact.
- Use .440 inch diameter ceramic (99% Al_2O_3 350,000 psi) rotor.
- Maintain maximum body wall thickness in area of stator contact holes (equal to that of Figure 5-3 (LA23220) octagonal design).
- Move the stator contact holes out of the 45° maximum shear plane.
- Incorporate brush type contacts.
- Incorporate mechanical fastening of contacts and rotor parts (i.e., eliminate bonding and brazing).

The impact strength for this configuration was to be determined by tests and would represent the best attempt at optimizing the design for all design constraints.

The design which incorporates these features is shown in Figure 5-1 (LA23527). A complete drawing package has been prepared for this configuration. Three complete units plus three structural impact samples were fabricated and tested. The results of the impact tests and a comparison to the approximate analytically predicted impact behavior are presented in Table 6-3 (Test Nos. 18, 19 and 20) and Section 6.2.2.

6.0 STUDIES, ANALYSES AND EXPERIMENTAL TESTS

6.1 Impact Analyses

6.1.1 Computor Study

A single degree of freedom analytical model of the switch was made in an attempt to predict the behavior of the material under the impact mode. The results are presented in Appendix A and indicates that the failure mode may be a function of the applied strain rate and the change in the fracture cross sectional area. Since the mechanism of this cross sectional change is not known, the analysis would have to be refined by several empirical data points. This early analysis showed that the 100 pound weight dropped from 100 feet was more energy than could be absorbed by the switch in the lateral axis and predicated an 80% achievement level.

One of the most significant parts of the analysis, however, can be observed through Figures 5 and 6 of Appendix A. These show approximately a 60% decrease in structural strength results in the lateral axis impact when the rotor does not provide any structural support. (1/2 inch rotor bore diameter in a 1 inch square cross section.)

However, the analysis was not conservative in that it did not consider the stress concentration of the rotor hole or the stress concentration of the 30 stator holes and used an optimistic value of allowable strain. Therefore, a significant reduction in impact performance was expected due to these stress concentrations.

6.1.2 Relative Housing Stress

The octagonal shaped design test units (Figure 5-3, EX23220) exhibited high impact strength capabilities with shear fracture failure characteristics. This failure mode is along a plane containing the stator holes and is located at the maximum shear stress plane (45^o from impact surface). However, the octagonal design utilizes a small rotor (.29 diameter) which has several undesirable characteristics (see Section 2.0).

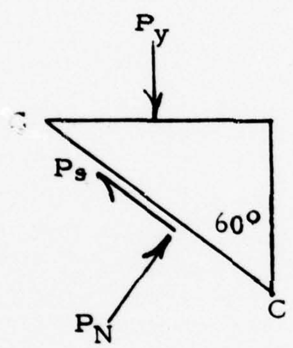
A large rotor/octagonal shaped unit would have to significantly sacrafice the shear stress area to stay within the 8 ounce weight limitation. In an effort to produce a design which would not reduce the impact strength and would incorporate a more practical larger rotor (.44 diameter), the baseline design was configured with the same shear section thickness at the stator contact holes. In addition, the stator contact holes were offset 15° from the maximum shear plane to reduce the effective stress.

The following analysis shows that the shear failure mode is still prevalent in this new configuration. It was expected that the two designs would then be comparable in strength.

CASE I COMPRESSIVE LOAD P_y (Y DIRECTION)

Stress @ Section A-A (Refer to Figure 6-1)

$$\text{Stress @ A-A} = S_{AA} = \frac{P}{A} = \frac{P_y}{2.165\ (1.225 - .575)} = .7106\ P_y$$



$$P_N \text{ Cos } 60 = P_S \text{ Sin } 60$$

$$P_N = P_S \text{ Tan } 60$$

$$P_y = P_N \text{ Sin } 60 - P_S \text{ Cos } 60 = 0$$

$$P_y = P_N \text{ Sin } 60 + P_S \text{ Cos } 60$$

$$P_y = P_S\ (\text{Sin } 60 \text{ Tan } 60 + \text{Cos } 60) = 2\ P_S$$

$$P_S = .5\ P_y$$

$$\text{Stress @ CC} = S_{CC} = \frac{P_S}{A_{shear}} \quad \frac{.5\ P_y}{(2.165 - 8 \times .086)\ (1.325 - .575)} = .4514\ P_y$$

$$\text{Safety Factor} \quad AA = S.F._{AA} = \frac{S_{Allowable}}{K\ S_{AA}} \quad \frac{S_{Allowable}}{.7106\ K\ P_y}$$

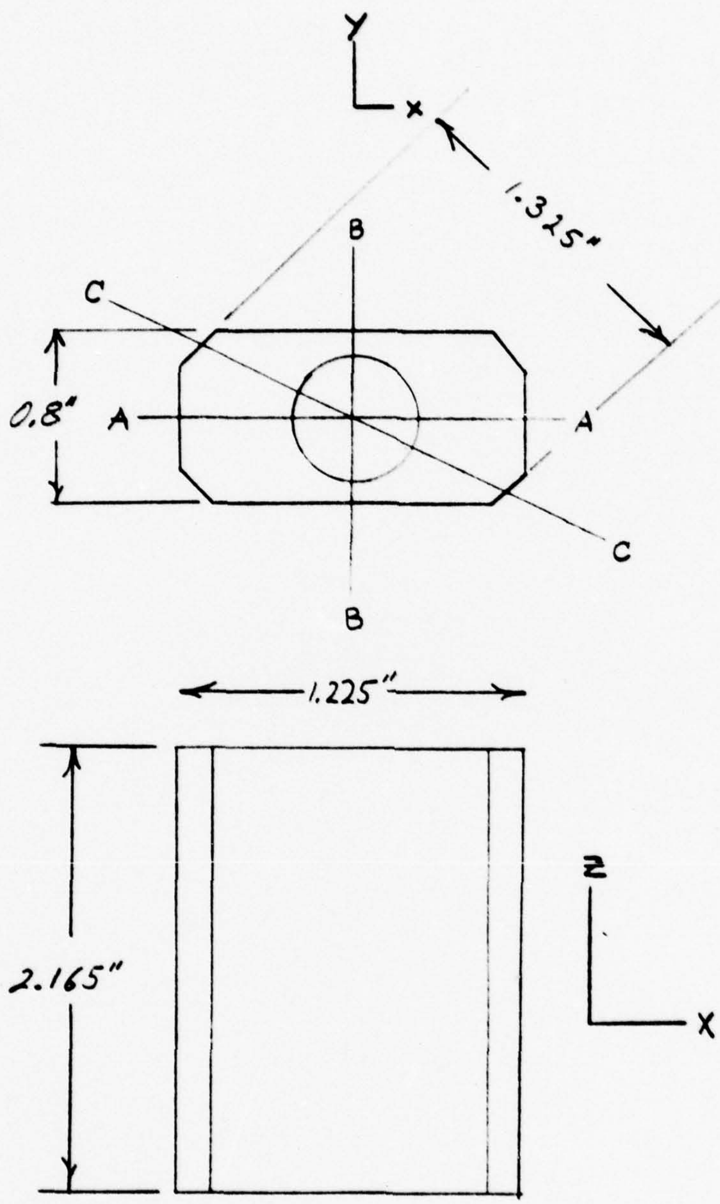


FIGURE 6-1. BASELINE DESIGN

$$S.F._{CC} = \frac{SS_{Allowable}}{K_1 \; S_{CC}} = \frac{S_{Allowable}}{2K_1 \; S_{CC}} = \frac{S_{Allowable}}{.9028 \; K_1 \; P_y}$$

Where

K = Stress concentration factor due to rotor bore

K_1 = Stress concentration factor due to 8 stator holes

$S_{Allowable}$ = Normal stress allowable

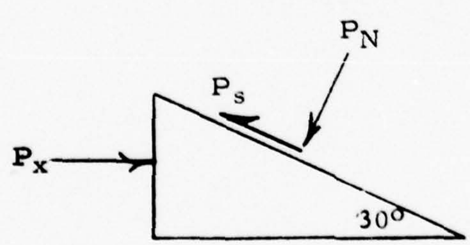
$SS_{Allowable}$ = Shear stress allowable = $\frac{S_{Allowable}}{2}$

$$\text{Relative Stress} = \frac{S.F._{AA}}{S.F._{CC}} = \frac{.9028 \; K_1}{.7106 \; K} = 1.27 \; \frac{K_1}{K}$$

Since $K_1 \geq K$ (Probably - 8 holes vs. 1 hole)

Unit has less safety factor in shear.

CASE II COMPRESSIVE LOAD P_x (X DIRECTION)



$P_N = P_S \text{ Tan } 30$

$P_x = P_N \text{ Sin } 30 + P_S \text{ Cos } 30$

$P_x = P_S (\text{Sin } 30 \text{ Tan } 30 + \text{Cos } 30)$

$P_S = .866 \; P_x$

$$S_{BB} = \frac{P_x}{2.165 \, (.8 - .575)} = 2.053 \; P_x$$

$$S_{CC} = \frac{.866\ P_x}{(2.165 - 8 \times .086)(1.325 - .575)} = .782\ P_x$$

$$\text{Relative Stress} = \frac{S.F._{BB}}{S.F._{CC}} = \frac{2 \times .782\ K_1}{2.053\ K} = .762\ \frac{K_1}{K}$$

If $K_1 = 1.3\ K$ (Reasonable 8 holes vs. 1 hole)

Unit is equally strong in tension and shear.

Thus, the units should be approximately as strong as the octagonal shaped units and exhibit a shear type failure. However, because a Y direction load results in a shear stress of 45% of the load, and a X direction load results in a shear stress of 78% of the load, the unit is not as strong when impacted along the X axis. Therefore, the X direction impact capability should be approximately 60% of that of the Y direction impact strength (i.e., $\frac{.45}{.78} \approx .60$).

It should be noted that the baseline design test units were not as strong as the octagonal units when impacted along the Y axis. While a weaker Y impact strength is predicted (see above) the lower level was not expected. An examination of the differences between the two test configurations has shown the following:

	Octagonal Test Units	Baseline Test Units
Diameter of stator holes	.080	.086
C bore around stator holes	None	.107 Dia.
Spacing between stator holes	.210	.200
Maximum number of stator holes per plane	6	8

All of the above have the effect of reducing the shear area and possibly increasing the stress concentration factor of the baseline design. Each of these contribute to a lower impact stress capability.

6.2 Contact Design Analyses

Several contact materials and design configurations were studied in an attempt to reduce the contact circuit resistance. Table 6-1 is a

TABLE 6-1

SUMMARY OF CONTACT MATERIALS CONSIDERED FOR TWO POSITION FAIL SAFE SWITCH SUBASSEMBLY

	Stator Material / Rotor Material	Melt Temp. (^oF)	Resistivity (CMF)	Yield Stress (lb/in^2)	Hardness Brinell	Modulus of E (lb/in^2)	Density (gm/cm^3)	Natural Frequency (KHz)	Temp. at 5 Amp (^oF)	Circuit Resist. ($m\Omega$)	No. of Parallel Contacts
	Paliney M Annealed / Paliney M Cold Worked	2380	240 / 220	$20x10^3$ / $80x10^3$	100 / 180	$16x10^6$	12.7	4.1	673	92.5	4
	Paliney 9 / Paliney 9	1950	220	$120x10^3$	228	$17x10^6$	11.9	4.4	673	115.8	4
	Paliney 7 / Paliney 7	1860	190	$45x10^3$	275	$17x10^6$	11.8	4.4	592	103.6	4
	Paladium Iridium / Paladium Iridium	3272	180	$100x10^3$	230	$25x10^6$	21.5	4.0	565	92.8	2
	Tantalum / Tantalum	6170	120	$160x10^3$	238	$21x10^6$	16.9	4.4	402	75.4	4
	Rhenium / Rhenium	5755	114	$160x10^3$	380	$68x10^6$	21.0	6.6	386	69.1	4
	Neyoro g / Paliney 7	1700 / 1860	87 / 190	$145x10^3$	335 / 275	$16x10^6$ / $17x10^6$	15.9 / 11.8	4.4	592	81.6	4
	Paliney M Annealed / Paliney 6	2380 / 1890	240 / 155	$20x10^3$ / $110x10^3$	100 / 275	$16x10^6$	12.7 / 10.4	4.5	497	75.4	4
	Paliney M Annealed / Paliney M Cold Worked	2380	240 / 220	$20x10^3$ / $80x10^3$	100 / 180	$16x10^6$	12.7	2.4	646	79	2
Test Configuration 5 Units	BeCu Alloy 172 / BeCu Alloy 172	1590	55	$175x10^3$	128	$18.5x10^6$	8.4	3.2	218	35.3	2
Test Configuration 1 Unit Abnormal Temp.	BeCu Alloy 145 / BeCu Alloy 175	1924 / 1885	11.2 / 22.8	$40x10^3$ / $110x10^3$	128 / 128	$17x10^6$ / $19x10^6$	8.9 / 8.9	3.2	136	22	2

summary of the materials studied. The movable contacts can be practically fabricated from two materials, Paliney M and BeCu 175. The Paliney M material would satisfy all of the requirements except for circuit resistance (79 milliohms versus the required 30 milliohms). A BeCu alloy combination of 175 and 145 offers a much lower circuit resistance (22 milliohms), however, it results in a somewhat lower abnormal temperature capability (i.e., 1885°F versus 1850 ± 100°F required). Tantalum and Rhenium are among those materials which meet the 1950°F maximum temperature, yield a more favorable circuit resistance than Paliney M; however, these materials were dropped from further consideration because:

- Tantalum tends to form a nonconductive oxide when switching under load.

- Rhenium aging characteristics are relatively unknown for the required 20 year storage life and would represent a high development risk.

The total circuit resistance is comprised of the bulk resistance of each of the contact subcomponents and the resistance at the interface of the sliding or bearing surfaces. The resistance at this interface is called the constriction resistance (R_C) and is a function of material hardness and contact pressure on a good clean newly assembled surface. During storage and test cycling, surface films will raise this value above that calculated. A factor of 2 is commonly applied for high noble metals (Paliney M). A factor of 5 should be applied for lesser noble materials (BeCu).

The single largest contribution to the total switch circuit resistance is the constriction resistance. This effect can be reduced by providing parallel paths at the stator/brush contact interface. Calculations in Table 6-1 were developed for both 2 and 3 parallel brush contacts. The two parallel brush approach was selected because of the design size limitations.

6.2.1 Circuit Resistance

Design Parameters

The following analysis reflects the proposed design configuration. All sample calculations are presented for the Paliney M material.

Material	Stationary Contact Paliney M - Annealed	Rotor Contact Paliney M - Cold Worked
Hardness Brinell	100	180
Yield Stress (psi)	20,000	80,000
Resistivity ohm-cir mil/ft	240	220
Effective Length (in)	0.377	0.342
Diameter (in)	0.040	0.0067
Contact Force (grams)	--	5 - 8

Bulk Resistance

$$R = \rho \frac{L}{A} = \rho \frac{L}{d^2}$$

R = resistance, ohms

A = cross sectioned area, circular mils

ρ = resistivity, $\frac{\text{ohm circular mils}}{\text{ft}}$

L = length, feet

d = cross sectional diameter, mils

Stator

$$R_s = \frac{240 \times \frac{0.60}{12}}{40^2} = 7.5 \text{ milliohms}$$

Rotor Contact

$$R_R = \frac{220 \times \frac{.601}{12}}{22.6^2} = 21.6 \text{ milliohms}$$

Constriction Resistance

$$R_c = 23.4 \times 10^{-6} (\rho_1 + \rho_2) \sqrt{\frac{HB}{P}}$$

Where:

R_c = constriction resistance, ohms

ρ_1, ρ_2 = resistivities $\frac{\text{ohm circular mils}}{\text{ft}}$

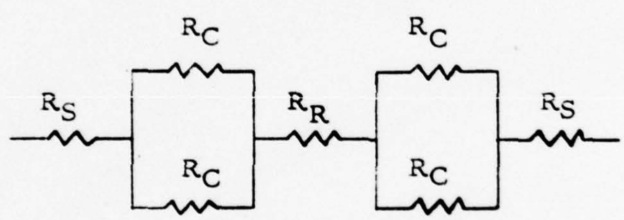
H_B = Brinell hardness of softer member

P = force, grams

Applying a factor of 2 for storage and cycling effects (a factor of 5 was applied for BeCu contacts)

$$R_c = 2 \times 23.4 \times 10^{-6} (240 + 220) \sqrt{\frac{100}{25.8}} = 42.4 \text{ milliohms}$$

Equivalent Circuit



$$R_{Total} = 2\,R_S + R_c + R_R$$

$$= 2 \times 7.5 + 21.6 + 42.4 = 79 \text{ milliohms}$$

The calculated value of 79 milliohms includes the multiplication factor of 2 to account for circuit degradation with age and cycling.

6.2.2 Contact Current Capacity

The steady state current carrying capacity of the contacts in the closed position can be found from the following formula:

$$I = 0.11\, D^{1.17} \left(\frac{T_2 - T_a}{\rho} \right)^{1/2}$$

Where:

I = current through the conductor, amperes

D = diameter of wire in mils

T_2 = temperature within the conductor, °C

T_a = ambient temperature, °C

ρ = resistivity of wire, ohm-cir mil/ft

Paliney M has a solidous temperature of 2380°F and an annealing temperature of 1950°F. As long as the conductor temperature does not approach the annealing temperature, the structural integrity and spring properties of the cold worked material will not be affected. Solving the above equation for T_2 yields:

$$T_2 = \frac{I^2 \rho}{(0.11)^2\, D^{2.34}} + T_a$$

for a steady state circuit current of 5 amps (2.5 amps for each of the 2 brushes in parallel) and ambient temperature of 25°C

$$T_2 = \frac{2.5^2 \times 220}{(0.11)^2 \times 12.36^{2.34}} + 25 = 341^\circ C = 646^\circ F$$

Because this is well below the annealing temperature, the contact configuration will comfortably carry 5 amps steady state. This is true for all materials listed in Table 6-1.

Empirical results have shown that the current carrying capacity of the material can be increased by a factor of 5 if the current pulse lasts 0.5 second and by a factor of 10 if the current pulse is 50 milliseconds in duration. Thus, the proposed circuit design can withstand many 20 amp DC pulses for 20 milliseconds without degradation.

6.2.3 <u>Insulation Resistance</u>

A 0.022 inch thick ceramic insulation surrounds each of the stationary contacts. This will provide an insulation resistance value between each of the contacts and the core well above 10,000 megohms at

500 VDC. When the switch is in the off position, the ceramic sleeve will also protect each contact from all other contacts.

6.2.4 Static Voltage

A preferential path for breakdown of static voltage will be from either input terminal to case or output terminal to case. Breakdown from input to output terminal is prevented by the geometry of the switch. The proposed switch design incorporates controls of all internal air gap paths to be at least 0.060 inch while providing a 0.056 inch air gap between the stationary contact and the case. At a dielectric strength breakdown voltage of 45 volts/mil (dirty air), this 0.004 inch difference represents 180 volt breakdown differential between internal and external paths. The aluminum oxide is of sufficient thickness to prevent breakdown through the rotor assembly or at the internal portions of the input and output terminals.

6.2.5 Voltage Breakdown

The breakdown voltage for each mating pair of contacts is contacts is controlled by the external 0.056 inch air gap. This represents a breakdown voltage of 2520 VDC in dirty air, i.e., 56 mils x 45 volts/mil = 2520 VDC.

6.2.6 Contact Chatter (Natural Frequency)

The resonant frequency of the contact in the free state is given by:

$$f_N = \frac{h}{2\pi - L^2} \sqrt{\frac{2 E g}{3 \rho}}$$

Where

$g = 386 \text{ in/sec}^2$

$E = 16 \times 10^6 \text{ lb/in}^2$

$h = 0.010$ inch

$L = 0.249$ inch effective length

ρ - .459 pound/in^3

$$\therefore f_N = \frac{.01}{2\pi \times .249^2} \sqrt{\frac{2 \times 16 \times 10^6 \times 386}{3 \times .459}}$$

$$f_N = 2432 \text{ Hz}$$

This shows that the natural frequency of the unrestrained contact will be above 2.4 KHz. With the switch in the on position, the free end of the contact is loaded and a non linear condition exists. This has the effect of at least doubling the calculated resonant frequency to 4.8 KHz. Because the input frequency is limited to 2 KHz, it would require a third harmonic of the input to excite contact deflection. Such a high harmonic would be extremely weak and unlikely to create sufficient deflection to cause contact chatter.

6.3 Experimental Impact Tests

Table 6-2 is a summary of experimental impact tests conducted on full scale switch structural models.

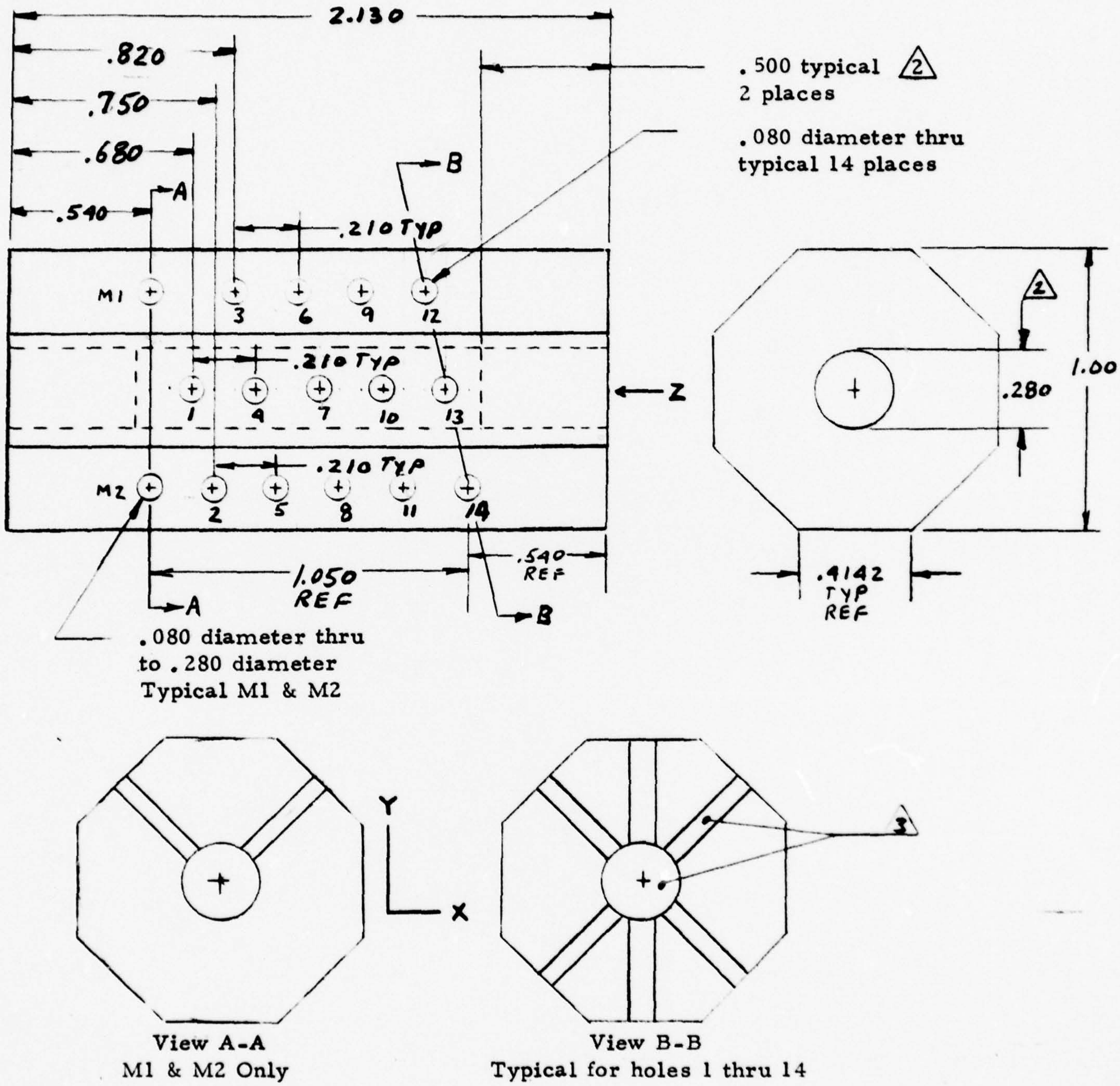
The sample configurations are defined as follows:

Octagonal	- per Figure 6-2
Square	- per Figure 6-3
Square (LA23397)	- per Figure 5-4
Baseline (LA23527)	- per Figure 5-1

6.4 Failure Modes and Effects Analysis

A Failure Modes and Effects Analysis (FMEA) was conducted in accordance with CDRL A009 and DI-R-1734. The FMEA is presented in Table 6-3.

FIGURE 6-2. OCTAGONAL CONFIGURATION



NOTES

1 Material 4340 steel, hardened to Rockwell C53 after machining.

2 Drill thru .280 diameter then plug ends .500 deep with material 1. Maximum clearance plug to stator .002.

3 Fill all cavities with Hysol Epoxy 1C and cure two hours at $140^{\circ}F$.

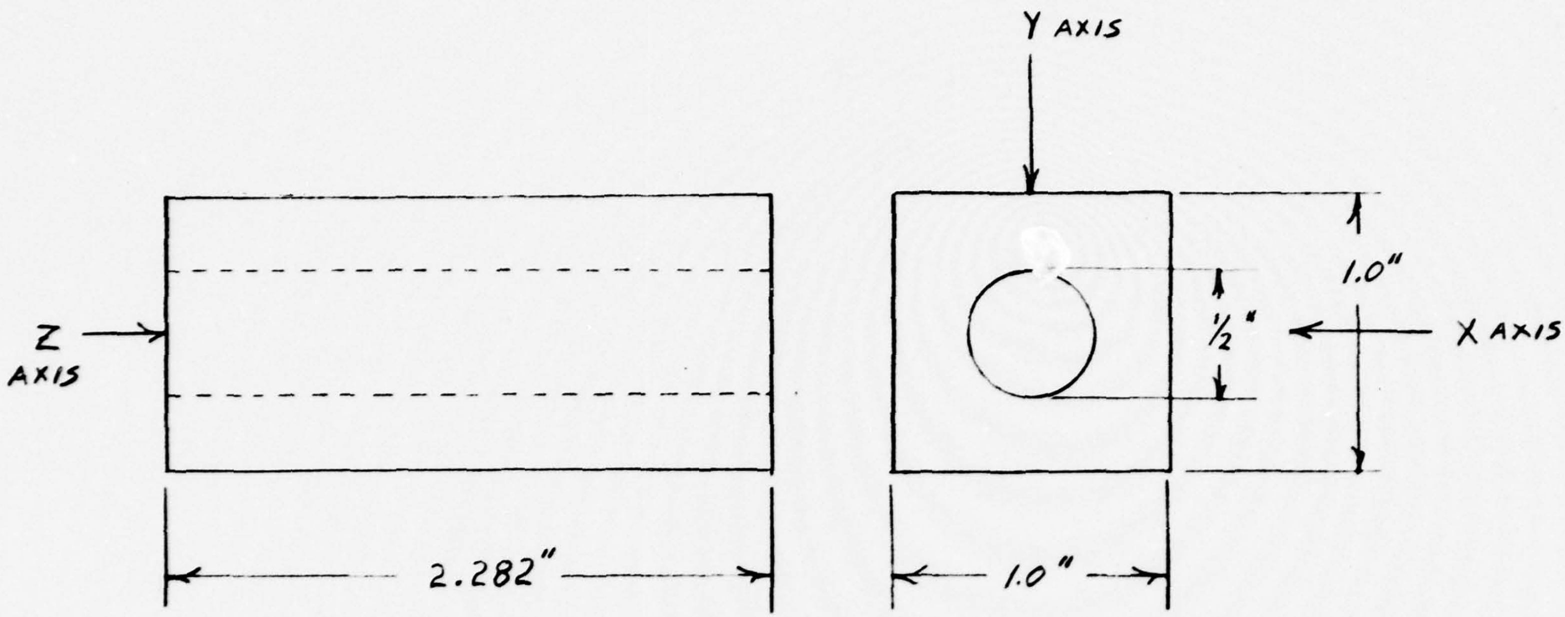


FIGURE 6-3. SQUARE SAMPLE CONFIGURATION

TABLE 6-2

SUMMARY OF EXPERIMENTAL IMPACT TESTS

Test No.	Sample Configuration	Materials Body	Materials Rotor	Contact Holes	Impact Axis	Equivalent Drop Height (Ft)	Results
1	Octagonal	4340 R_c 53	Epoxy	Yes, Potted W/Epoxy	Y	19	No Damage
2	Square	302 SS	Al_2O_3 350 kpsi	No	Y	30	Compressed 9.8% No Fraction Hole Shape Maintained
3	Square	302 SS	Ceramic 25 kpsi	No	Y	31	Compressed 15.6% No Fracture Hole Distorted
4	Octagonal	4340 R_c 53	Epoxy	Yes, Potted W/Epoxy	Y	31	No Damage
5	Not Used						
6	Square	4340 R_c 53	Al_2O_3 350 kpsi	No	Y	30	No Body Damage Rotor Cracked but moves freely
7	Octagonal	4340 R_c 53	Epoxy	Yes, Potted W/Epoxy	Y	56	Compressed .65%
8	Square	4340 R_c 53	Al_2O_3 350 kpsi	No	Y	74	No Body Damage Rotor Cracked but moves freely
9	Octagonal	4340 R_c 53	None	Yes	Y	76	Body Fractured
10	Reused Sample 1				Y	64	Compressed 1.3%
11	Reused Sample 8				Y	98	Compressed 1.9%
12	Octagonal	4340 R_c 53	None	Yes	X	62	Body Fractured
13	Octagonal	4340 R_c 53	None	Yes	Z	60	Compressed 2.2%
14	Reused Sample 6		New Al_2O_3 350 kpsi		Y	110	No Body Damage Rotor Cracked
15	Square LA23397	4340 R_c 44	Al_2O_3 350 kpsi	Yes, Potted W/Epoxy	Y	99	Body Fractured
16	Square LA23397	4340 R_c 38	Al_2O_3 350 kpsi	Yes, Potted W/Epoxy	Y	59	Body Fractured
17	Square LA23397	4340 R_c 30	Al_2O_3 350 kpsi	Yes, Potted W/Epoxy	Y	103	Body Fractured
18	Rectangular LA23527	4340 R_c 53	Al_2O_3 350 kpsi	Yes, Potted W/Epoxy	Y	50	No Body Damage Minor Fracture of Rotor Majority of Contact Grooves Intact
19	Rectangular LA23527	4340 R_c 53	Al_2O_3 350 kpsi	Yes, Potted W/Epoxy	X	50	Body Fractured
20	Rectangular LA23527	4340 R_c 53	Al_2O_3 350 kpsi	Yes, Potted W/Epoxy	X	40	Body Fractured

TABLE 6-3

FAILURE MODES AND EFFECTS ANALYSIS

PROGRAM Two Position Fail Safe Switch

SUBSYSTEM________

COMPONENT________ PART NO.________

SUBASSEMBLY________ PART NO.________

SHEET 1 OF 8

PREPARED BY J.J.Sheridan

SCHEMATIC LA23527 and subsequent

FAILURE MODE	EFFECT ON COMPONENT AND/OR SYSTEM	CAUSE OF FAILURE	REMARKS
1. The rotor fails to move 90^{o} from position 1 (0^{o}) to position 2 (90^{o}) when activated by the switch driver.	1. The rotor brush assembly contacts would not achieve position 2.	1.1 Distorted insulating sleeve, due to defective bonding causes binding.	1.1 The insulating sleeve (around the inner periphery of the housing) is of AD99 alumina Ceramic. The dielectric constant of Alumina is 8 to 9, providing high insulation. A controlled bonding process will insure that the insulating sleeving does not cause binding of the Brush Assemblies and Rotor.
		1.2 Misaligned Bushing and Shim assembly on drive end of rotor.	1.2 Misalignment of either or both of these parts could cause the rotor to bind during an attempt at rotation. This misalignment would also change end-play tolerances. Close attention to tolerancing, material selection and assembly will prevent this problem.
2. One or more input/output circuits is open when switch position is changed. Monitor assembly shows a proper switch position change.	2. Affected In/Out circuit would be inoperative.	2.1 One-half of a Brush Assembly breaks causing an open circuit, or a brush assembly spring clip breaks removing support for the brush assembly.	2.1 The brush assemblies are constructed of Paliney M wire. Paliney M has been used in mechanical choppers which undergo millions of cycles of "make" and "break" contacts in their lifetime. The spring clip is constructed of Paliney M.

TABLE 6-3 (Cont'd)

FAILURE MODE AND EFFECTS ANALYSIS

PART NO.
COMPONENT

SHEET 2 OF 8

FAILURE MODE	EFFECT ON COMPONENT AND/OR SYSTEM	CAUSE OF FAILURE	REMARKS
3. Brush Assembly contacts fail to mate with stator contacts.	3. A high resistance contact would result, causing internal arcing when contacts are subjected to high voltages with no or intermittent continuity through the rotor to stator circuit(s).	3.1 Excessive rotor radial and axial movement during vibration. 3.2 Misalignment of contacts.	3.1 Design tolerancing and shimming will preclude rotor bounce and end play. Additionally, keeping the void between rotor and housing at a minimum will prevent excessive rotor bounce. 3.2 During assembly of switch parts, alignment procedures, if accurately followed, will preclude misalignment of contacts.
4. The Insulation Resistance in the switch OFF position is less than 10,000 megohms between one or more pairs of in and out terminations and between any of these terminations and case.	4. With the application of a DC voltage in excess of 500 volts, internal arcing to ground would destroy the particular through circuit which is arcing.	4.1 Defective Insulation on the housing inner periphery.	4.1 If the detent holds the switch in the OFF position, all the ceramic insulation would have to be reduced to pulverized dust to cause out-of-specification insulation readings in the OFF position. The alumina ceramic used does not react in this manner. Contact spacing is sufficient to provide the isolation required to maintain satisfactory readings. The test program will demonstrate the integrity of the unit and its ability to produce in-specification readings.
5. Contact resistance in the switch ON position of one or more switch pairs exceeds 30 milliohms.	5. A high resistance contact causes an undesired voltage drop, and arcing with the application of high (500VDC upwards) voltage.	5.1 Misalignment of contacts.	5.1 See item 3.2.
6. One or more sets of contacts will not pass a steady state current of 5 $\pm$ 0.25 amperes dc.	6. The affected set(s) of contacts will be ineffective in operation.	6.1 Misalignment of contacts. 6.2 Defective insulation.	6.1 See item 3.2. 6.2 See item 4.1.

TABLE 6-3 (Cont'd)

FAILURE MODE AND EFFECTS ANALYSIS

PART NO.
COMPONENT

SHEET 3 OF 8

FAILURE MODE	EFFECT ON COMPONENT AND/OR SYSTEM	CAUSE OF FAILURE	REMARKS
7. One or more sets of contacts will not pass a 20 ± 1 ampere DC pulse of 20 milli-seconds duration (duration measured at the 6db level).	7. The affected set(s) of contacts will be ineffective in operation.	7.1 Misalignment of contacts.	7.1 See item 3.1.
		7.2 Defective insulation.	7.2 See item 4.1.
		7.3 Contamination and/or corrosion.	7.3 Contamination in the form of moisture or dirty ambient atmosphere will be prevented by O-ring seals at the inboard side of the stator contacts. Materials selected will not corrode, or develop carbon paths.
8. One or more inputs (outputs) arc to ground internally in the OFF position when the contact is sub-jected to a 20 ± 1KVDC surge voltage.	8. This high voltage arc could envelop a set of input or output contacts, transmitting the voltage to the input or an output circuit load.	8.1 Defective insulation.	8.1 A spark ring providing .050" spacing of leadwire to case (as opposed to the normal spacing of 0.68") is located on the stator contact to provide a preferential path to case for voltages at the con-tact in excess of 2500 volts. See item 4.1 for Insulation Resistance.
9. One or more sets of input/output contact arcs to ground inter-nally or reads a leak-age current in excess of 1.0 milliampere when exposed to a 2000 ± 100 VDC poten-tial in the switch OFF position.	9. Affected set(s) of contacts will be unacceptable for circuit use, if the monitor circuit shows that the switch is open.	9.1 Defective insulation.	9.1 Contact spacing provides a .068" gap between stator conductor and case. This allows withstanding a minimum of 2700V in humid air. Isolation between internal contacts is provided by the high strength alumina ceramic (AD99) stator as-sembly, and the alumina ceramic insulation around the inner periphery of the housing.

TABLE 6-3 (Cont'd)

FAILURE MODE AND EFFECTS ANALYSIS

PART NO.
COMPONENT

SHEET 4 OF 8

FAILURE MODE	EFFECT ON COMPONENT AND/OR SYSTEM	CAUSE OF FAILURE	REMARKS
10. As a result of life testing, one or more sets of contacts has a contact resistance in excess of 30 milliohms and/or an insulation resistance less than 10,000 megohms, or reads open in the switch ON position, when a 20VDC voltage is applied using a 0.5 ± 0.025 ampere load.	10. Affected sets of contacts will be unacceptable for circuit use.	10.1 Misaligned contacts.	10.1 See item 3.2.
		10.2 Defective insulation.	10.2 See item 4.1. Successful completion of tests to be performed will demonstrate the quality of the various components of the switch.
11. The switch fails to function properly over the temperature range of -65°F to +160°F.	11. The switch would be unacceptable for circuit use.	11.1 Thermal expansion.	11.1 Material selection - providing similar thermal coefficients precludes thermal expansion from expanding the rotor faster than the stator, which event could possibly jam the rotor.
		11.2 Misaligned contacts.	11.2 See item 3.2.
		11.3 Defective insulation.	11.3 See item 4.1.
12. One or more sets of input/output contacts has a contact resistance in excess of 40 milliohms after exposure to thermal shock.	12. Affected set(s) of contacts will be unacceptable for circuit use.	12.1 Misaligned contacts.	12.1 See item 3.2.
		12.2 Expansion of rotor.	12.2 See item 11.1.

TABLE 6-3 (Cont'd)

FAILURE MODE AND EFFECTS ANALYSIS

PART NO.
COMPONENT

SHEET 5 OF 8

FAILURE MODE	EFFECT ON COMPONENT AND/OR SYSTEM	CAUSE OF FAILURE	REMARKS
13. Switch interior pressure equals external pressure during and after pressure test.	13. A switch defective in this respect would be subjected to external ambient atmosphere which may be contaminant, dirty or gassy and is unacceptable for circuit case.	13.1 Defective O-ring seal at stator.	13.1 This application of O-rings has been used successfully on past programs, such as the timer for MK11A, B, and C. Successful completion of the test program will demonstrate the integrity of the O-rings.
14. One or more sets of input/output contacts has a contact resistance in excess of 30 milliohms and an insulation resistance of less than 10,000 megohms after subjection to humidity tests.	14. A switch defective in this respect has been subjected to external ambient moisture which causes short circuits and ground and is therefore unacceptable for circuit use.	14.1 Defective O-ring seal.	14.1 See item 13.1.
15. One or more contacts is damaged during vibration tests in the switch OFF position, while the insulation resistance readings drop below 10,000 megohms.	15. Affected contacts would be unacceptable for circuit use.	15.1 Defective insulation in housing and around stator contact assembly(ies).	15.1 See item 9.1.

TABLE 6-3 (Cont'd)

FAILURE MODE AND EFFECTS ANALYSIS

PART NO.
COMPONENT

SHEET 6 OF 8

FAILURE MODE	EFFECT ON COMPONENT AND/OR SYSTEM	CAUSE OF FAILURE	REMARKS
16. One or more contacts is damaged during vibration tests in the switch OFF position, while the switch contact *resistance* exceeds 30 milliohms.	16. Affected contacts would be unacceptable for circuit use.	16.1 Misaligned contacts. 16.2 Rotor bounce both radially and end-wise causing excessive load on both brush assemblies and stator contacts.	16.1 See item 3.2. 16.2 See item 2.2.
17. One or more contacts is damaged during shock tests in the switch OFF position and/or the insulation resistance and contact resistance change beyond requirements.	17. Affected contacts would be unacceptable for circuit use.	17.1 Defective insulation. 17.2 Misaligned contacts.	17.1 See item 4.1. 17.2 See item 3.2.
18. The insulation resistance of one or more contacts is below 10,000 megohms after the switch is subjected to a temperature of $1850^{o} \pm 100^{o}F$ for 60 minutes in the switch OFF position.	18. Affected contacts would be unacceptable for circuit use.	18.1 Defective insulation.	18.1 The materials selected preclude damage to insulation from heat. Paliney M, the brush assembly and contact materials melt at 2380 F. Alumina, the insulating material melts at 3670 F. The steel housing melting point is 2600 F.

TABLE 6-3 (Cont'd)

FAILURE MODE AND EFFECTS ANALYSIS

PART NO.
COMPONENT

SHEET 7 OF 8

FAILURE MODE	EFFECT ON COMPONENT AND/OR SYSTEM	CAUSE OF FAILURE	REMARKS
19. The insulation resistance of one or more contacts is below 10,000 megohms after the switch is subjected to a crush force of 50,000 lbs. applied in each of three directions for one minute, with the switch in the OFF position, at an applied 500VDC.	19. Affected contacts would be unacceptable for circuit use.	19.1 Defective insulation.	19.1 If the detent holds the switch in the OFF position, all the ceramic insulation would have to be reduced to pulverized dust to cause out-of-specification insulation readings in the OFF position. The alumina ceramic used does not react in this manner. Additionally, contact spacing is sufficient to provide the isolation required to maintain satisfactory readings. Selection of high strength material, 4340 steel for the switch housing precludes rupturing the switch in this abnormal environment. Successful completion of the test program will demonstrate the unit's integrity and its ability to perform to specification.
20. The insulation resistance of one or more contacts is below 10,000 megohms after the switch is exposed to impact tests of TBD lbs. dropped TBD feet on three of its mutually perpendicular axes, with the switch in the OFF position. Note: External terminations which are deformed by these impact tests, causing shorts to case ground,	20. Affected contacts are unacceptable for circuit use.	20.1 Defective insulation.	20.1 See item 19.1. Additionally, inasmuch as there is a minimum of voids in the switch assembly, cracked or isolated pieces of insulation have no room to move around if broken away from their parent material. Successful completion of the test program will demonstrate the unit's integrity and its ability to perform to specification.

TABLE 6-3 (Cont'd)

FAILURE MODE AND EFFECTS ANALYSIS

PART NO.
COMPONENT

SHEET 8 OF 8

FAILURE MODE	EFFECT ON COMPONENT AND/OR SYSTEM	CAUSE OF FAILURE	REMARKS
20. (Cont'd) shall be cleared of case ground before taking insulation resistance readings.			

7.0 TEST PROGRAM

Six switch assemblies and three switch structural models were fabricated and tested in accordance with the test plan of Reference 2. Table 7-1 presents a summary of the tests and the test results. The details of the tests and results are contained in Reference 3 and in Section 2.0, Conclusions, and Section 6.1.2, Relative Housing Stress.

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2. Test Plan, Two Position Fail Safe Switch, ESDT/R-F310-602, Rev. 1, October 1977.
3. Report of Test on Experimental Two Position Fail Safe Switch, November 1977.

Legend
Number - Refer to notes
P - Pass
F - Fail

TABLE 7-1

TWO POSITION FAIL SAFE SWITCH

TABULAR SUMMARY SHEET

Unit No.	Acceptance Tests Test Plan Paragraph 2.1	Vibration Test Plan Paragraph 2.3.1	Vibration-Operating Test Plan Paragraph 2.3.2	Shock Test Plan Paragraph 2.3.3	Thermal Shock Test Plan Paragraph 2.3.4	Life Cycle Test Plan Paragraph 2.2.1	Static Voltage Test Plan Paragraph 2.2.2	Current Capacity Test Plan Paragraph 2.2.3	Surge Current Test Plan Paragraph 2.2.4	Heat Resistance Test Plan Paragraph 2.4.1	Crush Test Plan Paragraph 2.4.2	Impact Test Plan Paragraph 2.4.3
1	P_1	---	---	---	---	P	P	P	P	---	P	---
2	P_1	---	P	P	P	---	P	P	P	---	---	---
3	P_1	P	P	P	P	---	P	P	P	---	---	---
1A	P_1	---	---	---	P	---	---	---	---	F_2	---	---
2A	P_1	---	---	---	---	P	---	---	---	---	---	---
3A	P_1	---	---	---	---	---	---	---	---	---	---	6
4	---	---	---	---	---	---	---	---	---	---	---	P_3
5	---	---	---	---	---	---	---	---	---	---	---	F_4
6	---	---	---	---	---	---	---	---	---	---	---	F_5

TABLE 7-1 (Cont'd)

TWO POSITION FAIL SAFE SWITCH

TABULAR SUMMARY NOTES

1. All test units weighed approximately 4-6 grams in excess of the 0.5 pound (227 grams) specification maximum. The modifications described in Section 3.0 of the test plan account for this variation.

2. Unit exhibited insulation resistance in range of greater than 50,000 megohms to .52 megohm Disassembly and examination of unit showed presence of carbonized material. A review of the assembly processes showed that an epoxy adhesive was used in bonding the insulator EX-23530-1 to the housing EX-23529-1 where a ceramic (high temperature/non-carbonizing) material was intended.

3. Passed 50-foot drop test (5,000-foot pound impact) lateral (Y) axis (see Figure 6-1).

4. Failed 50-foot drop test in cross (X) axis (see Figure 6-1). It appears that the unit failed because of buckling of the thin side wall. The failure also appears to be partial, indicating test level slightly exceeded structural capability.

5. Based on result of unit #5 impact test, unit #6 was subjected to 40-foot drop test in same cross (X) axis. The unit failed. The impact resulted in the housing fracturing in four major pieces along the stator contact holes.

6. Not tested.

APPENDIX A

IMPACT COMPUTOR STUDY

PARA. NO.		TITLE: Two Position Fail Safe Switch	ANAL. BY	[signature]
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INTRODUCTION

The analysis presented here predicts the amount of energy absorbed by the two position Fail Safe Switch (2PFSS) during severe impact environments. A single degree of freedom (SDOF) model is employed with the mass being the mass of the drop weight and the 'spring' being the 2PFSS with stiffness EA/L. Figure 1 shows the drop test being simulated by the model, the stiffness of the switch being highly nonlinear. It is this nonlinear behavior that determines the response of the SDOF system and therefore, the maximum compressive strain. This maximum compressive strain, when compared to the material compressive strain allowable (~ 11%) determines failure.

MODEL

Figure 2 shows an Elastic-Perfectly Plastic stress strain curve for 4340 steel. From this curve the tangent modulus is monitored allowing stiffness (EA/L) to vary nonlinearly with deflection. Figures 3 - 6 examine the maximum and residual strains predicted by the analysis from which survival/failure predictions may be made. If, for a given strain energy level, the maximum strain (response) exceeds the strain allowable, failure has occurred. Similarly, if the maximum strain (response) is less than the allowable, the switch has survived. Having predicted the maximum strain level below the allowable, the residual strain for 4340 steel is approximately 1% less.

DISCUSSION OF PREDICTIONS

Assuming half the energy of the drop test goes into strain energy of the switch, i.e., 5,000 ft-lbs of the 10,000 ft-lb drop test, Figure 3 shows that for the axial case with the rotor in, the 11% strain allowable is not exceeded. Figure 4 shows that 3,500 ft-lbs may be absorbed before inducing failure with the rotor removed. Similarly, for the lateral case with rotor in, the full 5,000 ft-lbs may be absorbed without precipitating failure, according to the predictions. The lateral case with rotor removed however, has a predicted energy level of only 2,000 ft-lbs. These predictions are based on the stress strain curve of Figure 2 and the 'original' cross sectional area. Since the cross sectional area changes according to some unknown function of deflection, the analysis provides conservative results. To account for these assumptions, Figures 3-6 show a third curve which represents the degree of conservatism. It is obtained from scaling the predicted values to proposal test data. This third curve is crude since it was obtained from a very limited amount of empirical data.

Figure 7 shows plots of accelerations/velocities/displacement/ compressive strains vs. time. These figures represent the predictions for the design switch as modeled in Figure 1. It should be noted that the axial model is far more valid than the lateral model. This is because the lateral model considers only the material aside the hole in its stiffness computation. That is, the material above and below the hole absorbs no strain energy in the model (conservative). Also, the lateral model has a stress concentration created by the rotor bore. This results in non-conservative predictions.

DISCUSSION OF RESULTS

Having made predictions of the strain energy limit, an effort was made to test the predictions. One extra switch casing from the proposal tests was tested under identical conditions laterally with the rotor removed (.675 square x 1.6 lg. x .356 dia. base). The predicted maximum energy level was obtained from Figure 6. About 60 percent (3000 ft-lbs, Figure 6, vs. 5000 ft-lbs, Figure 5) of the 'rotor in' energy could be absorbed by the case with the rotor out. Therefore, the drop test consisted of 2160 ft-lbs (60% of 3600) or 1500 lbs from 1.44 feet. This was not an attempt to test the switch design, but rather an attempt to test our predicting capability. The specimen, with the rotor completely removed, is much too conservative a test for the switch since the switch has 0.26 inches of rotor support on each end in the lateral configuration. The 2160 ft-lb drop test resulted in a compressive shear failure. It is believed that the predictions could have been more precise by using a somewhat lower strain allowable. The 11 percent allowable is valid for slow/static strain rates. However, there are indications that at higher strain rates the strain allowable decreases (brittle fracture) and the ultimate strength increases. A sample of the material, the rotor from the extra specimen of the proposal tests, was tested in our laboratory at

PARA. NO.		TITLE: Two Position Fail Safe Switch	ANAL. BY	[signature]
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two different strain rates, 1200 and 52,000 $\mu\epsilon$/sec. Figure 8 shows the results of those tests with appreciable differences in strain allowables and ultimate tensile strength. Although this test showed the strain allowable almost halved, many more tests are required and at the strain rates of 435. million $\mu\epsilon$/sec (lateral) and 184. million $\mu\epsilon$/sec (axial). However, better predictions might be made if a strain allowable of $\sim$ 9.% was used.

PARA. NO.		TITLE:	ANAL. BY	[signature]
DWG. NO.			DATE	5/76
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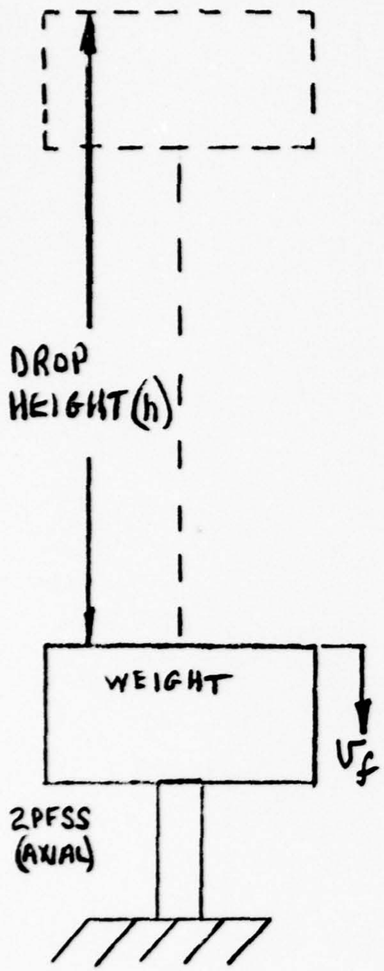
Figure 1

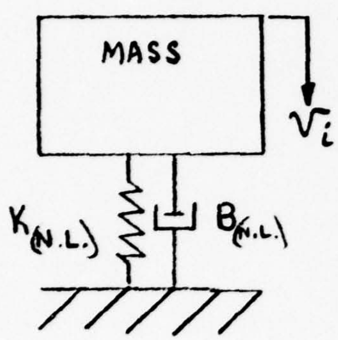
2 PFSS DROP TEST MODEL

- The instant the weight contacts the switch (@ velocity $v_f = \sqrt{2gh}$) the 1 D.O.F. model is initiated.

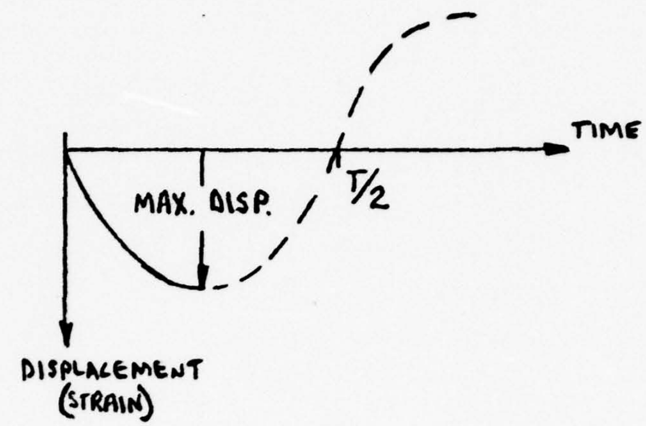
- The 1 D.O.F. Model is of interest for 1/4 the period 'T' at which time the maximum displacement is attained.

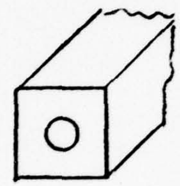


TEST CONFIGURATION



1 D.O.F. MODEL





- The switch is modeled as a square bar with a hole completely through it.

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figure 2

Elastic-Perfectly Plastic Stress/Strain Curve (4340)

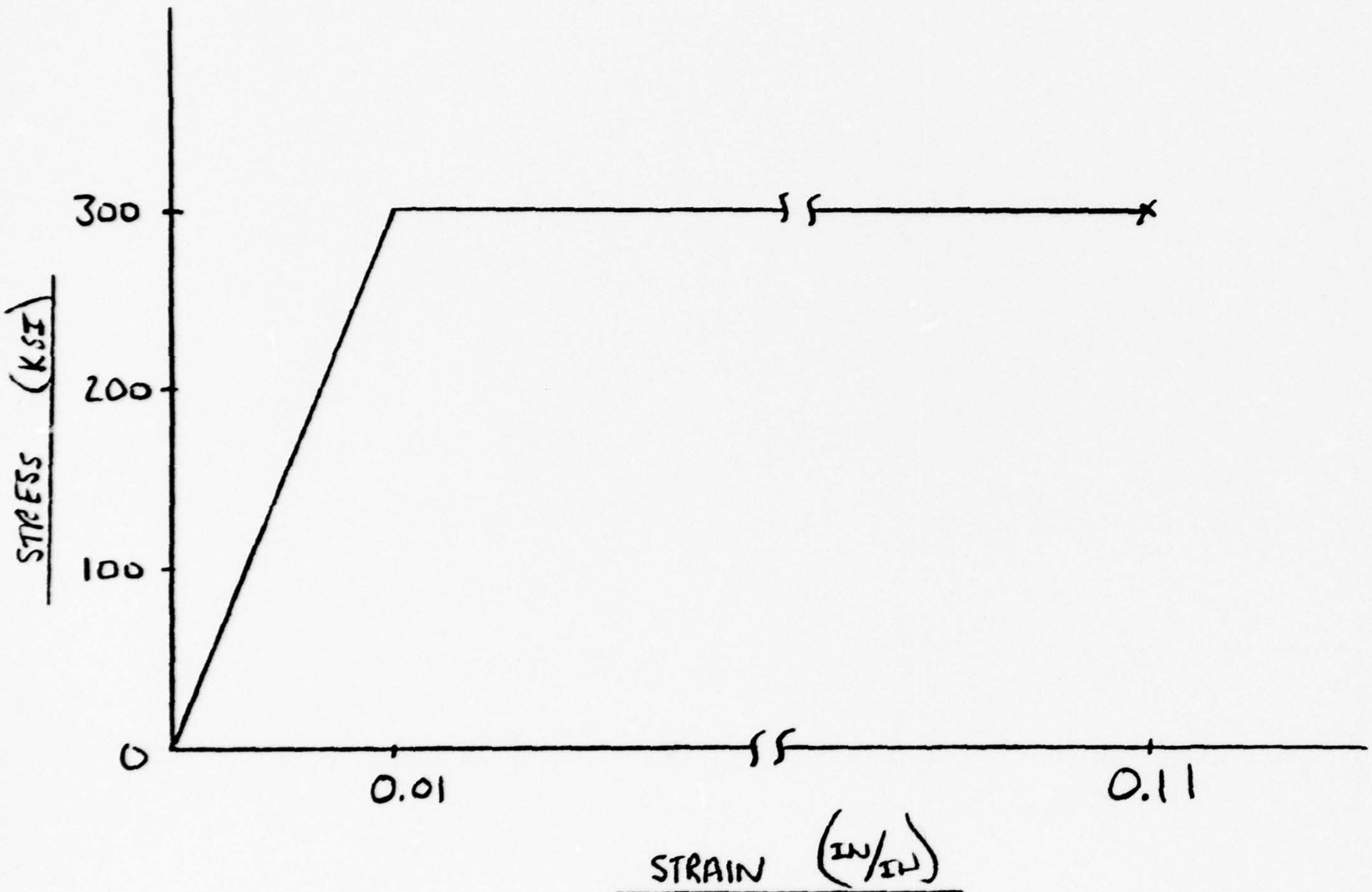

Figure 3

Energy Absorbed vs. Maximum/Residual Strain

Axial / Rotor In / 0.95 Sg x 2.25 Lg

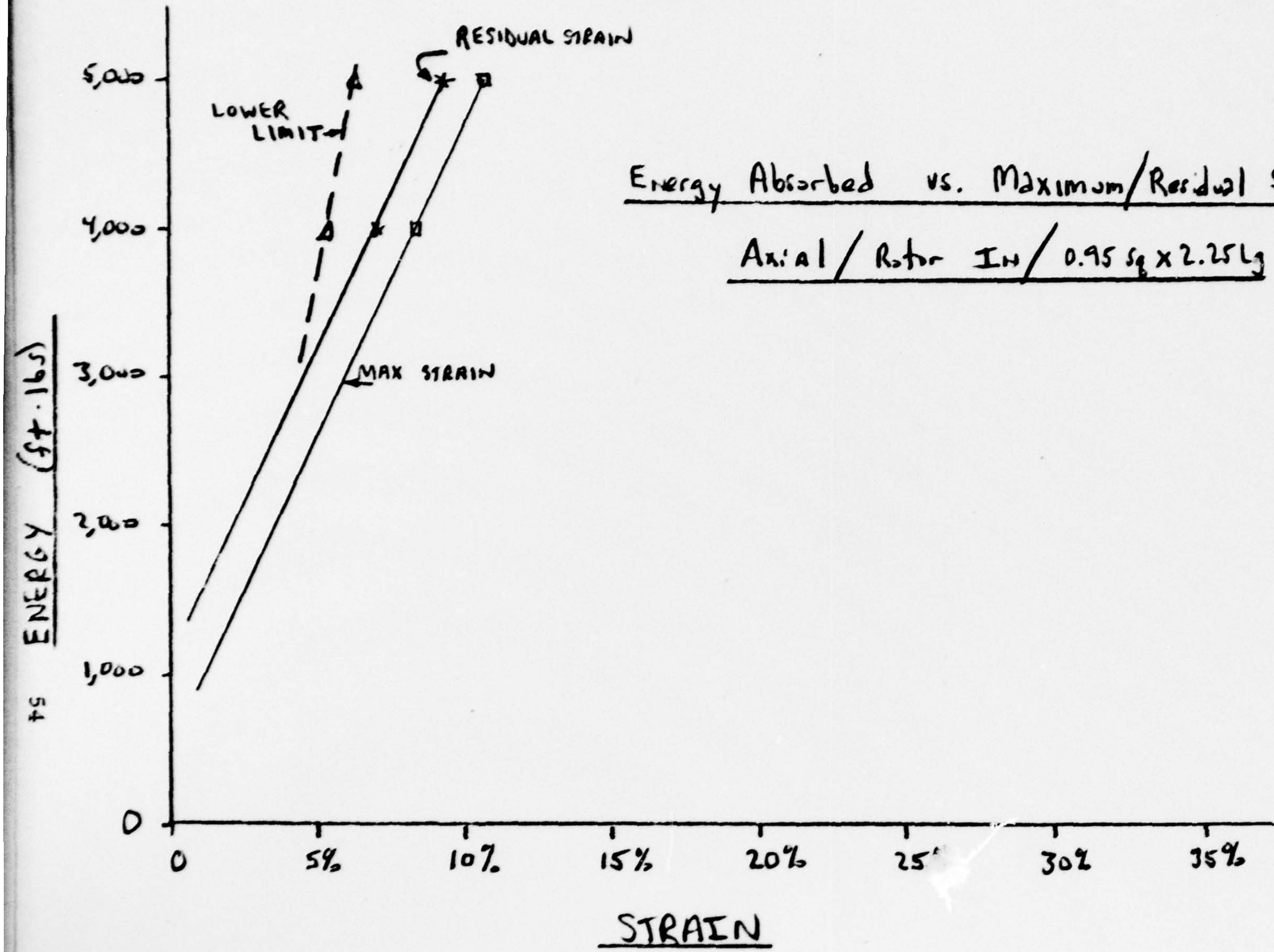

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Figure 4

Energy Absorbed vs. Maximum/Residual Strain

Axial/Rotor Out/0.95 Sg x 2.25 Lg

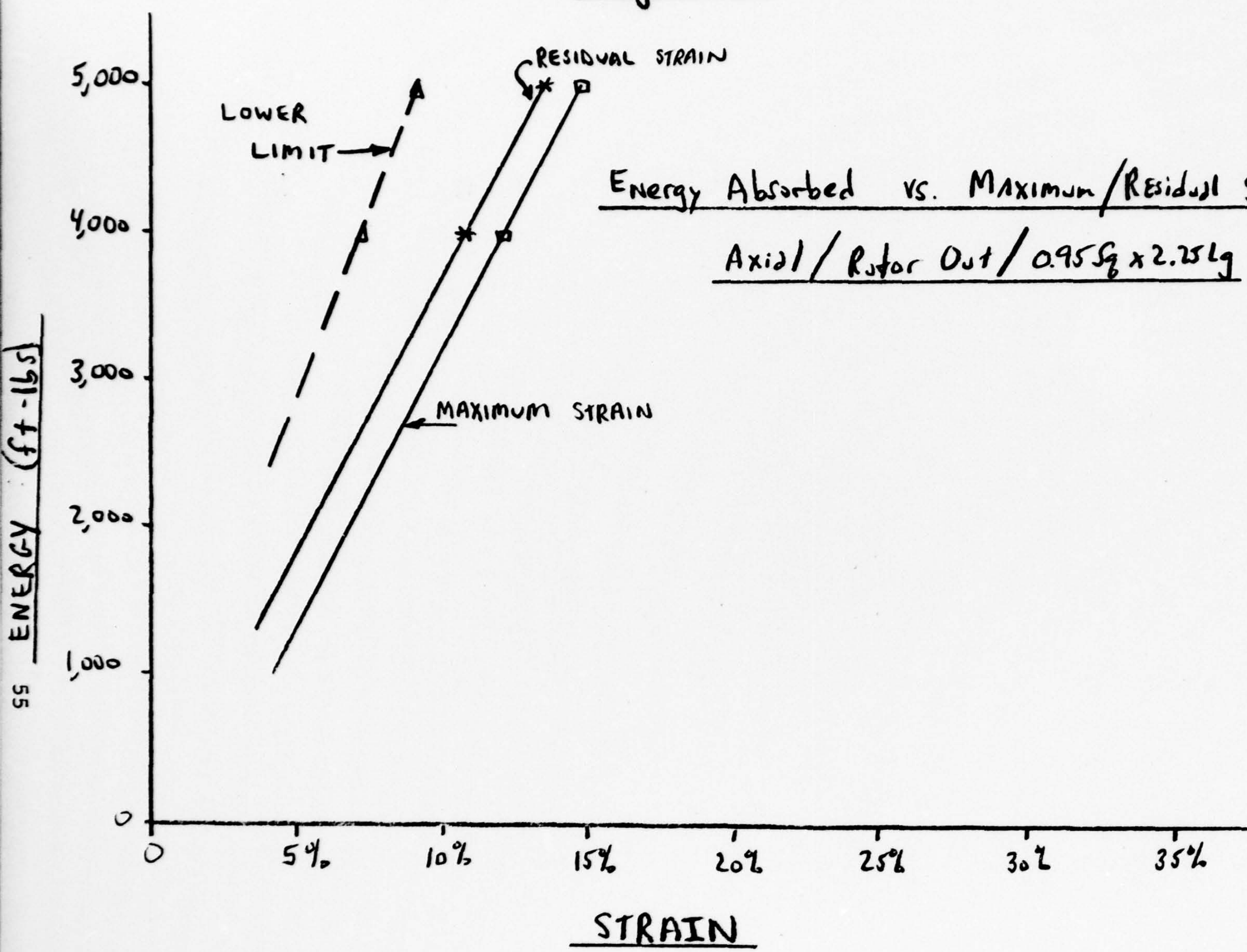

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Figure 5

Energy Absorbed vs. Maximum/Residual Strain

LATERAL / Rotor In / 0.95 Sy x 2.25 Lg

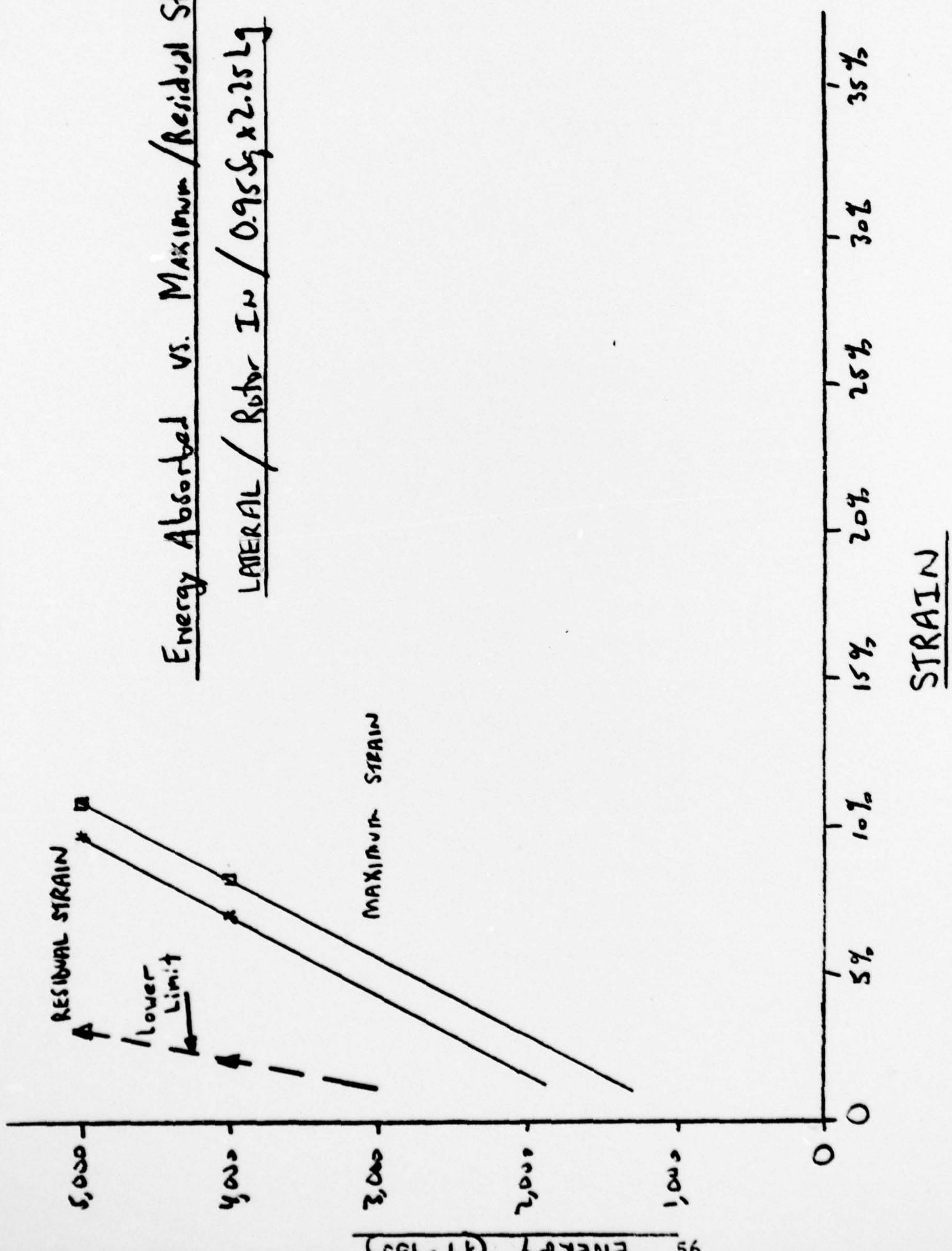

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Figure 6

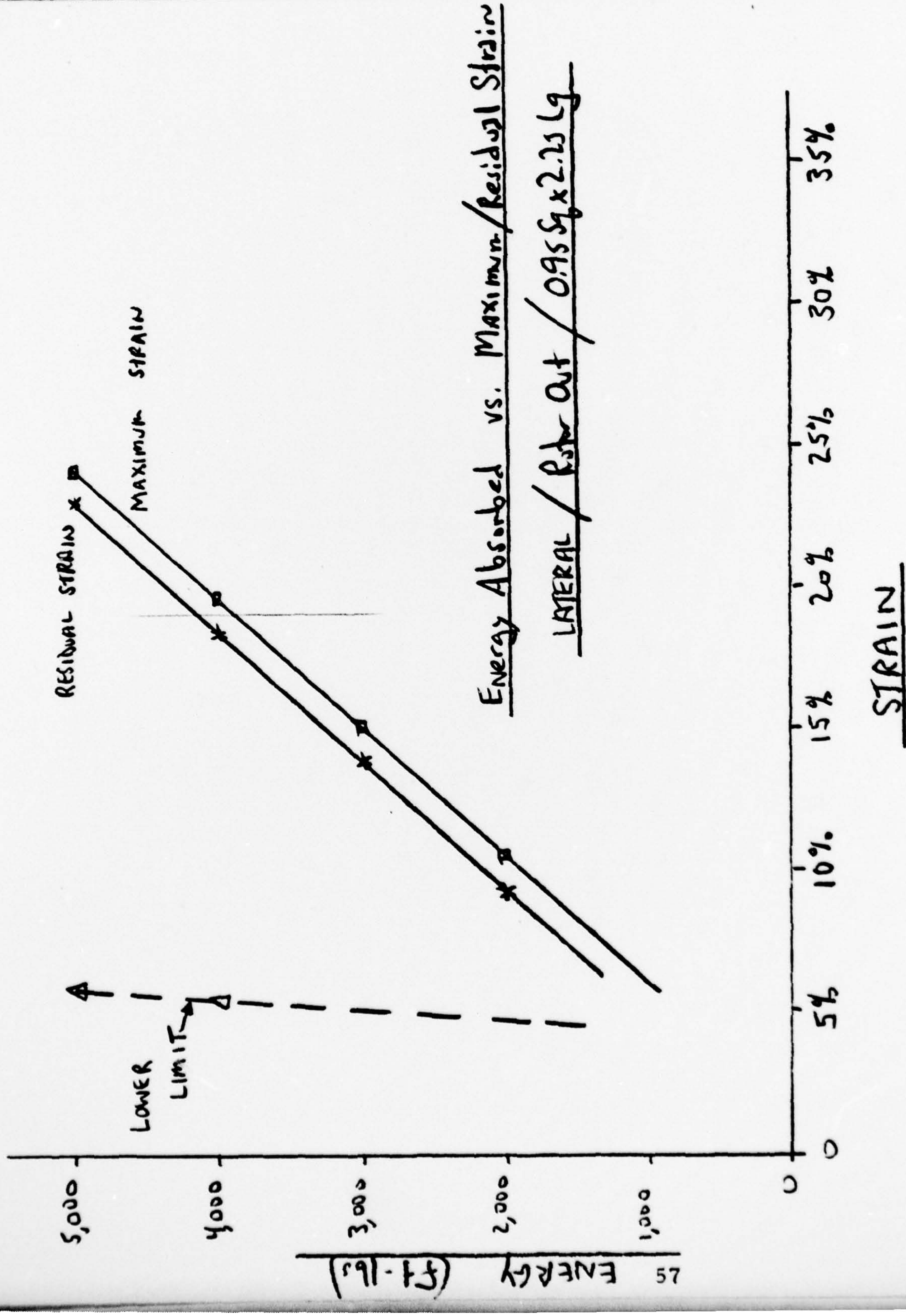
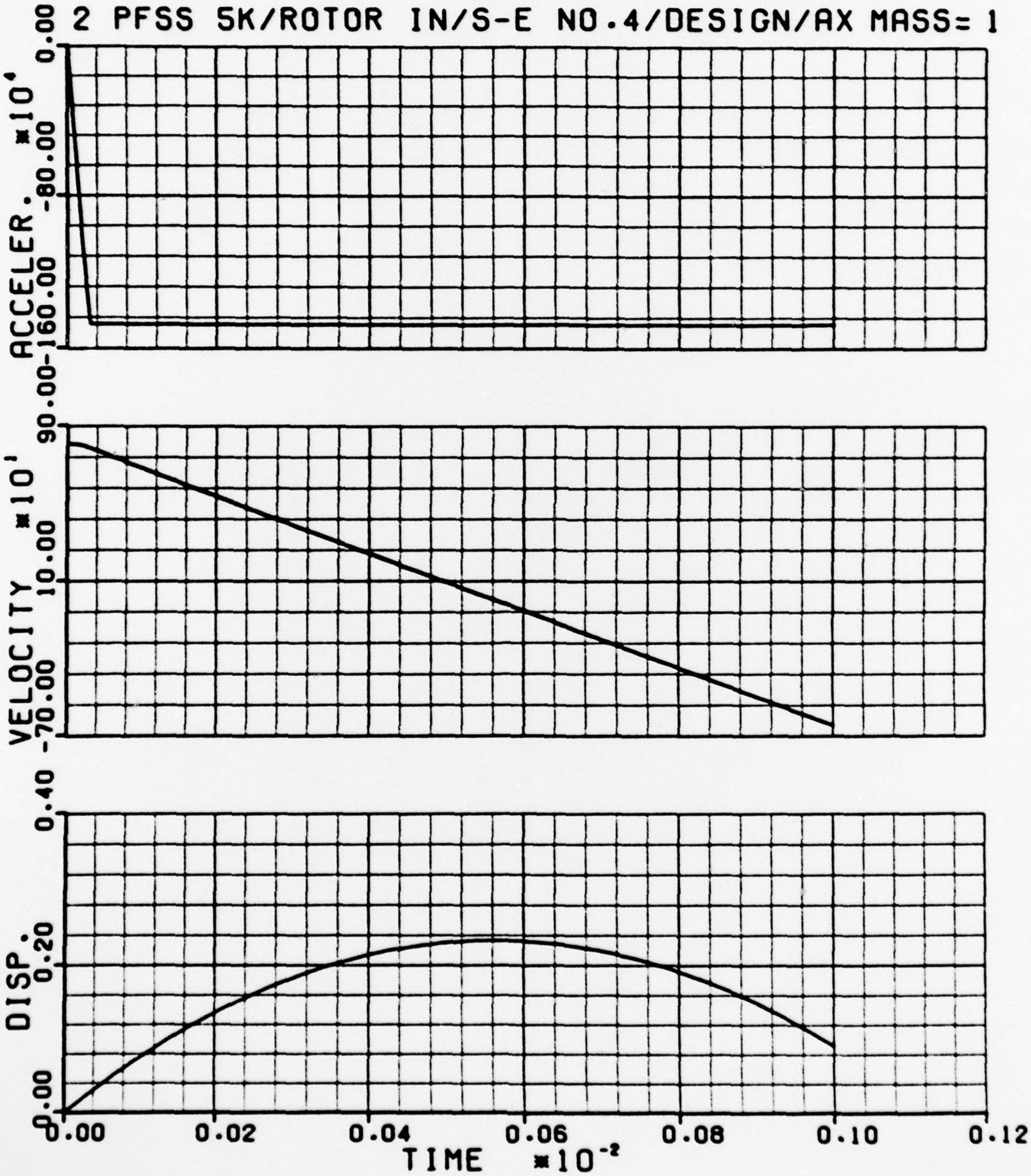


Figure 7 a①



2 PFSS 5K/ROTOR IN/S-E NO.4/DESIGN/AX MASS= 1
ACCELER. ×10⁴
0.00
-80.00
-160.00
VELOCITY ×10¹
90.00
10.00
-70.00
DISP.
0.40
0.20
0.00
0.00
0.02
0.04
0.06
0.08
0.10
0.12
TIME ×10⁻²

Figure 7 a (2)

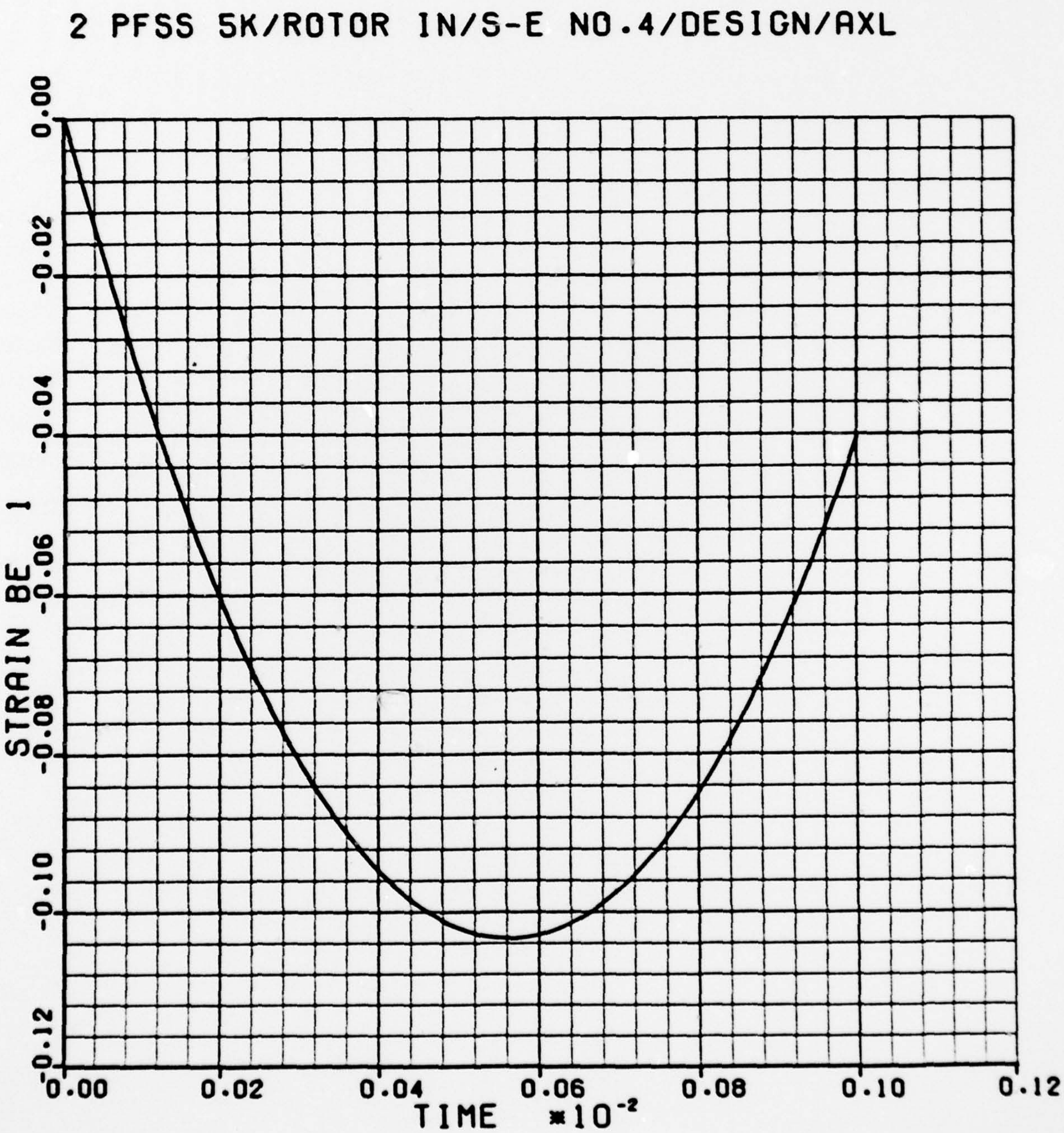

2 PFSS 5K/ROTOR IN/S-E NO.4/DESIGN/AXL
STRAIN BE 1
0.00
-0.02
-0.04
-0.06
-0.08
-0.10
-0.12
0.00
0.02
0.04
0.06
0.08
0.10
0.12
TIME *10⁻²

Figure 7 b(1)

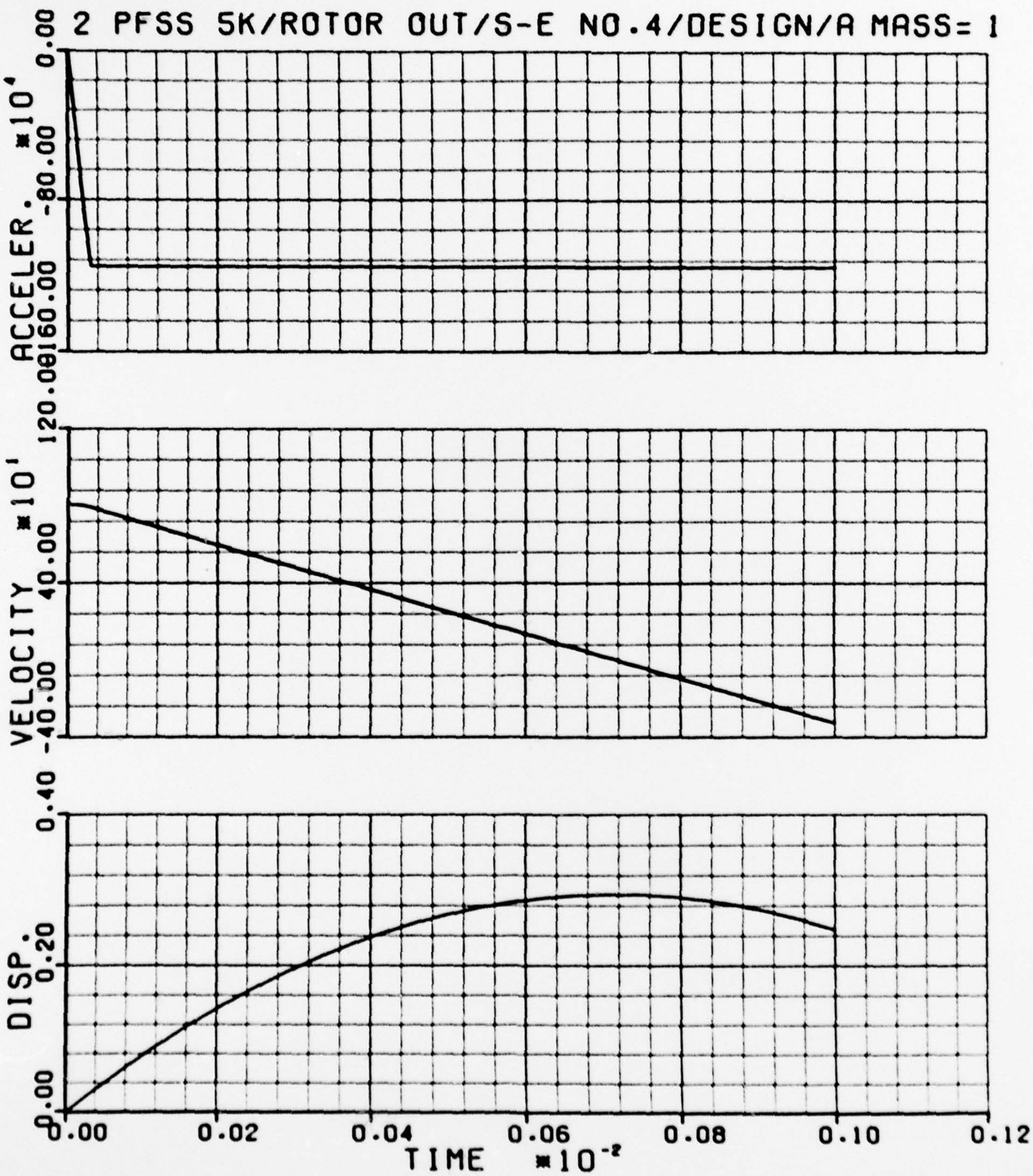
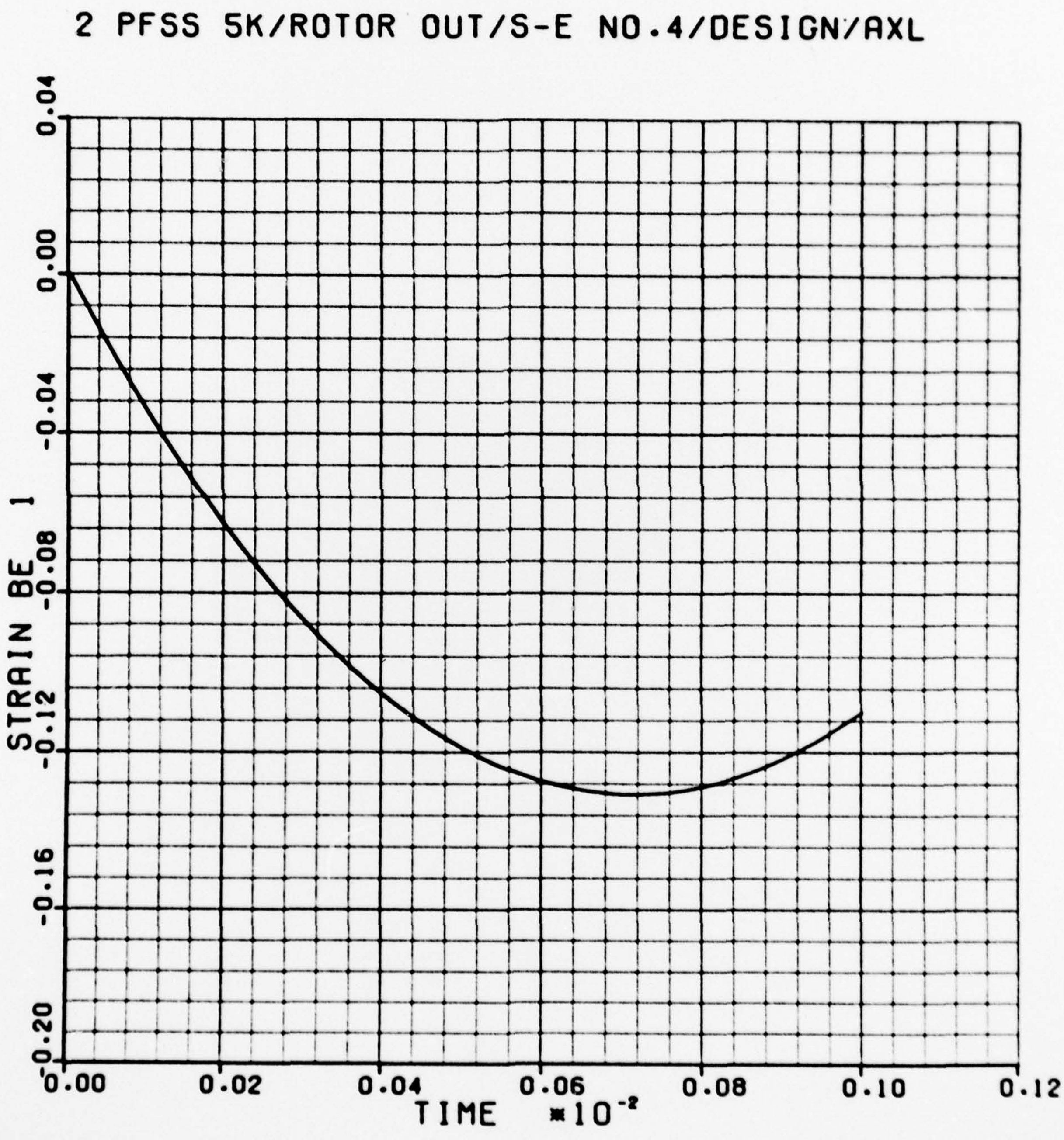

2 PFSS 5K/ROTOR OUT/S-E NO.4/DESIGN/A MASS= 1
ACCELER. *10^4
0.00
-80.00
-160.00
VELOCITY *10^1
120.00
40.00
-40.00
DISP.
0.40
0.20
0.00
0.00
0.02
0.04
0.06
0.08
0.10
0.12
TIME *10^-2

Figure 7 b②



2 PFSS 5K/ROTOR OUT/S-E NO.4/DESIGN/AXL
0.04
0.00
-0.04
-0.08
-0.12
-0.16
-0.20
STRAIN BE 1
0.00
0.02
0.04
0.06
0.08
0.10
0.12
TIME *10^-2

Figure 7 c①

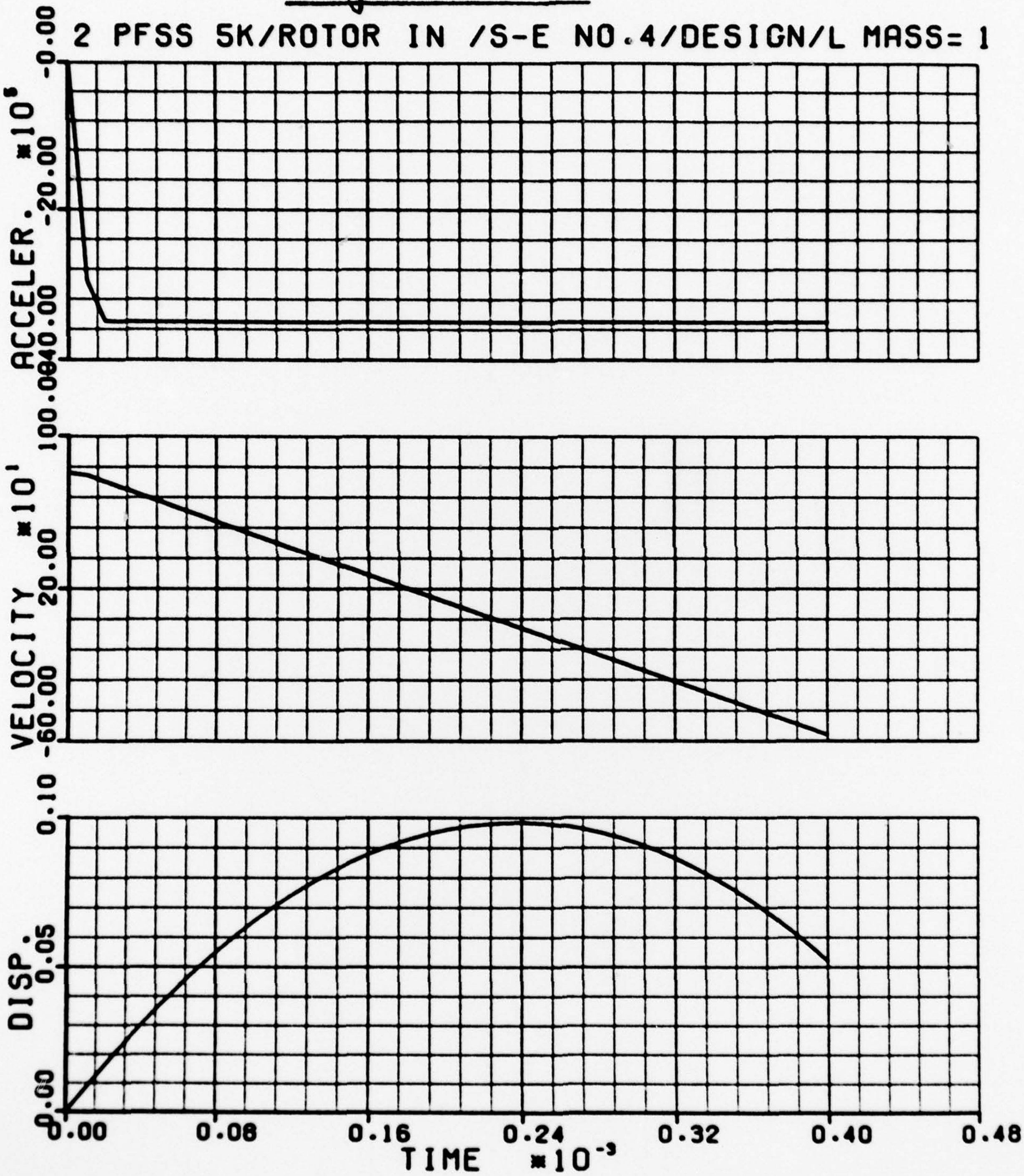

2 PFSS 5K/ROTOR IN /S-E NO.4/DESIGN/L MASS= 1
ACCELER. ×10⁶
-0.00
-20.00
-40.00
VELOCITY ×10¹
100.00
20.00
-60.00
DISP.
0.10
0.05
0.00
0.00
0.08
0.16
0.24
0.32
0.40
0.48
TIME ×10⁻³

Figure 7 c(2)

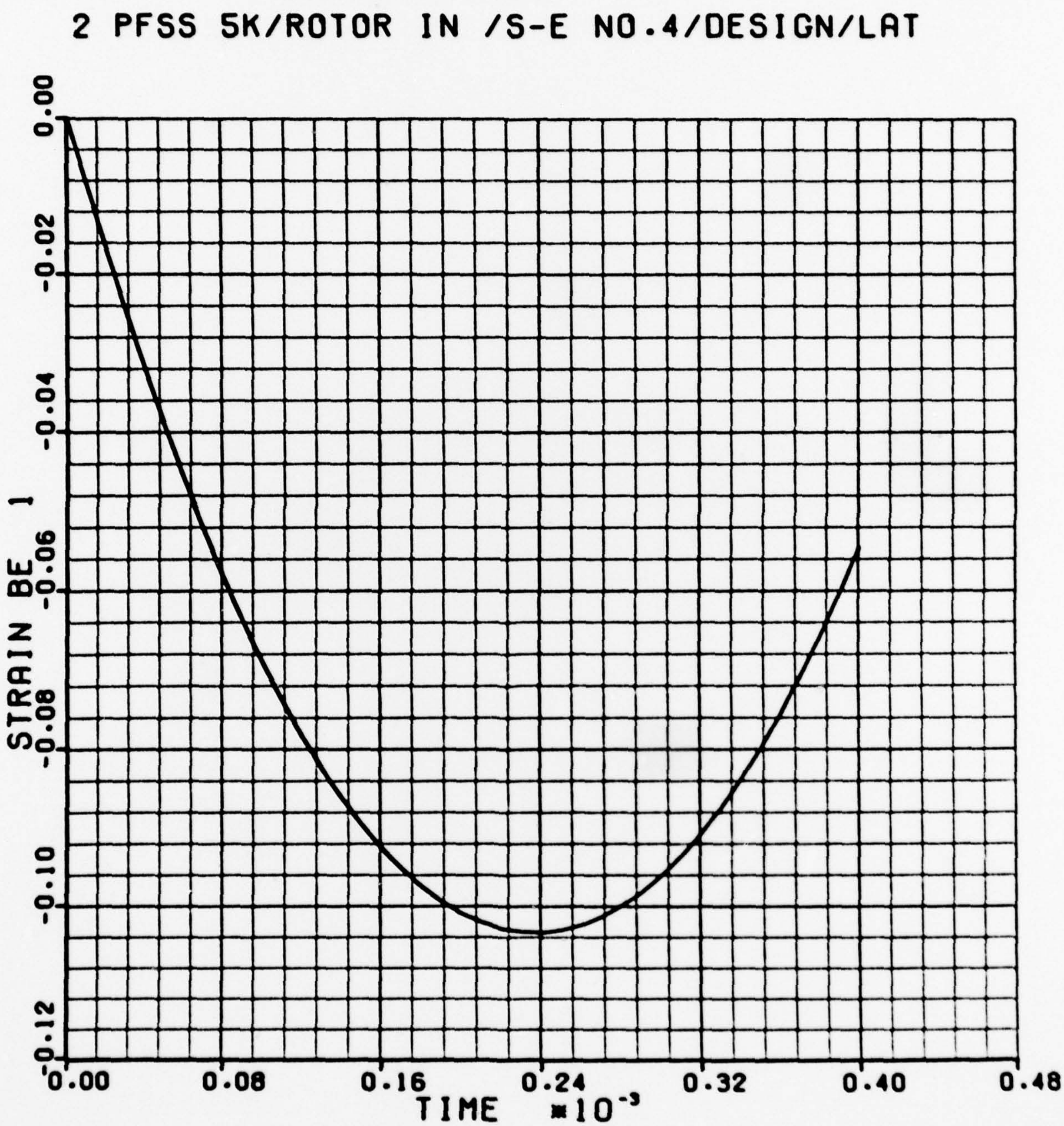
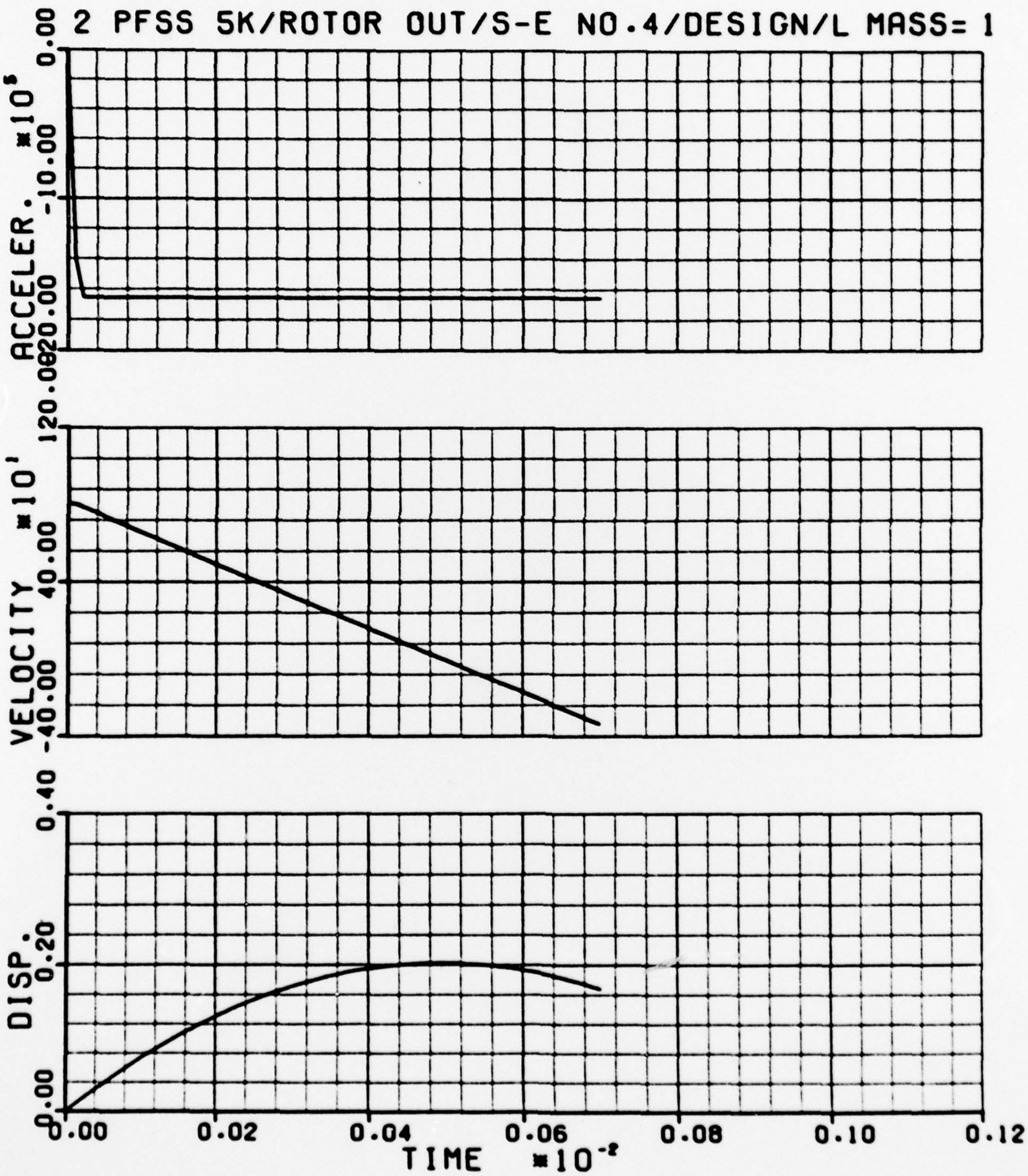

2 PFSS 5K/ROTOR IN /S-E NO.4/DESIGN/LAT
STRAIN BE 1
0.00
-0.02
-0.04
-0.06
-0.08
-0.10
-0.12
0.00
0.08
0.16
0.24
0.32
0.40
0.48
TIME *10^-3

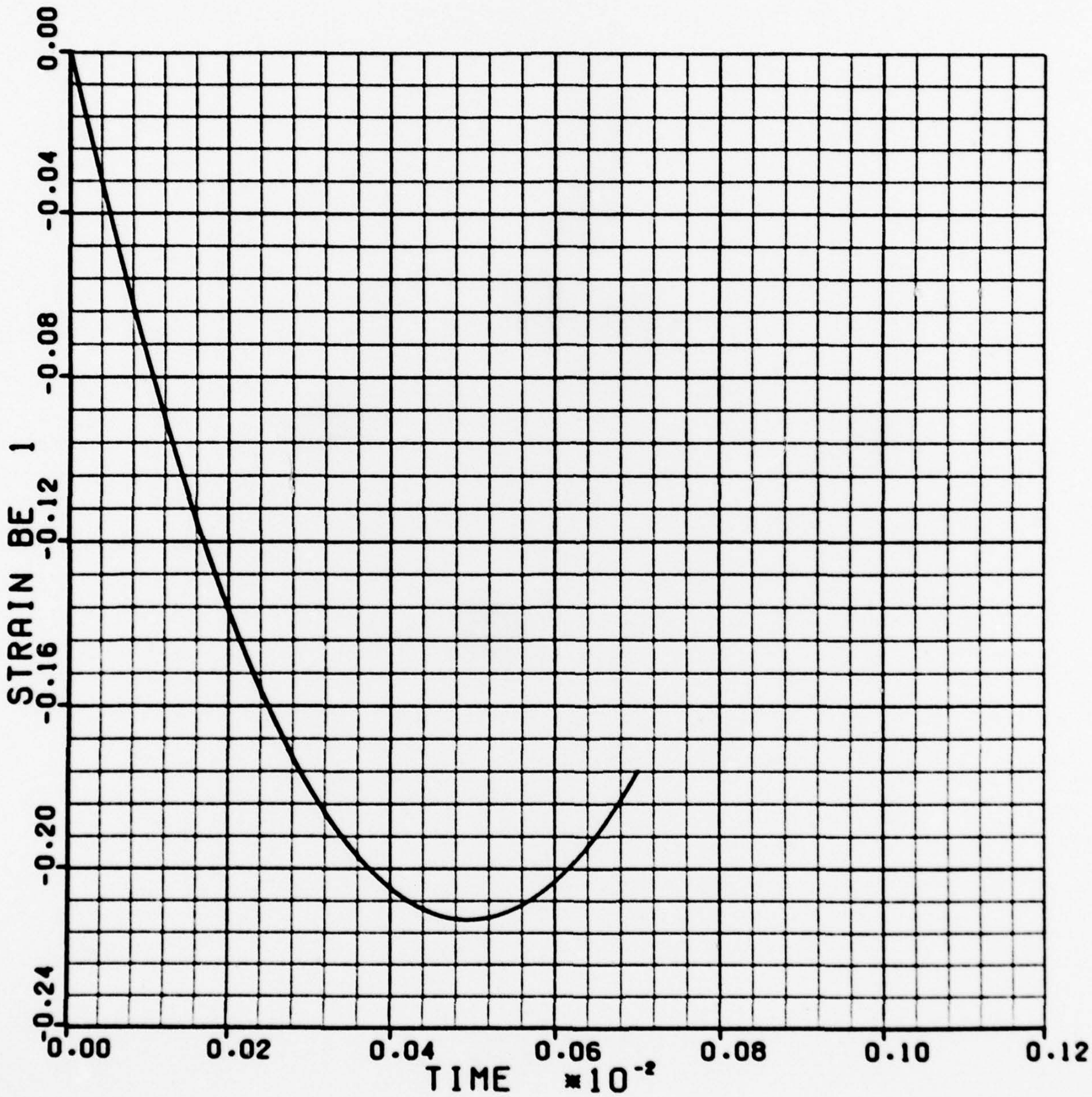
Figure 7 d ①



2 PFSS 5K/ROTOR OUT/S-E NO.4/DESIGN/L MASS= 1
ACCELER. ×10^5
0.00
-10.00
-20.00
VELOCITY ×10^1
120.00
40.00
-40.00
DISP.
0.40
0.20
0.00
0.00
0.02
0.04
0.06
0.08
0.10
0.12
TIME ×10^-2

Figure 7 d②

2 PFSS 5K/ROTOR OUT/S-E NO.4/DESIGN/LAT

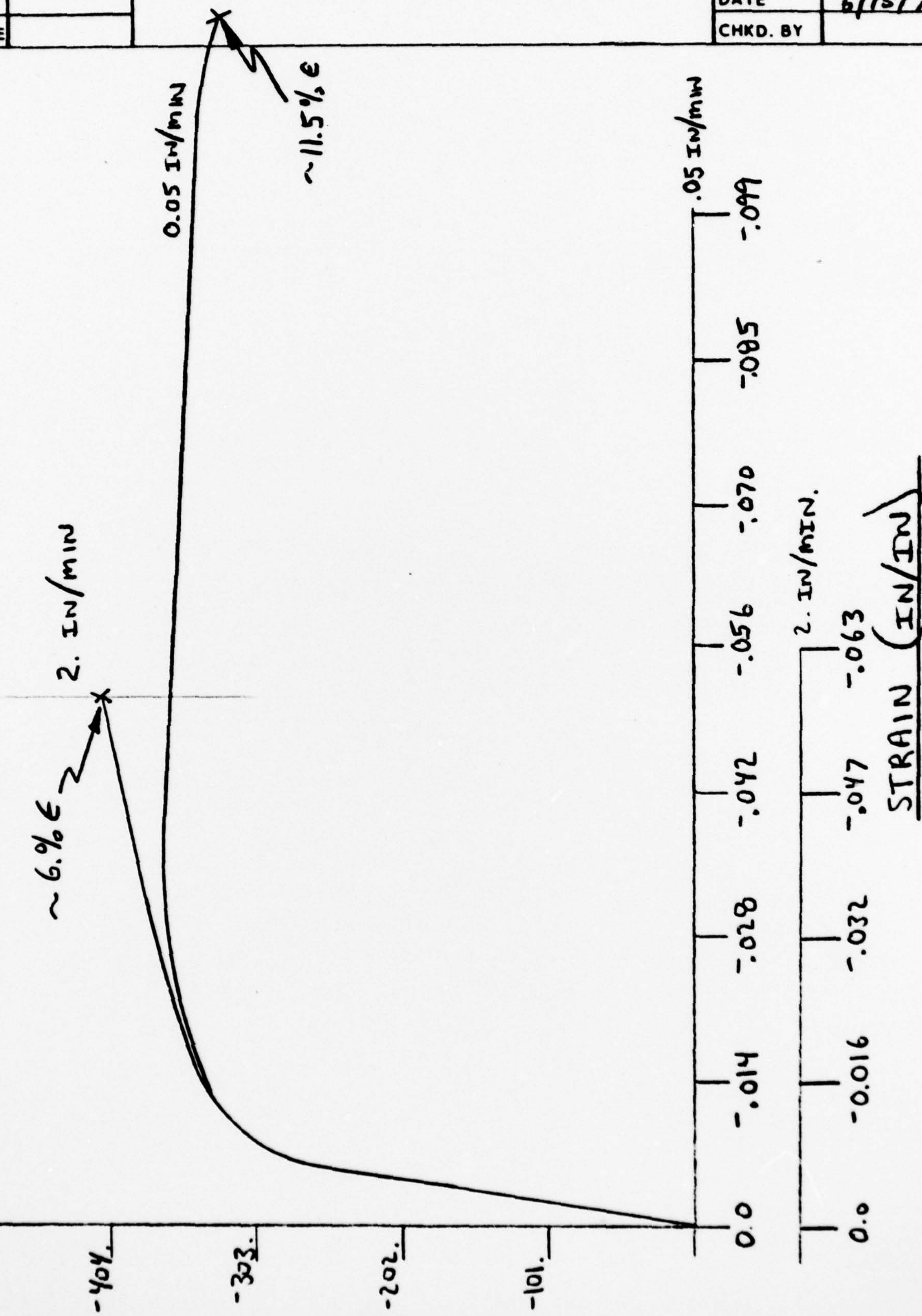


0-0400
1-64

PARA. NO.		TITLE:	ANAL. BY	
DWG. NO.			DATE	6/10/76
LOADS ARE			CHKD. BY	

FIGURE 8

4340 COMPRESSION σ-ε CURVE



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FAIL SAFE SWITCH
HARD SWITCH
STRONG LINK SWITCH

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The report describes the exploratory development of a 15 contact, two position switch designed to fail safe in abnormal impact, crush and fire environments. The report also describes the results of experimental tests conducted on the switch.

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