PUBLIC SERVICE COMPANY OF COLORADO

P. O. BOX 840 · DENVER, COLORADO 80201

OSCAR R. LEE
VICE PRESIDENT

April 15, 1983
Fort St. Vrain
Unit No. 1
P-83132

Mr. John T. Collins, Regional Administrator
Nuclear Regulatory Commission
Region IV
Office of Inspection and Enforcement
611 Ryan Plaza Drive, Suite 1000
Arlington, TX 76012

DOCKET NO: 50-267

SUBJECT: Fort St. Vrain CRDM Temperature

REFERENCES: (1) R. Clark (NRC) letter to O.R. Lee (PSC) dated 12/2/82 (G-82384)
(2) Fort St. Vrain FSAR Section 3.2.3.4.2
(3) Fort St. Vrain Technical Specification SR 5.1.1
(4) Fort St. Vrain FSAR Section 3.5.3, Table 3.5-6

Dear Mr. Collins:

In response to your request to provide a commitment in the form of a Technical Specification which will limit the Fort St. Vrain (FSV) Control Rod Drive Mechanisms' (CRDM) maximum operating temperature to 215°F, our Engineering Department has evaluated the LANL study which was submitted to us by reference (1). This report concluded that the maximum CRDM operating temperature of 215°F will not be exceeded at 100% reactor power providing all the orifice valves are open at least 40%. A review of the effects of keeping the orifice valves open a minimum of 40% up to 100% power, along with our position on limiting the operating temperature of the CRDM's to 215°F is discussed in this letter.

H005

After reviewing the LANL study, PSC's Engineers could not identify the logic used in selecting 215°F as a temperature limitation. There weren't any specific details mentioned in the LANL Report which indicated why the CRDM's would be expected to experience problems at temperatures greater than 215°F. Therefore, we have concluded that this maximum operating limit was selected without any supportive technical basis.

In addition to the lack of technical basis, it is our position that restricting the orifice valve position to greater than 40% open at 100% power would pose unacceptable operational problems. Operation in this manner would lead to loss of temperature control for older fuel regions and would make control of steam temperatures virtually impossible. More importantly, newly fueled regions would be starved of flow necessary to maintain compliance with FSV Technical Specification LCO 4.1.7 (Core Inlet Orifice Valves, Limiting Condition for Operation). As a result, in order to run the CRDM's at less than 215°F temperature, we would be forced to run newer fuel at much higher than normal temperatures, possibly sacrificing some fuel particle integrity. Therefore, we have concluded that restricting the orifice valve position to 40% minimum opening at 100% power level is not compatible with the safe or efficient operation of Fort St. Vrain.

It is important to make a distinction between the CRDM operational considerations and safe shutdown functional capability considerations. Imposing a limit on CRDM maximum operating temperature might be beneficial from an operational standpoint. However, the safe shutdown functional capabilities and, therefore, the safety and well-being of the public are not affected by high temperatures. No electrical or other power source is required to achieve full insertion of the rods and no power source of any kind is required to limit the speed of the rod insertion during a scram (reference (2)). Hence, it is apparent that regardless of whether the temperature of the control rod drive mechanisms are limited to 215°F, or allowed to operate at the predicted maximum temperature of 250°F, the plant has the capability of achieving a safe shutdown configuration, thus protecting the public from any radiological emergency due to failure of a CRDM. In addition, Fort St. Vrain has a completely independent, redundant reactivity control system, the Reserve Shutdown System, that can shut down the reactor in the unlikely event that the normal control rod system malfunctions.

An in-situ performance test on the CRDM's is performed weekly when the plant is at power to assure the control rods can be inserted properly. This "Rod Drop" test is run in conjunction with a temperature surveillance test on the CRDM's (Reference (3) and Attachment 1). The present rod drop test is the most reliable and informative means of monitoring the safe shutdown functional capability of the control rod drive mechanisms on a continuing basis under all power conditions.

GA Technologies Inc. (formerly General Atomic Company) performed a detailed analysis to determine the thermal expansion and mechanical interference effects in the CRDM gear mechanisms due to high temperatures (Attachment 2) . This analysis assumed a maximum temperature of 280°F based on extrapolation of actual data taken with the reactor at a power level of 40%. Worst case tolerance combinations at 280°F resulted in probabilities of the gears jamming of less than one in one million for one CRDM and one in one billion for two CRDM's failing to scram. The control system design provides adequate shutdown margin even with the two maximum worth rod pairs withdrawn (reference (4)). PSC has reviewed and concurs with this analysis.

The following is a summary of research conducted on the temperature limits of the CRD motors. Electrically, there are three areas of concern: the motor, the cable, and the penetration connection. An analysis of the motor shows it to be capable of withstanding an ambient temperature of 272°F (Attachment 3). The cables are rated at 257°F (see Fig. 1). The connectors are rated up to 350°F (see Fig. 2 and Fig. 3). Therefore, the limiting electrical component (neglecting any synergistic effects) from a thermal standpoint would be the cables (257°F).

PSC has reviewed the recommendations in the LANL report to decrease the temperature of the CRDM's. Only the LANL recommended items 1 and 2 are realistic for implementation at FSV. The additional cooling of purge gas could be designed into the helium purification system, but this option is the least effective from a thermal standpoint. It is not feasible for all rods to have the purge flow rate increased simultaneously because the additional amount of purified helium required would exceed the available capacity from the helium purification system. Increased helium flow in selected CRDM's is feasible, but this would be very difficult to administer operationally.

PSC's position is that no technical specification temperature limit should be imposed upon the control rod drive mechanisms. We have based our decision on the fact that the operational history of the CRDM's has displayed no signs of problems due to thermal effects, the temperature rating of the components, and the CRDM's are in-situ tested routinely more frequently than Technical Specification surveillance requirements. Also, as we mentioned earlier, the fact that the electrical operation of the CRDM's is not necessary for safe shutdown of the reactor was an influencing factor for our decision. We will continue to closely monitor the operation of the control rod drive mechanisms, and we will keep our records on their operational history up-to-date. NRC concurrence with this position is requested.

If you have any questions please contact Mr. J.R. Reesy at (303) 571-8406.

Very truly yours,

O. R. Lee, Vice President
Electric Production

ORL/DYA:pa

Enclosures

ATTACHMENTS

1. Fort St. Vrain Surveillance SR-RE-4-W
2. W. A. Graul, "Fort St. Vrain Control Rod Drive Mechanism - Thermal Expansion Effects", GA Letter GP-1014, June 9, 1981
3. I. G. Khamis, "Reply to D. W. Ketchen", GA Memo FSV-ME:DWK:19:78

LIST OF FIGURES

1. Shim Motor; Gulf General Atomic Dwg. # SLR-D1201-218
2. Closure Assembly; Gulf General Atomic Dwg. # SLR-D1201-275
3. ITT Cannon Catalog; pg. 233 (1980 edition)

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

In the Matter	)	
	)	
Public Service Company of Colorado	)	Docket No. 50-267
Fort St. Vrain Unit No. 1	)	

AFFIDAVIT

O. R. Lee, being duly sworn, hereby deposes and says that he is Vice President of Public Service Company of Colorado; that he is duly authorized to sign and file with the Nuclear Regulatory Commission the attached response to the NRC Letter from R. Clark to O. R. Lee dated December 2, 1982 (G-82384); that he is familiar with the content thereof; and that the matters set forth therein are true and correct to the best of his knowledge, information and belief.

ORLee

O. R. Lee
Vice President

STATE OF Colorado)
)
COUNTY OF Denver)

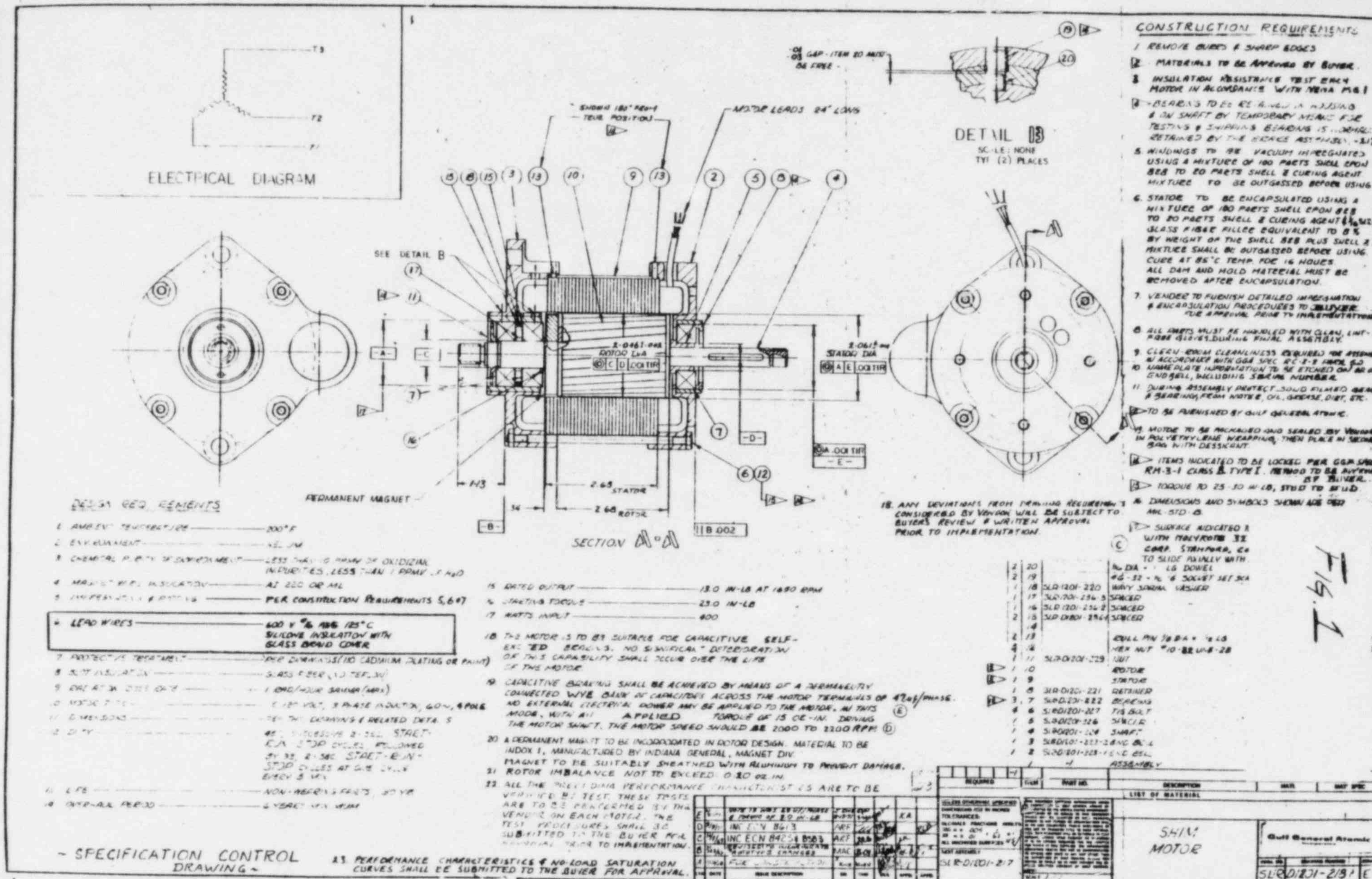
Subscribed and sworn to before me, a Notary Public in and for ______ ________ on this 15th day of april, 1983.

Ina LeBlanc

Notary Public
4026 E. 113th Place
Denver, Co 80233

My commission expires august 19, 1983.

Fig. 1



ELECTRICAL DIAGRAM
T3
T2
T1
SEE DETAIL B
PERMANENT MAGNET
MOTOR LEADS 24" LONG
STATOR DIA
ROTOR DIA
2.65 STATOR
2.68 ROTOR
SECTION A-A
DETAIL B
SCALE: NONE
TYP (2) PLACES
CONSTRUCTION REQUIREMENTS
1 REMOVE BURRS & SHARP EDGES
2 MATERIALS TO BE APPROVED BY BUYER.
3 INSULATION RESISTANCE TEST EACH MOTOR IN ACCORDANCE WITH NEMA MG 1
5. WINDINGS TO BE VACUUM IMPREGNATED USING A MIXTURE OF 100 PARTS SHELL EPON 828 TO 20 PARTS SHELL Z CURING AGENT MIXTURE TO BE OUTGASSED BEFORE USING.
6. STATOR TO BE ENCAPSULATED USING A MIXTURE OF 100 PARTS SHELL EPON 828 TO 20 PARTS SHELL Z CURING AGENT & GLASS FIBER FILLER EQUIVALENT TO 8% BY WEIGHT OF THE SHELL 828 PLUS SHELL Z. MIXTURE SHALL BE OUTGASSED BEFORE USING. CURE AT 85°C TEMP. FOR 16 HOURS. ALL DAM AND HOLD MATERIAL MUST BE REMOVED AFTER ENCAPSULATION.
7. VENDER TO FURNISH DETAILED IMPREGNATION & ENCAPSULATION PROCEDURES TO BUYER FOR APPROVAL PRIOR TO IMPLEMENTATION.
8. ALL PARTS MUST BE HANDLED WITH CLEAN, LINT-FREE GLOVES DURING FINAL ASSEMBLY.
11. DURING ASSEMBLY PROTECT SOLID FILMED GEAR & BEARING FROM NOTE 8, OIL, GREASE, DIRT, ETC.
TO BE FURNISHED BY GULF GENERAL ATOMIC.
TORQUE TO 25-30 IN-LB, STUD TO STUD.
DIMENSIONS AND SYMBOLS SHOWN ARE PER MIL-STD-8.
18. ANY DEVIATIONS FROM DRAWING REQUIREMENTS CONSIDERED BY VENDOR WILL BE SUBJECT TO BUYERS REVIEW & WRITTEN APPROVAL PRIOR TO IMPLEMENTATION.
DESIGN REQUIREMENTS
1 AMBIENT TEMPERATURE — 200°F
2 ENVIRONMENT — HELIUM
4 MAGNET WIRE INSULATION — AI 220 OR ML
5 IMPREGNATION & POTTING — PER CONSTRUCTION REQUIREMENTS 5, 6 & 7
6 LEAD WIRES — 600 V #16 AWG 125°C SILICONE INSULATION WITH GLASS BRAID COVER
7 PROTECTIVE TREATMENT — PER DRAWINGS (NO CADMIUM PLATING OR PAINT)
8 SLOT INSULATION — GLASS FIBER (NO TEFLON)
10 MOTOR TYPE — 3 PHASE INDUCTION, 60 ~, 4 POLE
11 DIMENSIONS — PER THE DRAWING & RELATED DATA
13 LIFE — NON-WEARING PARTS, 30 YR
15 RATED OUTPUT — 13.0 IN-LB AT 1650 RPM
16 STARTING TORQUE — 23.0 IN-LB
17 WATTS INPUT — 400
18 THE MOTOR IS TO BE SUITABLE FOR CAPACITIVE SELF-EXCITED BRAKING. NO SIGNIFICANT DETERIORATION OF THIS CAPABILITY SHALL OCCUR OVER THE LIFE OF THE MOTOR.
19 CAPACITIVE BRAKING SHALL BE ACHIEVED BY MEANS OF A PERMANENTLY CONNECTED WYE BANK OF CAPACITORS ACROSS THE MOTOR TERMINALS OF 47 µf/PHASE. NO EXTERNAL ELECTRICAL POWER MAY BE APPLIED TO THE MOTOR. IN THIS MODE, WITH AN APPLIED TORQUE OF 15 OZ-IN. DRIVING THE MOTOR SHAFT, THE MOTOR SPEED SHOULD BE 2000 TO 2200 RPM.
20 A PERMANENT MAGNET TO BE INCORPORATED IN ROTOR DESIGN. MATERIAL TO BE INDOX 1, MANUFACTURED BY INDIANA GENERAL, MAGNET DIV. MAGNET TO BE SUITABLY SHEATHED WITH ALUMINUM TO PREVENT DAMAGE.
21 ROTOR IMBALANCE NOT TO EXCEED 0.20 OZ-IN.
22 ALL THE PRECEDING PERFORMANCE CHARACTERISTICS ARE TO BE VERIFIED BY TEST. THESE TESTS ARE TO BE PERFORMED BY THE VENDOR ON EACH MOTOR. THE TEST PROCEDURES SHALL BE SUBMITTED TO THE BUYER FOR APPROVAL PRIOR TO IMPLEMENTATION.
23 PERFORMANCE CHARACTERISTICS & NO-LOAD SATURATION CURVES SHALL BE SUBMITTED TO THE BUYER FOR APPROVAL.
LIST OF MATERIAL
ROTOR
STATOR
RETAINER
BEARING
TIE BOLT
SPACER
SHAFT
ASSEMBLY
SHIM MOTOR
Gulf General Atomic
SLR-D1201-213
- SPECIFICATION CONTROL DRAWING -

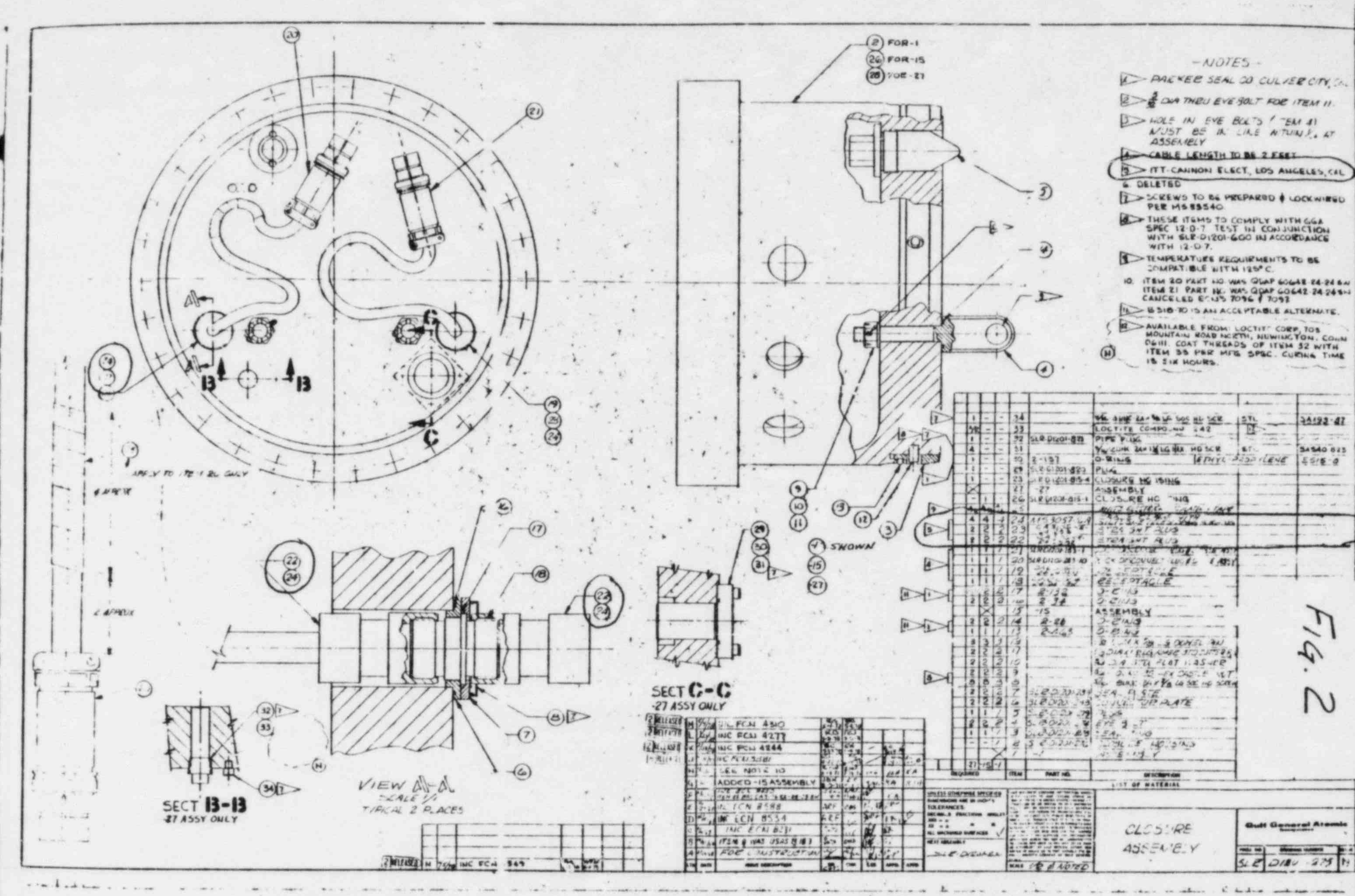

-NOTES-
PACKER SEAL CO CULVER CITY, CAL
ITT-CANNON ELECT, LOS ANGELES, CAL
6. DELETED
SCREWS TO BE PREPARED & LOCKWIRED PER MS33540
THESE ITEMS TO COMPLY WITH GGA SPEC 12-0-7. TEST IN CONJUNCTION WITH SLE-D1201-600 IN ACCORDANCE WITH 12-0-7.
TEMPERATURE REQUIREMENTS TO BE COMPATIBLE WITH 125°C.
10. ITEM 20 PART NO WAS QGAP 60648 24-24 SN ITEM 21 PART NO WAS QGAP 60642 24-24 SN CANCELED ECN'S 7096 & 7093
B510-10 IS AN ACCEPTABLE ALTERNATE.
AVAILABLE FROM LOCTITE CORP, 705 MOUNTAIN ROAD NORTH, NEWINGTON, CONN 06111. COAT THREADS OF ITEM 32 WITH ITEM 33 PER MFG SPEC. CURING TIME IS SIX HOURS.
2 FOR-1
26 FOR-15
28 FOR-27
SHOWN
SECT C-C
-27 ASSY ONLY
SECT B-B
-27 ASSY ONLY
VIEW A-A
SCALE 1/1
TYPICAL 2 PLACES
LIST OF MATERIAL
CLOSURE ASSEMBLY
Gulf General Atomic

Fig. 2

FROM: ITT CANNON CATALOG
1980-1981 EDITION

FIG. 3

Printed Circuit/Input-Output

BACKPANELS printed circuit and metal backpanel packaging systems
ECS connectors

Edgecard connectors with single beam preloaded contacts on .100", .125" and .156" centers, mounted on custom-made precision-punched aluminum panels. Integrally molded card guides of 1/4" and 2" heights.

CONTACTS
Any number of contacts available
WIRE-WRAPPING TERMINATION

PRESS-T-MATE™

Custom backpanel packaging using inherent reliability of P.C. interconnections with latest cardedge connectors, contacts in .100" x .100", .100" x .200", .125" x .125" and .125" x .250" center spacings feed-thru .025" post contacts. Metal backpanels are also available.

CONTACTS
By Request
WIRE-WRAPPING TERMINATION

BPC CATALOG

Dual In-Line sockets for IC's

Economically designed, low cost, low profile sockets that unplug. size 14, 16, 24, 28, and 40 contact layouts in solder pin versions. Size 14 and 16 contact

14-40 CONTACTS
Amps
3
SOLDER OR WIRE-WRAPPING TERMINATIONS

DICA CATALOG

Filters — RFI/EMI

DPXJ

Rack/panel filter connectors in single, two, three or four gang shells interchangeable with standard DPX, DPXMA, DPXME and meets requirements of ARINC 404. Provide optimum attenuation of RFI/EMI.

CONTACTS
Contact/Wire Size
22
20
16
Coax. contacts avail.
SOLDER TERMINATION
Consult factory for availability of crimp filter contacts

FDPXJ CATALOG

D*J

Rectangular subminiature filter connectors intermateable with standard D subminiature and MIL 24308 types. Optimum RFI/EMI attenuation provided.

CONTACTS
Contact/Wire Size
[illegible]

FDJ CATALOG

PVJ

Bayonet Coupling

Miniature circular [illegible] provide optimum attenuation [illegible] RFI/EMI. PVJ equivalents [illegible] MIL C 26482 and MIL C [illegible]

CONTACTS
[illegible]

PVJ CATALOG

KJJ/KJJL

Bayonet Coupling

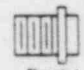
KJJ now provides [illegible] miniature circular [illegible] combine functions of standard [illegible] tor and a feed-thru filter [illegible] plete package. Meet applica[illegible] tions of MIL C 38999 [illegible] RFI/EMI attenuation.

CONTACTS
[illegible]

KJJ CATALOG

Circular

SRC — miniature circular, rugged, general purpose



Threaded Coupling

Lightweight, economical, used for test instrumentation, electronic and industrial equipment, and other general purpose application

3-24 CONTACTS
Contact/Wire Size
20
16
SOLDER OR CRIMP TERMINATION

SRC CATALOG

MR — standard weatherproof, submersible

Submersible

Rugged environmental MIL-C-5015 type, designed to MIL-C-12520R

1-56 CONTACTS
Contact/Wire Size
16
12
8
4
0
SOLDER TERMINATION

HEC CATALOG

WATERPROOF connectors

For extreme underwater geophysical applications, uses MIL-C-5015 contact arrangements. Acme thread coupling.

1-56 CONTACTS
Contact/Wire Size
16
12
8
4
0
Coax. contacts avail.
SOLDER TERMINATION

HEC CATALOG

HIGH TEMPERATURE connectors

Threaded Coupling

HRM — 1300 °F, nuclear radiation-resistant miniature circular connector

CA-HR — 650 ° & 1000 °F, radiation-resistant

1-73 CONTACTS
Contact/Wire Size
16
12
8
4
0
CRIMP OR WELD TERMINATIONS

HEC CATALOG

FIREWALL CONNECTORS

Threaded Coupling

MS-K — 350 °F, meets MIL-C-5015 fireproof test, crimp contacts

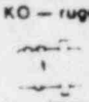
CA-KE — 350 °F, moisture-resistant, for sealable wires, meets MIL-C-5015 fireproof test or 350 °F continuous

FRF — Firewall connector with front release crimp snap-in MS90453, MS90454 contacts, moisture sealed, exceeds MIL-C-5015 fireproof requirements, 400 °F continuous, 800 °F shorter term

1-47 CONTACTS
Contact/Wire Size
16
12
8
4
0
CRIMP TERMINATION

HEC CATALOG

KO — rugged lightweight



Acme Thread

Miniature environmental version of standard K connector with special Acme thread.

3-50 CONTACTS
Contact/Wire Size
[illegible]
16
[illegible]
SOLDER TERMINATION

MC CATALOG

MC — subminiature sealed connectors

Designed for efficient space handling and environmental conditions.

3-12 CONTACTS
Contact/Wire Size
[illegible]
SOLDER TERMINATION

MC CATALOG

TITLE: CRD TEMPERATURE DATA COLLECTION

DEPARTMENT: RESULTS

ISSUANCE AUTHORIZED BY	[signature] (WB)		
PORC REVIEW	PORC 496 DEC 22 1982		EFFECTIVE DATE 12-29-82

Do not start test before ~~1-8-83~~ 1-15-83 [initials] Week # 3

and must be completed by 1-21 83 Sch. Clerk

This procedure cannot be run in its entirety for the following reasons:

____ 1. This system is not operating.

____ 2. This system is not required to be operating and has a frequency of one month or less (reference Technical Specification, paragraph 2.18).

____ 3. Reactor is in "scrammed" condition.

____ 4. Loop I is in "Loop Shutdown" condition.

____ 5. Loop II is in "Loop Shutdown" condition.

____ 6. 1A Helium circulator is in "tripped condition".

____ 7. 1B Helium circulator is in "tripped condition".

____ 8. 1C Helium circulator is in "tripped condition".

____ 9. 1D Helium circulator is in "tripped condition".

____ 10. Other________________________________

____

____

____ 11. Reschedule test for________________________

____
Department Supervisor

1.0 PURPOSE

The purpose of this test is to provide for regular temperature recordings of the CRD assemblies that are equipped with temperature devices.

2.0 PRECAUTIONS, LIMITATIONS, AND SPECIAL ASSISTANCE

None.

3.0 PREREQUISITES

3.1 Test Equipment

Name	Identification No.	Last Calibration Date
None		
DVM	M-3147	9-82

3.2 References ______

4.0 AUTHORIZATIONS

4.1 Departmental Approval — Jim Weller (Dept. Supervisor) — 1-14-83 (Date)

4.2 Mech/Elec Clearance Issued, if required: Number Not Required

4.3 Radiation Work Permit Issued, if required: Number Not Required

4.4 Permission to initiate test — Reigel (Shift Supervisor) — 1-19-83 (Date)

5.0 PROCEDURE

5.1 PRELIMINARY CHECKS

5.1.1 The temperatures are to be read when the reactor power level is ≥ 50% or the core Δp is ≥ 3 psid and,

a) As soon as possible after weekly control rod drop tests (SR 5.1.1b-M) have been performed.

b) When the reactor steady-state power level is changed ±10% or more. This test can be done at the same time that the linear power channels are calibrated because of the change in the power level.

✓

5.2 TEST PROCEDURE (FOR DATA COLLECTION ONLY)

5.2.1 The temperatures to be read are the CRD motor, orifice valve motor plate and upper helium environment temperatures of the CRD's which have had RTD's (Resistance Temperature Devices) installed in the aforementioned areas. RTD's will eventually be installed in all the CRD assemblies as the CRD's are pulled out for maintenance and refueling over the next few years. (See data sheets for recording of temperatures.)

Kathy Long 1-26-83
Test Conductor Signature Date

5.2.2 All temperatures should be less than 300°F, if not, contact Results Department Supervisor. ✓

Test Conductor Signature   1-20-83 Date

DATA SHEET

Reactor POWER 70 %

Average Core Inlet Temp. 653 °F

Core ΔP PSID 2.68

Primary Coolant Flow 76.2 %

REGION	ORIFICE POSITION (% OPEN)	CRD POSITION (INCHES)	CRD MOTOR TEMP. (°F)	ORIFICE VALVE MOTOR PLATE TEMP. (°F)	UPPER HELIUM ENVIRONMENT TEMP. (°F)
15	24.1	[illegible]	156.2	172.4	145.4
4	NA	192.1	159.8	192.2	158
34	18.1	190.2	192.2	203	206.6
31	21.4	190.2	190.6	186.8	172.4
5	62.0	190.2	213.1	230.7	[illegible]
35	33.6	188.5	185.6	230.3	NA

Kathy Long
Test Conductor Signature

1-20-83
Date

DATA SHEET

Reactor POWER ________ % Average Core Inlet Temp. ________ °F

Core ΔP PSID ________ Primary Coolant Flow ________ %

REGION	ORIFICE POSITION (% OPEN)	CRD POSITION (INCHES)	CRD MOTOR TEMP. (°F)	ORIFICE VALVE MOTOR PLATE TEMP. (°F)	UPPER HELIUM ENVIRONMENT TEMP. (°F)

Kathy Long
Test Conductor Signature

1-20-83
Date

6.0 TEST CONDUCTOR'S REPORT

6.1 Were any procedure changes or deviations made to the test and DCCF/PDR initiated? (Attach copies if applicable)
Yes____ No ✓

6.2 Were all steps successfully completed as stated in test.
Yes ✓ No ~~__~~

6.3 If the answer to 6.2 is NO, notify Department Supervisor and list conditions and/or PTR number(s):

NA

6.4 Test completed except for items noted in 6.3

Kathy Long ____ 1-20-83
Test Conductor ____ Date

6.5 Test sheets and data sheets reviewed and approved except for items noted in 6.3

[signature] ____ 1-20-83
Department Representative ____ Date

7.0 DEPARTMENT SUPERVISOR'S/TEST CONDUCTOR'S REVIEW

(If the answer to 6.2 is YES, sections 7.0 and 8.0 are not applicable go to Section 9.0)

7.1 Does the failure described in 6.3 require any action or impose any limit to operation per the applicable LCO(s)?
Yes____ No____ N/A____

7.2 Applicable LCO(s)________

Action or Limit________

7.3 Is the reason test is not being completed at this time due to plant or equipment status?
Yes____ No____ N/A____

7.4 If the answer to 7.3 is YES, list condition(s) and/or PTR number(s):

____

7.5 Is retest necessary for items listed in 6.3 and/or 7.4?
Yes____ No____ N/A____

7.6 If the answer to 7.5 is YES; list specific section(s) or step(s) to be retested.

____

Dept. Supervisor/Test Conductor — Date

8.0 RETEST SECTION
(If the answer to 7.5 is NO go to Section 9.0)

8.1 Verify satisfactory retest of section(s) or step(s) listed in 7.6

Retest Conductor — Date

8.2 Retest reviewed.

Department Representative — Date

9.0 APPROVALS

9.1 Test results approved. Satisfactory results confirm compliance with applicable LCO(s).

[signature] — 1-20-83
Department Supervisor — Date

9.2 Notification of satisfactory test results and test conclusion:

W. Franklin — 1-20-83
Shift Supervisor — Date

9.3 Requires Station Manager evaluation:

Department Supervisor — Date

9.4
Station Manager — Date

10.0 DATA SHEETS RECEIVED, VERIFIED SECTION 9.0 COMPLETE, AND SURVEILLANCE TEST RECORDS UPDATED.

Darlene Horehan — 1-20-83
Scheduling Technician — Date

RECC'D 6-17-81

GENERAL ATOMIC COMPANY
P.O. BOX 81608
SAN DIEGO, CALIFORNIA 92138
(714) 455-3000

June 9, 1981
GP-1014

SYS-12

Mr. D. W. Warembourg
Manager, Nuclear Production
Public Service Company of Colorado
16805 Road 19 1/2
Platteville, CO 80651

Subject: Fort St. Vrain Control Rod Drive Mechanism - Thermal Expansion Effects

Dear Mr. Warembourg:

In the process of reviewing the function of the Fort St. Vrain control rod drive mechanism, a concern was raised regarding potential for gear jamming under worst case tolerance stack-up and high temperature operating conditions. Although this was considered to be a highly unlikely event, a review was initiated at GAC expense to quantify the extent of any potential interference and to assess the likelihood of encountering a problem.

Results of these investigations showed that the chances of encountering a failure to scram is extremely remote (less than 1 in 1,000,000). In addition, the rod drop surveillance tests, currently conducted regularly during plant operation and as higher temperatures are encountered during fluctuation testing above 70% power, give positive assurance that the mechanism remains functional.

The following summary memos and design calculations are enclosed for your information and use:

1) CE:MDD:RR:124:81, "Control Rod Drive Mechanism - Thermal Expansion Effects," dated 31 March 1981.

2) CE:MDD:ECH:123:81, "Thermal Expansion of the Control Rod Mechanisms at 280^{o}F," dated 31 March 1981.

3) SAB:035:RL:81, "Control Rod Drive Clearances," dated 24 March 1981.

NO RESPONSE REQ'D

4) Design Doc. No. 906015, "Control Rod Drive Clearances," dated May 11, 1981.

5) Design Doc. No. C-12-006, "Control Rod Drive Component Clearances at 280°F," dated April 22, 1981.

A copy of this material has been sent to Mr. Swart by separate letter. Should you have any questions, please contact R. Rosenberg at (714) 455-2174.

Very truly yours,

for

William A. Graul, Manager
Fort St. Vrain Project

Enclosures

INTERNAL CORRESPONDENCE

GA 1076

FROM R. Rosenberg RR

TO G. Bramblett

IN REPLY REFER TO Proj. 1900

CE:MDD:RR:124:81

DATE March 31, 1981

SUBJECT Control Rod Drive Mechanism - Thermal Expansion Effects

Ref: a) Memo CE:MDD:ECH:123:81, E. C. Harvey to R. Rosenberg, "Thermal Expansion of Control Rod Drive at 280°F" dated 3/31/81.

b) Memo SAB:035:RL:81, R. Leary to Files, "Control Rod Drive Clearances" dated 3/24/81.

The effects of thermal expansion on the ability of the control rod drives to scram upon demand were assessed (see Reference a, attached) for environmental temperatures up to 280°F.

Under worst case tolerance stack-up conditions two areas were found where gears potentially could jam, however, an in-depth review of both areas has lead to the conclusion the control rod drives should perform the scram function normally.

In the first instance a situation starting at 120°F could occur in the instrument gear train which would cause these gears to jam (again, assuming worst case tolerance stack-ups). However, sufficient torque is produced by the dead weight of the control rods to fail the jammed gear teeth and permit a scram to occur.

In the second instance, jamming of the main gear train under worst case conditions could occur at 145°F. Reference b examines the probability of the multiplicity of tolerances involved all going to their maximum limits and also aligned to produce the worst case conditions. The conclusion of reference b) is the chances of this occurring in one drive are less than 1 in 1,000,000 and in two or more drives the chances are less than 1 in 1,000,000,000.

RR:cc

cc: R. A. B. Old
E. Harvey
R. Leary
D. Alberstein
EDF

INTERNAL CORRESPONDENCE

GA 1076

FROM E. C. Harvey *E C Harvey*

TO R. Rosenberg

IN REPLY REFER TO Proj. 1900 CE:MDD:ECH:123:81

DATE March 31, 1981

SUBJECT Thermal Expansion of the Control Rod Drive Mechanisms at 280°F

Ref.
1. "Control Rod Drive Clearances at 280°F", E. C. Harvey, Document C-12-006, 29 January 1981.
2. "Thermal Expansion of the Control Rod Drive Assembly Components at 280°F", E. C. Harvey, Memo MHE:MDD:ECH:65:81.
3. "Control Rod Clearances", R. Leavy, Memo SAB:035:RL:81.

SUMMARY

An analysis, reference 1, was made to determine the maximum (best) or minimum (worse) case clearances between various components on the Ft. St. Vrain Control Rod Drive Assembly at a temperature of 280°F. No problems are anticipated due to the increase in clearance between the main drive bearing bushings and the housings (see Figures 1 and 2). Also, no pr blems are anticipated due to the resultant clearance increase between the bearing bushings located in the guide pulley assembly (see Figure 3). The potentiometer gear train, see Figure 2, has two aluminum gears in mesh with stainless steel gears. The gears are mounted on shafts in meehanite castings. This combination of materials results in a worse case interference of .0032 inches due to a net center distance decrease between the gears. If the tolerance build-up at 280°F results in an interference condition, the torque available at the drum shaft, due to the static weight of the control rod, is sufficient to strip the aluminum gear teeth, thus a scram would not be inhibited. However, a loss of position readout and "rod-in" indication would occur.

A potential .0007 inch interference is possible between two gears in the main drive gear system at 280°F for a worse case tolerance condition, which could inhibit a control rod scram. However, it is extremely unlikely that all components will in fact be at the worst tolerance. A statistical analysis was made, see reference 3, and based on conservative assumptions, a very low ($\sim 10^{-6}$) probability of an interference in any given drive is calculated. The probability of two or more interferences among the 37 control rod drives is found to be extremely remote ($\sim 10^{-9}$).

DISCUSSION OF ANALYSIS

1. Bushing SLR-D1201-209 and Housing SLR-D1201-207 (see Figure 1)

The stainless steel bushing is press-fitted into an aluminum housing at room temperature. A worse case clearance of .0007 inches is possible at 280°F. The switch assembly housing will retain the bushing, and no problems are anticipated.

2. Gear SLR-D1201-208 and Housing SLR-D1201-207 (see Figure 2)

The stainless steel gear is press-fitted into the aluminum housing at room temperature. A worse case clearance of .0007 inches is possible at 280°F. The gear is held in place by a dog-point set screw, and is therefore acceptably retained.

3. Bearing SLR-D1201-259 and Bushing SLR-D1201-209, plus Bearing SLR-D1201-260 and Gear SLR-D1201-208 (see Figure 1)

A .0007 inch worse case clearance exists at room temperature. The materials are similar, therefore the same clearance would exist at 280°F.

4. Potentiometer Gear Train SLR-D1201-208, -239, -241, -242, and Housings SLR-D1201-230, -231 (see Figure 2)

Gears and Housings Part Numbers	Center Distance Decrease at 280°F	Clearance at 68°F		Resultant Clearance or Interference at 280°F	
		Min.	Max.	Worst Tolerance Case	Best Tolerance Case
SLR-D1201-208, -239 SLR-D1201-230, -231	.0019"	*.0004"	.0132"	Interference .0015"	Clearance .0013"
SLR-D1201-241, -242 SLR-D1201-230, -231	.0041"	.0009"	.0153"	Interference .0032"	Clearance .0112"

*At 280°F

A potential interference condition exists between both pairs of gears in the potentiometer gear train (see tabulation above and graph number 1). If an interference condition occurs the torque available at the drum shaft due to static weight of the control rod is sufficient to strip the aluminum gear teeth. A force four times the ultimate bending strength of the gear teeth exists in the event of an interference, thus a scram would not be inhibited, however a loss of position readout and "rod-in" indication would occur.

5. Guide Pulleys SLR-D1201-213, -1, -2, -3 and Bushings SLR-D1201-213-4, -5, plus Bearings SLR-D1201-216 (see Figure 3)

The stainless steel bushings are press-fitted into the aluminum pulleys at room temperature. A worse case clearance equal to .0005 inches maximum is possible at 280°F. The bushings in the pulley, and the pulleys are not held captive at 280°F, thus the rotation of the pulleys could be inhibited. If this were to occur a scram would not be inhibited, because the cables would slide.

The bearings and bushings are manufactured from similar materials, therefore, the tolerance fit that exists at room temperature would exist at 280°F.

6. Ring Gear SLR-D1201-202-7 and Pinion SLR-D1201-202-6 (see Figure 1)

The pinion and ring gear engagement clearance (worse case) increases .0006 inches at 280°F, and therefore no problem at this location is expected.

7. Gear Train SLR-D1201-202-2, -3, -4, -5, -6, -10, -11 and Housings SLR-D1201-230, -231 (see Figure 1)

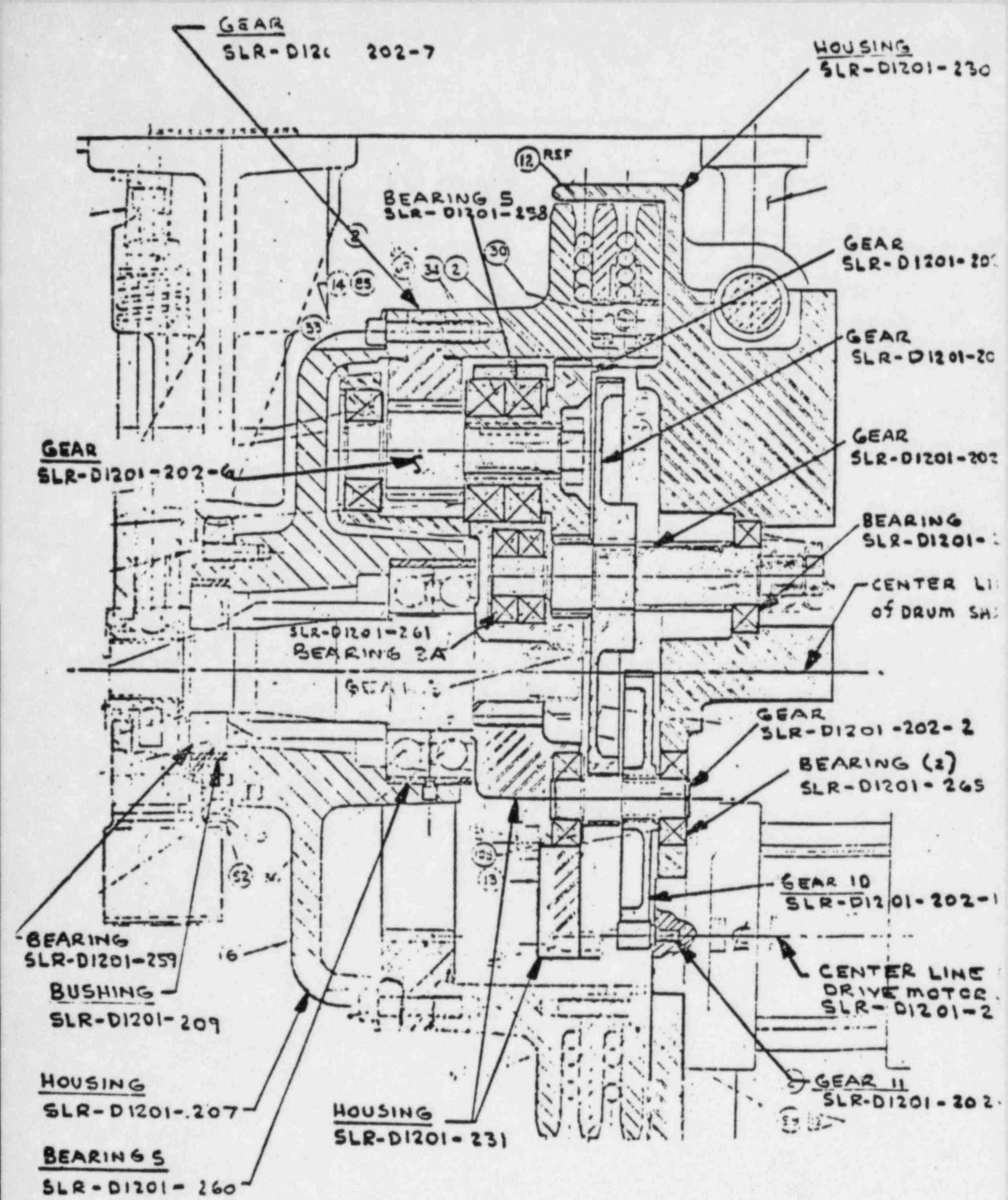
Gears and Housings Part Numbers	Center Distance Decrease at 280°F	Clearance at 68°F		Resultant Clearance or Interference at 280°F	
		Min.	Max.	Worst Tolerance Case	Best Tolerance Case
SLR-D1201-202-10, -11 and SLR-D1201-217, -230, -231	.0007"	.0009"	.0150"	Clearance .0002"	Clearance .0157"
SLR-D1201-202-2, -3 and SLR-D1201-230, -231	.0011"	.0004"	.0130"	Interference .0007"	Clearance .0119"
SLR-D1201-202-4, -5 and SLR-D1201-230, -231	.0006"	.0008"	.0206"	Clearance .0002"	Clearance .0200"

The gears are manufactured from nitralloy 135 and are mounted in meehanite castings. The center distance decreases on each mating gear set at 280°F (see tabulation above). A potential .0007 inch interference is possible between gears SLR-D1201-202-3 and -4 for a worse case tolerance condition at 280°F, which would inhibit a control rod scram. However, this same pair of gears

could have a maximum clearance of .0119 inches for a best tolerance case. This relationship is shown in graph number 2. It is extremely unlikely that all the tolerances (17) will be in a worse case condition. A statistical analysis was made, see reference 3, and based on what are believed to be conservative assumptions a very low ($\sim 10^{-6}$) probability of an interference in any given drive is calculated. The probability of two or more interferences among 37 control rod drives is found to be extremely remote ($\sim 10^{-9}$). If the control rods are lowered 3.1 inches during control rod surveillance drop tests, gear SLR-D1201-202-3 would rotate one revolution. This would be an indication that no interference exists.

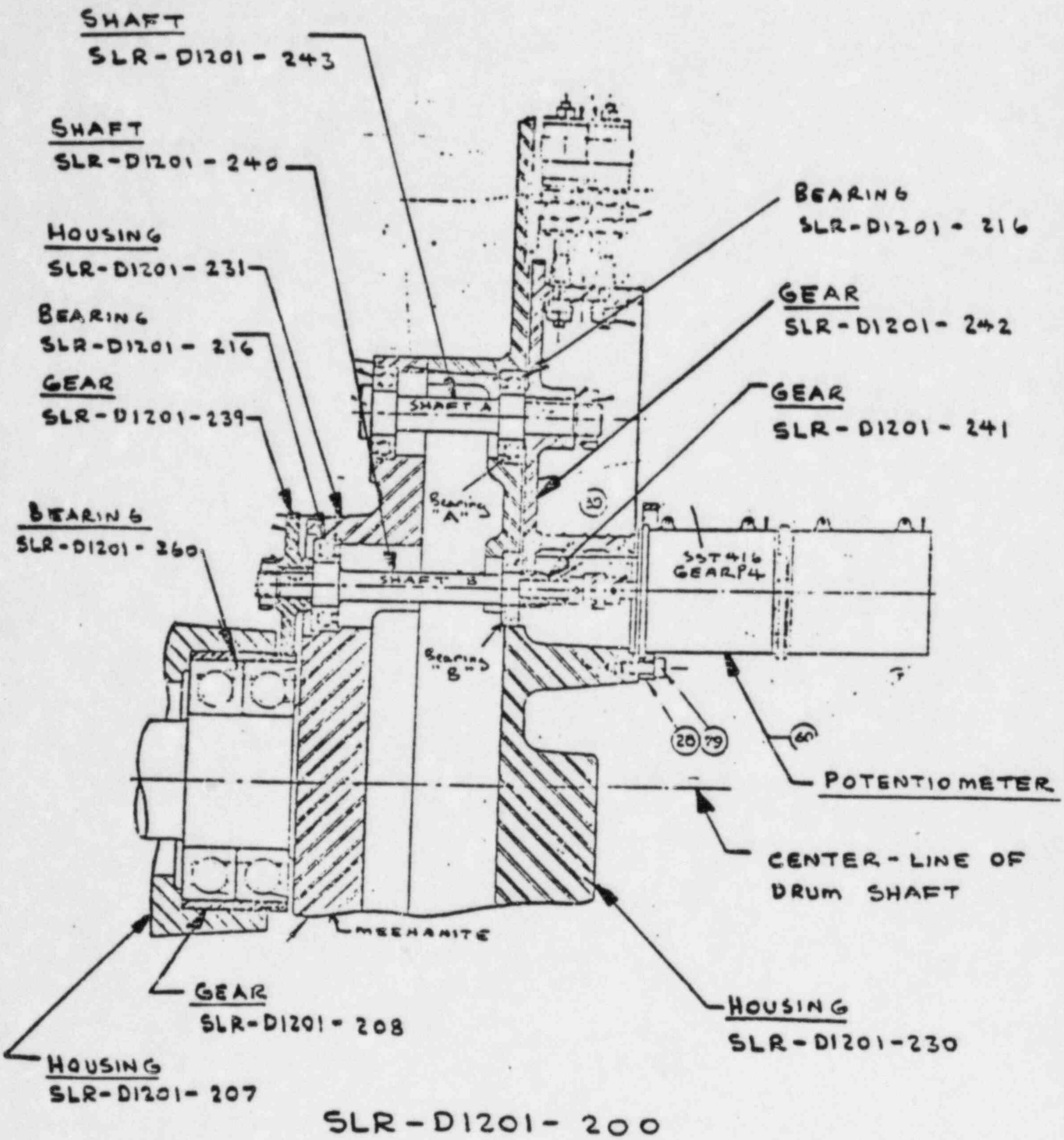
ECH:cc

cc: D. Alberstein
J. K. Anderson
G. C. Bramblett
B. C. Hawke
R. A. B. Old
EDF



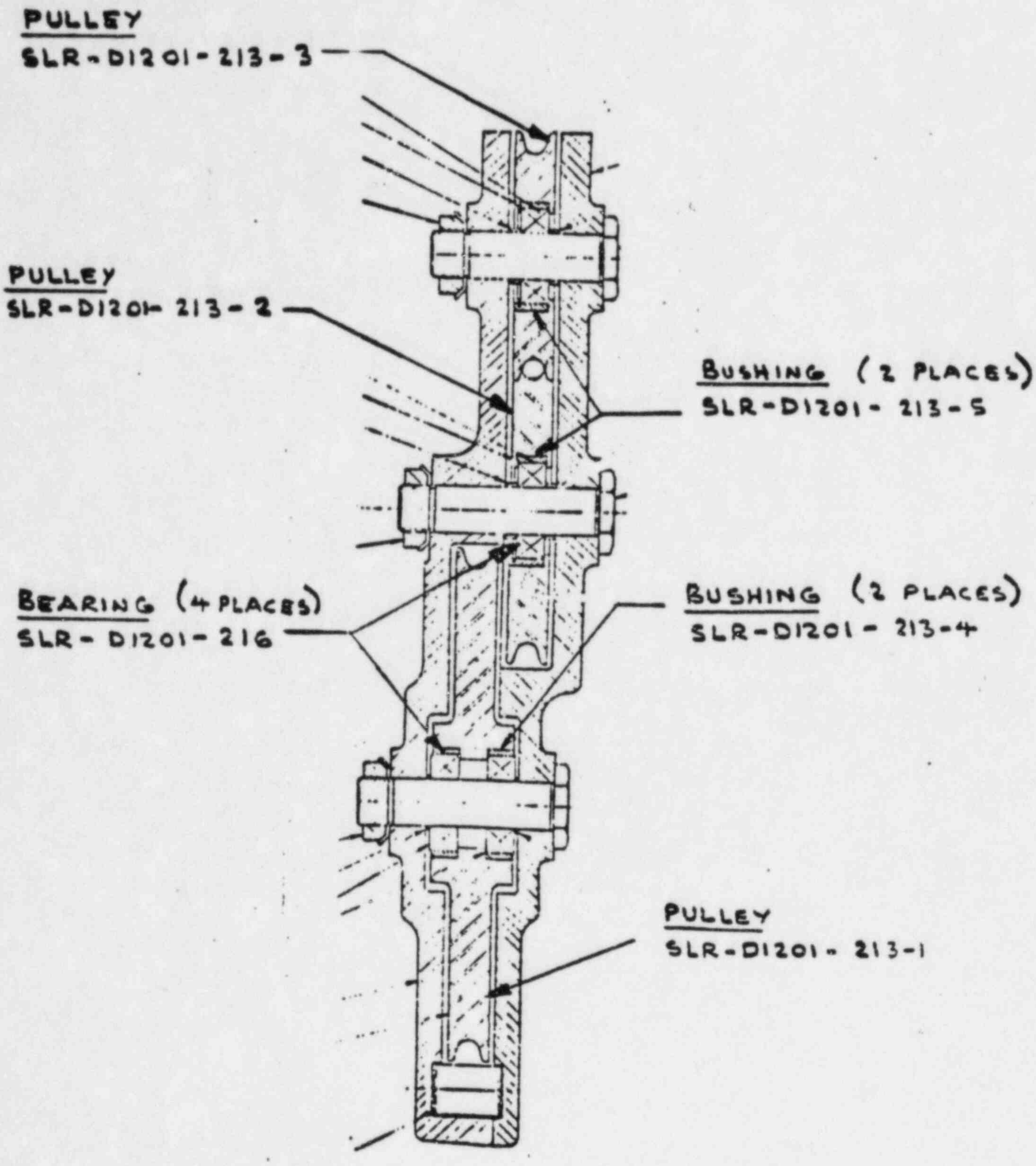
SLR-D1201-200
CONTROL ROD DRIVE GEARS ASSEMBLY

FIGURE 1



SLR-D1201-200
POTENTIOMETER DRIVE ASSEMBLY

FIGURE 2

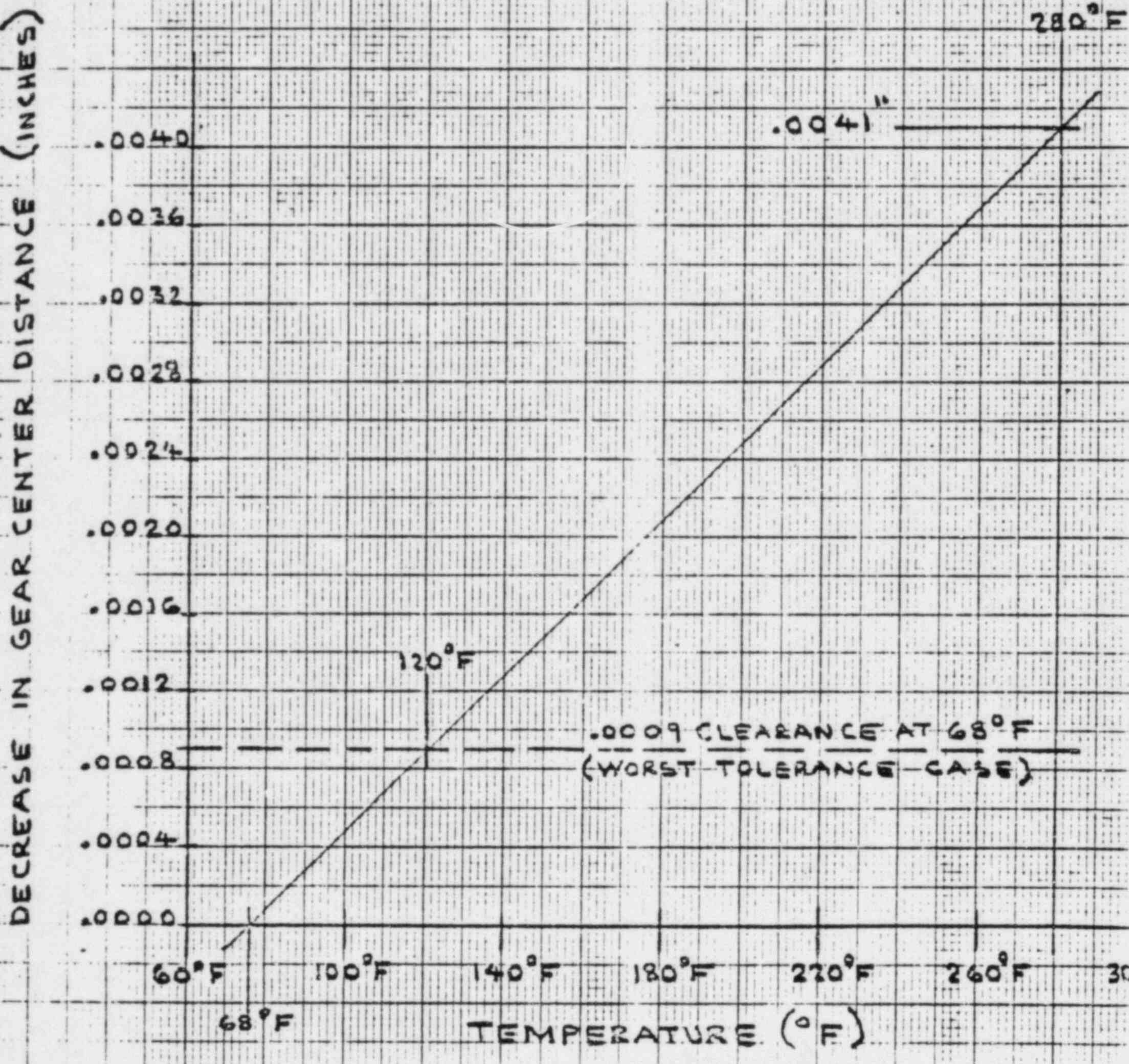


SLR-D1201-210
GUIDE PULLEY ASSEMBLY

FIGURE 3

GEARS — POTENTIOMETER DRIVE
SLR-D1201-241 and
SLR-D1201-242

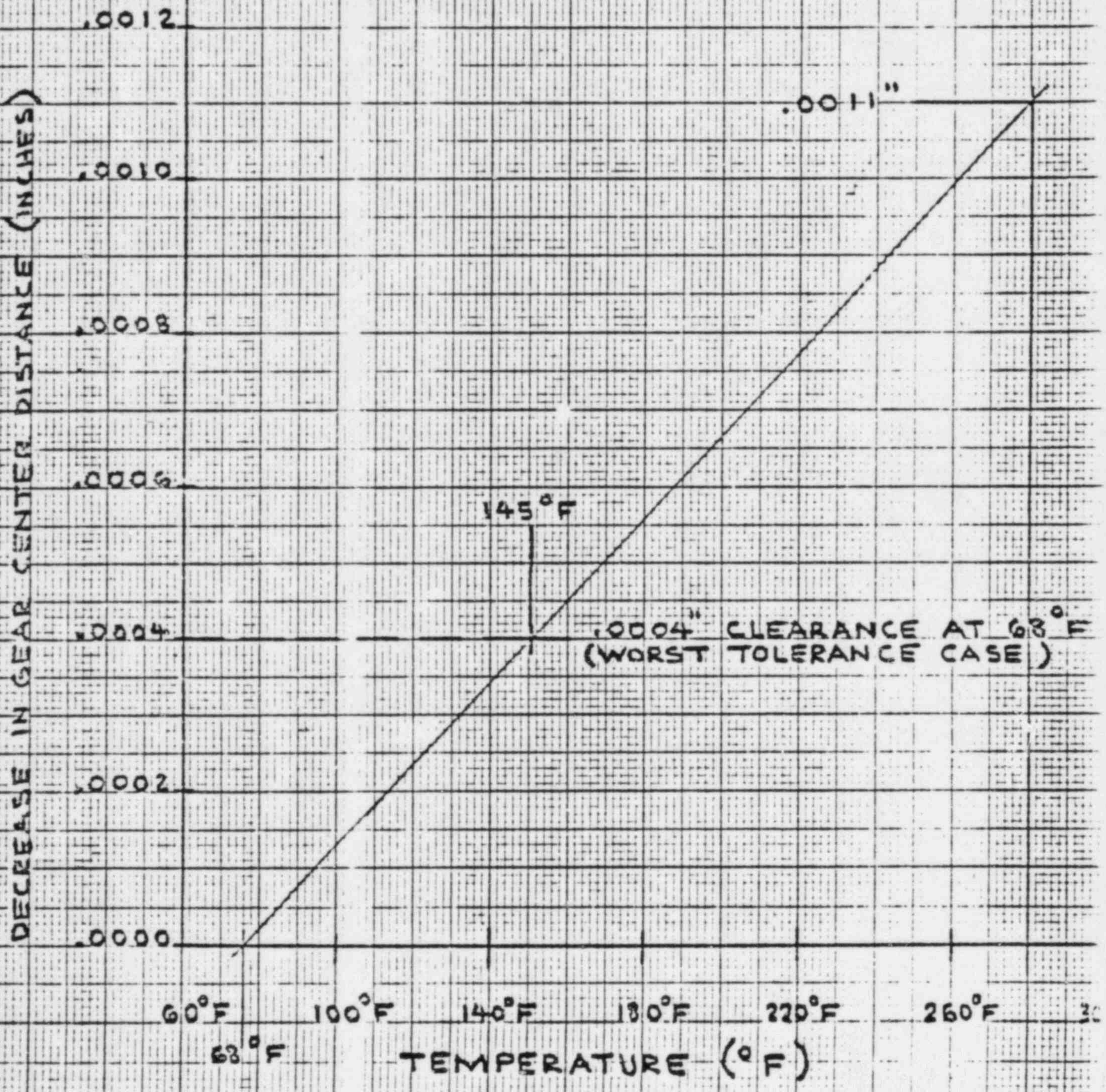
NOTE: .0153" CLEARANCE EXISTS AT 68°F FOR A BEST TOLERANCE CASE.



GRAPH No 1

GEARS - MAIN DRIVE TRAIN
SLR-D1201-202-2 and -3

NOTE: .0130" CLEARANCE EXISTS AT 68°F FOR A BEST TOLERANCE CASE



GRAPH No 2

INTERNAL CORRESPONDENCE

GA 1076

FROM R. Leary *RHL*

TO Files

IN REPLY REFER TO SAB:035:RL:81·

DATE March 24, 1981

SUBJECT Control Rod Drive Clearances

Ref. 1.: "Control Rod Drive Clearances at 280°F," E. C. Harvey, Document C-12-006.

SUMMARY

In the cited reference, a "worst" case control rod drive clearance analysis for gears 2 and 3 is presented which indicates a possible interference at 280°F. Seventeen components of the total clearance are identified together with their associated tolerances. If the most unfavorable tolerance is selected for each component, a minimum clearance of 0.0004" at 68° results. This is not sufficient to accommodate an anticipated 0.0011" center distance decrease at 280°F. However, it is extremely unlikely that all seventeen components will in fact be at the "worst" tolerance. The analysis presented here treats this problem from a statistical point of view. Based on what are believed to be conservative, even pessimistic, assumptions, a very low ($\sim10^{-6}$) probability of an interference in any given drive is calculated. The probability of two or more interferences among 37 control rod drives is found to be extremely remote - $\sim10^{-9}$.

DISCUSSION

The tolerances from Ref. 1 for the seventeen components of the total clearance for gears 2 and 3 are presented in the "worst" and "best" condition columns in Table 1. If the "worst" condition values are summed, the overall clearance is 0.0004' at 68°F. This is not adequate to allow an anticipated 0.0011" center distance decrease at 280°. However, it is implausible that all seventeen components will actually be at the "worst" condition tolerance. In order to estimate the actual probability of an interference, a statistical treatment is necessary.

The following assumptions are made.

i) The seventeen components of the total clearance are independent and additive — that is, the total clearance is simply the sum of the individual components.

ii) Each component can be treated as a random variable with a normal (Gaussian) distribution. The mean and standard deviation, due to lack of explicit data, are determined using engineering judgment.

Table 1

	Worst Condition	Best Condition	"Mean"	Standard Deviation
a) Gear 2 — composite tol.	0.0008	0.0000	0.00060	0.00010
b) Gear 3 — composite tol.	0.0011	0.0000	0.00083	0.00014
c) Tooth thinning				
Gear 2	(0.0024)	(0.0047)	(0.00355)	0.00058
Gear 3	(0.0027)	(0.0054)	(0.00405)	0.00068
d) Radial play — bearing 10A	(0.0004)	(0.0006)	(0.00050)	0.00005
e) Radial runout — bearing 10A	0.0006	0.0000	0.00003	0.00015
f) Eccentricity — bearing shafts	0.0005	0.0000	0.00038	0.00006
g) Eccentricity — housing	0.0005	0.0000	0.00038	0.00006
h) Radial clearance — housing	(0.0003)	(0.0008)	(0.00042)	0.00006
i) Radial clearance — gear 2 brg.	0.0002	(0.0001)	0.00013	0.00004
j) Radial play — bearing 4C	(0.0004)	(0.0006)	(0.00050)	0.00005
k) Radial runout — bearing 4C	0.0006	0.0000	0.00030	0.00015
l) Eccentricity — bearing shafts	0.0004	0.0000	0.00030	0.00005
m) Eccentricity — housing	0.0005	0.0000	0.00038	0.00006
n) Eccentricity — gear 3	0.0004	0.0000	0.00030	0.00005
o) Radial clearance — housing	0.0003	(0.0003)	0.00015	0.00008
p) Radial clearance — brg. 4C	(0.0001)	(0.0004)	(0.00018)	0.00004
q) Radial clearance — gear 3	0.0000	(0.0004)	(0.00010)	0.00005
Clearance	(0.0004)	(0.0133)	(0.0055)	0.00093

For most components, engineering judgment indicates that the manufacturing process might bias the mean toward the "worst" condition side of the tolerance range. For such components, a mean value was computed from a weighted average of the "worst" and "best" condition values, with 75% weighting on the "worst" value. Thus the assumed mean value is three times closer to the "worst" condition than the "best." The assumed standard deviation is half the difference between the mean and the "worst" value, so the "worst" value is a "2σ" limit on the distribution. For several components, namely c, d, e, j, and k in Table 1, it was thought that the manufacturing process might bias the mean toward the "best" condition or at least no worse than the midpoint of the tolerance range. Here a 50% weighting on both the "worst" and "best" values (i.e. range midpoint) was used. The standard deviation was calculated as above.

The assumed means and standard deviations are listed in Table 1. It follows from assumption i) and the laws of statistics that the mean clearance is the sum of the individual component means with standard deviation equal to the square root of the sum of the squares of the individual component standard deviations. These values are computed to be

Mean Clearance	0.0055"
Standard Deviation	0.00093"

Based on these values, the probability of an interference at 280° or equivalently a clearance of less than 0.0011" at 68° can be found from tables of the normal distribution. It is seen that the value 0.0011" is approximately 4.7 standard deviations below the mean clearance, i.e.,

$$(0.0055 - 0.0011)/0.00093 = 4.7$$

The probability of obtaining a value this small is extremely remote — actually beyond the limits of most tables of the normal distribution. A useful approximation for such extreme values is given by

$$P(x) = \frac{1}{\sqrt{2\pi}} \frac{e^{-x^2/2}}{x}$$

where $P(x)$ is the probability of obtaining a value more than x-standard deviations below the mean. For $x = 4.7$, the formula yields a probability of 1.4×10^{-6}.

Based on this value, the probability of a single interference among 37 control rod drives is approximately 5×10^{-5}. The probability of two interferences is given by

$$\binom{37}{2}\left(1.4 \times 10^{-6}\right)^2 \left(1 - 1.4 \times 10^{-6}\right)^{35}$$

$$= 1.3 \times 10^{-9}$$

The probability of more than two interferences is so remote as to be negligible.

RL:sc

cc: D. Alberstein
G. Brambiett
W. Davison
W. Graul
E. Harvey
R. Old
W. Simon

GA 1485(REV. 11/80)

ISSUE SUMMARY

TITLE: Control Rod Drive Clearances	☐ R & D ☐ DV & S ☒ DESIGN	APPROVAL LEVEL 2

DISCIPLINE	SYSTEM	DOC. TYPE	PROJECT	DOCUMENT NO.	ISSUE NO./LTR.
M	12	CFL	1900	906015	A

QUALITY ASSURANCE LEVEL	SAFETY CLASSIFICATION	SEISMIC CATEGORY	ELECTRICAL CLASSIFICATION
I	2	I	IE

1 RELEASED

ISSUE	DATE	PREPARED BY	APPROVAL ENGINEERING	APPROVAL QA	APPROVAL PROJECT	ISSUE DESCRIPTION
A	MAY 11 1981	R. Leary RH.L.	W. Davison	Petty-cord	G. Bramblett Ro. A.G.Bramblett	Initial Release

CONTINUE ISSUE SUMMARY ON GA FORM 1485-1.

FT. ST. VRAIN
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Prior to Use

NEXT INDENTURED DOCUMENTS

905982

REV																												
SH																												
REV																												
SH	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56
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SH	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28

GENERAL ATOMIC COMPANY

CALCULATIONS FOR Control Rod Drive Clearances						NEXT IND DOC
EQUIP. NO	DISC	SYSTEM 12	DOC. TYPE CFL	PROJ. 1900	DOC. NO. 906015-	PAGE 2 OF 6
PREPARED BY R. Leary		DATE 4/29/81	INDEP. REVIEWER H. St. John			DATE 4/29/81
REVIEWED BY H. St. John		DATE 4/29/81	REF. DOCUMENTS:			
APPROVED BY W. Davison		DATE 4/29/81				

SUMMARY

In the cited reference, a "worst" case control rod drive clearance analysis for gears 2 and 3 is presented which indicates a possible interference at 280°F. Seventeen components of the total clearance are identified together with their associated tolerances. If the most unfavorable tolerance is selected for each component, a minimum clearance of 0.0004" at 68° results. This is not sufficient to accommodate an anticipated 0.0011" center distance decrease at 280°F. However, it is extremely unlikely that all seventeen components will in fact be at the "worst" tolerance. The analysis presented here treats this problem from a statistical point of view. Based on what are believed to be conservative, even pessimistic, assumptions, a very low ($\sim 10^{-6}$) probability of an interference in any given drive is calculated. The probability of two or more interferences among 37 control rod drives is found to be extremely remote - $\sim 10^{-9}$.

DISCUSSION

The tolerances from Ref. 1 for the seventeen components of the total clearance for gears 2 and 3 are presented in the "worst" and "best" condition columns in Table 1. If the "worst" condition values are summed, the overall clearance is 0.0004" at 68°F. This is not adequate to allow an anticipated 0.0011" center distance decrease at 280°. However, it is implausible that all seventeen components will actually be at the "worst" condition tolerance. In order to estimate the actual probability of an interference, a statistical treatment is necessary.

The following assumptions are made.

i) The seventeen components of the total clearance are independent and additive — that is, the total clearance is simply the sum of the individual components.

ii) Each component can be treated as a random variable with a normal (Gaussian) distribution. The mean and standard deviation, due to lack of explicit data, are determined using engineering judgment.

Ref. 1. "Control Rod Drive Clearances at 280°F," E. C. Harvey, Document C-12-006.

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i) Radial clearance — gear 2 brg.	0.0002	(0.0001)	0.00013	0.00004
j) Radial play — bearing 4C	(0.0004)	(0.0006)	(0.00050)	0.00005
k) Radial runout — bearing 4C	0.0006	0.0000	0.00030	0.00015
l) Eccentricity — bearing shafts	0.0004	0.0000	0.00030	0.00005
m) Eccentricity — housing	0.0005	0.0000	0.00038	0.00006
n) Eccentricity — gear 3	0.0004	0.0000	0.00030	0.00005
o) Radial clearance — housing	0.0003	(0.0003)	0.00015	0.00008
p) Radial clearance — brg. 4C	(0.0001)	(0.0004)	(0.00018)	0.00004
q) Radial clearance — gear 3	0.0000	(0.0004)	(0.00010)	0.00005
Clearance	(0.0004)	(0.0133)	(0.0055)	0.00093

For most components, engineering judgment indicates that the manufacturing process might bias the mean toward the "worst" condition side of the tolerance range. For such components, a mean value was computed from a weighted average of the "worst" and "best" condition values, with 75% weighting on the "worst" value. Thus the assumed mean value is three times closer to the "worst" condition than the "best." The assumed standard deviation is half the difference between the man and the "worst" value, so the "worst" value is a "2σ" limit on the distribution. For several components, namely c, d, e, j, and k in Table 1, it was thought that the manufacturing process might bias the mean toward the "best" condition or at least no worse than the midpoint of the tolerance range. Here a 50% weighting on both the "worst" and "best" values (i.e. range midpoint) was used. The standard deviation was calculated as above.

The assumed means and standard deviations are listed in Table 1. It follows from assumption i) and the laws of statistics that the mean clearance is the sum of the individual component means with standard deviation equal to the square root of the sum of the squares of the individual component standard deviations. These values are computed to be

Mean Clearance	0.0055"
Standard Deviation	0.00093"

Based on these values, the probability of an interference at 280° or equivalently a clearance of less than 0.0011" at 68° can be found from tables of the normal distribution. It is seen that the value 0.0011" is approximately 4.7 standard deviations below the mean clearance, i.e.,

$$(0.0055 - 0.0011)/0.00093 = 4.7$$

The probability of obtaining a value this small is extremely remote — actually beyond the limits of most tables of the normal distribution. A useful approximation for such extreme values is given by

$$P(x) = \frac{1}{\sqrt{2\pi}} \frac{e^{-x^2/2}}{x}$$

where P(x) is the probability of obtaining a value more than x-standard deviations below the mean. For x = 4.7, the formula yields a probability of 1.4×10^{-6}.

Based on this value, the probability of a single interference among 37 control rod drives is approximately 5×10^{-5}. The probability of two interferences is given by

$$\binom{37}{2}\left(1.4 \times 10^{-6}\right)^2 \left(1 - 1.4 \times 10^{-6}\right)^{35}$$

$$= 1.3 \times 10^{-9}$$

The probability of more than two interferences is so remote as to be negligible.

GA1543(REV. 11/80)

CALCULATION REVIEW REPORT

TITLE: Control Rod Drive Clearances

APPROVAL LEVEL 2

QAL LEVEL I

DISCIPLINE	SYSTEM	DOC. TYPE	PROJECT	DOCUMENT NO.	ISSUE NO./LTR.
M	12	CFL	1900	906015	A

INDEPENDENT REVIEWER:

NAME H. E. St. John

ORGANIZATION 612

REVIEWER SELECTION APPROVAL: BR MGR [signature] DATE 4/22/81

REVIEW METHOD:	YES	NO	ERROR DETECTED
ARITHMETIC CHECK	✓		none
LOGIC CHECK	✓		none
ALTERNATE METHOD USED			
SPOT CHECK PERFORMED	✓		none
COMPUTER PROGRAM USED			

REMARKS: (ATTACH LIST OF DOCUMENTS USED IN REVIEW)

The calculations indicate that out of 37 control rod drives we may expect, on the average, that 5.2×10^{-5} drives will fail. This number is sufficiently remote to justfy the calculational technique and assumptions.

CALCULATIONS FOUND TO BE VALID AND CONCLUSIONS TO BE CORRECT:

INDEPENDENT REVIEWER [signature] DATE 4/30/81

SIGNATURE

GA 1485(REV. 11/80)

ISSUE SUMMARY

TITLE: CONTROL ROD DRIVE COMPONENT CLEARANCES AT 280°F

☐ R & D
☐ DV & S
☐ DESIGN

APPROVAL LEVEL 2

DISCIPLINE	SYSTEM	DOC. TYPE	PROJECT	DOCUMENT NO.	ISSUE NO./LTR.
M	12	CFL	1900	C-12-006	A

QUALITY ASSURANCE LEVEL	SAFETY CLASSIFICATION	SEISMIC CATEGORY	ELECTRICAL CLASSIFICATION
I	2	I	1E

3 RELEASED

ISSUE	DATE	PREPARED BY	APPROVAL: ENGINEERING	APPROVAL: QA	APPROVAL: PROJECT	ISSUE DESCRIPTION
A	APR 2 2 1981	E.C.Harvey	R.Rosenberg	D.Pettycord	G.C.Bramblett	Initial Issue Originating Project: 1981-100

CONTINUE ISSUE SUMMARY ON GA FORM 1485-1.

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NEXT INDENTURED DOCUMENTS

GADR-10

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SH																												
REV																												
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REV																												
SH	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28

GA 268 A REV. 9-77

GENERAL ATOMIC COMPANY

CALCULATIONS FOR Control Rod Drive Component Clearances at 280°F						NEXT IND DOC GADR 10
EQUIP. NO D-1201	DISC M	SYSTEM 12	DOC. TYPE CFL	PROJ. 1900	DOC. NO C-12-006/A	PAGE 2 OF
PREPARED BY E.C.Harvey		DATE 3/13/81	INDEP. REVIEWER B.C.Hawke			DATE
REVIEWED BY R. Old		DATE 3/13/81	REF. DOCUMENTS:			
APPROVED BY R. Rosenberg		DATE 3/13/81	SLR-D1201-200			

GA 268 REV. 6-79

GENERAL ATOMIC COMPAN .

CALCULATIONS FOR CONTROL ROD DRIVE COMPONENT CLEARANCES AT 230°F			
EQUIP. NO. D1201	PROJ. NO. 1900	CALC. NO. C-12-006/A	PAGE 3 OF 45
PREPARED BY E. HARVEY	DATE 29 JAN 81	REF. DOCUMENTS: CHARGE Nº 1981-100	
REVIEWED BY	DATE		
APPROVED BY	DATE	DOCUMENT GADR 10	

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CALCULATIONS FOR CONTROL ROD DRIVE COMPONENT CLEARANCES AT 280°F			
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1.0 INTRODUCTION & SUMMARY

THIS ANALYSIS DETERMINES THE CLEARANCES BETWEEN SEVERAL COMPONENTS IN THE CONTROL ROD DRIVE ASSEMBLY AT A TEMPERATURE OF 280°F.

1.1 The BEARING Sleeves will have a maximum diametral clearance of .0007 AT 280°F. The sleeves are not restrained and could move horizontally (Calc 3.1 THRU 3.4, 3.6 and 3.7)

1.2 The potentiometer gear train has two aluminum gears. The center distance between gears SLR-D1201-241 & -242 decreases .0041" at 280°F. A resultant interference equal to .0030 at a worse tolerance condition exists, however, at a best tolerance condition a clearance equal to .0112 is possible. The torque available at the drum shaft is sufficient to strip the aluminum gears. Loss of position readout would occur. (Calc. 3.5)

1.3 The Ring Gear & Pinion SLR-D1201-202-6 & -7 engagement clearance will increase .0006" at 280°F (Calc. 3.8)

1.4 Main Gear Drive Train Engagement at 280°F.

GEARS (Calc. 3.9)	CENTER DISTANCE DECREASE @ 280°F	CLEARANCE AT 68°F		RESULTANT CLEARANCE/ INTERFERENCE AT 280°F WORST CASE
		MIN	MAX	
* SLR-D1201-202-2 & 3	.0011	.0004	.0130	Interference .0007
SLR-D1201-202-4 & 5	.0006	.0003	.0206	Clearance .0002
SLR-D1201-202-10 & 11	.0007	.0009	.0150	Clearance .0002

Approximate Control Rod Stroke to move gear SLR-D1201-202-3 one revolution equals 3.05"

* PROBABILITY ANALYSIS SHOULD BE MADE TO SHOW THAT THE .0007" INTERFERENCE IS EXTREMELY LOW.

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2.0 LIST OF MATERIAL REFERENCES

2.1 ENGINEERING ALLOY DIGEST INC. – ALUMINUM A356

ALLOY DIGEST — DATA ON WORLD WIDE METALS AND ALLOYS

ALUMINUM A356

Filing Code: Al-192
Aluminum Alloy

NOVEMBER 1969

Published by
Engineering Alloys Digest, Inc.
Upper Montclair, New Jersey

ALUMINUM A356
(Heat Treatable Aluminum Casting Alloy)

Aluminum A356 is a sand and permanent mold casting alloy that responds to an age-hardening heat treatment. It is recommended for aircraft and missile components where high strength and corrosion resistance are required.

Composition:

Silicon	6.5-7.5
Magnesium	0.20-0.40
Copper	0.20 max.
Iron	0.20 max.
Manganese	0.10 max.
Zinc	0.10 max.
Titanium	0.20 max.
Others, each	0.05 max.
, total	0.15 max.
Aluminum	Remainder

Physical Constants:

Specific gravity	2.67-2.68
Density, lb/cu.in.	0.097
Melting range, °F	1035-1135
Electrical conductivity, % IACS	39-43
Thermal conductivity, c.g.s. units	0.36-0.40
Thermal coef. expansion/°F	
68-212°F	11.9×10^{-6}
68-572°F	13.0×10^{-6}
Modulus of elasticity, psi	10.5×10^{6}

2.2 ENGINEERING ALLOY DIGEST INC – SST 440 C

ALLOY DIGEST — DATA ON WORLD WIDE METALS AND ALLOYS

ALLEGHENY LUDLUM 440C

Filing Code: SS-93
Stainless Steel

SEPTEMBER 1959

Published by
Engineering Alloys Digest, Inc.
Upper Montclair, New Jersey

ALLEGHENY LUDLUM 440C
(High-Carbon Chromium Stainless Steel, Type 440C)

ALLEGHENY LUDLUM 440C is a general purpose, hardenable high-carbon chromium steel designed to provide stainless properties with maximum hardness and high strength.

Composition:

Carbon	0.95 - 1.20
Manganese	1.25 max.
Silicon	1.00 max.
Phosphorus	0.04 max.
Sulphur	0.04 max.
Chromium	16.50 - 18.00
Molybdenum	0.75 max.
Nickel	0.50 max.
Iron	Remainder

Physical Constants:

Specific gravity	7.68
Density, lb./cu. in.	0.277
Specific heat, BTU/lb./°F. (32-212°F.)	0.11
Electrical resistance, ohms/cir. mil. ft.	361
Thermal coef. expansion/°F. (32-212°F.)	0.0000056
Thermal conductivity, BTU/ft²/ft/hr/°F (68-212°F.)	203
Modulus of elasticity, psi	29,000,000
Structure	Martensitic

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2.3 ENGINEERING ALLOY DIGEST INC. - NITRALLOY 135 MODIFIED

Alloy DIGEST — DATA ON WORLD WIDE METALS AND ALLOYS

NITRALLOY 135 MODIFIED

Filing Code: SA-24
Steel-Alloy

DECEMBER 1954

Published by
Engineering Alloy Digest, Inc.
Upper Montclair, New Jersey

NITRALLOY 135 MODIFIED

(Nitriding Steel)

NITRALLOY 135 MODIFIED is a special alloy steel which can be nitrided, that is, surface hardened without final quenching by the action of ammonia gas at relatively low temperatures. (Also known as Nitralloy Type G Modified).

Composition:

Carbon	0.38-0.45
Manganese	0.40-0.70
Silicon	0.20-0.40
Chromium	1.40-1.80
Aluminum	0.85-1.20
Molybdenum	0.30-0.45
Iron	Remainder

Physical Constants:

Density, lb./cu. in.	0.283
Thermal conductivity, BTU/hr/ft²/ft/°F @ 212°F.	30
Thermal coef. expansion/°F. (32-932°F.)	0.0000065
Specific heat, BTU/lb./°F.	0.11-0.12
Electrical resistance, microhm-cm	27-29
Modulus of elasticity, psi	$29\text{-}30 \times 10^6$

2.4 HANDBOOK OF MEEHANITE METAL, White Plains, N.Y.
BULLETIN No 49, Revised 1966, Page 56

TABLE V

APPROXIMATE RATES OF THERMAL EXPANSION

TYPE	Room Temperature to 200°F	400°F	600°F	800°F	1000°F	1200°F	1400°F	1600°F
	All Times 10^{-6} Inches Per Inch Per °F							
GE30	5.85	5.95	6.35	6.80	7.90	9.05		
GC40	5.45	5.75	6.25	6.70	7.60	9.00		
GA50	5.05	5.35	6.10	6.50	7.20	7.80		
GM60	5.00	5.30	6.00	6.40	7.05	7.50	7.80	8.30
AQ	5.00	5.65	6.35	6.50	6.75	7.20	7.70	8.30
AQ(1)	6.65	9.40	10.95	9.75	8.15	8.20	8.40	9.10
AQ(2)	5.85	5.95	7.70	7.75	7.05	7.20	7.55	8.20
CR	10.00	10.20	10.40	10.20	10.10	10.30	10.60	
HR	5.85	5.95	6.15	6.35	7.15	7.75	8.25	9.30
HS	5.85	6.25	6.35	6.50	7.00	7.20	7.40	7.50
SP80	5.85	5.95	6.15	6.40	6.85	7.05	7.25	7.35
SH100	6.55	6.65	6.75	6.80	7.40	7.80	8.25	8.50
SF60	5.85	6.10	6.25	6.50	6.95	7.10	7.35	7.40

AQ(1) water quenched.
AQ(2) air quenched.

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2.5 The Aluminum Association

THE ALUMINUM ASSOCIATION
750 THIRD AVENUE, NEW YORK CITY 10017

Issued August 1969

Second Printing August 1970

ALLOY	AVERAGE COEFFICIENT OF THERMAL EXPANSION* In/In/°C				In/In/°F			
	−60C to +20C	20C to 100C	20C to 200C	20C to 300C	−76F to +68F	68F to 212F	68F to 392F	68F to 572F
5050	21.8	23.8	24.7	25.6	12.1	13.2	13.7	14.2
5052	22.1	23.8	24.8	25.7	12.3	13.2	13.8	14.3
5056	22.5	24.1	25.2	26.1	12.5	13.4	14.0	14.5
5083	22.0	23.8	24.8	25.7	12.2	13.2	13.8	14.3
5086	22.0	23.8	24.8	25.7	12.2	13.2	13.8	14.3
5154	22.1	23.9	24.8	25.9	12.3	13.3	13.8	14.4
5454	21.8	23.6	24.5	25.6	12.1	13.1	13.6	14.2
5456	22.1	23.9	24.8	25.9	12.3	13.3	13.8	14.4
5457	21.8	23.7	24.7	25.6	12.1	13.2	13.7	14.2
6053	21.8	23.0	24.1	25.2	12.1	12.8	13.4	14.0
6061	21.8	23.4	24.3	25.4	12.1	13.0	13.5	14.1
6063	21.8	23.4	24.5	25.6	12.1	13.0	13.6	14.2
6101	21.6	23.4	24.3	25.2	12.0	13.0	13.5	14.0
6151	21.8	23.0	24.1	25.0	12.1	12.8	13.4	13.9
6951	----	----	----	----	----	13.0	----	----
7075	21.8	23.2	24.3	25.9	12.1	12.9	13.5	14.4
7079	21.8	23.4	24.7	25.6	12.1	13.0	13.7	14.2
7178	21.6	23.4	24.5	26.1	12.0	13.0	13.6	14.5

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3.0 Determine the Clearances between the Control Rod Drive Components at 280°F

3.1 Cable Drum Housing and Bushing Clearance

Cable Drum Housing SLR-D1201-207
MATERIAL AMS4217 D - A356 T6 ALUMINUM
Coeff. of Thermal Expansion = 12.1×10^{-6} in/in/°F
(Reference 2.1)
Housing Max. O.D. = 3.030"
Diameter Increase = $\alpha D \Delta T = 12.1 \times 10^{-6} (3.030)(280-63)$
$\Delta D = .0079"$
Housing Diameter at 280°F = 3.030 + .0079 = 3.0879"

Bushing SLR-D1201-209
MATERIAL SST 416
Coeff. of Thermal Expansion = 5.6×10^{-6} in/in/°F
(Same as 440C - Reference 2.2)
Bushing minimum O.D. = 3.0835"
Diameter Increase = $\Delta D = \alpha D \Delta T = 5.6 \times 10^{-6} \times (3.0835)(280-63)$
$\Delta D = .0037"$
Bushing Diameter at 280°F = 3.0835 + .0037 = 3.0872"

Clearance Between Cable Drum Housing and Bushing = 3.0879 - 3.0872 = .0007"

See Figure 1

Note: Bushing is not retained

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3.2 Cable Drum Housing and Gear Clearance

Cable Drum Housing SLR-D1201-207

MATERIAL: AMS 4217D – A356T6 ALUMINUM

COEFF. OF THERMAL EXPANSION = 12.1×10^{-6} in/IN/°F

Reference 2.1

HOUSING MAX. O.D. = 3.787"

Diameter Increase = $\Delta D = \alpha D \Delta T = 12.1 \times 10^{-6} (3.787)(280 - 63)$

$\Delta D = .0097$

Housing Diameter at 280°F = 3.7967"

GEAR SLR-D1201-208

MATERIAL SST 416

COEFF. of Thermal Expansion = 5.6×10^{-6} in/IN/°F

(Same as 440C – Reference 2.2)

GEAR MINIMUM DIAMETER 3.7915"

DIAMETER INCREASE = $\Delta D = \alpha D \Delta T = 5.6 \times 10^{-6} (3.7915)(280 - 63)$

$\Delta D = .0045"$

Gear Dia. at 280°F = 3.7915 + .0045 = 3.7960"

Clearance between Cable Drum Housing and Gear = 3.7967 – 3.7960 = .0007"

See Figure 1

Note: Gear is restrained in position by a set screw.

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3.3 Cable Drum Bushing and Bearing Clearance

BUSHING SLR-D1201-209
Material SST 416
Coeff. of Thermal Expansion = $\alpha = 5.6 \times 10^{-6}$ in/in/°F
(Same as 440C - Reference 2.2)
BUSHING Maximum ID = 2.8346

Bearing SLR-D1201-259
Material SST 440C
Coeff. of Thermal Expansion = $\alpha = 5.6 \times 10^{-6}$ in/in/°F ← Reference 2.2
Bearing Minimum O.D. = 2.8341 ABEC Class 1

NOTE: .0005" Clearance Exists at Room temperature and would exist at 230 °F, because the coeff. of thermal expansion is the same for both details.

3.4 Cable Drum Gear and Bearing Clearance

GEAR SLR-D1201-208
Material SST 416
Gear Max I.D. = 3.5434

Bearing SLR-D1201-260
Material SST 440C
Bearing Minimum O.D. = 3.5427 ABEC Class 1

<u>NOTE</u>: .0007" Clearance exists at room temperature and would exist at 230 °F because coeff. of thermal expansion is the same for both details.

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CALCULATIONS FOR	CONTROL ROD DRIVE COMPONENT CLEARANCES AT 280°F		
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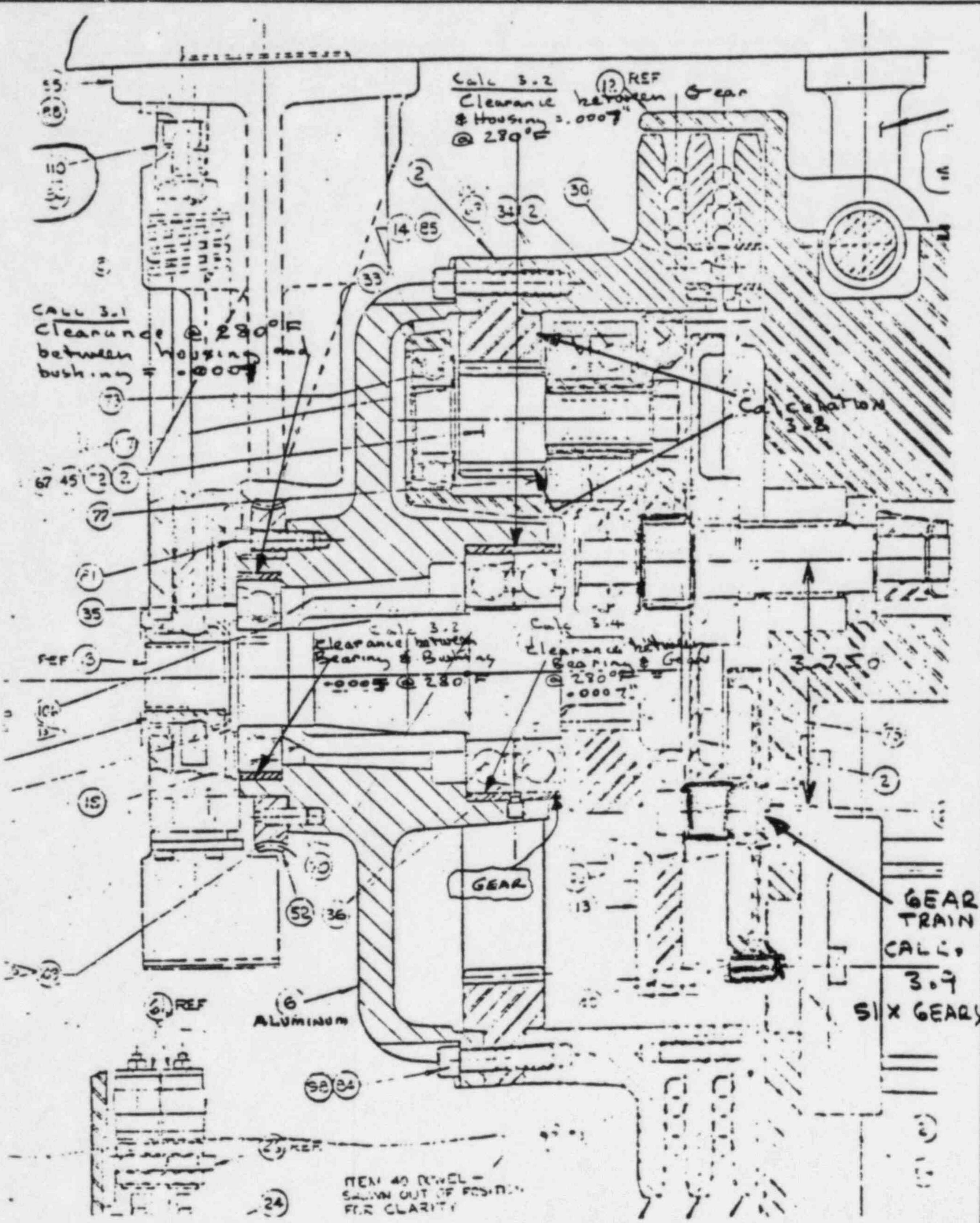

FIGURE 1

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CALCULATIONS FOR CONTROL ROD DRIVE CLEARANCES AT 280°F			
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3.5 GEARS SLR-D1201-203 & -239
ENGAGEMENT at 280°F
PLUS
GEARS SLR-D1201-242 & -241
ENGAGEMENT at 280°F

3.5.1 Determine the Center Distance Change at 280°F on Gears SLR-D1201-203 and SLR-D1201-239

GEAR SLR-D1201-208 Potententiometer Drive (P1)
Material: SST 416
α_1 = Coeff of Thermal Expansion = 5.6×10^{-6} in/in/°F
(See Calc. 2.2. - Same as 440C)
Pitch Dia. = 3.750

GEAR SLR-D1201-239 Potentiometer Drive (P2)
material: 7075 T6
α_2 = Coeff. of Thermal Expansion = 13.13×10^{-6} in/in/°F
(See Calc. 2.5)
Pitch Diameter = 2.0833

Center Line Increase - Relative to Gears = ΔL

$\alpha_1(PD_1/2)\Delta T + \alpha_2(PD_2/2)\Delta T = (5.6\times10^{-6})(3.75/2)(280-68) + (13.13\times10^{-6})(2.0833/2)(280-68) = .0051"$

∴ REQUIRED CENTER DISTANCE $= \left(\frac{3.75+2.0833}{2} + .0051\right) = 2.9213"$ @ 280°F

HOUSING CENTER DISTANCE DIMENSION @ 280°F
HOUSING SLR-D1201-231, MATL - MEEHANITE GM60
α_3 = Coeff of Expansion = 5.12×10^{-6} in/in/°F (Calc 2.3)
Center Distance Minimum = 2.9167
ΔL = Center Distance Increase = $\alpha_3 L \Delta T$ =
$\Delta L = 5.12\times10^{-6}(2.9167)(230-68) = .0032$
∴ Housing Center Distance = .0032 + 2.9167 = 2.9199"

Center Distance Decrease = 2.9218 - 2.9199 = .0019"

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3.5.1.1 Determine the Effects of THINNING ON CENTER DISTANCE

$$\text{NOMINAL CENTER DISTANCE} = \frac{\text{PITCH DIA. GEAR-239} + \text{PITCH DIA GEAR-208}}{2} = \frac{3.75 + 2.0833}{2} = 2.91665$$

BACKLASH for CLASS 9A GEARS WITH 48 DP
=.003 TO .007 (per AGMA 390.02 Table 12)
See Calc 3.5.2.1

Tooth THINNING TO OBTAIN BACKLASH = .0015/.0035
per gear (per AGMA 390.02 Table 12) See Calc. 3.5.2.1

GEAR -239, 48 DP, 100 TEETH, 2.0833 P.D.
Minimum Effect on Center Distance = .0026 × 1.5/2 = .00195
Maximum Effect on Center Distance = .0026 × 3.5/2 = .00455
See Calc. 3.5.2.1

Gear -208, 48 DP, 180 TEETH, 3.750 P.D.
Minimum Effect on Center Distance = .00268 × 1.5/2 = .00201
Maximum Effect on Center Distance = .00263 × 3.5/2 = .00460

TOTAL MINIMUM EFFECT ON CENTER DISTANCE
for Gears -208 & 239 = .00195 + .00201 = .0040"

TOTAL MAXIMUM Effect on Center Distance
for Gears -208 & -239 = .00455 + .00469 = .0092"

3.5.1.2 TOTAL COMPOSITE ERROR (TCE)

GEAR -208 TCE = .0017

GEAR -239 TCE = .0015

(PER AGMA 390.03 Table IV A)

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3.5.1.3 Center Distance Variation on Gears SLR-D1201-208 and SLR-D1201-239

	TEMP. = 68°F	
	WORST CONDITION	BEST CONDITION
a) Gear-208 Total Comp. Tol./2 = .0017/2	.0009	.0000
b) Gear-239 Total Comp. Tol./2 = .0015/2	.0008	.0000
c) Tooth Thinning Effect on Center Distance to Obtain .003/.007 Backlash	(.0040)	(.0092)
d) Radial Play Bearing-260 (.0008/.0012)/2	(.0004)	(.0006)
e) Radial Runout Bearing-260 (.0009/2)	.0005	.0000
f) Eccentricity - Housing Bearing Mtg .0014/2	.0007	.0000
~~g) " - Gear O.D./I.D. (-208) .0013/2~~	~~.0007~~	~~.0000~~
h) " - Shaft -231 at Bearings .0005/2	.0003	.0000
* i) Radial Clearance - Gear-208 O.D. & Housing-207	.0030	.0023
j) " " - Gear-208 / Bearing-260 O.D.	.0004	(.0004)
k) " " - Bearing-260 I.D./Shaft	.0002	(.0004)
l) Eccentricity - Gear-239/Brg on Shaft-240 .0002/2	.0001	.0000
m) " - Bearings on Housings .0010/2	.0005	.0000
n) " - Bearings on Shaft .0002/2	.0001	.0000
o) Radial Clearance - Gear-239 ID & Shaft-240	(.0002)	(.0007)
p) " " - Bearing-216 O.D. & Housing-231	.0001	(.0003)
q) " " - Bearing-216 ID & Shaft-240	.0001	(.0003)
r) Radial Play - Bearing-216 (.0008/.0012)/2	(.0004)	(.0006)
s) Radial Runout Bearing-216 .0012/2	.0006	.0000
Radial Clearance = Diametral/2		
	.0033 INTERFERENCE	(.0102) CLEARANCE

* AT 280° .0007" Clearance exists (Calc. 3.2)

∴ Worst Condition at 280°F = .0033 - .0030 - .0007 = (.0004")

∴ Best Condition at 280°F = -.0102 - .0023 - .0007 = -.0132"

Center Distance Decrease at 280°F = .0019"

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3.5.2 GEARS SLR-D1201-241 & 242 Engagement at 280°F.

GEAR P3, SLR-D1201-242, MATERIAL: ALUM. 7075T6
Coeff of Thermal Expansion = 13.13×10^{-6} IN/IN/°F, Ref. 2.5
PITCH DIA./2 = 4.6667/2 = 2.3334 = P'
INCREASE IN P' = $\alpha D \Delta T$ = $13.13\times10^{-6}\times(2.3334)(280-68)$ = .0065

GEAR P4, SLR-D1201-241, MATERIAL: SST 416
Coeff. of Thermal Expansion = 5.6×10^{-6} IN/IN/°F, Ref 2.2
PITCH DIA/2 = .5000/2 = .2500 = P'
Increase In P' = $\alpha P' \Delta T$ = $5.6\times10^{-4}(.2500)(280-63)$ = .0003"

Required Gear Pitch Diameter Center Distance due to Gear Dia. Increase = 2.3334 + .0065 + .250 + .0003 = 2.5902

Center Distance of Gears In Housing at 280°F

Housing SLR-D1201-230, MATERIAL MEEHANITE GM60
Coeff. of Thermal Expansion = 5.12×10^{-6} in/IN/°F, Ref 2.4
Center Distance (MINIMUM) = 2.5833
Center Distance Increase = $\alpha D(\Delta T)$ = $5.12\times10^{-6}(2.5833)(280-63)$
= .0028"
Housing Center Distance = 2.5833 + .0023 = 2.5861"

<u>Center Distance Decrease @ 280°F</u> = 2.5902 − 2.5861 = <u>.0041</u>

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3.5.2.1 Determine the Effects of Thinning on Center Distance

$$\text{Nominal Center Distance} = \frac{\text{PITCH DIA. GEAR 3P} + \text{PITCH DIA GEAR 4P}}{2} = \frac{4.6667 + .50}{2} = 2.5834$$

Backlash for Class 9A Gears with 48 DP
= .003 to .007 (per AGMA 390.02 Table 12)

TOOTH THINNING TO OBTAIN BACKLASH = .0015/.0035 per Gear

Table 12 Backlash Allowance and Tolerance for Fine-Pitch Spur, Helical and Herringbone Gearing
(All Values in Inches)

Reference AGMA 390.02

Backlash Designation (1)	Normal Diametral Pitch Range (2)	Tooth Thinning to Obtain Backlash (Note 1) Allowance (per gear) (3)	Tolerance (per gear) (4)	Resulting Approximate Backlash (per mesh) Normal Plane (Note 2) (5)
A	20 thru 45	.002	0 to .002	.004 to .008
	46 thru 70	.0015	0 to .002	.003 to .007
	71 thru 90	.001	0 to .00175	.002 to .0055
	91 thru 200	.00075	0 to .00075	.0015 to .003
B	20 thru 60	.001	0 to .001	.002 to .004
	61 thru 120	.00075	0 to .00075	.0015 to .003
	121 thru 200	.0005	0 to .0005	.001 to .002
C	20 thru 60	.0005	0 to .0005	.001 to .002
	61 thru 120	.00035	0 to .0004	.0007 to .0015
	121 thru 200	.0002	0 to .0003	.0004 to .001

TABLE 12. CHANGE IN MEASUREMENT OVER WIRES FOR .001" CHANGE IN TOOTH THICKNESS

Number of teeth	14½° Ex.	14½° In.	17½° Ex.	17½° In.	20° Ex.	20° In.	25° Ex.	25° In.	30° Ex.	30° In.
10	.0024	.0027	.0022	.0024	.0020	.0023	.0017	.0020	.0015	.0017
20	.0028	.0029	.0025	.0027	.0023	.0024	.0019	.0020	.0016	.0017
30	.0030	.0031	.0026	.0028	.0024	.0024	.0020	.0019	.0016	.0017
40	.0031	.0033	.0027	.0029	.0025	.0025	.0020	.0019	.0017	.0016
50	.0032	.0034	.0028	.0029	.0025	.0025	.0020	.0019	.0017	.0016
100	.0035	.0035	.0030	.0030	.0026	.0026	.0021	.0018	.0017	.0016
200	.0037	.0036	.0031	.0030	.0027	.0026	.0021	.0017	.0017	.0016

Table 12 applies when using 1.728" external and 1.44" internal gear wires.

Reference

Precision Measuring Tools by Van Keuren Catalog 33

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GENERAL ATOMIC COMPANY

CALCULATIONS FOR CONTROL ROD DRIVE COMPONENT CLEARANCES AT 280°F			
EQUIP. NO. D1201	PROJ. NO. 1900	CALC. NO. C-12-006/A	PAGE 17 OF
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REVIEWED BY	DATE		
APPROVED BY	DATE		

3.5.2.2 (CONTD)

GEAR P3, 48 DP, 224 TEETH
Minimum Effect on Center Distance =
.0027 × 1.5/2 = .0020

Maximum Effect on Center Distance =
.0027 × 3.5/2 = .0047

Gear P4, 48 DP, 24 Teeth
Minimum Effect on Center Distance =
.0023 × 1.5/2 = .0017

Maximum Effect on Center Distance =
.0023 × 3.5/2 = .0040

TOTAL MINIMUM EFFECT on Center Distance
for Gears P3 & P4 = .0020 + .0013 = .0037"

TOTAL MAXIMUM EFFECT on Center Distance
for Gears P3 & P4 = .0047 + .0041 = .0087

3.5.2.3 TOOTH ERROR Class 9A Gears

Gear P3 PD = 4.6667 N = 224 Teeth
TOTAL Composite Tolerance = .0017

Gear P4 PD = .5000 N = 24 Teeth
TOTAL Composite Tolerance = .0013

(per AGMA 390.03 Table IV A)

CALCULATIONS FOR CONTROL ROD DRIVE COMPONENT CLEARANCES at 230°F			
EQUIP. NO. D1201	PROJ. NO. 1900	CALC. NO. C-12-0061A	PAGE 18 OF
PREPARED BY E. HARVEY	DATE 4 FEB. 81	REF. DOCUMENTS: ** GEAR TOLERANCES BY P.M. DEAN	
REVIEWED BY	DATE		
APPROVED BY	DATE		

3.5.2-4

NOMINAL CENTER DISTANCE MUST BE INCREASED TO ASSURE THAT IMPERFECTIONS IN PARTS WILL NOT REDUCE CENTER DISTANCE TO LESS THAN THE NOMINAL CENTER DISTANCE = 2.5333"

GEARS SLR-D1201-241 & -242		Temp. = 68°F WORST CONDITION	BEST CONDITION
a) Max Radial Runout Bearing "A" SS3L02	ABEC 1 .0012/2	.0006	.0000
b) Max Radial Runout Bearing "B" SSR3	ABEC 1 .0010/2	.0005	.0000
c) RADIAL PLAY - BEARING "A" (.0008/.0012)/2		(.0004)	(.0006)
d) RADIAL PLAY - BEARING "B" (.0008/2) (EST)		(.0004)	(.0006)
e) Eccentricity - Shaft "A", Bearing to Gear .0000/.0009		.0005	.0000
f) " - Shaft "B", Bearing to Gear .0000/.0004		.0002	.0000
* g) Radial Clearance - Bearing "A" & Housing	P.F. .0005 GAP .0006	.0005	(.0006)
h) " " - Bearing "A" & Shaft "A"	P.F. .0001 GAP .0005	.0001	(.0005)
i) " " - Shaft "A" & Gear P3	GAP .0018 GAP .0006	(.0006)	(.0018)
* j) " " - Bearing "B" & Housing	PF .0001 GAP .0003	.0001	(.0003)
k) " " - Bearing "B" & Shaft "B"	PF .0004 GAP .0002	.0004	(.0002)
l) " " - Shaft "B" & Gear P4	GAP .0004 GAP .0014	(.0004)	(.0014)
m) (TOTAL COMPOSITE TOLERANCE)/2 - GEAR P3	AGMA 390.03	.0009	.0000
N) (TOTAL COMPOSITE TOLERANCE)/2 - GEAR P4		.0007	.0000
o) TOOTH THINNING Effect on Center Distance to A Class A BACKLASH (Calc 3.5.2.5) GEARS P3 & P4	(THINNING .0021 per GEAR)	(.0037)	(.0087)
MID-POINT CLEARANCE = (.0011+.0153)/2 = (.0082) clearance →		(.0011) Clearance	(.0152) Clearance

MINIMUM CENTER DISTANCE @ 68°F for a WORST CONDITION } = 2.5833 + (.0011) = 2.5822

SPECIFIED CENTER DISTANCE @ 68°F (SLR-D1201-230) } = 2.5833/2.5340

HOWEVER, AT 68°F A CLEARANCE = .0153" COULD EXIST for BEST TOLERANCE CONDITIONS.
(RESULTANT CENTER DISTANCE = 2.5986/2.5993 @ 68°F)

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GENERAL ATOMIC COMPAN.

CALCULATIONS FOR	CONTROL ROD DRIVE COMPONENT CLEARANCES at 280°F				
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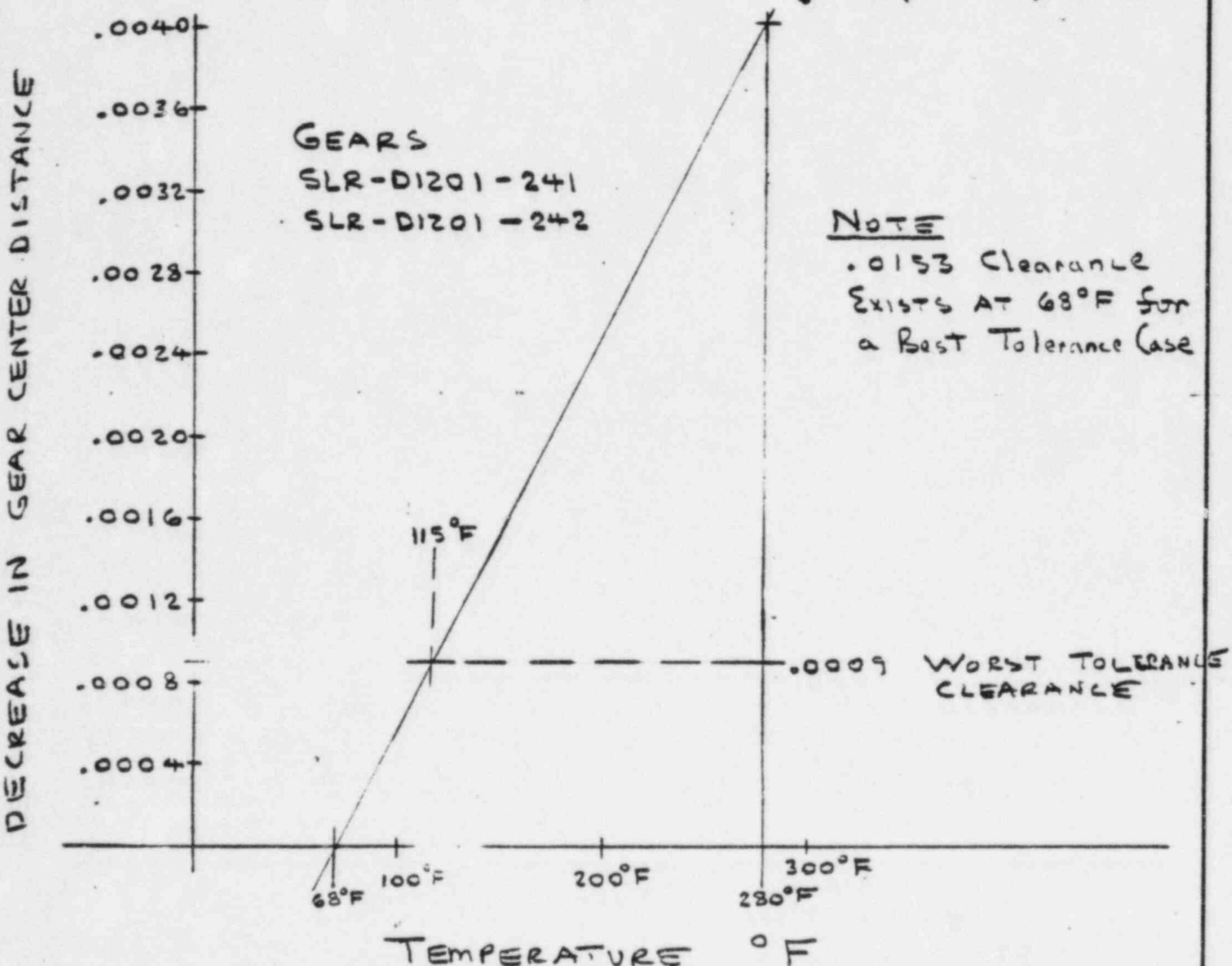
APPROVED BY		DATE			

3.5.2.4 (CONTD)

* At 280°F the tolerances for items (g) & (j) at the worst condition would be .0006 and .0002 respectively, with a net total result = .0009" clearance

Minimum Center Distance at 280°F for a Worst Condition = 2.5832 − .0007 + .0041 = 2.5867"

(Resultant thermal expansion of components) ↑



CALCULATIONS FOR	CONTROL ROD DRIVE CLEARANCES AT 280°F		
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APPROVED BY	DATE		

3.5.2.5 Determine the amount of linear movement of the control rod that is necessary to demonstrate 360° movement of the Gear SLR-D1201-242

See Figure 2

GEAR №	Number of Teeth	Number of Revolutions	
SLR-D1201-242 (Gear P3)	224	1	(360°)
SLR-D1201-241 (Gear P4)	24	$\frac{224}{24} = 9.333$	(3360°)
SLR-D1201-239 (Gear P2)	100	9.333	(3360°)
SLR-D1201-208 (Gear P1)	180	$\frac{100}{180}(9.333) = 5.185$	(1867°)

SLR-D1201-208 GEAR Is Attached to the DRUM SHAFT, THEREFORE, IN ORDER TO ROTATE GEAR SLR-D1201-242 ONE REVOLUTION, THE DRUM SHAFT WOULD HAVE TO ROTATE 5.185 REVOLUTIONS

DRUM DIA. (APPROX)	CIRCUMFERENCE	SUMMATION (CONTROL ROD STROKE)
12.00	37.699	37.699"
12.50	39.269	76.968"
13.00	40.841	117.809"
13.50	42.411	160.221"
14.00	43.982	204.203" ← STROKE = 192"

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CALCULATIONS FOR	CONTROL ROD DRIVE COMPONENT CLEARANCES at 230°F				
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PREPARED BY	S. HARVEY	DATE 27 JAN 81		REF. DOCUMENTS:	
REVIEWED BY		DATE		SLR-D1201-200	
APPROVED BY		DATE			

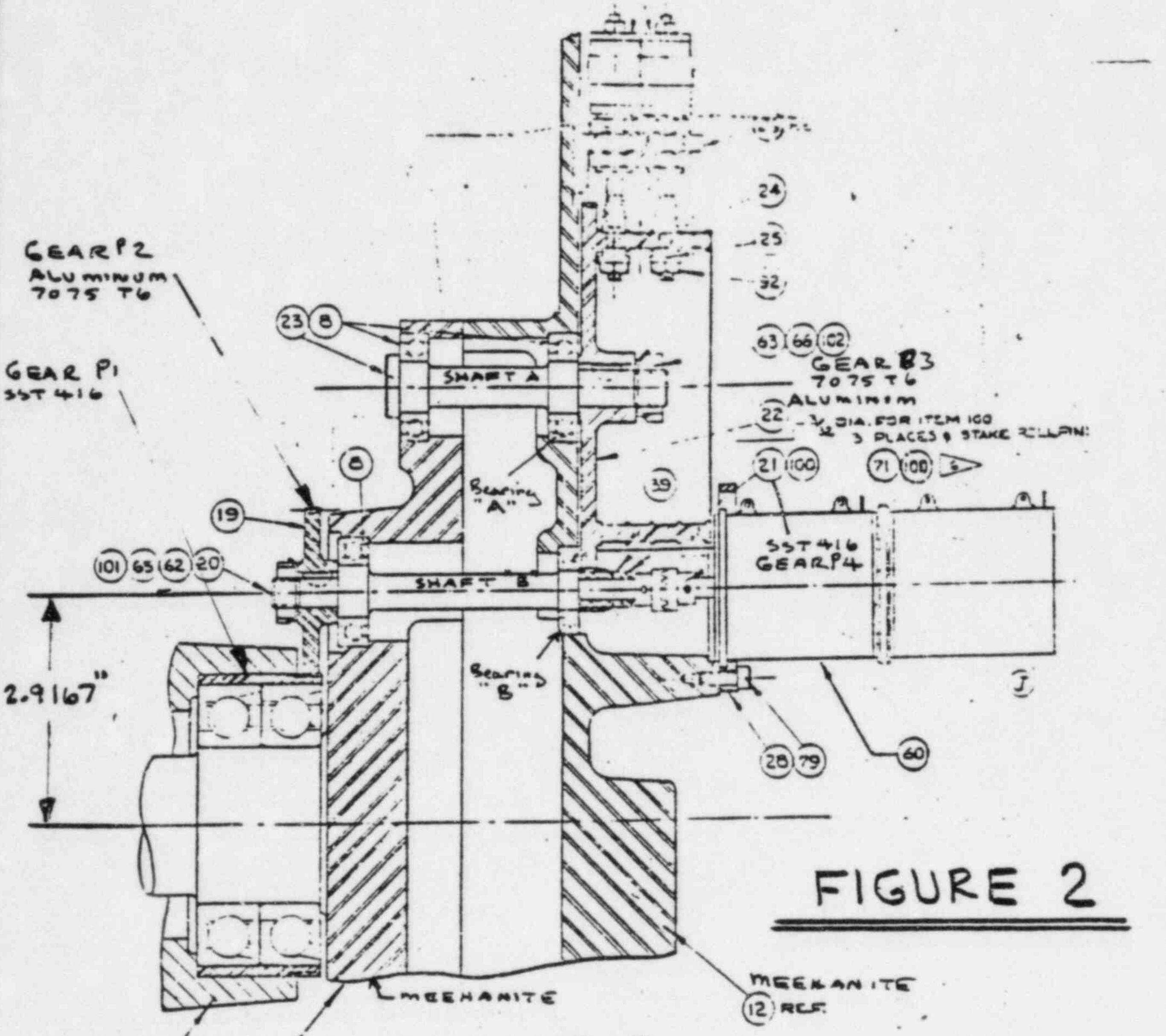

FIGURE 2

SECTION B-B

NOTE: The center distance decreases .0041 on gears 3 & 4, and .0019 on gears 1 & 2

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CALCULATIONS FOR CONTROL ROD DRIVE COMPONENT CLEARANCES AT 230°F			
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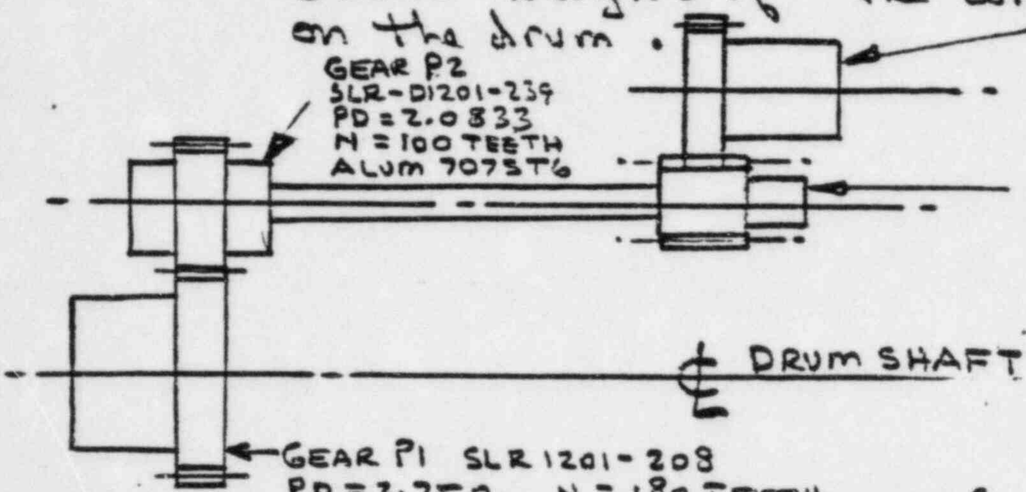
APPROVED BY	DATE		

3.5.3 Assume Gears P3 & P4 will not rotate due to temperature increase to 230°F. What forces are generated due to the static weight of the control rods on the drum.



Control Rod Weight
Drum Radius

Available Torque at Drum Shaft due to Static weight of CRD = 250 X 6 = 1500 inch lbs.

Force Generated at Pitch Line of Gears P1 & P2 = $\frac{1500}{3.75/2}$ = 800 lbs.

Torque at Potentiometer Shaft = 800 X $\frac{2.0333}{2}$ = 833.33 inch lbs.

Force Generated at Pitch Line of Gears P3 & P4 = $\frac{833.33}{.500/2}$ = 3333.3 lbs.

CALCULATIONS FOR	CONTROL ROD DRIVE COMPONENT				
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APPROVED BY		DATE			

3.5.4 What forces can the pins & gear teeth resist before failure

3.5.4.1 Set Screw retaining Gear P1 in the Aluminum Housing SLR D1201-207

1/4-20 Dog Point Set Screw
Dia = .156" (DOG POINT)
Area = $\pi/4\,(.156)^2$ = .0191 in^2
Alloy Steel - Shear Ultimate Stress = 102600 PSI
Shear Ultimate = 102600 X .0191 = 1900 lbs
Force Available = 1500/(3.79/2) = 792 lbs.

3.5.4.2 Roll Pin in Gear P4

3/32 DIA. SST
ESNA Double Shear Rating = 1000 lbs.
Force Available = 833.3/.250 = 3333 lbs (Double Shear)

3.5.4.3 Gear Teeth - Alum. Alloy 7075 T6
Ultimate Tensile Stress = 83000 PSI
Ultimate Shear Stress = 43000 PSI
48 DP., 20° PA

* $W_t = FJ\sigma/P$ = Transmitted Force (Bending Formula)
P = Diametral Pitch = 48
σ = Ultimate Tensile Stress = 83000 PSI
F = Face width = .188 Gear 3; .250 Gear 2
* J = Form Factor = .475 Gear 3, .500 Gear 2

W_t (Gear P2) = .250(.500)83000/48 = 216 lbs.
Force Available = 800 lbs

W_t (Gear P3) = .188(.475)83000/48 = 154 lbs
Force Available = 3333 lbs.

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CALCULATIONS FOR CONTROL ROD DRIVE COMPONENT CLEARANCES at 230°F			
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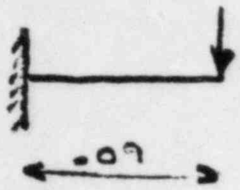
3.5.4.4 Shaft Deflection and Shear
SLR-D1201-240



Dia. = .250

$I = \pi D^4/64 = .000192 \text{ in}^4$

Deflection $= WL^3/3EI = \delta$

$\delta/W = L^3/3EI$

Deflection / 1000 lb force $= \dfrac{.09^3 \times 1000}{3(30\times10^6).000192} = .00004''$

Shaft Material SST 416 Annealed

Tensile Ultimate = 70000 PSI

Shear Ultimate = .577 × 70000 = 40390 PSI

AREA $= \frac{\pi}{4}(.25)^2 = .0491 \text{ in.}^2$

Shear Ultimate = .0491 × 40390 = 1983 lbs

3.5.4.5 WOODRUFF KEY No 303 in Gear 2 Rating

WIDTH = .094" Length = .374"

Material = Steel 4130 R_c 40

Key Spec 00-K-220 a

Ultimate Tensile Stress = 180000 PSI

Ultimate Shear Stress = .577 × 180000 = 103860 PSI

Shear Rating = 103860 (.094 × .374) = 3650 lbs.

Force Available = 833.3/(.406/2) = 4104 lbs.

CALCULATIONS FOR CONTROL ROD DRIVE COMPONENT CLEARANCES AT 280°F			
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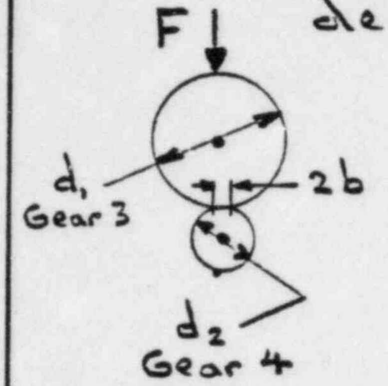
3.5.5 Determine the Rolling Resistance at 280°F if the center distance decreases (.0041" − .0009) = .0032"



.0041 = decrease in the distance the gears are spaced at 280°F (Calc 3.5.2)

.0009 = center distance clearance that exists at 68°F for a worst tolerance condition (Calc.3.5.2.6)

$$b = \left[\frac{2F(1-\gamma^2)\left(\frac{1}{E_1}+\frac{1}{E_2}\right)}{\pi L\left(\frac{1}{d_1}+\frac{1}{d_2}\right)} \right]^{1/2}$$

Mechanical Eng. Design by Shigley - First Ed. P42

γ = POISSON'S RATIO = .31 Alum & SST Assumed the same

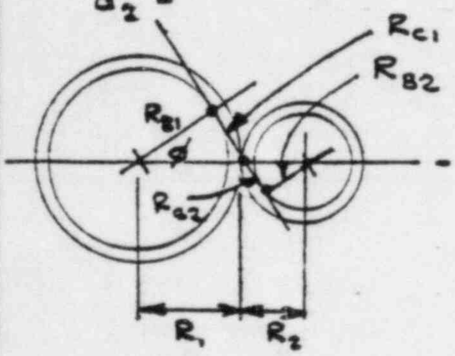
E_1 = Modulus of Elasticity of Gear 3 = 10.3×10^6 PSI

E_2 = Modulus of Elasticity of Gear 4 = 27.6×10^6 PSI

L = Width of Gear = .188"

d_1 = Diameter representing 2 X Radius of Gear Curvature

d_2 = " " " " " " "



ϕ = PRESSURE ANGLE = 20°

R_1 = PD GEAR P3/2 = 4.6667/2 = 2.3333

R_2 = PD GEAR P4/2 = .5000/2 = .250

$R_{C1} = R_1 \sin\phi$ = .7980"

$R_{C2} = R_2 \sin\phi$ = .0855

$d_1 = 2R_{C1}$ = 1.596"

$d_2 = 2R_{C2}$ = .1710"

Assumption: Aluminum will deform more than SST 416 R_c 28

Ultimate Tensile Stress - ALUM 7075T6 = 33000 PSI

Ultimate Tensile Stress - SST416 R_c 23 = 125000 PSI

Assume Aluminum will deform 60%, SST 40%

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CALCULATIONS FOR CONTROL ROD DRIVE COMPONENT CLEARANCES at 280°F			
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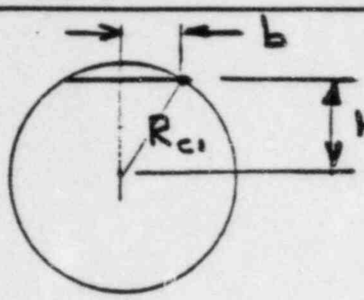


Aluminum Gear Deformation =
$.6 \times .0032 = .0019''$

$H = R_{c1} - .0019 = .798 - .0019 = .7961$

$b = \left[.7980^2 - .7961^2\right]^{1/2} = .0550''$

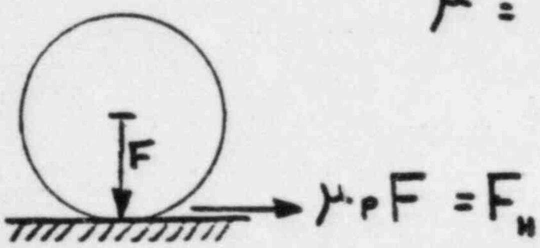
Substitute in Original Equation and Determine "F"

$$.0550 = \left[\frac{2F(1-.31^2)\left(\frac{1}{10.3\times10^6}+\frac{1}{27.6\times10^6}\right)}{\pi(.188)\left(\frac{1}{1.596}+\frac{1}{.171}\right)}\right]^{1/2}$$

$$.0550 = \left[\frac{2F(.9039)(.1333\times10^{-6})}{\pi(.188)(6.4745)}\right]^{1/2}$$

$F = 48002$ lbs.

μ = Coeff. of Rolling Friction = .01 MAX. if NO plastic deformation occurs.



Assume $\mu_P = .03$ for Plastic Deformation

$F_H = \mu_P F = .03 \times 48002 = 1440$ lbs.

Gear Teeth Ultimate Strength Rating = 216 lbs.
∴ Gear teeth will strip prior to rolling of gears.

CALCULATIONS FOR CONTROL ROD DRIVE COMPONENT CLEARANCES AT 280°F			
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3.6 GUIDE PULLEY & BUSHING CLEARANCE (See FIGURE 3)

PULLEY : SLR-D1201-213-1/2/3

MATERIAL: ALUMINUM 7075 T6

COEFF of THERMAL EXPANSION = 13.13×10^{-6} in/in/°F
Reference 2.5

Pulley Housing maximum Dia = 1.5630"

Diameter increase = $\alpha D \Delta T = 13.13 \times 10^{-6} (1.563)(280-68)$

$\Delta D = .0044$"

Pulley Dia. at 280°F = .0044 + 1.5630 = 1.5674"

Bushing SLR-D1201-213-4 & 5

Material : SST 416

Coeff. of Thermal Expansion = 5.6×10^{-6} in/in/°F
(Same as SST440C, Reference 2.2)

Sleeve Minimum Dia. 1.565

Diameter Increase = $\Delta D = \alpha D \Delta T = 5.6 \times 10^{-6} (1.565)(280-68)$

$\Delta D = .0019$"

Diameter of Sleeve at 280°F = .0019 + 1.565 = 1.5669

Clearance at 280°F between Pulley and bushing
= 1.5674 − 1.5669 = .0005"

NOTE : Bushings are not restrained at 280°F.

Pulleys SLR-D1201-213-2,-3 are not restrained at 280°F.

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CALCULATIONS FOR CONTROL AND DRIVE COMPONENT CLEARANCES @ 230°F			
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3.7 Guide Pulley Bushing and Bearing Clearance

Bushing: SLR-D1201-213
Material: SST 416

Bearing: SLR-D1201-216
Material: SST 440 C

Coefficient of Thermal expansion is the same for both components. Therefore, the clearance that exists at room temperature would exist at 280°F.

Sleeve I.D. maximum	=	1.3780"	
Bearing O.D. minimum	=	1.3775"	
Clearance	=	.0005"	MAXIMUM FIT
PRESS FIT	=	.0001	MINIMUM FIT

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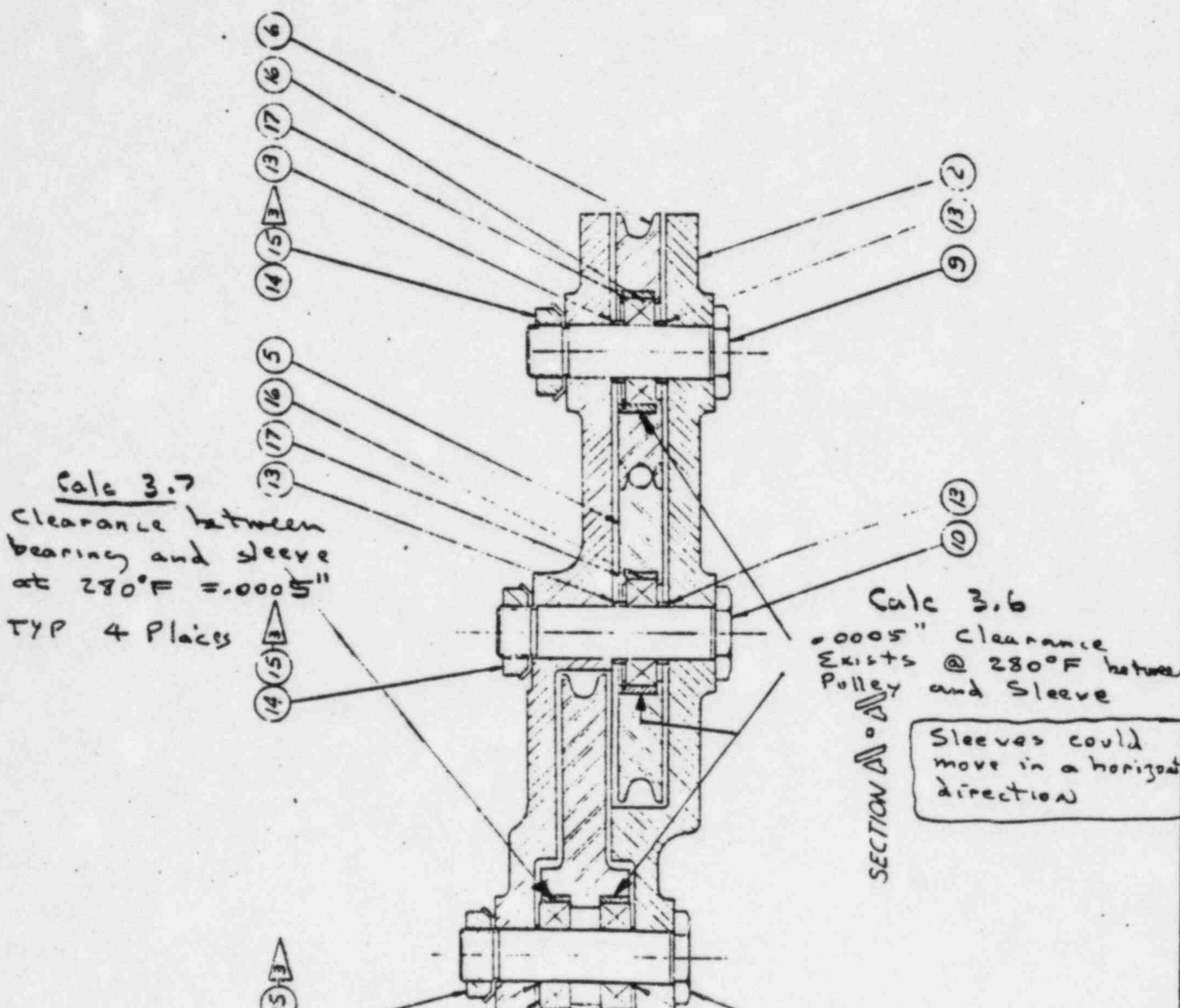

FIGURE 3

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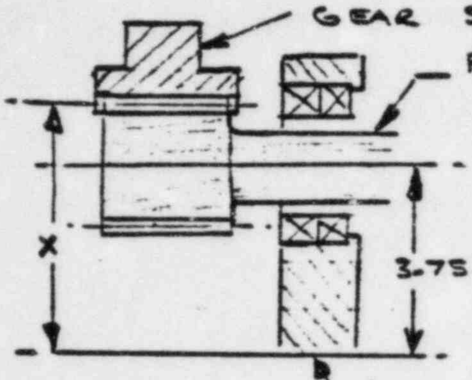
CALCULATIONS FOR CONTROL ROD DRIVE COMPONENT CLEARANCES AT 230°F			
EQUIP. NO. D1201	PROJ. NO. 1900	CALC. NO. C-12-006A	PAGE 30 OF
PREPARED BY E. HARVEY	DATE 23 JAN 81	REF. DOCUMENTS: SLR-D1201-202 GEAR TRAIN	
REVIEWED BY	DATE		
APPROVED BY	DATE		

3.8 RING GEAR ENGAGEMENT



HOUSING: SLR-D1201-231, MATERIAL - MEEHANITE GM60
Coeff. of Thermal Expansion = 5.12×10^{-6} in/in/°F, Ref. 2.4
Center Distance = 3.7505" max.
Center Distance Increase = $\Delta L = \alpha L \Delta T = 5.12 \times 10^{-6}(3.7505)(230-68)$
$\Delta L = .0041$
Center Distance at 280°F = 3.7505 + .0041 = 3.7546"

PINION: SLR-D1201-202-6, MATERIAL - NITRALLOY 135 MODIFIED
Coeff. of Thermal Expansion = 6.5×10^{-6} in/in/°F, Ref. 2.3
Pitch Diameter/2 = 1.500/2 = .7500"
(PD/2) INCREASE = $\alpha D \Delta T = 6.5 \times 10^{-6}(.75)(230-63)$
$\Delta PD = .0010"$
PITCH DIAMETER /2 AT 280°F = .750 + .001 = .7510"

TOTAL DISTANCE "X" at 280° = .7510 + 3.7546
"X" = 4.5056"

RING GEAR: SLR-D1201-202-7, MATERIAL - NITRALLOY 135 MOD
COEFF. of THERMAL EXPANSION = 6.5×10^{-6} in/in/°F, Ref 2.4
PITCH DIA./2 = 9.000/2 = 4.500"
(PITCH DIA/2) INCREASE = $\alpha(PD/2)\Delta T = 6.5 \times 10^{-6}(4.5)(230-63)$
$\Delta PD/2 = .0062$
PITCH DIA/2 at 280°F = .0062 + 4.500 = 4.5062"
∴ CLEARANCE INCREASE = 4.5062 - 4.5056 = .0006"

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3.9 GEAR TRAIN SLR-D1201-202 ENGAGEMENT AT 280°F

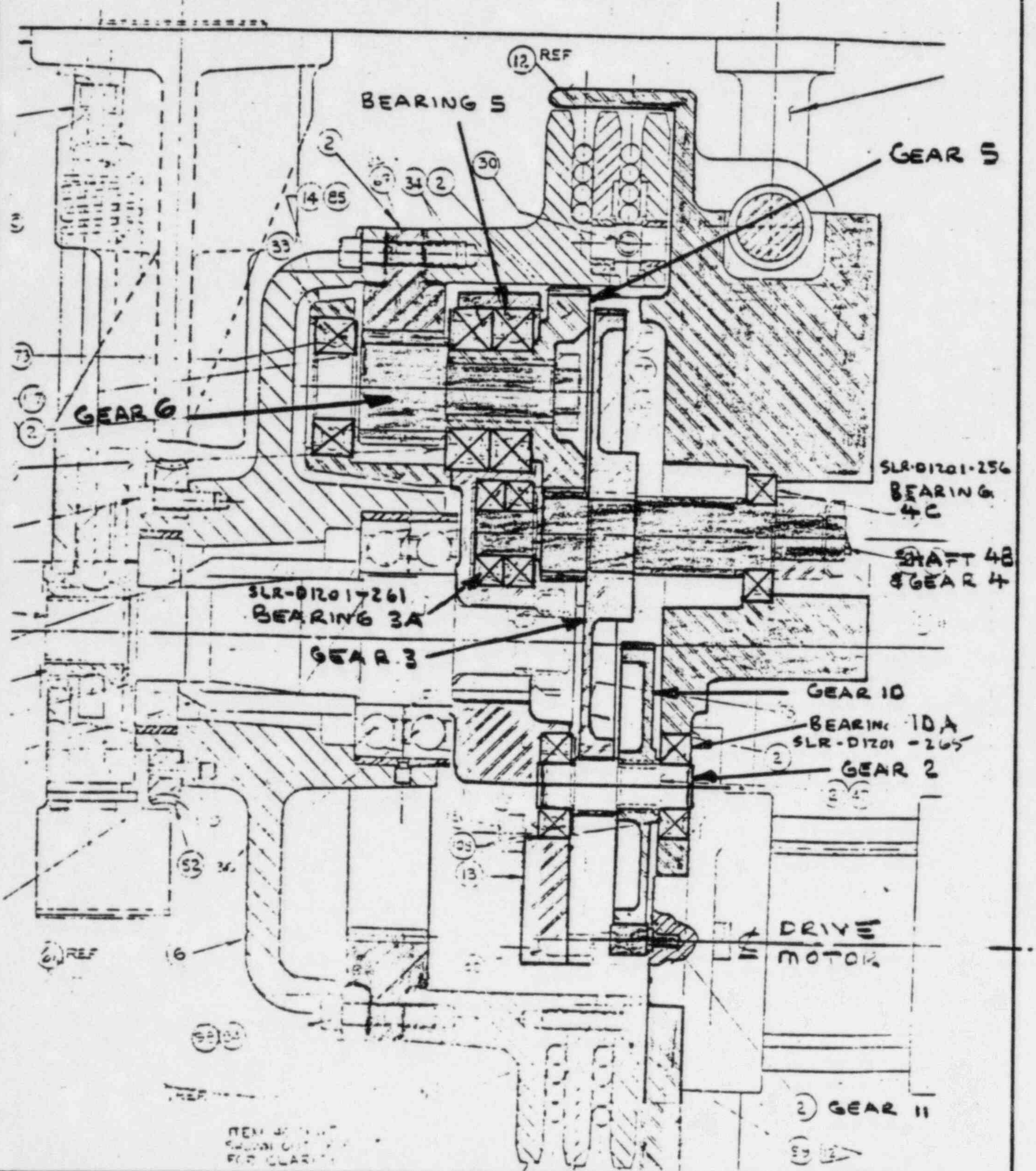

FIGURE 3.9.1

CALCULATIONS FOR CONTROL ROD DRIVE CLEARANCES AT 280°F			
EQUIP. NO. D1201	PROJ. NO. 1900	CALC. NO. C-12-006/A	PAGE 32 OF
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APPROVED BY	DATE		

3.9.1 GEARS SLR-D1201-202-10 & -11 ENGAGEMENT AT 280°F

3.9.1.1 DETERMINE CENTER DISTANCE CHANGE AT 280°F (DECREASE .0007")

GEARS - SLR-D1201-202-10 & -11
MATERIAL - NITRALLOY 135 MODIFIED
α_1 = COEFF. of THERMAL EXPANSION =
$\alpha_1 = 6.5 \times 10^{-6}$ IN/IN/°F (See Calc. 2.3)

HOUSING - SLR-D1201-230
MATERIAL: MEEHANITE GM60
α_2 = COEFF of THERMAL EXPANSION =
$\alpha_2 = 5.12 \times 10^{-6}$ IN/IN/°F (See Calc. 2.4)

Specified Center Distance @ 68°F = 2.3440/2.3450
SLR-D1201-230

CENTER DISTANCE DECREASE @ 280°F = ΔL

$$\Delta L = (\alpha_1 - \alpha_2) L (\Delta T)$$

$$\Delta L = (6.5 - 5.12)\, 2.345\, (280 - 68) = .0007'' \leftarrow$$

$$\text{NOMINAL CENTER DISTANCE} = \frac{\text{PITCH DIA. GEAR 10} + \text{PITCH DIA GEAR 11}}{2} = \frac{4.25 + .4375}{2} = 2.34375$$

*BACKLASH FOR CLASS 9A GEARS WITH 32 D.P.
= .004/.008 AGMA 390.02 Table 12

*TOOTH THINNING = .0020 + (.0000/.0020)
= .0020/.0040 per gear
(TO OBTAIN BACKLASH)

CALCULATIONS FOR CONTROL ROD DRIVE CLEARACES at 230°F			
EQUIP. NO. D1201	PROJ. NO. 1900	CALC. NO. C-12-006/A	PAGE 33 OF
PREPARED BY E. HARVEY	DATE 23 FEB 81	REF. DOCUMENTS: * See Reference Data in Calculation 3.5.2.1	
REVIEWED BY	DATE		
APPROVED BY	DATE		

3.9.1.2 THINNING EFFECT ON CENTER DISTANCE

GEAR 10 32 DP, 136 TEETH

* MINIMUM EFFECT OF THINNING ON CENTER DISTANCE = .00264(2.0/2) = .00264"

* MAXIMUM EFFECT OF THINNING ON CENTER DISTANCE = .00264(4.0/2) = .00528

GEAR 11 32 DP, 14 TEETH

* MINIMUM EFFECT OF THINNING ON CENTER DISTANCE = .00246(2.0/2) = .00246"

* MAXIMUM EFFECT OF THINNING ON CENTER DISTANCE = .00246(4.0/2) = .00492"

TOTAL MINIMUM EFFECT, GEARS 10 & 11, ON CENTER DISTANCE = .00264 + .00246 = .0051" ←

TOTAL MAXIMUM EFFECT, GEARS 10 & 11, ON CENTER DISTANCE = .00528 + .00492 = .0102 ←

3.9.1.3 TOOTH ERROR CLASS 9A Gears

GEAR 10 136 Teeth, 4.250 P.D., 32 DP

TOOTH TO TOOTH COMPOSITE TOLERANCE = .0008"

TOTAL COMPOSITE TOLERANCE = .00196"

GEAR 11 14 TEETH, .4375 P.D., 32 DP

TOOTH TO TOOTH COMPOSITE TOLERANCE = .0009"

TOTAL COMPOSITE TOLERANCE = .00157"

Reference AGMA 390.03 Table IV A

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GENERAL ATOMIC COMPAN.

CALCULATIONS FOR CONTROL ROD DRIVE CLEARANCES AT 230°F			
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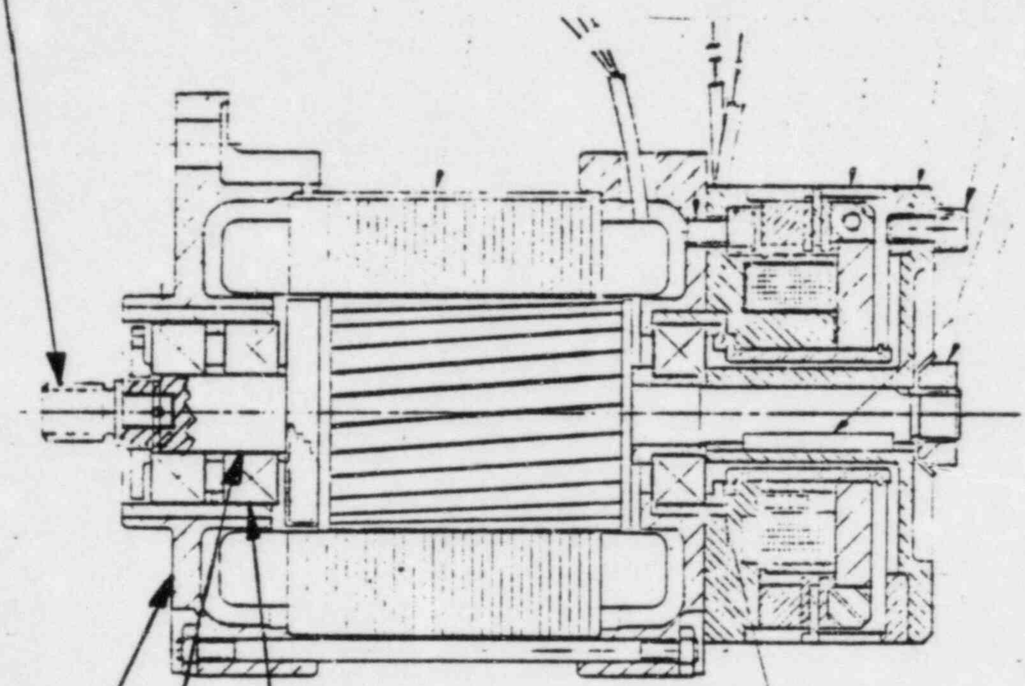
REVIEWED BY	DATE		
APPROVED BY	DATE		

GEAR 11 SLR-D1201-202-11



BEARING 11A, SLR-D1201-222 SST 440C

SHAFT 11B, SLR-D1201-224 SST 304

HOUSING 11C, SLR-D1201-223-2 ALUM B26

SLEEVE 11D, SLR-D1201-225-1 SST 440C

DRIVE MOTOR ASSEMBLY
FIGURE 3.9.2

(Reference SLR-D1201-217)

CALCULATIONS FOR CONTROL ROD DRIVE CLEARANCES AT 230°F			
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APPROVED BY	DATE		

3.9.1.4 Center Distance Variation - Gears 10 & 11

(See Engineering Drawings for Dimensions)

	TEMP. = 68 °F WORST CONDITION	BEST CONDITION
a) GEAR 11 TOTAL COMPOSITE TOLERANCE/2 = .0016/2	.0008	.0000
b) GEAR 10 TOTAL COMPOSITE TOLERANCE/2 = .0020/2	.0010	.0000
c) TOOTH THINNING, TO OBTAIN .004/.008 BACKLASH, EFFECT ON CENTER DISTANCE (CALC. 3.9.1.2)	(.0051)	(.0102)
d) ECCENTRICITY/2 - SHAFT 11B - BEARING/GEAR (.001/2)	.0005	.0000
e) RADIAL RUNOUT BEARING 11A (3203) ABEC 1 (.0012/2)	.0006	.0000
f) ECCENTRICITY/2 - HOUSING I.D./O.D (.0010/2)	.0005	.0000
* g) RADIAL CLEARANCE - HOUSING MTG. DIA. -230 & -223	.0000	(.0015)
* h) " " - BEARING 11A O.D / SLEEVE	(.0001)	(.0006)
* i) " " - BEARING 11A I.D / SHAFT	(.0001)	(.0004)
* j) " " - GEAR 11 MTG / SHAFT 11B	.0003	.0002
k) RADIAL PLAY BEARING 11A (.0008/.0012)/2	(.0004)	(.0006)
l) RADIAL PLAY BEARING 10A (.0008/.0012)/2	(.0004)	(.0006)
m) ECCENTRICITY/2 - 2 BEARING SHAFTS SLR D1201-202-2 (.0010/2)	.0005	.0000
n) RADIAL RUNOUT BEARING 10A (3203) (.0012/2)	.0006	.0000
o) ECCENTRICITY - HOUSING (-230)/HOUSING (-231) (.0010/2)	.0005	.0000
* p) RADIAL CLEARANCE - HOUSING (-230)/BEARING 10A O.D.	(.0003)	(.0008)
* q) " " - GEAR 2 @ BRG. / BEARING I.D.	.0002	(.0001)
* r) " " - GEAR 10 / GEAR 2 MTG DIA	.0000	(.0004)
* RADIAL CLEARANCE = DIAMETRAL CLEARANCE/2		
	(.0009) clearance	(.0150) clearance

MID-POINT CLEARANCE $= \frac{.0009 + .0150}{2} = .0080$ clearance

Center distance required for a worst tolerance condition = 2.3438 - .0009 = 2.3429 @ 68°F

Specified Center Distance = 2.3440 / 2.3450

Center Distance Decrease at 230°F = .0007"

∴ Acceptable for Gears SLR-D1201-202-10 & -11 ←

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GENERAL ATOMIC COMPAN .

CALCULATIONS FOR CONTROL ROD DRIVE CLEARANCES AT 280°F			
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PREPARED BY E. HARVEY	DATE 24 FEB 81	REF. DOCUMENTS:	
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APPROVED BY	DATE		

3.9.2 GEARS SLR-D1201-200-2 & 3 ENGAGEMENT at 280°F

3.9.2.1 Determine the center distance decrease at 280°F

GEARS: SLR-D1201-200-2 & 3
MATERIAL: NITRALLOY 135 MODIFIED
α_1 = COEFF. of THERMAL EXPANSION =
$\alpha_1 = 6.5 \times 10^{-6}$ in/in/°F (See Calc. 2.3)

HOUSINGS: SLR-D1201-230 & 231
MATERIAL: MEEHANITE GM60
α_2 = COEFF. of THERMAL EXPANSION =
$\alpha_2 = 5.12 \times 10^{-6}$ in/in/°F (See Calc. 2.4)

SPECIFIED CENTER DISTANCE at 68°F = 3.7500/3.7510
SLR-D1201-230 & 231

CENTER DISTANCE DECREASE AT 280°F = ΔL

$$\Delta L = (\alpha_1 - \alpha_2) L (\Delta T)$$

$$\Delta L = (6.5 - 5.12)10^{-6}(3.751)(280-68) = .0011''$$

$$\left.\begin{array}{l}\text{NOMINAL}\\\text{CENTER}\\\text{DISTANCE}\end{array}\right\} = \frac{\text{PITCH DIA. GEAR 2} + \text{PITCH DIA. GEAR 3}}{2} = \frac{6.6875 + .8125}{2} = 3.750''$$

* BACKLASH FOR CLASS 9A GEARS WITH 32 DP
= .004/.008 (AGMA 390.02)

* TOOTH THINNING = .0020 + (.0000/.0020)
= .0020/.0040 per gear to obtain backlash.

* See Reference Data in CALCULATION 3.5.2.1

CALCULATIONS FOR CONTROL ROD DRIVE CLEARANCES AT 230°F			
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REVIEWED BY	DATE		
APPROVED BY	DATE		

3.9.2.2 Thinning Effect on Center Distance

Gear 2 : 32 DP, 26 TEETH

* minimum Effect of Thinning on Center Distance = .00236 (2.0/2) = .00236"

* maximum Effect of THINNING on Center Distance = .00236 (4.0/2) = .00472"

GEAR 3 : 32 DP, 214 TEETH

* minimum Effect of Thinning on Center Distance = .00271 (2.0/2) = .00271"

* maximum Effect of THINNING on Center DISTANCE = .00271 (4.0/2) = .00542"

TOTAL minimum Effect of THINNING, GEARS 2 & 3 ON CENTER DISTANCE = .00236 + .00271 = .00507"

TOTAL maximum Effect of THINNING, GEARS 2 & 3 ON CENTER DISTANCE = .00472 + .00542 = .00979

3.9.2.3 TOOTH ERROR CLASS 9A GEARS PER AGMA 390.03 TABLE IV A

GEAR 2 : 26 TEETH, 32 DP, .8125" P.D.
TOTAL COMPOSITE TOLERANCE = .00157"

GEAR 3 : 214 TEETH, 32 DP, 6.6875" P.D.
TOTAL COMPOSITE TOLERANCE = .0021"

CALCULATIONS FOR	CONTROL ROD DRIVE CLEARANCES AT 230°F			
EQUIP. NO. D 1201	PROJ. NO. 1900	CALC. NO. C-12-006/A	PAGE 53 OF	
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REVIEWED BY	DATE			
APPROVED BY	DATE			

3.9.2.4 Center Distance Variation - Gears 2 & 3

(See Engineering Drawings for Dimensions)	TEMP. = 68°F WORST CONDITION	BEST CONDITION
✓ a) GEAR 2 - TOTAL COMPOSITE TOL. /2 = .0016/2	.0008	.0000
✓ b) GEAR 3 - TOTAL COMPOSITE TOL. /2 = .0021/2	.0011	.0000
✓ c) TOOTH THINNING EFFECT ON CENTER DISTANCE TO OBTAIN .004/.008 BACKLASH	(.0051)	(.0098)
d) RADIAL PLAY - BEARING 10A (.0008/.0012)/2	(.0004)	(.0006)
e) RADIAL RUNOUT BEARING 10A (.0012/2)	.0006	.0000
f) ECCENTRICITY - BEARING SHAFTS (SLR-D1201-2) .0010/2	.0005	.0000
g) " - HOUSING -230/HOUSING -231 (.001/2)	.0005	.0000
* h) RADIAL CLEARANCE - HOUSING -230/BEARING 10A O.D.	(.0003)	(.0008)
* i) " " - GEAR 2 @ BRG./ BEARING 10A I.D.	.0002	(.0001)
✓ j) RADIAL PLAY - BEARING 4C (.0008/.0012)/2	(.0004)	(.0006)
✓ k) RADIAL RUNOUT BEARING 4C (.0012/2)	.0006	.0000
✓ l) ECCENTRICITY - BEARING SHAFTS (SLR-D1201-202-4) .0007/2	.0004	.0000
✓ m) " HOUSING (-230)/HOUSING (-231) .001/2	.0005	.0000
NO n) " GEAR 3 /BEARING 4C .0007/2	.0004	.0000
✓* o) RADIAL CLEARANCE - HOUSING -230/BEARING 4C O.D.	.0003	(.0003)
✓* p) " " - BEARING 4C ID /SHAFT	(.0001)	(.0004)
✓* q) - GEAR 3 /SHAFT	.0000	(.0004)
(* Radial Clearance = Diametral Clearance/2)		
MIDPOINT CLEARANCE = (.0004 + .0130)/2 = .0067 Clearance	(.0004) clearance	(.0130) clearance

$$\text{MIDPOINT CLEARANCE} = \frac{.0004 + .0130}{2} = .0067 \text{ Clearance}$$

Center Distance Required for a worst tolerance condition at 68°F = 3.7500 − .0004 = 3.7496"

Specified Center Distance at 68°F = 3.7500/3.7510 (SLR-D1201-230 & -231)

Center Distance Decrease at 280°F = .0011"

Center Distance Decrease at 200°F = .0007"

CALCULATIONS FOR CONTROL ROD DRIVE CLEARANCES at 280°F			
EQUIP. NO. D1201	PROJ. NO. 1900	CALC. NO. C-12-006/A	PAGE 39 OF
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A possible interference = .0007" exists at 280°F (WORST TOL. CASE=.0011 -.0004)

(A possible interference =.0003 exists @ 200°F - Worst Tol. Case)

A possible clearance = .0119 exists at 280°F (Best Conditions .0130-.0011)

GEAR №	Number of Teeth	Number of Revolutions
SLR-D1201-202-3	214	1
SLR-D1201-202-4	20	1
SLR-D1201-202-5	48	$(20/48)1 = .41666$
SLR-D1201-202-6	15	.4166
SLR-D1201-202-7	90	$(15/90).4166 = .06944$

In Order to Rotate Gear SLR-D1201-202-3 one revolution the drum shaft would have to rotate .06944 Revolutions.

Approx. Control Rod Stroke to rotate gear SLR-D1201-202-3 one revolution =

$.06944 \times \pi \times 14 = 3.05''$ (DRUM DIA.= 14" max.)

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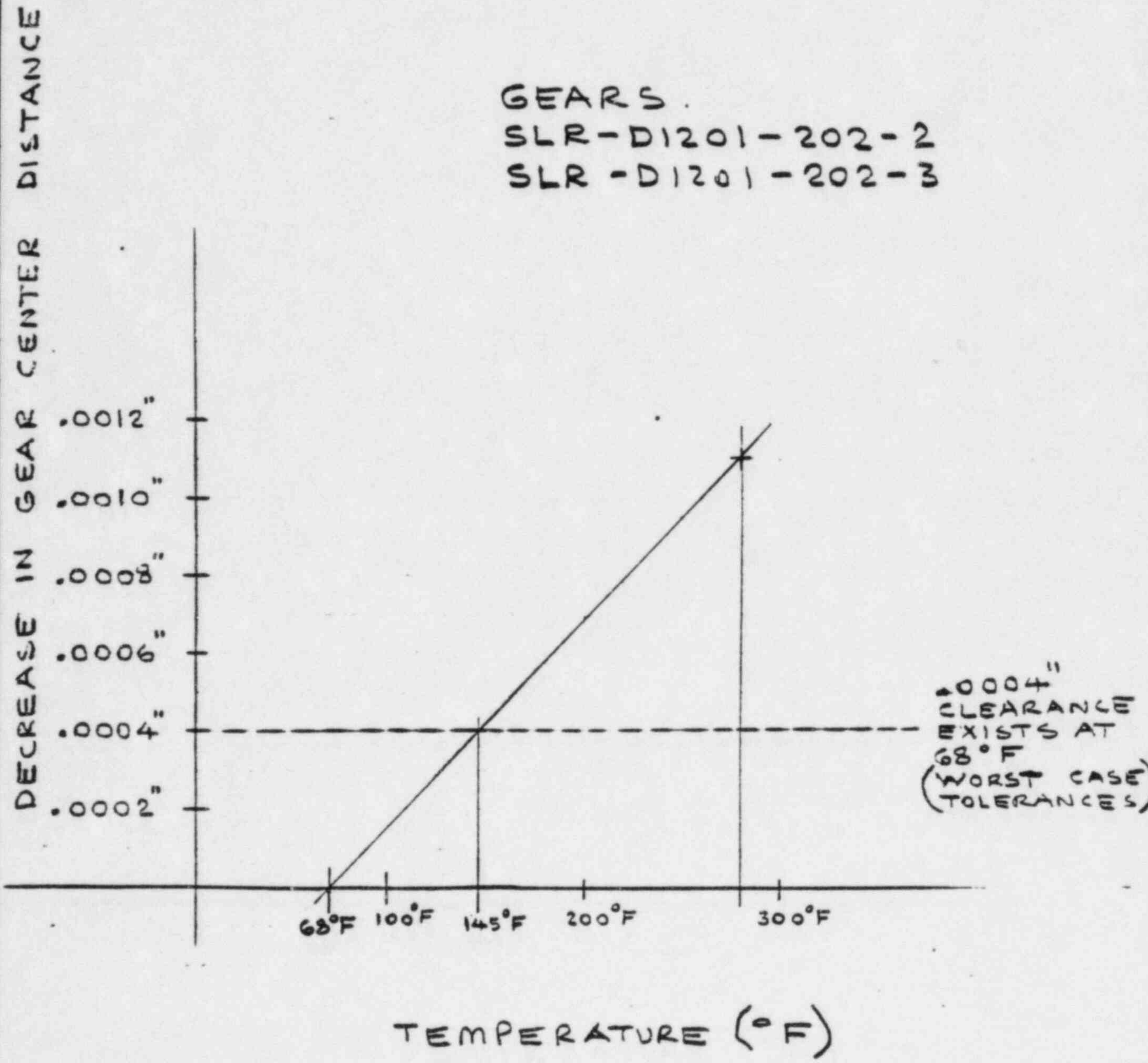
CALCULATIONS FOR CONTROL ROD DRIVE CLEARANCES AT 280°F			
EQUIP. NO. D1201	PROJ. NO. 1900	CALC. NO. C-12-006/P	PAGE 40 OF
PREPARED BY E. HARVEY	DATE 26 FEB. 81	REF. DOCUMENTS:	
REVIEWED BY	DATE		
APPROVED BY	DATE		



NOTE: .0130" CLEARANCE EXISTS AT 68°F for a BEST TOLERANCE CONDITION

CALCULATIONS FOR CONTROL ROD DRIVE CLEARANCES AT 280°F			
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APPROVED BY	DATE		

3.9.2.5 Assume GEARS 2 & 3 will not rotate due to a temperature increase to 280°F. What forces are generated at the pitch diameter due to the static weight of the control rods.

Available Torque at the drum shaft due to the static weight of the control rods $= 6 \times 250 = 1500$ in. lbs.

(6 = Drum Radius; 250 = Control Rod Wt)

Force Generated at Pitch Line of Gears SLR-D1201-202-6 & -7 $= \frac{1500}{9.00/2} = 333.33$ LBS.

(9.00 = P.D. of GEAR -7)

Torque at Gear SLR-D1201-202-6 $= 333.33 \times \frac{1.500}{2} = 250$ INCH LBS.

Force at Pitch Line of GEAR SLR-D1201-202-5 $= \frac{250}{3.00/2} = 166.67$ LBS.

Torque at Pitch Line of GEAR SLR-D1201-202-4 $= 166.67 \times \frac{1.250}{2} = 104.166$ inch lbs.

Force at Pitch Line of GEAR SLR-D1201-202-3 $= \frac{104.166}{4.6875/2} = 44$ lbs.

TORQUE @ GEAR 2 $= 44 \times .3125/2 = 17.8$ LB.IN.

FORCE @ PITCH LINE GEAR 10 $= 17.8/(4.25/2) = 8.41$ LBS

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GENERAL ATOMIC COMPANY

CALCULATIONS FOR CONTROL ROD DRIVE CLEARANCES AT 280°F			
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REVIEWED BY	DATE		
APPROVED BY	DATE		

3.9.3 GEARS SLR-D1201-202-4 & -5 ENGAGEMENT AT 280°F. (See FIG. 3.9.1)

3.9.3.1 Determine Center Distance Change at 280°F

GEARS: SLR-D1201-202-4 & -5

Material: NITRALLOY 135 MODIFIED

α_1 = COEFF of THERMAL EXPANSION = 6.5×10^{-6} in/IN/°F

(See Calc. 2.3)

HOUSING: SLR-D1201-231

Material: Meehanite GM60

α_2 = Coeff. of Thermal Expansion = 5.12×10^{-6} IN/IN/°F

(See Calc. 2.4)

Specified Center Distance = 2.1250/2.1255 @ 68°F

SLR-D1201-231

Center Distance Decrease at 280°F = ΔL

$\Delta L = (\alpha_1 - \alpha_2) L \Delta t = (6.5 - 5.12) 10^{-6} (2.1255)(280 - 68)$ ←

$\Delta L = .0006"$

$$\text{NOMINAL CENTER DISTANCE} = \frac{\text{PITCH DIA GEAR 4} + \text{PITCH DIA. GEAR 5}}{2} = \frac{1.25 + 3.00}{2} = 2.125$$

BACKLASH for Class 9A GEARS WITH 16 DP = .005 − .015 AGMA 390.02 Table 8

TOOTH THINNING TO OBTAIN BACKLASH

= .0025/.0075 per gear

= ONE-HALF BACKLASH

(See Reference Data in Calculation 3.5.2.1)

CALCULATIONS FOR	CONTROL ROD DRIVE CLEARANCES AT 230°F		
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APPROVED BY	DATE		

3.9.3.2 THINNING Effect on Center Distance

GEAR -5 16 DP 48 TEETH 20° P.A.

minimum Effect of Thinning on Center Distance
= .0025(2.5/2) = .00313"

maximum Effect of THINNING on Center Distance
= .0025(7.5/2) = .00938"

GEAR -4 16 DP, 20 TEETH, 20° PA

minimum Effect of THINNING ON CENTER DISTANCE
= .0023 (2.5/2) = .00288"

maximum Effect of THINNING ON CENTER DISTANCE
= .0023 (7.5/2) = .00863"

TOTAL minimum Effect of THINNING GEARS 4 & 5
ON CENTER DISTANCE = .00313 + .00288 = .0060"

TOTAL maximum Effect of THINNING GEARS 4 & 5
ON CENTER DISTANCE = .00938 + .00863 = .0180"

3.9.3.3 TOOTH ERROR CLASS 9A GEARS
PER AGMA 390.03 TABLE IV A

GEAR-5 16 DP 48 TEETH PD = 3.000"
TOTAL COMPOSITE TOLERANCE = .00242

GEAR -4 16 DP 20 TEETH P.D. = 1.250"
TOTAL COMPOSITE TOLERANCE = .00221

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CALCULATIONS FOR	CONTROL ROD DRIVE CLEARANCES at 280°F				
EQUIP. NO.	D1201	PROJ. NO. 1900		CALC. NO. C-12-0061/2	PAGE 44 OF
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APPROVED BY		DATE			

3.9.3.4 Center Distance Variation - GEARS 4 & 5

(See Engineering Drawings for Tolerances)

	TEMP. = 68°F WORST CONDITION	BEST CONDITION
a) GEAR 4 TOTAL COMPOSITE TOLERANCE/2 = .0022/2	.0011	.0000
b) Gear 5 TOTAL COMPOSITE TOLERANCE/2 = .0024/2	.0012	.0000
c) TOOTH THINNING EFFECT ON CENTER DISTANCE TO OBTAIN .005/.015 BACKLASH	(.0060)	(.0180)
d) Radial Play - Bearing 4/3A (.0008/.0012)/2	(.0004)	(.0006)
e) Radial Runout - Bearing 4/3A (.0012)/2	.0006	.0000
f) Eccentricity - Bearing Shafts SLR-D1201-202-4 .0007/2	.0004	.0000
g) " - Housing-230 / HOUSING-231 .001/2	.0005	.0000
* h) Radial Clearance - Housing-230/BEARING 4C O.D.	.0003	(.0003)
* i) " " - Bearing 4C I.D. / SHAFT SLR-D1201-253	(.0001)	(.0004)
j) RADIAL PLAY - BEARING 5 (.0008/.0012)/2	(.0004)	(.0006)
K) RADIAL RUNOUT - BEARING 5 (.0015/2)	.0008	.0000
l) ECCENTRICITY - BEARING 5 I.D./GEAR 5 P.D. .0010/2	.0005	.0000
m) PERPENDICULARITY - HOUSING-231 .001	.0005	.0000
* n) RADIAL CLEARANCE - HOUSING-231/BEARING 5 O.D.	.0003	(.0003)
* o) " " - BEARING 5 I.D. / GEAR 5	(.0001)	(.0004)
* Radial Clearance = Diametral Clearance/2		
	(.0008) clearance	(.0206) clearance

MID POINT CLEARANCE = $\frac{.0008 + .0206}{2}$ = .0107 clearance

Center Distance Required for a worst tolerance Condition at 68°F = 2.1250 - .0008 = 2.1242"

Specified Center Distance = 2.1250"/2.1255"
SLR-D1201-231

Center Distance Decrease at 280°F = .0006"

∴ ACCEPTABLE AT 280°F for Gears SLR-D1201-202-4, -5

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GA1543(REV. 11/80)

CALCULATION REVIEW REPORT

TITLE: Control Rod Drive Component Clearances at 280°F

APPROVAL LEVEL 2

QAL LEVEL I

DISCIPLINE	SYSTEM	DOC. TYPE	PROJECT	DOCUMENT NO.	ISSUE NO./LTR.
M	12	CFL	1900	C-12-006	A

INDEPENDENT REVIEWER:

NAME B. C. Hawke

ORGANIZATION Machine Design & Development (Org. 637)

REVIEWER SELECTION APPROVAL: BR MGR R. Rosenberg RR DATE 13 March 1981

REVIEW METHOD:	YES	NO	ERROR DETECTED
ARITHMETIC CHECK	X		None
LOGIC CHECK	X		None
ALTERNATE METHOD USED			
SPOT CHECK PERFORMED			
COMPUTER PROGRAM USED			

REMARKS: (ATTACH LIST OF DOCUMENTS USED IN REVIEW)

CALCULATIONS FOUND TO BE VALID AND CONCLUSIONS TO BE CORRECT:

INDEPENDENT REVIEWER [signature] DATE April 20 1981
SIGNATURE

INTERNAL CORRESPONDENCE
GA 1070

1— [illegible]

Copy

FROM I. G. Khamis IGK.

TO Distribution

IN REPLY REFER TO CAE:PCC:IGK:020:78

DATE 5/19/78

SUBJECT REPLY TO D. W. KETCHEN MEMO, FSV-ME:DWK:19:78

A. QUESTIONS:

1. What is effect of high-temperature operation on CRD Motors?

   a. Torque-speed Curve (motor)

   b. EMF-speed Curve (generator)

Answer: There will be a slight change in both operations while functioning as a motor or a generator due to an increase in the motor resistance at higher temperatures (less than 272°F). The motor components are rated for a 272°F as shown in Appendix A. The temperature coefficient of resistance for copper is approximately equal to 0.0022 ohm/ohm/Δ°F, thus the change in armature and motor resistances for a 100°F change in temperature is negligible.

2. What are the performance characteristics of failed motor components?

   a. Shorted Windings

   b. Open Windings

   c. Loss of Permanent Magnet

Answer: Refer to Appendix B.

3. What is the motor performance with one control rod?

Answer: The torque on the motor shaft will be approximately one half. The motor armature current will be decreased. The scram time will also be very approximately doubled as shown in this speed torque equation.

$$W \times L = J_M + J_L \frac{dV_1}{dt} + KV_1$$

$$\frac{1}{2} W \times L = (J_M + \frac{J_L}{2}) \frac{dV_2}{dt} + KV_2$$

when

W = weight of two rods

L = moment arm length

J_M = motor inertia

J_L = load inertia reflected to the motor shaft

V_1 = falling speed while scramming two rods

V_2 = falling speed while scramming one rod

K = dynamic braking damping constant

S = laplace transformer

$$WL = (J_M + J_L)\ SV_1(S) + KV_1(S)$$

$$\frac{WL}{2} = (J_M + \frac{J_L}{2})\ SV_2(S) + KV_2(S)$$

$$V_1(S) = \frac{1}{K} \frac{WL}{\frac{(J_M + J_L)}{K} S + 1} = \frac{WL}{K} \frac{1}{\tau_1 (S) + 1} = \frac{WL}{J_M + J_L} \bar{c}^{\frac{K t}{J_M + J_L}}$$

$$V_2(J) = \frac{\frac{1}{2} WL}{K \frac{(J_M + \frac{J_L}{2}) S + 1}{\frac{2}{K}}} = \frac{WL}{2K} \frac{1}{\tau_2(S) + 1} = \frac{WL}{2(J_M + \frac{J_L}{2})} \bar{c}^{\frac{K t}{J_M + \frac{J_L}{2}}}$$

$$\tau_1(S) = \frac{J_M + J_L}{K} \qquad \tau_2(S) = \frac{J_M + \frac{J_L}{2}}{K}$$

Magnitude of $V_1(S)$ is slightly less than $2V_2(S)$.

The reflected load inertia to the rotor shaft is very small.

The time response $\tau_1(S)$ is slightly larger than $\tau_2(S)$.

The dynamic braking acts like a damper.

The maximum velocity attained while scramming one rod is one-half of that while scramming two rods and it reaches this top speed in a slightly shorter time.

4. What are the limits of dynamic braking for various capacitor sizes?

Answer: The capacitor chosen supplies the magnetizing requirements for the motor to self-excite as a generator and to reach the rated voltage. Any increase in capacitance will cause unwanted overvoltages. A decrease in capacitance will not self-excite the generator due to the fact that the added KVAR is less than the motor magnetizing requirements.

IGK:td

Appendix A - Maximum Temperature Rerating of Fort St. Vrain - CRD Motor

Appendix B - Fort St. Vrain Control Rod Drive Motor Faults Effects & Characteristics While Operating at High Temperature

References:

1. "Application Guide for Shunt Capacitors on Industrial Distribution Systems at Medium Voltage Levels", IEEE Transactions on Industry Applications, Vol. IA-12, No. 5, September/October 1976, Donald F. Miller.

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MAXIMUM TEMPERATURE RERATING OF FORT ST. VRAIN

CRD MOTOR

I. G. Khamis: [signature]

Date: 3/24/1978

The basic materials of the CRD induction motor are magnetic steel, stator copper, rotor aluminum and copper, magnet aluminum sheath, and insulation. In addition, steel for the enclosure components along with bearing materials make up the main materials of the elements.

Of all these, the insulation fixes the motor operating temperature, since the temperature limit of the motor insulation is extremely low compared with the limiting temperature of the major materials.

There are other secondary components such as: the lead wire and solder, the encapsulating material, the magnet, the slot insulation and the bearing lubricant. Their temperature limit is listed in Table I.

The rerating of the maximum operating temperature for the CRD motor is based upon the following:

1) The electrical system is supposed to be free of pollutants such as: voltage variations from nominal, frequency variations, unbalanced phase voltages, surges or transients, flicker, distortion in the sine wave and fault disturbances.

2) Temperature rise due to any mechanical defects such as: bearing failure, excessive friction, poor ventilation, locked rotor, etc., are neglected.

3) The motor operates at a maximum torque of less than 25% of its 13 in-lb rated torque output at a very low duty cycle.

4) During its cycling period, approximately once every five minutes, the motor will experience its highest temperature rise. Previous test indicates even though at a faster cycling period once every 2 seconds, only a slight temperature rise (around $40^{o}F$) above ambient temperature was detected.

5) When the CRD scrams, the motor acts as a generator and provides a dynamic braking by dissipating the inertial energy across the bank of the capacitors.

6) As "a rule of thumb" commonly applied to motor insulation life is that for every 10°C rise above rated temperature, winding life will be reduced by one-half, or according to this formula:

$$\text{Life Expectancy} = \text{Rated Life} \times \frac{1}{2^n}$$

$$\text{where } n = \frac{\text{Actual °C Rise} - \text{Rated °C Rise}}{10°C}$$

7) The nominal life expectancy of a motor well maintained and operating at rated load is 20 years.

8) The temperature rise is proportional to the losses in the stator, the rotor and the mechanical friction. The electrical losses and also the mechanical losses are proportional to the $(\text{torque})^2$. Thus, temperature rise will reasonably conform to this fomula:

$$\text{Degree C Rise} = \text{Rate Rise} \times \left(\frac{\text{Percent Motor Load}}{100}\right)^2$$

9) The CRD motor insulation is Class H, and the maximum degree centigrade rise equals 180°C which includes ambient temperature, hot spot allowance (0.1% of the maximum rise by resistance) and the rise by resistance temperature.

Using the above equations, assumptions and modes of operations, the CRD motor could be safely and reasonably rerated to operate at a temperature of 135°C (275°F) and at an insulation life expectancy of at least 40 years.

Calculations

1. Motor ^{o}C Rise = $15^{o}C$ = $59^{o}F$ (Higher than the worst temperature experienced ($40^{o}F$) during extensive cycling period.

2. Allow $10^{o}C$ rise in temperature due to abnormal conditions such as excessive radiation or friction torque increase.

3. Allow $20^{o}C$ to accommodate for a winding life expectancy of 4 times $\left(\frac{1}{2^{-20/10}}\right)$ the nominal life of 20 years.

The maximum ambient temperature the CRD motor can experience:

$$180 - (1 + 0.1) \times 15 - 10 - 20 = 133.5^{o}C = 272.3^{o}F$$

TEMPERATURE LIMITS OF CRD MOTOR COMPONENTS

ITEM NUMBER	DESCRIPTION	TEMPERATURE LIMIT	REMARKS
1.	Insulation	356°F	Class H Insulation
2.	Lead Wire	302°F	Meets Mil-W-16878 (150°C)
3.	Slot Insulation	392°F	Glass Fiber
4.	Encapsulation	300°F (Minimum)	Shell Epon 828 with Shell Z Curing Agent
5.	Lead Wire Solder	Above 500°F	Electron Beam Method was used to fuse the lead wires.
6.	Lubricant	750°F	Dry Film Lubricant
7.	Magnet	850°F	The Curie Temperature of Indox I is 850°F. (Temperature at which magnet starts losing its magnetism.) There will be a slight drop in the coercive force of the magnet by operating at 300°F.

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FORT ST. VRAIN CONTROL ROD DRIVE

MOTOR FAULTS EFFECTS & CHARACTERISTICS WHILE

OPERATING AT HIGH TEMPERATURE

I. G. Khanis

3/29/78

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The main cause of failure of the motor operating at high temperature will be failure in the stator windings. The internal faults occurring are usually an open winding, a shorted winding, or two windings shorted or paralleled. Also a three-phase, line-to-line fault is likely to occur at the windings' terminals. Faults may occur from turn-to-turn in the same phase, or between windings in the same phase of a multiple winding. Certain types of faults are more likely to occur than others due to the details of the motor design and application. In our case, the CRD motor is a special one and a historical failure study on it is not available so all kinds of failures will be taken into consideration.

A short circuit in the CRD Y connected motor can be: 1) near the line, 2) near the middle, or 3) near the neutral. The above cases would result in an unbalanced phase or voltages and currents across the motor windings. Also due to the temperature rise and the unequal distribution of heat within the motor internal, unequal stator and rotor resistances may occur.

The faults can either occur while the CRD induction machine is acting as a generator or a motor and while it is in motion, at standstill, jogging up and down or during scram. The effects of the faults would vary with the above instances. For example, the motor would not start at standstill during a single-phase failure but it would continue rotating if the failure happens while it is in motion. Also, one fault could result in another fault.

In order to accurately predict the effects of the various faults on the induction machine, a complete simulation either on an analog or a digital computer is recommended. Nevertheless, Table I and Table II list most of the various faults and their effect on the motor and generator operation.

TABLE I

MOTOR OPERATION

CASE	FAILURE	CONSEQUENCES
1.	Single-Phase Open	Motor at standstill: the resultant electrical torque (difference between positive & negative torque) will not be as large as the starting torque of the motor. Motor will start humming at standstill. High temperature rise will occur and the overload protection should interrupt the current or a complete burnout of the motor would result. Motor running at full speed: the motor will keep on running at a pulsating torque which is composed of double the line frequency about a low mean value. The line currents would increase by 173%. If motor is loaded at 60% or less, no protection is adequate, unless loss of phase relay is included. The motor will overheat due to the high negative current sequence. Also, the open phase voltage increases as the motor approaches synchronous speed. The motor will slow down due to negative torque and thus the slip increases.
2.	Single-Phase Shorted (across the windings)	The mean value of the torque would be greatly reduced and the double frequency oscillations would be mostly marked and their magnitude is a function of both the amount of unbalance and speed of the motor. The motor would take a longer time to reach full speed from standstill. Short circuit protection should interrupt the phase where short circuit occurred.
3.	Two-Phase Paralleled or Shorted Together	The motor will keep on running at a pulsating torque with double frequency as in Case 1 but with larger magnitude and a greater mean value. Also, if started by other means (mechanical) it will reach synchronous speed at a faster time than Case I. It will not start at standstill by itself.
4.	More Than One Phase Open	Motor will come to a complete halt.
5.	Unbalanced Rotor or Armature Resistances Due to Partial Short in the Bars or Windings	An oscillating torque would result and the intensity of it is related to the maximum deviation from normal values. Oscillations are more pronounced in the rotor resistance unequalness.

TABLE I (Continued)

CASE	FAILURE	CONSEQUENCES
6.	A Three-Phase Line-to-Line Fault	A very high line current would result but of a very short duration while the motor is operating at steady-state under rated conditions. The short circuit protection should clear this fault.
7.	Loss of Magnetism	No affect on motor operation.

CONCLUSIONS:

1. Any fault conditions would result in high temperatures which sharply reduces the life of the motor insulation.

2. To prevent blocking the rotor, the motor should be protected against excessive heating, short circuits in any of the windings, a loss of any phase current, and an unbalance in stator voltages.

3. In any case, the power to the CRD motor should be interrupted completely at any fault condition and scram should entail.

TABLE II

GENERATOR OPERATION

CASE	FAILURE	CONSEQUENCES
1.	Single-Phase Open	There will be no build-up of voltage across this phase and thus the dynamic braking would be reduced by 87% ($\approx\sqrt{3}/2$)%. This unbalance would cause an oscillating dynamic braking current.
2.	Single-Phase Shorted (across the winding)	As in Case 1, the only voltage across the resistance will be the residual voltage. The dynamic braking would be oscillating as in Case 1 but of slightly larger magnitude.
3.	Two phases Paralleled or Shorted Together	As in Case 1, there will be no build-up across the open phase. The total dynamic braking would be reduced but it would be increased in the paralleled phase. A more pronounced oscillation in the dynamic braking occurs.
4.	More Than One Phase Open	Dynamic braking would be completely lost.
5.	Unbalance Rotor or Armature Resistances Due to Partial Short in the Bars or Windings	An oscillating dynamic braking would result of magnitude and oscillation which is related to the maximum deviation from normal values. Also, it is more pronounced in the rotor side. A complete short in the rotor bars (very unlikely) would cause maximum dynamic braking.
6.	A Three-Phase Line-to-Line Short	There will be no voltage build-up other than the residual voltage. The magnitude of the dynamic braking would be greatly reduced almost negligible.
7.	Loss of Magnetism	The dynamic braking will be lost completely.

CONCLUSIONS:

The worst-case is loss of the dynamic braking completely and thus the control rod drive would free fall.

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