26
9-2-80
26
MASTER

SAND80-0481
UNLIMITED RELEASE
UC-13

THE SANDIA NATIONAL LABORATORIES
8.8-METRE (29-FOOT) AND 10.7-METRE (35-FOOT)
CENTRIFUGE FACILITIES

P. H. ADAMS, R. L. AULT, AND D. L. FULTON

Prepared by Sandia Laboratories, Albuquerque, New Mexico 87185
and Livermore, California 94550 for the United States Department of
Energy under Contract DE-AC04-76DP00789.

PRINTED MAY 1980

Sandia National Laboratories

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

Issued by Sandia Laboratories, operated for the United States
Department of Energy by Sandia Corporation.

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

SAND80-0481
Unlimited Release

Distribution
Category UC-13

THE SANDIA NATIONAL LABORATORIES
8.8-METRE (29-FOOT) AND 10.7-METRE (35-FOOT)
CENTRIFUGE FACILITIES

P. H. Adams,
R. L. Ault,
and
D. L. Fulton
Centrifuge, Climatic, Radiant Heat Division 1531
Sandia Laboratories
Albuquerque, New Mexico 87185

DISCLAIMER

This book was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Printed in the United States of America

Available from:

National Technical Information Service
U. S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

Price: Printed Copy \$9.00; Microfiche \$3.00

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

SAND80-0481

THE SANDIA NATIONAL LABORATORIES
8.8-METRE (29-FOOT) AND 10.7-METRE (35-FOOT)
CENTRIFUGE FACILITIES*

May 1980

ABSTRACT

This report: (1) outlines the capabilities and limitations of the two Centrifuges and gives other details which must be considered in preparing test specifications and designing fixtures, (2) gives the theory and terminology of centrifuge testing, and (3) describes the layout, operating principles, support functions, and reference material for each facility.

*This work was supported by the United States Department of Energy (DoE).

CONTENTS

	<u>PAGE</u>
LIST OF SYMBOLS	ix
DEFINITIONS	xi
INTRODUCTION	1
DISCUSSION	3
 <u>A. GENERAL DESCRIPTION</u>	
A1. Major Facilities and Support Equipment	3
A2. Function of Centrifuge Facilities	3
A3. Remote Equipment	5
 <u>B. 10.7-METRE (35-FOOT) CENTRIFUGE</u>	
B1. Manufacturer	7
B2. Capabilities	7
B3. Centrifuge Arm	11
B4. Power Head Assembly	13
B5. Operation of Centrifuge	18
B6. Power and Data Transmission	18
B7. Centrifuge Enclosure	19
B8. Allowable Size of Test Specimen	21
B9. Television Monitor	21
B10. Impact Testing	21
 <u>C. 8.8-METRE (29-FOOT) CENTRIFUGE</u>	
C1. Manufacturer	23
C2. Capabilities	23
C3. Centrifuge Arm	27
C4. Power Head Assembly	29

CONTENTS (CONT'D)	<u>PAGE</u>
C5. Operation of Centrifuge	33
C6. Power and Data Transmission	34
C7. Centrifuge Enclosure	34
C8. Allowable Size of Test Specimen	36
C9. Television Monitor	37
 <u>D. VIBRATION SYSTEM FOR 8.8-METRE (29-FOOT) CENTRIFUGE</u>	
D1. General	39
D2. Components	39
D3. Mounting	44
D4. Capabilities	44
D5. Limitations	45
 <u>E. TEST CONTROL</u>	
E1. Centrifuge	47
E2. Vibration	50
 <u>F. DATA ACQUISITION</u>	
F1. General	
F2. Signal Conditioning and Transmission of DC Data	53
F3. Vibration and Shock Data	58
F4. System Computer	59
F5. Remote Operation	60
F6. Data Analysis and Presentation	63
F7. Patch Panels, Interconnections, and Wiring	63
 <u>G. HYDRAULIC SYSTEM</u>	
G1. Pump House	67
G2. Storage Tanks	70
G3. Hydraulic Circuitry	70
G4. Electronic Control	72
G5. Computer Control	72

CONTENTS (CONT'D)	<u>PAGE</u>
ACKNOWLEDGEMENTS	75
<u>APPENDIX 1</u>	
Theoretical Analysis of the Acceleration Environment Provided by a Centrifuge	77
<u>APPENDIX 2</u>	
Calculation of the Normal Acceleration Level in Terms of G	81
<u>APPENDIX 3</u>	
Acceleration (G) Gradient on a Test Specimen	85
<u>APPENDIX 4</u>	
List of Drawings for 10.7-Metre (35-foot) Centrifuge Facility	87
<u>APPENDIX 5</u>	
Denison Fluid Motors	93
<u>APPENDIX 6</u>	
Impact Testing with the 10.7-Metre (35-foot) Centrifuge Facility	97
<u>APPENDIX 7</u>	
List of Drawings for 8.8-Metre (29-foot) Centrifuge Facility	127
<u>APPENDIX 8</u>	
Factory Specifications on Vibration System for 8.8-Metre (29-foot) Centrifuge Facility	131
<u>APPENDIX 9</u>	
Factory Specification Sheet for Power Amplifier	137
<u>APPENDIX 10</u>	
Computer Control System	141
<u>APPENDIX 11</u>	
Digital Data Acquisition and Analysis System for the 8.8- and 10.7-Metre Centrifuge Facilities - System Capabilities Report	147
<u>APPENDIX A</u>	
Sample Interactive Operator/System Dialog for Program CENT	169
<u>APPENDIX B</u>	
Sample Data Plot of Strain Data Stored by Program CENT	173

CONTENTS (CONT'D)

PAGE

APPENDIX C

Sample Test Verification Plot of G Versus Time as Stored
by Program CENT

175

APPENDIX 12

Denison Hydroilic Pumps

177

DISTRIBUTION

185

LIST OF FIGURES

		<u>PAGE</u>
Fig. 1.	Layout of Sandia Laboratories Area III	4
Fig. 2.	Speed Vs. Time Characteristics of 10.7-Metre (35-foot) Centrifuge for Unfaired/No-Load Conditions	9
Fig. 3.	Speed Vs. Time Characteristics of 10.7-Metre (35-foot) Centrifuge for Faired/No-Load Conditions	10
Fig. 4.	10.7-Metre Centrifuge	12
Fig. 5.	Fixture Support Plates on 10.7-Metre Centrifuge	14
Fig. 6.	Details of Fixture Mounting Plates on 10.7-Metre (35-foot) Centrifuge	15
Fig. 7.	Counterweight Compartment on the 10.7-Metre Centrifuge	16
Fig. 8.	Sectional Representation of Power Head Assembly on 10.7-Metre (35-foot) Centrifuge	17
Fig. 9.	Outside of 10.7-Metre Centrifuge Facility	20
Fig. 10.	Speed Vs. Time Characteristics of 8.8-Metre (29-foot) Centrifuge for Unfaired/No-Load Conditions	25
Fig. 11.	Speed Vs. Time Characteristics for 8.8-Metre (29-foot) Centrifuge for Faired/No-Load Conditions	26
Fig. 12.	8.8-Metre (29-foot) Centrifuge Facility	28
Fig. 13.	Fixture Support Plates on the 8.8-Metre Centrifuge	30
Fig. 14.	Details of Fixture Mounting Plates on 8.8-Metre (29-foot) Centrifuge	31
Fig. 15.	8.8-Metre (29-foot) Centrifuge Power Head and Slip Ring Assembly	32
Fig. 16.	Crane Building Access to 8.8-Metre Centrifuge	35
Fig. 17.	Details of Slip Table Connecting the Two Shakers	40
Fig. 18.	Power Amplifier for 8.8-Metre (29-foot) Centrifuge Shaker System	41
Fig. 19.	25-Foot Centrifuge with Shaker System	42
Fig. 20.	Shaker Interface Cavity	43

LIST OF FIGURES (CONT'D)

PAGE

Fig. 21.	Vibration Control Console, Centrifuge Local Control Console, and Data Console	48
Fig. 22.	Control Computer System	49
Fig. 23.	Vibration Control Console Located in Bldg. 6526	51
Fig. 24.	On-Board PCM Data System and Bridge Completion Networks (350 Ω)	56
Fig. 25.	End of Centrifuge Arm Patch Panel	61
Fig. 26.	Center of Boom Patch Panel	62
Fig. 27.	Control Room Patch Panel (Contractor Interface) Showing Standard Banana, Coax, Giant Banana, and RF Patching	62
Fig. 28.	Pump House Interior	68
Fig. 29.	Electric Motor/Hydraulic Pump Combination	69
Fig. 30.	Master Panel and Electric Motor Control Panels in the Pump House	71
Fig. 31.	Oil Filter System for Hydraulic Supply Oil	73

LIST OF SYMBOLS

A_N = normal acceleration resulting from Centrifuge arm rotation (see Appendix 1)

A_T = tangential acceleration resulting from Centrifuge arm rotation (see Appendix 1)

cps = cycles/second (frequency)

G = acceleration ratio

g = grams

G_N = normal acceleration ratio $A_N/(9.82)$. The symbol G, without a subscript, is also to signify normal acceleration ratio.

G-newtons = dynamic load (see Definitions)

G_T = tangential acceleration ratio $A_T/(9.82)$

HP = horsepower

Hz = hertz

K = temperature, Kelvin

k = kilo

lpm = litres/minute (flow rate)

M = mega

m = metres

N = newton

Pa = pascals

R = radius

rad = radians

S = arc length

(Continued)

List of Symbols (Cont'd)

s = seconds

t = time

V = volts

v = velocity

v_t = tangential velocity

θ = angle

ω = radians/second

ns = nanoseconds

Ω = ohms

μ = micro

ϵ = strain

DEFINITIONS

Acceleration Gradient - At any fixed speed of the Centrifuge, the normal acceleration is a linear function of the distance from the center of rotation to the point of reference. Thus, an acceleration gradient will exist between planes of a test specimen not located at the same radial distance (see Appendix 3, for example).

Normal Acceleration - See Appendix 1.

Tangential Acceleration - See Appendix 1.

Dynamic Load - This is the radial force on the Centrifuge arm as a result of rotation. The design limitations of the Centrifuge arm are expressed in terms of dynamic load. For example, a 45.4 kg (100 lb) test item experiencing 100 G normal acceleration produces a 44.5 G-kN (10 000 G-lb) dynamic load (force) on the arm.

THE SANDIA LABORATORIES
8.8-METRE (29-FOOT) AND 10.7-METRE (35-FOOT)
CENTRIFUGE FACILITIES

INTRODUCTION

This report is intended to: (1) aid test personnel and consultants in the design of test specifications and test fixtures, (2) provide a reference to information about the Centrifuge facilities, (3) describe the operation of the facilities, and (4) state the theory and terminology of Centrifuge testing.

DISCUSSION

A. GENERAL DESCRIPTION

A1. Major Facilities and Support Equipment

(See Fig. 1)

(a) 10.7-Metre (35-foot) Centrifuge (Bldg. 6520)

(b) 8.8-Metre (29-foot) Centrifuge (Bldg. 6526)

(c) Local Centrifuge/Vibration Control and Data Acquisition Room (Bldg. 6526)

(d) Hydraulic Pump House (Bldg. 6523)

A2. Function of Centrifuge Facilities

(a) The primary function of the Centrifuge facilities is to permit test specimens to be subjected to a normal acceleration (directed radially inward to the center of rotation). This normal acceleration can be controlled at any level, constant or varying, between zero G and the maximum obtainable on the respective Centrifuge.

(b) The 8.8-Metre (29-foot) Centrifuge is equipped with a vibration system which will provide sinusoidal, random, or programmed vibration inputs to test specimens. The maximum allowable

weight of a test specimen which is to be vibrated is 45.4 kg (100 lb). The vibration and normal acceleration tests are conducted simultaneously.

A3. Remote Equipment

All explosive tests in excess of 45.4 kg (100 lb) on the 10.7-Metre (35-foot) Centrifuge and 2.3 kg (5 lb) on the 8.8-Metre (29-foot) Centrifuge are remotely controlled from the console in Building 6540, which is 300 m (1000 ft) from the Centrifuge complex (Fig. 1). Data acquisition equipment is also remotely controlled from this location.

B. 10.7-METRE (35-FOOT) CENTRIFUGE

B1. Manufacturer

Rucker Company; Oakland, California.

B2. Capabilities

(a) Capabilities of this Centrifuge are outlined in Table I, as follows.

TABLE I
10.7-METRE (35-FOOT) CENTRIFUGE CHARACTERISTICS

Maximum Speed (faired)	15.2 rad/s (145 rpm)
Maximum Speed (unfaired)	8.4 rad/s (80 rpm)
Weight Limit (fixture + test specimen)	4530.0 kg (10 000 lb)
Dynamic Load Limit	2 Mg-N (450 000 G-lb)
Maximum Normal Acceleration (10.7 m) (35 ft radius)	245 G
Overall Length of Rotating Arm	17.1 m (56 ft)
Radius (center of rotation to test specimen end)	10.82 m (35.5 ft)
Radius (center of rotation to counterweight end)	6.25 m (20.5 ft)

(b) Speed: Rotational speed can be varied or held constant at any level between .5 and 15.2 rad/s (5 and 145 rpm) when the specimen end of the Centrifuge arm is streamlined (faired). The speed of 15.2 rad/s (145 rpm) corresponds to a tip velocity of 164.6 m/s (368 mph) and a normal acceleration of 240 G at a radius of 10.8 m (35 ft).

A maximum of 8.4 rad/s (80 rpm) is obtainable when the specimen end is unfaired. At a 10.7 m (35 ft) radius, this corresponds to 76 G. (A theoretical analysis of the acceleration environment provided by the Centrifuge is presented in Appendix 1. The equation and its derivation, which expresses normal acceleration as a function of the angular velocity and radius, is included in Appendix 2.

(c) Tangential Acceleration: The intended environment for a test specimen is the normal acceleration due to rotation. However, there is also a tangential acceleration of the test specimen when the Centrifuge is increasing or decreasing in angular velocity (see Appendix 1). The time required to accelerate from a standstill to maximum angular velocity and the time required to decelerate (brake) from maximum to zero angular velocity was experimentally determined under no-load/unfaired and no-load/faired conditions. The results are presented in Figs. 2 and 3. On the basis of the results, the maximum tangential acceleration was less than $0.1 G_T$, which is a negligible test specimen environment. However, the results shown in Figs. 2 and 3 will aid in deriving test specifications when test time is of concern.

(d) Maximum Test Load: The weight of the test specimen and test fixture cannot exceed 4.5 Mg (10 000 lb).

(e) Maximum Dynamic Load: The dynamic load during a test cannot exceed 2 G-MN (450 000 G-lb). Thus, with a maximum load of 4.5 Mg (10 000 lb), the acceleration cannot exceed 45 G. As an example of the dynamic load limit, a 2.3-Mg (5000 lb) test

FIGURE 2. SPEED VS. TIME CHARACTERISTICS OF 10.7-METRE (35-FOOT) CENTRIFUGE FOR UNFAIRED/NO-LOAD CONDITIONS

FIGURE 3. SPEED VS. TIME CHARACTERISTICS OF 10.7-METRE (35-FOOT) CENTRIFUGE FOR FAIRED/NO-LOAD CONDITIONS

specimen-fixture combination cannot be tested in excess of 90 G ($2.3 \times 90 \times 9.8 = 2 \text{ G-MN}$, or $5000 \times 90 = 450\,000 \text{ G-lb}$).

(f) Acceleration Gradient: The acceleration gradient is a function of Centrifuge speed and the radial distance between the reference points. This gradient should be considered when deriving test specifications or designing test fixtures. (Acceleration gradient is discussed in Appendix 3).

B3. Centrifuge Arm

(Appendix 4 lists all drawings associated with the 10.7-Metre (35-foot) Centrifuge).

(a) The Centrifuge Arm: The Centrifuge arm is depicted in Fig. 4.

(b) Length of Arm: The arm has an overall length of 17.1 m (56 ft). The center of rotation is 10.82 m (35.5 ft) from the extreme of the test specimen end and is 6.25 m (20.5 ft) from the extreme of the counterweight end. The counterweight end of the arm is shorter to reduce aerodynamic drag.

(c) Weight of Arm: Approximately 23 Mg (25 tons).

(d) Type of Construction: The arm is a steel weldment consisting of two 406-mm (16-in) OD pipes (17.7 mm, or 0.5 in thickness) which extend parallel along the length of the arm (17.1 m, or 56 ft). There are seven stiffener plates perpendicular to the 406 mm (16 in) pipes and two stiffener plates extending parallel to the pipes. This construction is covered by a 12.7 mm (1/2 in) plate, which is reinforced with another 6.4 mm (1/4 in) plate near the arm's center of rotation. Trailing edges are provided on both ends of the arm for aerodynamic stability.

FIGURE 4. 10.7-METEE CENTRIFUGE

(e) Fixture Mounts: The fixture support plates are depicted in Fig. 5. These 25.4 mm (1 in) steel plates are welded to the arm construction. The distance between the two parallel plates is 1.88 m (74 in) and each plate contains two rows of 1-inch, eight NC bolt holes for mounting purposes. (The size of the plates and the bolt hole pattern are shown in Fig. 6.)

(f) Counterweights: Counterweights are used to statically balance the Centrifuge arm (with test specimen and fixture mounted) about the center of rotation. The compartment for the counterweights is depicted in Fig. 7. Using the present steel counterweights, this compartment has a capacity of 5.5 Mg (12 050 lb).

B4. Power Head Assembly

(a) Location: The power head assembly is contained in a pit area below the Centrifuge floor level.

(b) Support and Isolation: The power head assembly is supported by a large concrete reaction mass. This mass is separated from the remainder of the facility construction in order to isolate vibration and/or displacement feedback during Centrifuge operation.

(c) Fluid Motors: Seven Denison fluid motors (Series 800) are mounted to the power head assembly. The specification sheet for the motors is included in Appendix 5.

(d) Centrifuge Drive Mechanism: The Denison motor shafts extend out the top of the power head assembly. Pinion gears, connected to these shafts, drive the bull gear bolted to the Centrifuge arm spindle. This is a 14:1 gear reduction. Also geared to the bull gear is a tachometer generator used to indicate the speed of rotation of the Centrifuge arm (Fig. 8).

FIGURE 5. FIXTURE SUPPORT PLATES ON 10.7-METRE CENTRIFUGE

FIGURE 7. COUNTERWEIGHT COMPARTMENT ON THE 10.7-METRE CENTRIFUGE

FIGURE 8. SECTIONAL REPRESENTATION OF POWER HEAD
ASSEMBLY ON 10.7-METRE (35-FOOT) CENTRIFUGE

(e) Lubrication: One lubrication system is used for the power head. Two nozzles spray each pinion gear and the lubricant flows through the bearings back to the reservoir. Four nozzles spray into the main bearings--the lubricant then falling onto the lower bearings and then into the reservoir.

B5. Operation of Centrifuge

(a) Usage of Motors: All seven fluid motors are in operation during a test.

(b) Speed Control: Centrifuge speed is controlled by the volume of hydraulic fluid supplied to the fluid motors.

(c) Hydraulic Fluid Supply: Hydraulic fluid is supplied from the pump house (Bldg. 6523). Variable volume is made possible by six constant-volume and seven variable-volume Denison pumps (see Section G1-(b) for details on the Denison pumps). Any combination of these pumps may be used during a test.

(d) Centrifuge Braking: The hydraulic fluid flows through the seven fluid motors into a discharge manifold. From there, it flows through the brake valves which are pilot-operated relief valves. When the brake button is depressed at the control console, a solenoid-operated pilot valve closes the brake valves. The motors then act as pumps which provide the braking action. The degree of deceleration is controlled by adjustment of the braking pressure between 0 and 34.5 MPa (0 and 5000 psi).

B6. Power and Data Transmission

(a) PCM Encoder and Telemetry: The primary system for collecting data from the Centrifuge is a pulse code modulation (PCM) encoder having 160 data channels (96 low level and

64 high level). The digitized data is then transmitted to the control room via an S-band telemetry link.

(b) Slip Rings: There are 12 slip rings rated at 250 V x 100 A, 24 slip rings rated at 250 V x 5 A, and 150 slip rings rated at 32 V x 0.25 A.

(c) Slip Ring Housing: The slip rings are located at the base of the power head assembly. These are enclosed in a plastic case to protect them from dust and hydraulic fluid.

(d) Instrumentation and Power Cabling: Cabling between the outboard end of the Centrifuge and the slip rings is clamped inside the arm.

(e) Data Acquisition and Presentation: See Section F.

B7. Centrifuge Enclosure

(a) Barricade: The Centrifuge arm is surrounded by a 3 m (10 ft) high x 28 m (92 ft) diameter concrete barricade (Fig. 4).

(b) Access to Arm: Access is by two steel doors, each 1.5 m (5 ft) wide (total width: 3 m, or 10 ft).

(c) Work Area: Assembly of a test system before mounting to the Centrifuge may be done in the assembly room at Bldg. 6526. There is a small workshop near the barricade area (Fig. 9).

(d) Hoists: A crane monorail extends across the diameter of the barricaded area and about 6 m (20 ft) past the steel doors (Fig. 9). Two hoists (4.5 Mg, or 5 ton; and 3.6 Mg, or 4 ton) are mounted to this monorail. The maximum height between the hook and ground is 4.7 m (15.5 ft) and 5.3 m (17.5 ft) for the 4.5 and 3.6 Mg (4 and 5 ton) hoists, respectively. The hoists are used to mount test systems to the Centrifuge.

FIGURE 9. OUTSIDE OF 10.7-METRE CENTRIFUGE FACILITY

B8. Allowable Size of Test Specimen

(a) The physical size limitations on fixtures and test specimens are dependent upon the style of mounting. Dimensions which should be considered are:

1. Distance from floor to underside of Centrifuge arm (1.2 m, or 4 ft).
2. Distance from arm tip to barricade wall (3.2 m, or 10.5 ft).
3. Distance between specimen mounting plates (1.88 m, or 74 in).
4. Length of mounting plates (2.44 m, or 96 in).

B9. Television Monitor

(a) Location: A pan, tilt, and zoom TV camera is mounted on the tower shown in Fig. 9. Another pan and tilt camera is available for coverage of the facility and barricades during remote operation. This camera is located on a tower located in front of Bldg. 6530.

(b) Monitor Screens: Continuous viewing of the Centrifuge arm is possible from the local control room, the remote control room, and the pump house.

B10. Impact Testing

The 10.7-Metre (35-foot) Centrifuge can generate tangential velocities up to 183 m/s (600 ft/s). A release system has been designed which allows free flight impact testing from the 10.7-Metre (35-foot) Centrifuge arm into various target media.

The system provides an accurate release velocity and impact acceleration measurement, at relatively low cost. Appendix 6 gives a detailed explanation of impact testing capabilities on the 10.7-Metre (35-foot) Centrifuge.

C. 8.8-METRE (29-FOOT) CENTRIFUGE

C1. Manufacturer:

Rucker Company; Oakland, California.

C2. Capabilities

(a) See Table II for an outline of capabilities.

TABLE II
8.8-METRE (29-FOOT) CENTRIFUGE CHARACTERISTICS

Maximum Speed (faired)	974 rad/s (155 rpm)
Maximum Speed (unfaired)	785 rad/s (125 rpm)
Weight Limit (fixture + test specimen)	7.26 Mg (16 000 G-lb)
Dynamic Load Limit	7.3 G-MN (1 600 000 G-lb)
Maximum Normal Acceleration (29 ft radius) (8.8 m)	240 G
Overall Length of Rotating Arm	1.55 m (51 ft)
Radius (center of rotation to test specimen end)	8.8 m (29 ft)
Radius (center of rotation to counterweight end)	6.7 m (22 ft)

(b) Speed: The rotational speed of the arm can be varied or held constant at any level between .5 and 16.2 rad/s (5 and 155 rpm) when the specimen end of the arm is faired. A rotational speed of 16.2 rad/s (155 rpm) corresponds to a normal acceleration of 240 G and a tangential tip velocity of 123 m/s (275 mph) at a 8.8 m (29 ft) radius.

The maximum rpm of the unfaired arm is 13 rad/s (125 rpm), which corresponds to 150 G at a 8.8 m (29 ft) radius.

This Centrifuge is designed for 19.8 rad/s (300 G @ 7.6 m) [189 rpm (300 G @ 25 ft)]; however, the existing power unit provides only enough hydraulic fluid volume to maintain 16.2 rad/s (155 rpm) maximum. This 16.2 rad/s (155 rpm) maximum was achieved by completely enclosing the specimen arm with flat sheet metal pieces thus not increasing the frontal area of the arm. The specimens which are larger than the .6 m (24 in) depth of the specimen arm would increase the frontal area and, hence, decrease the maximum achievable rotational velocity. (A theoretical analysis of the acceleration environment provided by the Centrifuge is presented in Appendix 1. The equation, and its derivative, which expresses normal acceleration (G) as a function of the angular velocity and radius, is included in Appendix 2.)

(c) Tangential Acceleration: As discussed in Section B2-(c), there is a tangential acceleration of the test specimen when the Centrifuge is increasing or decreasing in angular velocity (see Appendix 1). The time required to accelerate from zero to maximum angular velocity and the time to brake from maximum angular velocity to zero were experimentally determined for no-load/unfaired and no-load/faired conditions. The results are presented in Figs. 10 and 11, respectively. From these results, it was calculated that the maximum tangential acceleration of the test specimen is negligible, being less than $0.15 G_T$; however, the results presented in Figs. 10 and 11 will aid in deriving test specifications when test time is of concern. (In Figs. 10 and 11, there are five curves each, due to the option available concerning the number of fluid motors used during a test. For maximum angular

FIGURE 10. SPEED VS. TIME CHARACTERISTICS OF 8.8-METRE (29-FOOT) CENTRIFUGE FOR UNFAIRED/NO-LOAD CONDITIONS

FIGURE 11. SPEED VS. TIME CHARACTERISTICS FOR 8.8-METRE (29-FOOT) CENTRIFUGE FOR FAIRED/NO-LOAD CONDITIONS

velocity, 10 fluid motors are used, while for maximum torque (and, hence, maximum tangential acceleration), 16 fluid motors are used. For further details concerning this option, refer to Section C5-(b).

(d) Maximum Test Load: Total weight of the test specimen and test fixture cannot exceed 7.3 Mg (16 000 lb).

(e) Maximum Dynamic Load: The dynamic load cannot exceed 7.3 G-MN (1.6 M G-lb). Thus, with a maximum test load of 7.3 Mg (16 000 lb), the normal acceleration cannot exceed 100 G.

(f) Acceleration Gradient: See Appendix 3.

C3. Centrifuge Arm

Appendix 7 lists all drawings associated with the 8.8-Metre (29-foot) Centrifuge.

(a) Length: The arm (Fig. 12) is 15.5 m (51 ft) tip to tip, with the center of rotation 8.8 m (29 ft) from the specimen end; thus, 6.7 m (22 ft) from the extreme of the counterweight end. The counterweight end is shortened to reduce aerodynamic drag.

(b) Weight: Approximately 27 Mg (30 tons).

(c) Type of Construction: The arm is constructed of two long tubular weldments clamped together on the spindle. Identical mounting surfaces for counterweight structure and specimen yokes are provided at each end (detailed drawings listed in Appendix 7). A trailing-edge fairing is attached to the counterweight end for aerodynamic stability.

FIGURE 12. 8.8-METRE (29-FOOT) CENTRIFUGE FACILITY

(d) Fixture Mounts: The 38 mm (1.5 in) steel fixture support plates (Fig. 13) are welded to the arm construction. The distance between the two parallel plates is 1.88 m (74 in) and each plate contains four rows of 1-in, eight NC bolt holes for mounting purposes (see Fig. 14 for the hole pattern for the plates).

(e) Counterweights: As previously explained, counterweights are used to statically balance the Centrifuge arm (with test fixture and test specimen) about the center of rotation. The compartment for the counterweights is at the extreme left of the arm in Fig. 12. The maximum weight, using steel counterweights, is 9.8 Mg (21 600 lb).

C4. Power Head Assembly

(a) Location: The power head assembly is located in a pit below the center of the arm (Fig. 15).

(b) Support and Isolation: The power head assembly is supported by a large concrete reaction mass which is separated from the remainder of the facility to isolate vibration and/or displacement during operation of the Centrifuge.

(c) Fluid Motors: Sixteen (16) Denison fluid motors (Series 800) are mounted to the power head assembly (Fig. 15). The factory specification sheet is included in Appendix 5.

(d) Centrifuge Drive Mechanism: The bull gear, which is bolted to the arm spindle, is driven by eight pinions. The pinion gears are mounted on drive shafts which extend from the top of the power head assembly. Eight drive gear boxes are mounted on the underside of the base with two fluid motors driving each gear box. A tachometer generator, used for speed indication, is geared to the bull gear.

FIGURE 13. FIXTURE SUPPORT PLATES ON THE 8.8-METRE CENTRIFUGE

NOTE: PARALLEL FACES 74 (1.88M) APART

FIGURE 14. DETAILS OF FIXTURE MOUNTING PLATES ON
8.8-METRE (29-FOOT) CENTRIFUGE

FIGURE 15. 8.8-METRE (29-FOOT) CENTRIFUGE POWER
HEAD AND SLIP RING ASSEMBLY

C5. Operation of Centrifuge

(a) Usage of Fluid Motors: The number of fluid motors used during a test is optional--the choice being 8, 10, 12, 14, or 16.

(b) Speed Control: Centrifuge speed is controlled by the volume of hydraulic fluid supplied to the fluid motors. Maximum rpm is obtainable with 10 fluid motors, while maximum torque at low speeds is obtainable with 16 fluid motors. The reason 10 motors provide maximum rpm is the limited volume output of the hydraulic pumps presently available. To drive 16 fluid motors at maximum angular velocity would require approximately $.072 \text{ m}^3/\text{s}$ (1140 gpm) (see Specifications in Appendix 5). The maximum output of the present system is $.029 \text{ m}^3/\text{s}$ (455 gpm).

(c) Hydraulic Fluid Supply: The hydraulic fluid is supplied from the pump house (Bldg. 6523). Variable volume is made possible by six constant-volume and seven variable-volume Denison pumps (see Section G1-(b) for details on the Denison pumps).

(d) Centrifuge Braking: The hydraulic fluid flows through the fluid motors into a discharge manifold. From there it flows through the brake valves, which are pilot-operated relief valves. When the brake button is depressed at the control console, a solenoid-operated pilot valve closes the brake valves. The motors then act as pumps which provide the braking action. The degree of deceleration is controlled by adjustment of the braking pressure between 0 and 34.5 MPa (5000 psi).

C6. Power and Data Transmission

(a) PCM Encoder and Telemetry: The primary system for collecting data from the Centrifuge is a pulse code modulation (PCM) encoder having 160 data channels (96 low level and 64 high level). The digitized data is then transmitted to the control room via an S-band telemetry link.

(b) Slip Rings: There are 16 slip rings rated at 440 V x 100 A, 25 slip rings rated at 115 V x 5 A, and 150 slip rings rated at 115 V x 1 A.

(c) Slip Ring Housing. The slip rings are housed at the lower portion of the power head assembly (Fig. 15). The rings are protected from dust and hydraulic fluid by a metal case.

(d) Instrumentation and Power Cabling: Cabling between the outboard end and the slip rings is clamped inside the arm.

(e) Data Acquisition and Presentation: See Section F.

C7. Centrifuge Enclosure

(a) Barricade: The Centrifuge arm is underground--the ceiling being at ground level. The pit which encloses the Centrifuge is 24.4 m (80 ft) in diameter and the walls are 3.6 m (12 ft) high (Fig. 12).

(b) Access to Arm: Access to the pit is gained through the crane building shown in Fig. 16. Large overhead doors are at each end of this building. As shown in Fig. 16, there are steel floor plates (3 x 3 m, or 10 x 10 ft) which extend across the diameter of the pit. When the plates are removed, a walkway along the inside of the building can be used.

FIGURE 16. CRANE BUILDING ACCESS TO 8.8-METRE CENTRIFUGE

The Centrifuge pit can also be reached by an underground passage from the local control room (Bldg. 6526).

(c) Work Area: Test assembly can be done in the crane building above the pit area. Light lab work area is also available in a 6 x 9 m (20 x 30 ft) room connecting into the Centrifuge pit.

(d) Hoists: There are two 9.1 Mg (10 ton) bridge cranes which extend the length of the crane building. The maximum height of the hooks above the floor of the crane building is 2.7 m (9 ft) and above the Centrifuge pit floor is 6.4 m (21 ft). For very long test specimens, fixtures, etc., a 1 x 1 m (3 x 3 ft) hole has been cut in the ceiling of the crane shack. Items are lowered through this hole and into the pit area.

C8. Allowable Size of Test Specimen

(a) The size limitations on fixtures and test specimens are dependent upon the style of mounting used. Dimensions which should be considered are:

1. Distance from pit floor to underside of arm (1.5 m, or 5 ft).
2. Distance from arm tip to tip wall (3.3 m, or 11 ft).
3. Distance between specimen mounting plates (1.88 m, or 74 in).
4. Length of mounting plates (3.5 m, or 11.5 ft).
5. Distance from top side of arm to pit ceiling (1.5 m, or 5 ft).

C9. Television Monitor

(a) Location: Two television cameras equipped with wide-angle lenses allow a continuous view of the Centrifuge arm. One camera is stationed in the east wall, another is located near the roof line in the north wall.

(b) Monitor Screens: Continuous viewing of the Centrifuge arm is possible from the local control room, the remote control room, and the pump house.

D. VIBRATION SYSTEM FOR 8.8-METRE (29-FOOT) CENTRIFUGE

D1. General

The vibration environment for test specimens mounted on the 8.8-Metre (29-foot) Centrifuge is provided by a Ling Electronics Model 300 shaker system. The vibration is applied simultaneously with the normal acceleration resulting from Centrifuge rotation. The factory specifications of this system are in Appendix 8.

D2. Components

(a) Shakers: The system consists of two Ling 300 shakers which operate on a push-pull arrangement (driven 3 rad, or 180°, out of phase).

(b) Shaker Connector: The two shakers are connected by a slip table. Up to the frequency where the slip table ceases to act as a rigid body, the shakers are additive in total force output. The slip table also functions as a mounting platform for test specimens; it has 31, 3/8-in, 24 bolt holes for mounting purposes (Fig. 17). The bolt hole pattern is 76.2 mm (3 in) square, on center.

(c) Amplifier: The power amplifier, which is located in Bldg. 6526, is shown in Fig. 18. The specifications of the amplifier are included in Appendix 9.

(d) Shaker Control Console: Described in Section E.

FIGURE 17. DETAILS OF SLIP TABLE CONNECTING THE TWO SHAKERS

FIGURE 18. POWER AMPLIFIER FOR 8.8-METRE (29-FOOT)
CENTRIFUGE SHAKER SYSTEM

FIGURE 19. 25-FOOT CENTRIFUGE WITH SHAKER SYSTEM

FIGURE 20. SHAKER INTERFACE CAVITY

D3. Mounting

Figure 19 is an artist's conception of the shaker system mounted on the Centrifuge. The yoke and shaker system weigh 6.8 Mg (15 100 lb). The yoke is designed to allow vibration either horizontally or vertically to the normal acceleration vector. Detailed drawings of the yoke system can be found in Sandia Laboratories drawings N73639, N73633, and N81311. Figure 20 is a photograph of the shaker interface cavity showing an actual test setup.

D4. Capabilities

(a) An outline of the vibration capabilities is included in Table III.

TABLE III
8.8-METRE (29-FOOT) CENTRIFUGE - VIBRATION SYSTEM CAPABILITIES

Force Output of Shakers (sine)	75 kN (16 800 lb) @ 37 kN (8400 lb) ea.
Vibration Frequency Range	10 to 3000 Hz (cps)
Maximum Displacement	25.4 mm (1 in) (peak to peak)
Maximum Velocity	0.177 m/s (70 ips)
Maximum Acceleration	70 G (0 to peak)
Maximum Specimen Weight	45 kg (100 lb)
Maximum Acceleration (from Centrifuge)	100 G
Rated Acceleration (from Centrifuge)	60 G
Environment	Sine, random or programmed

(b) Type of Input: The vibration input can be sinusoidal, random, or programmed from a tape recording or other external generator.

(c) Force Rating: Each shaker is rated at 37 kN (8400 lb) sine vector. Thus, the total force output is 75 kN (16 800 lb).

(d) Frequency Range: 10 to 3000 Hz (cps).

(e) Maximum Displacement: 25.4 mm (1 in) (peak to peak).

(f) Maximum Velocity: .18 m/s (70 in/s) (zero to peak).

(g) Rated Acceleration: The bare table acceleration is rated at 50 G vector.

D5. Limitations

(a) Specimen Weight: The weight of the test fixture-test specimen combination is limited to 45 kg (100 lb).

(b) Normal Acceleration: The rated normal (static) acceleration on the system is 60 G. The system is designed for a maximum normal acceleration of 100 G.

E. TEST CONTROL

E1. Centrifuge

(a) Local Console: The local control console for both the 8.8-Metre (25-foot) and 10.7-Metre (35-foot) Centrifuges is located in the underground control room (Bldg. 6526). The console contains a TV monitor, an electronic counter for rpm indication, pressure gages, pump controls, Selsyn meters for governing the flow rate to the fluid motors, a brake control, and an electronic timer. The console is depicted in Fig. 21. The pump motors must be started from the pump house.

(b) Remote Console: This control console is located in Bldg. 6540, which is approximately 300 m (1000 ft) from the Centrifuge complex. The remote console, which is identical to the local console, is used for all HE tests in excess of 45 kg (100 lb) and 2 kg (5 lb) on the 10.7-Metre (35-foot) and 8.8-Metre (25-foot) Centrifuges, respectively. Again, the pump motors must be started from the pump house.

(c) Computer Control: Computer control of Centrifuge angular velocity may be selected if desired. The control computer is an HP 2112A minicomputer with 32 k of solid-state memory. A Texas Instruments Model 733 terminal is used as the computer system console. See Appendix 10 for a detailed description of the computer control system. Figure 22 is a photograph of the control computer system.

FIGURE 21. (from left to right) VIBRATION CONTROL CONSOLE,
CENTRIFUGE LOCAL CONTROL CONSOLE, AND DATA CONSOLE

FIGURE 22. CONTROL COMPUTER SYSTEM

E2. Vibration

(a) Local Console: The local vibration-control console (Fig. 23) is located in Bldg. 6526. The console includes all equipment required for the control and monitor of filtered and/or unfiltered sinusoidal vibration sweeps. Random tests require a random equalizer. This equalizer is not permanently located in Bldg. 6526. It will either be lowered into the control room when needed, or long lines will be connected to the vibration control center (Bldg. 6650). Two types of equalization systems are available for use:

1. MB Electronics Model T-388 -- This system offers a choice of manual or automatic equalization. There are 80 comb filters in the system, each filter having a bandwidth of 25 Hz.
2. Computer Equalization by FFT and HP Computer -- This system operates from Bldg. 6650 via long lines.

FIGURE 23. VIBRATION CONTROL CONSOLE LOCATED IN BLDG. 6526

F. DATA ACQUISITION

F1. General

Data acquisition for low level/low frequency (0 to 100 Hz) signals (strain gage, pressure transducer, etc.) is generally accomplished through the PCM/Computer Data System. There are 160 channels available in this system (96 dedicated to 350 ohm strain gages).

Data acquisition for vibration, impact shock, and other high frequency (20 Hz to 45 kHz) signature is generally accomplished through the HP 2313 A/D Converter/Computer Data System. There are 16 differential channels (32 single ended) available in this system.

In all cases, the data is stored on magnetic disc by the computer and plotted by the computer on hardcopy data plots from a CRT after the test run.

Real-time, on-line plotting of the G versus time profile for a test is accomplished in addition to the regular data storage.

F2. Signal Conditioning and Transmission of DC Data

(a) PCM System: (Gulton Model 7000S Encoder) Both Centrifuges are equipped with this type of system, which includes a 160-channel encoder having the following specifications.

Number of Bits Per Data Word	9 (9 bits + sign)
Bit Range	0 to 511 full scale (+255.5)
Number of Data Channels	160 (all are always scanned)
Number of ID Bits	36 (9 bit frame ID word + 27 bit frame synch word)
Bit Rate	93.035 K bits/sec
Data Rate	63 data words per second per channel
Maximum Frequency Response Per Channel	100 Hz
Output Codes	Bi-phase L + NRZC (pre-mod filtered + unfiltered)
<u>Input Information:</u>	
Low Level Input 0 to 40 mV	96 channels
Amplifier Gain Ranges	62.5, 125, 250, 500

NOTE: Only one gain range/test is programmable.

There are 96, 350 ohm bridge completion units available to interface with strain gages for the low-level channels. These completion networks are driven by 5 V dc power supplies.

The sensitivity and full-scale ranges are tabulated below, together with maximum error experienced at ambient temperature 25⁰ C (77⁰ F). Only 350 ohm gages are accommodated.

The nominal microstrain values assume a bridge voltage of 5 V dc with a 350 ohm, 4 arm strain gage bridge. Actual strain range and sensitivity will vary with individual gages and with actual bridge voltage.

Voltage			Strain		Error at 25° C (% of F.S.)	Bit Swing
Gain Range	Input Range (mV)	Sensi- tivity (μ V/Bit)	Input Range ($\mu\epsilon$)	Sensi- tivity ($\mu\epsilon$ /Bit)		(Bits)
62.5	$\pm$ 40.88	160.	$\pm$ 15024	58.8	+ 0 , - .4	$\pm$ 255.5
125.0	$\pm$ 20.44	80.	$\pm$ 7512	29.4	+ .2 , - .58	$\pm$ 255.5
250.0*	$\pm$ 10.22	40.	$\pm$ 3756	14.7	+ .78 , - .58	$\pm$ 255.5
500.0	$\pm$ 5.11	20.	$\pm$ 1878	7.35	+ .78 , - .58	$\pm$ 255.5

*The 40 μ V per bit range (Gain = 250) will be the most frequently used range for Centrifuge tests due to the strain levels encountered in normal test operations at this facility. The A/D Converter step size will, therefore, provide a resolution of approximately 14.7 $\mu\epsilon$.

PCM Encoder High-Level Channels:

Number of Channels -- 64 (channels #97 - #160)
 Full-Scale Range -- $\pm$ 2.555 V
 Sensitivity -- 10 mV per bit
 Error -- less than .7 percent of full scale
 Bit Swing -- $\pm$ 255.5 bits

Figure 24 shows onboard bridge completion networks and PCM encoder system.

(b) PCM Bit Synchronizer, Decommutator, and Interface:

This equipment takes the serialized bit stream from the telemetry receiver or differential line receiver and establishes reference clocks and a synchronized bit stream which the decommutator, then reforms into parallel data words with word strobe pulses. The decommutator simultaneously puts out a BCD coded channel number with each data word. The PCM computer interface, custom designed for this project, accepts the first and last channel number information from the computer together with channel number information, frame, and word strobe pulses and data words from the decommutator. It allows only

FIGURE 24. ON-BOARD PCM DATA SYSTEM AND BRIDGE COMPLETION NETWORKS (350 Ω)

those channels selected to be strobed into the computer, thus limiting the data transfer to active PCM data channels and permitting direct memory access (DMA) hardware transfers rather than program-controlled transfers. Multiple successive samples of selected channels may be made and stored with one call to the interface.

Bit Synchronizer -- EMR Model 2726 with Model 2727
fixed frequency, fixed code selector.

Bit Rate -- 93 000 bits per second
Code -- Bi-Phase L

Other bit rates or code types would require a separate plug-in selector module.

Decommutator -- EMR Model 2746

This is a manually programmable unit capable of accepting a wide range of bit rates and frame and word lengths. The following settings are required for use with the Gulton PCM encoders.

Frame Length (words)	--	162 (160 data + 1 frame sync + 1 ID counter)
Data Word Length	--	9 bits
Frame Sync Word Length	--	27 bits
Frame Sync Word (binary)	--	111110101101001100110000000

(c) Telemetry Equipment: The telemetry link from the Centrifuge arm consists of a Conic CTS 702P S-band transmitter and a Microdyne Model 1100 AR receiver. The transmitter operates on a frequency assigned to the facility. It is a ruggedized, airborne-type unit capable of operating in an environment of 100 linear G. A detailed description of this equipment can be found in Appendix 2.

F3. Vibration and Shock Data

(a) Analog-to-Digital Converter (HP 2313): In addition to the PCM encoder for on-the-arm, low-level, relatively low-speed digitizing, an HP 2313 A/D system has been incorporated into the data acquisition system. Input signals from the Centrifuge arm will necessarily come through the slip ring assembly and should therefore be from higher voltage level, low output impedance devices. The converter will operate at programmable data rates of up to 45 kHz. It is intended to be used to monitor vibration signals for combined linear acceleration and vibration tests and to monitor switch closures and other parameters of systems under test which require the higher frequency capability. At present, this converter is equipped with a programmable pacer and a high level multiplexer card. It could be expanded to include additional channels of A/D converter inputs, both high and low level, and digital-to-analog outputs for analog control applications.

HP 2313 capabilities available at the facility include:

Analog-to-Digital Converter

Number of Channels	-- 32 single ended input or 16 differential input channels (any number may be sampled under program control).
Input Voltage Range	-- ± 10.24 V
Number of Bits Per Data Word	-- 12 (11 + sign)
Bit Range	-- ± 2048
Voltage Sensitivity	-- 5 mV per bit

Programmable Sample Pacer

Data Sample Rates	-- Programmed as a product of a variable integer μ s time base (1 to 255) times 10 to a variable integer power (0 - 7)
-------------------	--

(Cont'd)

Programmable Sample Pacer (Cont'd)

Data Rate	-- 2550 sec per sample through 45 000 samples per second.
-----------	---

A detailed description of this equipment may be found in Appendix 2.

F4. System Computer

(a) Minicomputer Controller: The system computer is an HP 2100A core memory unit with direct memory access and floating point arithmetic hardware. In conjunction with the magnetic disc (described below), the system uses Hewlett-Packard's Disc Operating System (DOS) for system control.

Computer Information

Word Size	-- 16 bits
Memory Size	-- 32 767 words
Memory Cycle Time	-- 980
Number of DMA Channels	-- 2
DMA Operating Speed	-- up to 1 MHz word rate shared by 2 channels
Input/Output Channels Available	-- 14

(b) Magnetic Disc: The system disc is an HP 7905 moving head disc containing one fixed and one removable disc platter. Each surface of the platters will hold up to 2.5 M, 16 bit computer words (5 M, 8-bit bytes). One surface of the fixed platter is devoted to disc control. There are 7.5 M words of storage available at any given time on the three remaining surfaces. Each surface is divided into 203 tracks. A track is subdivided into 96 sectors with a sector containing 128 words, 16 bits in length. Average access time to a particular track

and sector is 25 ms. A single disc surface could store approximately 75 full 32 k coreloads, or 1220 blocks of data containing 2048 integer words each.

(c) Operator's Console and Graphics Plotter (Fig. 21):

The operator's console is a Tektronix 4014-1 CRT terminal which has with it a Tektronix 4631 hardcopy unit. The terminal allows normal keyboard/operator interaction with output from the computer to the CRT at a nominal rate of 9600 baud in the alpha-numeric mode. In the graphics mode, the terminal becomes a high-speed, high-resolution plotter with viewable resolution of 1024 in the horizontal axis and 780 in the vertical axis. Report quality plots may be copied from the screen by the hardcopy unit. The Tektronix PLOT 10 software packages have been modified for use with the HP DOS. These provide automatic linear or log plot scaling and grid line generation. The PLOT 10 vector character generator has been modified and included to enable the use of rotatable, variable-sized characters for attractive plot labeling and annotation.

F5. Remote Operation

(a) Remote Terminal: A remote terminal has been included in the system for those tests which require that the Centrifuge facility be evacuated and that the test be controlled from the remote console located in Bldg. 6540. At present, this terminal is really a remote input/output device. Test control programs have been written to communicate with the terminal where the need exists; however, it does not now have the system capabilities of starting or terminating a program.

A Texas Instruments Model 730 terminal operating at 30 characters per second is used in conjunction with a set of Vadic modems operating over shielded data lines between the buildings.

FIGURE 25. END OF CENTRIFUGE ARM PATCH PANEL

FIGURE 26. CENTER OF BOOM PATCH PANEL.

FIGURE 27. CONTROL ROOM PATCH PANEL (CONTRACTOR INTERFACE) SHOWING STANDARD BANANA, COAX, GIANT BANANA, AND RF PATCHING

F6. Data Analysis and Presentation

(a) Data Collection: Test data is collected and stored on the disc operating system by one of the data acquisition programs available to the user. The program chosen will be determined by the user's needs. Some of the available software for data acquisition are listed on the following page.

F7. Patch Panels, Interconnections, and Wiring

(a) End of Centrifuge Arm Patch Panel: Figure 25 is a photograph of the patch panel located 5.03 m (16.5 ft) from the center of rotation of the 8.8-Metre (29-foot) Centrifuge. This patch panel allows access to 150 lines which carry 1 amp signals to the center of the Centrifuge rotation via standard banana jacks. The patch panel also allows patching of 25 (ea) 25A lines via giant banana jacks. (NOTE: 25A circuits not available when shakers are on Centrifuge.)

Two R.F. lines are available on RG213 type-N connectors.

(b) Center of Boom Patch Panel: Data information generated from the end of the Centrifuge arm can be routed through slip ring banana jacks to either the Bldg. 6526 control room or Bldg. 6540 control room, as desired, from this patch panel, see Fig. 26.

(c) Contractors Patch Panel in Building 6526 Control Room:

This patch panel can accommodate standard banana and/or coaxial wiring to either Centrifuge signal slip rings and instrumentation.

Giant banana jacks give access to the 25 (ea) 25A lines on the 8.8-Metre (29-foot) Centrifuge. Figure 27 is a photograph of this patch panel.

Data Acquisition Programs

CENT7 &CNT7 "CNT7

Data acquisition from the PCM encoder at selected G intervals plus G versus time history of test run.

CENT8 &CNT8 "CNT8

Data acquisition from the PCM encoder together with a single sample from each selected HP2313 A/D channel at selected G intervals plus G versus time history of test run.

TIMS2 &TMS2 "TMS2

Data acquisition from the HP2313 A/D converter of a block of test readings from selected channels at a data rate of up to 45 kHz plus G versus time history of test run.

SAMPL &SMPL "SMPL

Like TIMS2 but without G versus time history.

SPEDG &SPDG "SPDG

Real time G versus time plot plus file for history.

IMPAC &IMPC "IMPC

Data acquisition of AA block of test readings from an accelerometer data channel after sampling a second A/D channel searching for the release pulse.

Data Plotting and Analysis

PSD5 &PSD5 "PSD5

PSD analysis of time series data from programs.

PSD4 &PSD4 "PSD4

Like PSD5 except that the DC is removed by setting the first term of the frequency spectrum to zero before operating on each data block. Execute time is significantly greater than for program PSD5.

PPSD &PPSD "PPSD

Plotting of PSD files generated by programs PSD5 and PSD44

PLOTJ &PLTJ "PLTJ
 &PLS1
 &PLS2
 &PLS3

Plots the mean strain versus G for PCM-encoded data and scaled voltage versus G for HP2313 A/D data as recorded by CENT7 or CENT8. (Plot segments PLS1, PLS2, and PLS3 are used.)

(Continued)

Data Plotting and Analysis (Cont'd)

PLOTM &PLTM "PLTM
 &PMS1
 &PMS2
 &PMS3

Plots data entered manually from the keyboard in the same format as that used for program PLOTJ. (Plot segments PLMS1, PLMS2, and PLMS3 are used).

GTIM4 >M4 "GTM4

Plots G versus time data for confirmation of test environment. Programs CENT7, CENT8, SPEDG, and TIMS2 generate data files compatible with GTIM4.

PTIM2 &PTM2 "PTM2

Plots time series (amplitude versus time) data blocks generated by programs IMPAC, SAMPL, or TIMS2.

Data Listing

DLIST &DLST "DLST

Provides a listing of mean strain for all selected PCM channels at each G level at which data was stored by programs CENT7 or CENT8.

The following programs mentioned above also have data listing capabilities as an option to their primary function.

PLOTJ

Separate list for each channel of strain versus G.

GTIM4

List of G versus time data points.

PSD5

List of PSD versus frequency data points.

G. HYDRAULIC SYSTEM

G1. Pump House

(a) General: The interior of the pump house (Bldg. 6523) is depicted in Fig. 28. The contents are:

1. Electric motor/hydraulic pump combinations (13 total).
2. On/off control for each electric motor.
3. Centrifuge selector panel.
4. Filter system.
5. TV monitor.

Detailed drawings of the pump house and hydraulic system are referenced in Appendix 4.

(b) Electric Motor/Hydraulic Pump Combination: One of these systems is shown in Fig. 29. There are 13 of these systems in the pump house.

1. Electric Motors -- All motors are manufactured by Allis Chalmers. They are rated at 74.6 kW (100 hp) and operate at a constant speed of 126 rad/s (1200 rpm).
2. Hydraulic Pumps -- Six of the Denison pumps are constant volume, constant stroke with a flow rate of $.0022 \text{ m}^3/\text{s}$ (34.4 gpm). The remaining seven Denison pumps are variable volume ranging from zero to $.0022 \text{ m}^3/\text{s}$ (34.4 gpm) in flow rate. The maximum output of the pump system is $.029 \text{ m}^3/\text{s}$ (455 gpm). The volume of the variable-volume pumps is controlled by 124 W (1/6 hp) motors

FIGURE 28. PUMP HOUSE INTERIOR

FIGURE 29. ELECTRIC MOTOR/HYDRAULIC PUMP COMBINATION

geared to a Selsyn system. The Selsyn system is connected to the pump and controlled either from the pump house or from the remote console. The hydraulic circuitry is such that any single pump, or group of pumps, can be used without the other. All 13 pumps operate at the maximum 34.5 MPa (5000 psi).

The motors are started at no-load. When the volume control is set near zero, the pump displaces only enough oil for self lubrication. The pressure cannot be developed until the pressurization switch is depressed. The switch actuates the solenoid pilot valve which causes the relief valve to close. The relief valve is adjustable from 0 to 34.5 MPa (5000 psi). If the output of the pumps exceeds the demand of the Centrifuge, the excess fluid is bypassed to the reservoir. A description of the Denison Series 800 pump appears in Appendix 12.

(c) Centrifuge Selector Panel: The output of the hydraulic pumps can be directed to either the 10.7-Metre (35-foot) or the 8.8-Metre (29-foot) Centrifuge system, but not simultaneously. The selection is made on the master panel, shown in Fig. 30.

G2. Storage Tanks

(a) General: The hydraulic fluid storage tanks are located in a shed behind the pump house. The shed contains a .032 m³/s (500 gpm) charging pump in addition to the two 5.9 m³ (1300 gal) storage tanks.

G3. Hydraulic Circuitry

(a) General: The .032 m³/s (500 gpm) charging pump supplies the 13 Denison pumps in the pump house. The micron filter system

FIGURE 30. MASTER PANEL AND ELECTRIC MOTOR CONTROL
PANELS IN THE PUMP HOUSE

(Fig. 31) is intermediate to the storage tanks and the Denison pumps. Output of the pumps is directed to the fluid motors of either Centrifuge through 102 mm (4 in) pipes. The discharge from the fluid motors is returned to the storage tanks.

G4. Electronic Control

(a) General: The control circuitry is designed to allow the use of from 1 to 13 pumps during any test. The master control panel and two of the electric motor starting panels are shown in Fig. 30. (Since the rpm of the Centrifuge is a function of the flow rate to the Denison fluid motors, not all tests require the maximum flow rate from the pump house. The choice as to the number of pumps to be used depends upon the specified test level. For example, one pump operating at $.0022 \text{ m}^3/\text{s}$ (35 gpm) maximum output can drive the 10.7-Metre (35-foot) Centrifuge to 1.4 rad/s (13 rpm).

G5. Computer Control

For details on computer control, see Appendix 10, "Computer Control System".

FIGURE 31. OIL FILTER SYSTEM FOR HYDRAULIC SUPPLY OIL

ACKNOWLEDGEMENT

This report is an updating of the original report written by J. V. Otts. Material from reports by Marlyn W. Sterk, Robert N. Tomlinson, and R. H. Meyer was also utilized.

APPENDIX 1

Theoretical Analysis of the Acceleration Environment Provided by a Centrifuge

APPENDIX 1

Theoretical Analysis of the Acceleration Environment Provided by a Centrifuge

The centrifuge provides a curvilinear motion to a test item. Consider a test item moving along a curved path as shown in Figure a.

Assume also that the velocity of the test item is changing both in magnitude and direction as shown by the vector diagram in Figure b. This velocity change is from v to $(v + dv)$ during the time interval t to $(t + dt)$. The vector change of the velocity during the time dt is the difference, dv , as shown in Figure c.

By projecting the components of dv in the tangential and normal directions, the diagram in Figure d is obtained. This operation is vectorially stated by the following equation:

$$dv = (dv)_T + (dv)_N$$

Since acceleration is defined as

$$a = \frac{dv}{dt}$$

we obtain

$$a = \frac{dv}{dt} = \frac{(dv)_T}{dt} + \frac{(dv)_N}{dt} = A_T + A_N$$

where

A_T = tangential acceleration

A_N = normal acceleration.

The normal acceleration (A_N) is thus seen to be dependent on the velocity change of direction only. Since, in the limit, the vector $(dv)_N$ can be considered as an arc of radius v and subtended angle $d\theta$ [$(dv)_N = vd\theta$], the normal acceleration becomes

$$A_N = \frac{(dv)_N}{dt} = \frac{vd\theta}{dt}$$

Now, using the relationship $ds = rd\theta$; where ds is arc length and r is the radius of curvature,

$$\frac{d\theta}{dt} = \frac{1}{r} \frac{ds}{dt}$$

and since $ds/dt = v$, we have

$$A_N = \frac{v^2}{r}$$

It is important to note that the normal component of acceleration (A_N) is always directed toward the center of curvature.

The tangential acceleration is the change in magnitude of the velocity

$$A_T = \frac{dv_T}{dt} = \frac{d^2s}{dt^2}$$

where S is the arc, or scalar distance, moved around the circumference of the centrifuge rotation.

It can be seen that the acceleration experienced by the test item is the vector sum of the normal acceleration and the tangential acceleration; however, since the buildup of revolutions on the centrifuge is slow, and the test item is normally tested at a constant centrifuge speed, the tangential acceleration is not considered in the test specifications or the test results. The normal acceleration is the one of concern, and this can be at an increasing, decreasing, or constant level depending on the programming of the centrifuge revolutions.

APPENDIX 2

Calculation of the Normal Acceleration Level in Terms of G

APPENDIX 2

Calculation of the Normal Acceleration Level in Terms of G

Test specifications for the centrifuges are expressed in terms of G, where

$$G_N = \frac{A_N}{9.82}$$

and

A_N = normal acceleration in terms of m/s^2

$9.82 m/s^2$ = acceleration of gravity

The speed of the centrifuge is normally expressed in revolutions per minute, N. At a point on the centrifuge arm R centimeters from the center of rotation, the normal acceleration, A_N , is

$$A_N = \frac{v^2}{R} \quad (\text{Refer to Appendix 1})$$

where v is the velocity (m/s) and R the radius (metres).

Using the relationship

$$v = R\omega$$

where ω is rotational speed expressed in radians/second and

$$\omega = \frac{2\pi}{60} N = \frac{\pi}{30} N$$

we get

$$A_N = \frac{v^2}{R} = \frac{R^2 \omega^2}{R} = R\omega^2$$

$$A_N = R \left(\frac{\pi}{30} \right)^2 N^2$$

$$G_N = \frac{\pi^2}{9.82 \times 900} R N^2$$

$$G_N = .00112 R N^2$$

when R is radius in meters.

A nomogram of this relationship appears below. Knowing any two of the relationships G_N , rpm(N), and radius (R), it is possible to determine the remaining term from this graph.

APPENDIX 3

Acceleration (G) Gradient on a Test Specimen

APPENDIX 3

Acceleration (G) Gradient on a Test Specimen

Since the G level at a point is a linear function of the radius (R) from the center of rotation to that point, there will be a G gradient existing on any test item during rotation. For example, if the longitudinal axis of a test item is mounted radially on the centrifuge (Figure e) and it is 3.05 metre (10 ft) long, the ratio of the acceleration at the two ends would be:

$$\frac{G_x}{G(x+3.05)} = \frac{x}{x + 3.05}$$

This acceleration gradient should be considered during the derivation of test specifications. When calling out a G test level, the reference radius on the test item or centrifuge arm should be specifically stated.

APPENDIX 4

List of Drawings for 10.7-Metre (35-foot) Centrifuge Facility

APPENDIX 4

List of Drawings for 10.7-Metre (35-foot) Centrifuge Facility

Rucker Company Centrifuge

Drawing No.	Rev.	Description
52-270-D-23	5	Power unit frame
EF-30	3	Pump volume control
B-31	1	Gear coupling for Selsyn generator
D-32	3	Gear coupling for gear motor
D-33	1	Spacing flange for pump shaft
B-34	3	Gear coupling for rotary limit switch
B-35	1	Details, terminal block mounting bracket
D-36	0	Mounting bracket limit switch
D-37	3	Cover for pump volume control
D-38	2	Base plate for pump volume control
B-39	3	Bill of Materials for pump volume control
B-41	0	Details, mounting plate for Selsyn generator
EF-43	2	Power head
EF-46	3	Control console
D-47	0	Tachometer generator, centrifuge speed relay drive assembly
EF-48	7	Piping layout for power head
EF-49	2	Power head drive shaft assembly
EF-50	2	Spindle for power head
EF-51	2	Spindle housing
F-52	1	Pump house layout
E-53	6	Pump house foundation layout
EF-54-1	0	Power head base, bottom view
EF-54-2	0	Power head base, top view
EF-54-3	0	Power head, Section AA
EF-55	0	Power Section BB assembly
D-56	0	Bill of Materials for EF-43
D-67	3	Pressure and relief dump line installation
B-68	2	Suction line installation
A-69	1	Pump drain line installation
A-70	1	Pilot drain line installation
B-71	2	Suction manifold
B-72	0	Bill of Materials for Drawing D-47
D-79	4	Pressure manifold
B-80	3	Relief valve dump manifold
E-81	5	Steel base reinforcing layout
B-83	3	Pilot and pump drain manifolds

Drawing No.	Rev.	Description
52-270-E-90	3	Power unit (74.6 kW 0-100 HP)
B-91	2	Charging pump inlet line inst.
D-93	2	4.5 m ³ (1000 gal) tank assembly,
D-98	3	Construction details, 4.5 m ³ (1000 gal) tank assembly
B-101	0	Radial roller
B-102	0	H. C. ball thrust bearing
B-104	0	Radial roller
B-105	0	Part No. 34 Drawing 52-270-EF-30
EF-106	1	Cross section of trench piping
EF-107	3	Tank area piping
E-108	1	Return line connecting manifold
D-109	0	Connecting line to suction manifold
D-110	0	Manifold-return line to tank
B-111	0	Connecting line pilot drain manifold to tank
D-112	0	Assembly and details, filter support frame
D-113	2	Filter inlet manifold
D-114	2	Filter outlet manifold
B-115	1	Return manifold from pit
E-116	2	Lube oil and drain-pump assembly
B-117	1	Bill of Materials for E-116
E-118	1	Details and assembly of frame pit pumping units
D-119	0	Base for drain pumping unit
D-120	0	Base for lube oil pumping unit
E-121	0	Tank for drain pumping unit
D-122	0	Tank for lube oil pumping unit
D-123	0	Charging pump base details and assembly
EF-124	4	Pressure and return lines (outside)
B-127	0	Filter check valve line
EF-128	0	Lube oil pressure piping (power head)
EF-129	2	Lube oil return piping (power head)
D-130	0	Fluid motor drain manifold
E-131	4	Pit connecting piping
D-134	2	Frame for relief valves
D-136	1	Lube oil drain manifold
B-137	0	Pipe saddles, pit end
B-138	0	Fluid motor pressure line
D-139	3	Fluid motor return manifold
A-142	1	Relief valve outlet manifold
B-143	0	Fluid motor return line
D-144	2	Fluid motor pressure manifold
A-145	1	Relief valve inlet
D-146	0	Expansion loop assembly
EF-147	0	Manifold assembly drawing for power head
D-149	1	Return line, pump house section
E-150	0	Flange manhole box, typ. assembly

Drawing No.	Rev.	Description
52-270-A-155	1	Pressure line, Station 0+53.75 to Station 0+70.08
A-156	1	15.24 metre (500 ft) sections pressure line..
A-160	1	Return line, Station 0+53.75 to Station 0+70.08
A-161	1	15.24 metre (500 ft) section return line.
A-165	1	Expansion loop, pressure line
A-166	1	Expansion loop, return line
A-167	0	Box for Stations 2+20.08 and 2+70.08
E-169	0	Hydraulic circuit
A-170	0	Box for Station 0+70.08
A-171	0	Box for Station 0+53.75
A-172	0	Cover for manholes
E-173	0	Expansion loop box
A-174	0	Cover for expansion loop box
A-175	0	Fluid motor port dimensions
B-176	0	Relief valve outlets
A-179	1	Spool piece
A-181	0	Box for Station 3+20.08
D-183	0	Box and cover for valve
B-184	0	Layout of Nordstrom valve
A-168	0	Box for Station 1+70.08
A-187	0	Box for Station 1+20.08
D-189	0	Relief valve drain tubing
D-190	0	Relief
D-191	0	Auxiliary L. O. tank

Paceco Centrifuge

11730-D	2	Rotor arm-centrifuge
11731-C	2	Foot for centrifuge arm (Sandia DS-1613-24831)
11756-D	1	Power head assembly
11759-D	2	Power head details
11760-D	5	Spindle housing fabrication and machining detail
11761-U	1	Drive shaft, gears, housing-power head
11762-D	2	Speed relay and tachometer generator, gears, shafts and housings
11763-D	2	Miscellaneous details of power head

General Electric Centrifuge

Drawing No.	Rev.	Description
T5785953-1	4	Cabinetrol panel for main pump room
-2	2	
-3	2	
-4	2	
-5	2	
-6	4	
-7	1	Console panel for control room
-8	1	Cabinetrol panel for main pump room
-9	0	
-10	0	
-11	0	

Sandia Corporation Centrifuge

DS-1613-25024-D	0	Electrical connections between equipment building and special foundation
AL-ABF-7	0	Receptable, power and control, plans and details
24106-D	0	Centrifuge arm
24830-D	0	Centrifuge arm transverse sections
25021-C	0	Equipment building embedded conduit
25022-D	0	Special foundation
25023-D	0	Hydraulic lines and electrical duct
25893-C	0	Centrifuge arm counterweight end details
25894-C	0	Centrifuge arm center section details
25895-C	0	Centrifuge arm center section bottom view
DS(1613) 78405 (A)		Cover for pump volume control
78405 (B)		Cover for pump volume control
78404 (A)		Mounting bracket for rotary limit switch on pump volume centrifuge
78404 (B)		Mounting bracket for rotary limit switch on pump volume centrifuge
78403 (A)		Spacing flange for pump shaft on pump volume control
78403 (B)		Spacing flange for pump shaft on pump volume control
78402		Gear coupling for gear motor on pump volume control
78401		Power frame unit
78400 (A)		Fluid motor return line
78400 (B)		Fluid motor return line
78399 (A)		Fluid motor pressure line
78399 (B)		Fluid motor pressure line
78398		Suction line installation
78397		Mounting plate for Selsyn generator on pump volume control
78395		Gear coupling for rotary limit switch on pump volume control
78394		Gear coupling for Selsyn generator on pump volume control

<u>Drawing No.</u>	<u>Rev.</u>	<u>Description</u>
DS(1613) 78393		Fluid motor part
78392 (A)		Pilot drain line installation
78392 (B)		Pilot drain line installation
78391 (A)		Pump drain line installation
78391 (B)		Pump drain line installation
78406 (A)		Base plate for pump volume control
78406 (B)		Base plate for pump volume control
78408 (A)		Pressure and relief valve dump line installation
78408 (B)		Pressure and relief valve dump line installation
78409		Assembly and details filter support frame
78410 (A)		Fluid motor drain manifold and tubing power head
78410 (B)		Fluid motor drain manifold and tubing power head
78411		Fluid motor return manifold assembly
78412		Fluid motor pressure manifold welding assembly
78413		Rucker standard electrically controlled variable volume pumping unit, 74.6 kW (100 HP)
78414		Pit connections, piping
78416		Pump volume control
78417		Piping layout for power head
78418		Power head spindle and drive shaft assembly
78419		Power head base
78420		X-section of existing trench and pumping unit
78421		Pump house layout
78427		Mounting bracket for terminal block on pump volume control
78538		Thrust washer
78539		Relief valve dump manifold
78540		Pump and pilot valve drain manifold
79745 (A)		High pressure line addition
79745 (B)		High pressure line addition
25896-C	0	Centrifuge arm specimen end details
25897-C	0	Specimen plate
SK-1613-51033-C	0	Spindle ring for oil seal
51034-C	0	Oil seal reservoir
DS-1613-95164	0	Equipment and observation room
95165	0	6-T crane and access doors
SK9(1613)-26859		Proposed barricade extension, monorail and shelter
26860		Proposed barricade extension, monorail and shelter
26861		Proposed barricade extension, monorail and shelter
1613 SK-56201		Auxiliary lube oil filter assembly
SK 1613-56202		Auxiliary lube oil filter assembly
SK 1613-24515		Slip ring test jigs assembly
SK9(1613)-18622		Lube oil pumping unit - tank
SK9(1613)-16393		Lube oil pumping unit
74950		Manhole cover for boom
SK9(1613)-26860		Trailing edge centrifuge

APPENDIX 5

Denison Fluid Motors

DENISON FLUID MOTORS

600, 700 and 800 Series

Denison constant displacement, fixed stroke fluid motors are of axial piston design and possess the same basic design features as Denison pumps of the same series. They are offered in three sizes with ratings equal to about 180 hp in the largest size. Compact and symmetrical in shape, they may be incorporated in equipment where space is an important factor.

Denison motors are used in applications where frequent stopping and starting, reversals braking actions, etc. make other types of drives impractical. Typical among these are found in conveying, mining, construction and drilling equipment—where normal operation calls for the extreme in drive requirements. Driven by oil pressure, these motors can be stalled without injury to moving parts.

These motors may be operated at a maximum 5000 psi at speeds of from 2000 to 3000 rpm. They pro-

vide maximum torque ratings of 1160, 3235 and 5665 pound inches respectively in three sizes. In spite of these high ratings, the dimensional drawings on the reverse side of this sheet point out the comparative small size of each unit.

Three types of mountings may be obtained; for foot, flange or face mounting. Each type is covered in the dimensional drawings. Operating characteristics are given below for each model. Stepless variations, less than maximum, are possible dependent only on system pressures and oil flow to the motor.

These new motors are daily being placed in service for the heaviest jobs, where dependable power is essential. Denison engineers stand ready to adapt the cost-reducing features of Denison fluid motors to your application. Contact your nearest Denison representative or write the factory at Columbus, Ohio for more complete information at any time.

OPERATING CHARACTERISTICS

MODEL NUMBERS	SPEED		VOLUME			TORQUE				HORSEPOWER OUTPUT		Max. Working Pressure Psi
	Max. RPM	Min. RPM	Cu. In. Per Rev.	GPM Per 100 RPM	GPM at Max. RPM	Lb. In. Per 100 Psi	Lb. In. at Max. Psi	Stalled or Starting Torque % of Max.	Running Torque % of Max.	Per 100 RPM at Max. Psi	At Max. RPM and Max. Psi	
MA-232-560 Face MA-232-560-F Flange MA-232-560-B Foot	3000	100	1.46	.632	18.95	23.2	1160	88	93	1.84	55.2	5000
MA-642-570 Face MA-642-570-F Flange MA-642-570-B Foot	2500	100	4.07	1.76	44.1	64.7	3235	88	93	5.14	128.5	5000
MA-1132-580 Face MA-1132-580-F Flange MA-1132-580-B Foot	2000	100	7.13	3.08	61.7	113.3	5665	88	93	9.00	180	5000

DENISON ENGINEERING DIVISION

AMERICAN BRAKE SHOE COMPANY
COLUMBUS 16, OHIO

BRANCH OFFICES IN ATLANTA, CHICAGO, CLEVELAND, DETROIT, HOUSTON, LOS ANGELES AND NEWARK, N. J.

DIMENSIONAL DATA

	SERIES 600	SERIES 700	SERIES 800
	MODEL NUMBER		
DIMENSION	MA-232-560	MA-642-570	MA-992-580
A	4	5 1/2	6 1/2
B	1 3/8	1 1/2	2 3/8
C	12 1/4	15 1/2	19
D	1 1/4	1 3/4	1 7/8
F	6 1/8	8 3/8	10 1/8
G	2 1/2	2 7/8	3 3/8
H	16 Woodruff	.374/.375	.499/.500
J	1/2	3/4	3/4
K	3/4	1	1 1/4
M	9 1/4	11 1/4	13 1/8
N	1 1/2	2 1/2	3
O	4 3/4	5 1/2	6 3/8
P	5 3/4	7 3/4	9 3/4
R	4 1/2	6	8 1/4
S	3.874/3.872	4.749/4.746	5.999/5.996
U	1.061/1.060	1.624/1.623	2.124/2.123
V	1.152/1.142	1.790/1.780	2.345/2.335
W	3/8-16 NC	1/2-13 NC	5/8-11 NC

	SERIES 600	SERIES 700	SERIES 800
	MODEL NUMBER		
DIMENSION	MA-232-560F	MA-642-570F	MA-992-580F
A	2 3/8	3 3/4	4 1/2
B	1 1/4	1 1/4	3 1/8
C	12 1/4	15 1/2	19
D	2 3/8	3 1/4	3 3/8
F	6 1/8	8 3/8	10 1/8
G	2 1/2	2 7/8	3 3/8
H	16 Woodruff	.374/.375	.499/.500
J	1/2	3/4	3/4
K	3/4	1	1 1/4
M	9 1/4	11 1/4	13 1/8
N	1 1/2	2 1/2	3
O	4 3/4	5 1/2	6 3/8
R	8 1/2	10	12 1/2
S	6.999/6.996	7.999/7.996	10.999/10.996
T	3/4	1	1 1/4
U	1.061/1.060	1.624/1.623	2.124/2.123
V	1.152/1.142	1.790/1.780	2.345/2.335
W	3/8	3/8	3/8
X	10	11 1/4	14

	SERIES 600	SERIES 700	SERIES 800
	MODEL NUMBER		
DIMENSION	MA-232-560B	MA-642-570B	MA-992-580B
A	5 1/4	7 1/8	8 3/8
B	10 3/8	12 3/8	16 3/8
C	12 1/4	15 1/2	19
D	6 1/4	7 1/4	9 1/2
F	6 1/4	8 3/8	10 1/8
G	2 1/2	2 7/8	3 3/8
H	16 Woodruff	.374/.375	.499/.500
J	1/2	3/4	3/4
K	3/4	1	1 1/4
M	9 1/4	11 1/4	13 1/8
N	1 1/2	2 1/2	3
O	4 3/4	5 1/2	6 3/8
P	6 1/4	8 1/2	11
R	7 1/2	10	13
S	3 1/8	4 1/8	5 3/8
T	1	1 1/4	1 1/2
U	1.061/1.060	1.624/1.623	2.124/2.123
V	1.152/1.142	1.790/1.780	2.345/2.335
W	3/8	3/8	3/8
X	8 3/4	11 1/2	15
Y	4 3/4	6	7 1/2
Z	8	7 1/2	9 1/2

Printed in U.S.A.

APPENDIX 6

Impact Testing with the 10.7-Metre (35-Foot) Centrifuge Facility

ABSTRACT

An impact test technique whereby the tangential velocity of the 10.7 metre (35 foot) centrifuge is used to create the required impact environment is described. The options include impacting a test item into stationary targets and the reverse, moving a target into a stationary test item.

The accuracy, flexibility, low cost, and efficiency offered by this technique make it highly competitive for future impact test series.

Key Words: Centrifuge; Impact, Velocity

TABLE OF CONTENTS

	<u>Page</u>
Introduction	5
Centrifuge Test Environment	5
Radial Acceleration	5
Tangential Angular Acceleration	6
Tangential Velocity	6
Optional Impact Techniques	6
Test Item Free Flight Into Target	6
Target Free Flight Into Test Item	8
Moving of Target Into Orbital Path of Test Item	8
Moving of Test Item Into Orbital Path of Target	9
Extending of Test Item Radius To Impact Stationary Target	9
Raising or Lowering of Test Item To Impact Stationary Target	10
Acceleration of Test Item Radially Outward To Impact Target	10
Discussion	10
Free-Flight Impact Testing	11
Fixture Requirements	11
Release Mechanism	11
Target	13
Control of Impact Angle	14
Test Control and Data Acquisition	14
Free-Flight Impact Test Capabilities	15
Equations	16
Advantages	16
Disadvantages	16
Accident-Resistant Container (ARC) Test Series	17
Conclusions	21

LIST OF FIGURES

<u>Figure</u>		<u>Page</u>
1	Free-Flight Impact Test Technique	7
2	Free-Flight Environment of Test Item	7
3	Moving Target Into Orbital Path of Test Item	8
4	Moving Test Item Into Path of Rotating Target	9
5	Changing Test Item Position to Impact Stationary Target	10
6	Accelerating Test Item Radially Outward Into Target - Test Item and Target Mounted on Centrifuge	10
7	Typical Fixture for Impact Testing	11
8	Schematic of Holec Cable Cutter Firing Circuit	12
9	Switch Closure Technique	13
10	Physical Layout of 10.7-metre (35-foot) Centrifuge Facility	13
11	Space Relationship Between Target and Test Item	15
12	ARC Test Item Layout (axial impact)	17
13	ARC Test Setup (head-on impact)	18
14	Axial Impact Data - ARC Test Series	19
15	Axial Impact Data - ARC Test Series	20
16	Posttest ARC (axial impact)	22
17	ARC Test Item Layout (side-on impact)	23
18	ARC Test Setup (side-on impact)	24
19	Posttest ARC (side-on impact)	25
20	Side-On Impact Data - ARC Test Series	26
21	Side-On Impact Data - ARC Test Series	27

IMPACT TESTING WITH THE 10.7 METRE (35-FOOT) CENTRIFUGE

Introduction

The 10.7 (35-foot) radius centrifuge is an outdoor test facility located in Sandia Laboratories' Area III. The basic function of this centrifuge is to provide normal acceleration environments up to 250G which corresponds to 15.2 rad/s (145 rpm) at the 10.8 metre (35.5-foot) radius. The centrifuge structure can support a maximum test weight (test item plus fixture) of 4.5 Mg (10,000 pounds) and a normal acceleration/test weight product of 2G MN (450,000 g-pounds).

The centrifuge angular velocity, ω , is controllable to less than $\pm$ percent error over a range of .2 to 15 rad/s (2.0 to 145 rpm). Therefore, a test item mounted to the rotating arm (a maximum radius of 13.7 metres or of 45 feet) can be subjected to tangential velocities as high as 182.88 m/s (600 feet per second).

An impact test capability which utilizes the tangential velocity of the rotating arm has been developed, proved, and used in the Accident Resistant Container (ARC) test program. The new impact test technique has proved to be accurate, flexible, reliable, and repeatable. Also, the simplicity of fixturing and test setup enables fast reaction, setup, and turnaround times, as well as inexpensive testing. The new impact test technique should be considered for future environmental test programs. A description of the technique, capabilities, and applications are presented below. Additional centrifuge impact test techniques are also outlined. These include a test specimen on centrifuge, a target on centrifuge, and a special option where specimen/target impact is obtained through radial acceleration. In this case, the specimen and target are both mounted to the rotating arm.

The purpose of this report is to introduce the new impact test concept, outline the capabilities, and make all personnel aware of the potential for future test consideration.

Centrifuge Test Environment¹

¹An awareness of the test item's environment prior to, during, and after impact is essential to determining undesirable functional and/or structural effects. In most cases, the items discussed below will be found to be negligible, but they should nevertheless be considered.

A test item or target restrained on the rotating centrifuge arm experiences the following environment.

Radial Acceleration

At a radius of R metres and an angular velocity of ω rad/s, the radial acceleration is

$$G = \frac{a}{9.82} = 1.22 \times 10^{-3} R\omega^2$$

Tangential (Angular) Acceleration

Tangential acceleration is necessary for increase or decrease of the angular velocity. In the 10.7 metre (35-foot) centrifuge, a small ratio between driving torque and moment of inertia results in negligible angular acceleration ($<0.2G$). For example, the minimum time from 0 to 15.2 rad/s (0 to 145 rpm) is 270 seconds.

Tangential Velocity

At a radius of R metres and an angular velocity of ω rad/s, the tangential velocity is

$$V = R\omega \text{ metres/s.}$$

If the test item restraint is removed, the test item will free-fly on a path tangential to the circular orbit. The velocity, neglecting air drag, will be that expressed above.

Optional Impact Techniques

The three alternative configurations available are considered below.

1. Test item rotating on arm-target stationary.
2. Target rotating on arm-test item stationary.
3. Test item and target both rotating on arm.

If 1 or 2, above, is used, the relative velocity between the test item and target must be established by spinning the centrifuge up to the required speed. During buildup, two obvious restrictions must be met. First, the stationary object can never be allowed to intersect the orbital path of the centrifuge arm. (This applies throughout the entire test.) Second, the rotating test object cannot intersect

the stationary object prior to reaching the specified velocity of impact. With these restrictions noted, the alternative test configurations are discussed.*

Test Item Free Flight Into Target

The test item, upon removal of its restraint, will free-fly from the rotating arm on a path tangential to its circular orbit on the arm. The free-flight velocity (neglecting drag) will be

$$V = R\omega,$$

where V = free-flight velocity (m/s)

R = radius of test item when mounted (m)

ω = angular velocity of centrifuge arm (rad/s)

This technique is illustrated in Figure 1. Note that the test item is allowed to free-fly into the target, which is beyond the centrifuge (plus test item) orbital path. Prior to release from the arm, the test item experiences tangential acceleration (probably negligible at $<0.2G$) and normal acceleration. Postrelease environment includes rotation ω and Coriolis acceleration throughout the impact. Figure 2 depicts sequential positions of the test item up to the time of impact.

*Combined temperature/impact environments are available with each of the techniques considered. With existing Area III equipment, temperatures between 219K (-65°) and 366K (200° F) are obtainable. Temperatures up to 811K (1000° F) are possible with special equipment.

There is very little restriction on the size, weight, and type of target when using this technique, since the target is stationary. However, care must be taken to insure that the target (test specimen as well) does not rebound or fall into the centrifuge arm after impact. Transducer signals from the test item must be transferred to the rotating arm, where the signal conditioners and amplifiers are mounted. Therefore, trailing cables are necessary during free flight, impact, and rebound. Trailing wires tend to increase one's vulnerability to data problems; however, as shown later, these problems have been overcome on free-flight testing. The fact that relative position between the test item and rotating arm is small up to the time of impact reduces the potential trailing cable problem.

Figure 1. Free-Flight Impact Test Technique

Figure 2. Free-Flight Environment of Test Item

Target Free Flight Into Test Item

Upon release from the centrifuge arm, the target will free-fly along the tangent to its circular orbit. It will have the velocity and rotation as outlined in the foregoing section.

The advantages of target flight versus test item flight include the following.

1. Possibility of higher test specimen temperatures when specimen is not mounted to the arm.
2. No radial, tangential, or Coriolis accelerations on test item.
3. No test item rotation (ω).
4. No need for trailing cables.

The major disadvantages are the restrictions on the weight, size, and complexity of the target due to being mounted on the centrifuge. These restrictions are considered later.

Moving of Target Into Orbital Path of Test Item

The impact target can be dropped, raised, or radially pushed inward into the path of the test item once the proper velocity is obtained (see Figure 3). In this case the test item must be mounted at a radius greater than that of the arm (10.82 metres or 35.5 feet) to avoid target/arm collision once the target is moved into impact position. Test item extension beyond the centrifuge radius was attempted by means of nylon straps and a 22.7 kg (50-pound) aluminum cylinder of 127 mm (5-inch) diameter. The cylinder remained stable during velocities up to 91.4 m/s (300 feet per second) (the maximum tried). It may prove necessary to cut the support(s) immediately prior to impact in order to avoid external forces on the test item during impact and rebound.

Figure 3. Moving Target Into Orbital Path of Test Item

Having to move the target into position during the time interval of one revolution may impose limitations on the size, weight, and complexity of the target. As an example, movement of 4.5 Mg (10,000 pounds) a distance of 508 mm (20 inches) in less than 0.8 second would have been required in the recent test series.

Trailing cables are not expected to be a problem except in avoiding the cutters required for the test item extension mentioned above.

Moving of Test Item Into Orbital Path of Target

This technique is similar to that in the foregoing section, with the test item and target interchanged (see Figure 4). However, this one is more restrictive, since targets will be limited in size, weight, and complexity because of centrifuge limitations.

Figure 4. Moving Test Item Into Path of Rotating Target

Consideration must also be given to the dynamic load at impact and its effects on the centrifuge structure and bearings.

Extending of Test Item Radius To Impact Stationary Target

Once up to impact speed, the radius of the test item's orbit can be extended. This will be the same as that in Moving of Target Into Orbital Path of Test Item, except that the test item radius will have to be extended in less time than that required for one revolution. This technique is illustrated in Figure 5. Centripetal force could probably be used to extend the radius of the test item.

Figure 5. Changing Test Item Position to Impact Stationary Target

Raising or Lowering of Test Item To Impact Stationary Target

The target can be placed above or below the rotating arm. Once the specified velocity is achieved, the test item can be raised or lowered to impact.

Acceleration of Test Item Radially Outward To Impact Target

Figure 6. Accelerating Test Item Radially Outward Into Target - Test Item and Target Mounted on Centrifuge

The target and test item can both be mounted on the centrifuge. As depicted in Figure 6, the test item is accelerated along a restrained path (i.e., tubular guide) and allowed to free fly into the target mounted on the outer portion of the arm.

Sliding friction and the fact that test item acceleration changes with radius will probably result in less accurate control of impact velocity. However, this technique lends itself nicely to tests where multiguides and test items can be mounted for simultaneous or rapid sequential impacts.

Weight, size, and dynamic load restrictions as previously discussed apply.

General Discussion

Many of the foregoing techniques are well suited for sequential or simultaneous impact tests where the multitest series is performed while the centrifuge is maintained at a constant velocity or stepped through a series of velocities.

Free-Flight Impact Testing

Free-flight impact testing, the only technique developed and applied to a test series (ARC) to date, consists of securing the test item to the centrifuge arm. Once the centrifuge is rotating at the rpm corresponding to the desired impact velocity, the test item is released. Upon release, the test item free-flies on a tangential path leading to the target at a velocity equal to $R\omega$.

Fixture Requirements

The fixture required to adapt the test item to the centrifuge is quite simple, cheap, and easily fabricated. The basic requirements include the following:

1. The test item must be restrained at a static load of WG , where W is the weight of the test item and G is the normal acceleration on the test item prior to release.
2. The fixture cannot interfere with the test item after release from the rotating arm.
3. The fixture should allow adjustable radius of the test item.
4. The fixture must allow adjustable release angle for the test item in order to compensate for test item rotation during free flight. This angle offset is a function of impact angle, centrifuge speed, and free-flight distance to impact.

A typical fixture is shown in Figure 7. Basically, a support cradle and steel cable are mounted on a fixture plate which bolts to the centrifuge arm. The radius and the release angle are adjustable by manipulation of the steel plate.

Figure 7. Typical Fixture for Impact Testing

Release Mechanism

The timely release of the test item is accomplished by cutting the support cable (Figure 7). Accurate release is essential to control of the impact location and impact angle. Required

Figure 8 Schematic of Horex Cable Cutter
Firing Circuit

accuracy has been obtained with a Horex guillotine 12.7 mm (1/2-inch-diameter cable cutter. Firing time is controllable to less than 1 millisecond.

A schematic of the Horex firing circuit is shown in Figure 8. A thin black body is mounted to the centrifuge base (non-rotating). The position of the black body is adjustable to allow for selective firing location. A light source and photocell is mounted to the rotating arm and is caused to create a pulse during each revolution of the arm by the black body passing between light and P.E. cell (see Figure 9). A minimum of 3 ms is required to insure turning on an SCR in the trigger circuit. This time is obtained through the length of the black body which breaks the light beam. Once the required centrifuge rpm is reached, the circuit is activated by a manually controlled safety switch. After the safety switch is set manually, the cutter is activated by a 28-VDC, 6-ampere source the next time the light beam is broken. The accuracy of this release mechanism, coupled with built-in adjustment of release mechanism position, allows nearly precise selection of impact location and test item angle of impact. Also, this release technique has proved to be reliable through over 500 impact tests conducted to date.

It should be noted that when a single support cable is wrapped around the test item, the test item must be located near the center of gravity in order to avoid slippage or decoupling from the support cradle. Also, the criticality of inaccurate test item release suggests that a single cable be used if at all possible, since proper timing between two or more cutters would probably be difficult to achieve.

FIGURE 9. TRIGGER LIGHT INTERRUPT TECHNIQUE

Target

The major restrictions on target location are as follows:

1. The orbital path of the rotating arm, with test item, cannot intersect the target.
2. The target cannot be allowed to interfere with the rotating arm as a result of the impact.

The weight, size, and complexity (steel, concrete, water, etc) of the stationary target are essentially unrestricted. At present, the physical size of the centrifuge pit area (see Figure 10) must be considered.

Control of Impact Angle

The test item/target impact angle can be controlled, for a given velocity, through one or more of the following:

1. Test item release angle on rotating arm
2. Free-flight distance
3. Target angle

Items 1 and 2 are a function of the centrifuge rpm at the time of test item release.

Test Control and Data Acquisition

Control of centrifuge rotation is described in SC-TM-66-365. All tests, including test item release from arm, are remotely controlled from Building 6526 or from 6540, with safety requirements determining which building is used.

Impact data from transducers mounted on the test item are transmitted by trailing cables between the test item and centrifuge arm. Signal conditioners and amplifiers are located at the center of the arm, intermediate to the slip rings, through which data are transmitted to FM tape recorders located in the control room. The slip rings available for data or miscellaneous requirements are outlined below.

Slip-Ring Ratings on 10.7 Metre (35-Foot) Centrifuge

<u>Quantity</u>	<u>Characteristics</u>
12	250 V x 100 amp
24	250 V x 5 amp
150	32 V x 0.25 amp

Trailing wire breakage, prior to completion of the impact acceleration pulse, is no longer a serious problem. A technique of releasing the cable has been developed and proved to the extent that data have been successfully recorded on the last 25 impact shots.

Figure 10 Physical Layout of the 10.7 Metre Centrifuge Facility

Fortunately, long lengths of trailing cable are not required, because the relative distance between the test item and centrifuge arm will normally be small. This distance can be approximated by

$$d = X_T (\csc \theta - \cot \theta),$$

where

d = relative distance between impact point and centrifuge arm tip

X_T = free-flight distance of test item

θ = angle between release and impact points.

Figure 11 depicts the distance, d , as well as target/test item miss distance before release. As an example, a 1.8 metre (6-foot)-long trailing cable has been adequate for past tests where free-flight distance was approximately 4.3 metres (14 feet).

Figure 11. Space Relationship Between Target and Test Item

Free-Flight Impact Test Capabilities

Impact Velocity*	3 to 183 m/s (10 to 600 ft/sec) (+1%)
Weight (test item plus fixture)	4.5 Mg (10,000 pounds) maximum
Force in Centrifuge Arm (weight x G)	2G-MN (450,000 G-pounds)
Target	Optional
Impact Angle	Optional
Free-Flight Distance	Optional

* Maximum angular velocity (15.2 rad/s or 145 rpm) and test item radius (13.7 metres or 45 feet) are not possible simultaneously because of drag and static load limitations. However, with proper design it is felt that 183 m/s (600 feet per second) is possible. A tangential velocity of 157 m/s (515 feet per second) has been proved, since it corresponds to maximum rpm (15.2 rad/s or 145) at the tip of the centrifuge (10.7 metres or 35.5 feet). (13.7 metres (45 feet) would require extension of the present centrifuge arm.

Equations

Linear Acceleration (G)

$$G = 1.12 \times 10^{-3} R \omega^2$$

Tangential Velocity

$$V = R \omega$$

Arm Load (F)

$$F = W G,$$

where

R = radius of test item (m)

ω = centrifuge rotation (rad/s)

W = weight of test item plus fixture (g).

Advantages

1. Accurate and repeatable impact velocity ($\pm 1\%$).
2. Velocity control in the range of 3 to 183 m/s (10 to 600 ft/sec.)
3. Accurate and repeatable impact location on target.
4. Accurate and repeatable impact angle with target.
5. Negligible tangential acceleration (< 1.0 G) prior to impact.
6. High confidence in obtaining data as a result of a minimum of trailing wire.
7. Inexpensive cabling due to short trailing wire.
8. Inexpensive fixturing.
9. Fast setup and turnaround time.
10. Minimal test personnel requirements (two people).
11. Sequential or simultaneous firing of multitest item arrays.

Disadvantages

1. Test item undergoes high radial acceleration.
2. Test item undergoes rotation ω during free flight.
3. Coriolis acceleration during free flight and impact.
4. Rebound of test item must be treated with caution.

Accident-Resistant Container (ARC) Test Series

The ARC and Reentry Body Division, 1553, requested that the feasibility of impact testing on the centrifuge be determined in an effort to meet that division's test requirements and development schedules.

The need for both fast reaction and turnaround time dictated pursuit of the free-flight impact test technique. Impact velocity, location, and angle were accurately produced from the very first shot. However, because of breakage of the trailing wires shortly after impact, development of an accurate and reliable data retrieval technique took approximately one and one-half months of additional work. At this time, the test series is being expediently handled with a high degree of success (data 100 percent on last 25 shots).

The purpose of the ARC test series was to evaluate the energy absorption capabilities of various insulation materials being considered for use in the ARC. Figure 12 details the test item configuration used in the preliminary test series. In this case, the acceleration-versus-time history of the inner mass was used to evaluate the absorption characteristics of the various materials under study. The velocity at impact was normally set for 83.8 m/s (275 feet per second) into a steel target weighing 6.35 Mg (14,000 pounds). The test items were allowed to free-fly approximately 4.3 metres (14 feet) prior to impact.

NOTE: Not to scale

Figure 12. ARC Test Item Layout (axial impact)

Figure 13 shows one of the units, the release mechanism, and the target after impact. Data typical of the many (~ 50) axial impact tests are shown in Figures 14 and 15. Figure 16 depicts a cylinder after testing.

A second test series was initiated to evaluate the strength of several container sections when impacted side-on. The differences in each container were in the material and thickness of the inner cylinder, which represented an inner container, and in the type of wood which enclosed this inner cylinder. Figure 17 details the test item configuration. Figures 18 and 19 depict test setup for a side-on impact and a test unit after impact, respectively. Typical acceleration/time plots are shown in Figures 20 and 21.

The future workload on the ARC series will be heavy. In most cases, a test technique similar to that described herein will be used.

Conclusions

An impact test technique whereby the tangential velocity of the 35-foot centrifuge is used to create the required impact environment has been described. The options include impacting a test item into stationary targets and the reverse, moving a target into a stationary test item.

The accuracy, flexibility, low cost, and efficiency offered by this technique make it highly competitive for future impact test series.

Figure 13. ARC Test Setup (head-on impact)

Figure 14. Axial Impact Data - ARC Test Series

Figure 15. Axial Impact Data - ARC Test Series

Figure 16. Posttest ARC (axial impact)

Figure 17. ARC[®] Test Item Layout (side-on impact)

Figure 18. ARC Test Setup (side-on impact)

Figure 19. Posttest ARC (side-on impact)

Figure 20. Side-On Impact Data - ARC Test Series

Figure 21. Side-On Impact Data - ARC Test Series

APPENDIX 7

List of Drawings for 8.8-Metre (29-Foot)
Centrifuge Facility

APPENDIX

SECTION VI REFERENCE DRAWINGS

List of Drawings for 8.8 Metre (29-Foot) Centrifuge Facility

Reference drawings are presented in numerical sequence to facilitate access. They are supplied for assistance in installation, maintenance, and troubleshooting.

Following is a list of these drawings in next-assembly relationship.

Drawing No.	Title
E01737	8.8 Metre (29-Foot) Centrifuge General Assembly
..D01833	Layout field piping
..D01725	Sump power unit assembly
..D01834	Pit - valve junction
..D01004	Specimen yoke
..D01925	Cross member - specimen yoke
..C01933	Counterweight
..F01989	Hubpit piping assembly
..E01990	Rotor arm assembly
..F02365	Assembly, rotary joint drive
..D02290	Rotary joint, general assembly
..D02390	Electrical control equipment
..C03002	Outline, 1C-7095-Y1 Cabinetrol panel
..C03004 (2 sheets)	Outline, 1C-7890 control desk
..D03005	Elementary diagram, (Cabinetrol panels for main pumps)
..D03007A	Wiring diagram, (Cabinetrol panels for main pumps)
..D03008A	↓
..D03009A	
..D03010	
..D03014	
..D03015	
..D03016	Elementary diagram, (1C 7095MCC for main pump room)
..D03017	Elementary diagram, (1C 7095MCC for main pump room)
..D03018	Wiring diagram, (1C 7095MCC for main pump room)
..D03019	Miscellaneous information, (1C 7095MCC for main pump room)
..D03020	Connection diagram
..D03021	↓
..D03022	
..D02023	
..D02024	↓
..B02502	
..E02534	
	Trim counterweight
	Hubpit arrangement

<u>Drawing No.</u>	<u>Title</u>
..F02263	Lube oil unit
..F02506	Control panel assembly
..C02753	Panel, pilot valve assembly
.F02728	Drive assembly

Following is a list of the reference drawings in numerical sequence, as they appear in the manual.

<u>Drawing No.</u>	<u>Next Assembly</u>	<u>Title</u>
D01725	D01833	Sump power unit assembly
E01737	Top	8.8 Metre (29-Foot) Centrifuge General Assembly
D01833	E01737	Layout field piping
D01834	D01833	Pit - valve junction
D01884	E01737	Specimen yoke
D01925	E01737	Cross member - specimen yoke
C01933	E01737	Counterweight
F01989	E01737	Hubpit piping assembly
E01990	E01737	Rotor arm assembly
F02263	E02534	Lube oil unit
D02290	F02365	Rotary joint, general assembly
F02365	E01737	Assembly, rotary joint drive
B02502	E01737	Trim counterweight
F02506	E02534	Control panel assembly
E02534	E01737	Hubpit arrangement
F02728	E01737	Drive assembly
C02753	E02534	Panel, pilot valve assembly
C03002	D02390	Outline, 1C-7095-Y1 Cabinetrol panel
C03004 (2 sheets)	D02390	Outline, 1C-7890, control desk
D03005	D02390	Elementary diagram, (Cabinetrol panels for main pumps)
D03007A	D02390	Wiring diagram, (Cabinetrol panels for main pumps)
D03008A	D02390	
D03009A	D02390	
D03010	D02390	
D03014	D02390	
D03015	D02390	
D03016	D02390	Elementary diagram (1C 7095MCC for main pump room)
D03017	D02390	Elementary diagram (1C 7095MCC for main pump room)
D03018	D02390	Wiring diagram (1C 7095MCC for main pump room)
D03019	D02390	Miscellaneous info. (1C 7095MCC for main pump room)
D03020	D02390	Connection diagram
D03021	D02390	
D03022	D02390	
D03023	D02390	
D03024	D02390	

APPENDIX 8

Factory Specifications
on Vibration System for 8.8 Metre (29-Foot) Centrifuge

APPENDIX 8

Factory Specifications on Vibration System for 8.8 Metre (29-Foot) Centrifuge

SECTION 1 - GENERAL DESCRIPTION

1-1. INTRODUCTION

a. The Ling Electronics Model 300 Centrifuge Shaker System contains two wide frequency band electrodynamic shakers designed to convert electrical power into mechanical force. The system operates in a 10 Hz to 3000 Hz frequency range from either a sine or random waveform input. It is capable of producing a combined force of 74,726 newtons (sine vector) while operating in a high G static acceleration field.

b. The Model 300 Centrifuge Shaker System may be driven by either sine wave or random waveform input. The signal is controlled by signal conditioning equipment, amplified, and applied to the armature coils.

c. Each shaker consists of a magnetic structure which houses and supports an armature with a pneumatic centering device, and field coils. The two shakers are mounted on a structure which contains a hydraulic guidance system, allowing operation in a horizontal or vertical plane.

d. Each shaker is equipped with an overtravel protection device connected into the amplifier interlock system.

e. Both shakers in the Model 300 Centrifuge Shaker System are identical except for the length of the cables and hoses. All information in this manual applies to both shakers. For information on how the shakers relate to each other electrically and pneumatically, refer to the electrical and pneumatic schematic drawings included in paragraph 5-2.

1-2. PURPOSE

The Ling Electronics Model 300 Centrifuge Shaker System is designed to provide a means for environmental vibration testing in conditions of high centrifugal force, altitude, and temperature.

1-3. SPECIFICATIONS

a. Shaker System

Rated force (sine vector)..... 74,726 newtons (16,800 lbs)
Useful frequency range..... 10 to 300 Hz
Fundamental resonant frequency..... 2250 Hz
(bare table)
Rated bare table acceleration..... 50-G vector
Rated velocity..... 1.77 m/s (70 in/sec)
Rated displacement..... 12.7 mm peak-to-peak(.5 in.)
Effective overtravel limits..... 12.7 mm (.5 in.)
Rated load at 10-G vector..... 6423 newton (1,444 lbs)
Rated load at 20-G vector..... 2687 newton (604 lbs)
Rated load at 50-G vector..... 445 newton (100 lbs)

b. Armature

Rated current (each shaker)..... 750 amperes rms sine
wave
Resistance at 25°C (each shaker)... 0.022 ohm
Load mounts (on slip table)..... 3/8-24 UNF, 25.4 mm long,
stainless steel
Effective weight (each shaker).... .024 Mg (52 lbs)
Slip table weight..... .060 Mg (132 lbs)
Total moving weight..... .107 Mg (236 lbs)

c. Field (in series)

Rated current (dc)..... 250 amperes
Rated voltage (dc)..... 175 volts
Stray Field (3 inches above the
slip table)..... 1 gauss

	Degauss coil current.....	1.3 amperes
	Degauss coil voltage.....	175 volts
d.	Armature Guidance and Recentering System	
	Oil pressure.....	17.24 MPa (2500 psi)
	Air pressure.....	2.07 MPa (300 psi)
e.	Overall Dimensions and Weight (shaker system mounted on support frame)	
	Length.....	2.39 metres (94 in.)
	Width.....	.965 metres (28 in.)
	Height.....	1.02 metres (40 in.)
	Weight.....	5.443 Mg (12,000 lbs)
f.	Environmental Capabilities	
	Pressure range (altitude operation)-2286 to +76200 metre	
	Rated static acceleration field..	60 G
	Maximum static acceleration field	
	(by design).....	100 G
	Minimum design safety factors	
	(static acceleration).....	4

LING
Electronics

**DUAL SHAKERS
FOR
CENTRIFUGE
APPLICATIONS**

16,800 POUNDS FORCE

Push-pull configuration—Two 8,400 lbs. shakers are mounted on a common axis with extremely rigid side plates for centrifuge mounting. The shakers are operated push-pull to obtain the highest frequency range and provide capability for centrifuge operation.

High lateral load capability—The armatures are connected together with a hydrostatic bearing table for specimen mounting and lateral load support for the armature and test load.

Positive table position—To eliminate any offset in table position due to static "g" load, the shaker bodies are pressurized with air. The armatures have a position-sensing valving system that increases or decreases pressure to maintain proper armature position.

Operation in two positions—The mounting structure for the shakers is designed to permit operation of the system either parallel or perpendicular to the static acceleration.

SPECIFICATIONS

SHAKER—GENERAL

Force Rating (sine vector): 16,800 pounds
Maximum Load, 10 g vector: 1,444 pounds
Maximum Load, 20 g vector: 604 pounds
Maximum Load, 50 g vector: 100 pounds
Frequency Range: 5 to 3,000 cps
Fundamental Axial Resonant Frequency: 2,250 cps
Stroke, continuous duty: 0.5 inch (peak-to-peak)
Rated Static Acceleration: 60 g
Cooling Method: Closed-loop system circulates distilled water to cool the shaker; heat is removed in an external water-to-water heat exchanger. Standard heat exchangers for use with tower or raw water are available.
Temperature Range: -100°F to $+300^{\circ}\text{F}$

Total Moving Weight: 236 pounds
Table Size: 12" x 18" Mounting Points 3" o.c. x 3" o.c.

FIELD

Field Protection: Discharge rectifier
Field Power: 45 kw total

ARMATURE PROTECTION

Overtravel: Positive contact for electronic control

PHYSICAL SPECIFICATIONS

Total Weight: 12,000 pounds
Dimensions: 94" L x 38" W x 40" H

LING

Electronics

A DIVISION OF **LTV** LING ALTEC, Inc.

BULLETIN NO.
DBE-552A

1515 S. MANCHESTER AVE., ANAHEIM, CALIF. 92705

AC714 774-2000

APPENDIX 9

Factory Specification
Sheet for Power Amplifier

APPENDIX 9

Factory Specification Sheet for Power Amplifier

120,000 VA ELECTRONIC VIBRATION POWER AMPLIFIER

A Ling conception — Ling Electronics was first to conceive and build high power amplifiers to drive electrodynamic shakers. Ling continues its leadership by offering power generators of proven design and reliability... the direct result of employing sound engineering practices and highest quality components and workmanship.

Completely self contained — Three attractively styled, compact cabinets house transformers, water cooled heat exchanger, field supply and armature protector. This amplifier built for driving an electrodynamic shaker presents the finest in LING quality engineering, design experience and personal production line attention.

Complete front panel metering of all important operating functions.

Maximum reliability — The Ling Model PP-120/150 Amplifier, like all Ling Amplifiers, is designed, built and rated for continuous operation driving compatible shakers to full system performance.

Foolproof interlock system — Ling engineering provides full safeguards for personnel and equipment safety. Opening any door automatically turns off power, shorts out all high voltages and energizes convenience outlets and service lights.

All control circuitry included in amplifier — No console is required for amplifier operation. If remote control is desired, all the important amplifier controls and meters may be duplicated in a LING control console.

Supervisory light panel visually indicates proper operation of amplifier.

Instantaneous overload protection designed into critical circuits to protect all system components... yet permits rapid reset to normal operation, insuring minimum downtime.

Walk in accessibility provided at rear of each cubicle allows easy inspection and maintenance. A break away panel is also provided in the front of each cubicle.

**Model
PP-120/150
POWER
AMPLIFIER**

PLATE DISSIPATION: 150 KW continuously.

FREQUENCY RESPONSE: ± 1 db 10 to 10,000 cps

DUTY: Rated for continuous operation driving compatible shakers to full system performance.

INPUT IMPEDANCE: 10K ohms. Source impedance should be 600 ohms or less.

OUTPUT VOLTAGE: Provided to drive the selected shaker for proper sine or random operation. Can be selected either from the power amplifier or a control console.

- (1) Output Current
- (1) Field Current
- (1) Degaussing Current
- (2) Power Amplifier Plate Current
- (1) Power Amplifier Plate Voltage
- (2) Power Amplifier Bias Voltage
- (2) Power Amplifier Filament Voltage
- (2) Driver Amplifier Plate Current
- (1) Driver Amplifier Plate Voltage
- (1) Filament Running Time
- (1) Power Amplifier Running Time
- (1) Cooling Water Conductivity
- (1) Water Pressure
- (1) Water Temperature

POWER REQUIREMENTS: 440, 460, 480, 500 volts, 3 ϕ , 60 cps.
270 KVA amplifier and field supply. Equipment must be installed and operated in conformance with applicable Ling installation drawings and manuals.

B. Water cooling of Power Amplifier tubes is provided by a self-contained distilled water system of pump, tank and heat exchanger. The only external cooling water required for 150 KW plate dissipation is 45 gallons per minute of 82°F (maximum) raw water at 20 psi (min) inlet pressure.

SPECIFICATIONS

Top view diagram showing dimensions and component locations. Key features include:

- Overall dimensions: 54" TYP. (width), 84" (height).
- Internal dimensions: 19", 16", 7 1/4", 17 1/4", 13 3/4", 17 1/4", 14 1/4", 19 3/4", 10 1/4", 16 1/4", 8".
- Components and Labels:
 - 2" INLET
 - 2" OUTLET
 - EXTERNAL COOLING WATER
 - 25"
 - 1-5/8" DIA. EXHAUST FANS 350 CFM TYP 3 PLACES
 - 250 CFM
 - 700 CFM
 - 2 1/4" CONDUIT POWER INLET
 - 40 R TYP.
- Notes: "TOP VIEW" is indicated at the top center.

1. Field and Degaussing Supply
2. Armature Protector

APPENDIX 10

Computer Control System

APPENDIX 10

Computer Control System

A computerized control system at the SLA, Area 3 Centrifuge Facility was made operational in the fall of 1978. The main purpose of this system is control of both centrifuges angular velocity. However, it also monitors various safety devices and allows remote operation of previously manual operations.

The computer will allow some profiling of "G" curves, but this is limited to a number of constraints on the hydraulic power system. The size of the centrifuge's arm and the available hydraulic power are the main limiting factors. Also, to keep maintenance to a minimum, abrupt pressure changes in the system should be avoided.

A mathematical model of the centrifuge control system was used to determine many of the system's constraints. This same model is used in the control routines of the computer.

The original Centrifuge Control System is shown in Figures A and B. The hydraulic power system consists of 13 pumps which provide a flow of fluid to fluid motors. The number of fluid motors is selectable in the range of 8 to 16 motors on the 8.8 metre (25 foot) centrifuge, but is set at 7 motors on the 10.7 (35 foot) centrifuge. Pressure is built up at the motors, which is converted to a torque applied to the centrifuge arm. The centrifuge's angular velocity is controlled by varying the rate of flow supplied to the fluid motors, which varies the pressure and the torque.

Using a mathematical model, the computer can predict what flow rate is needed to reach a set "G" level. However, the parameters used in the model are subject to variations in day to day operation. Some of the parameters which may vary are air tempera-

ture, oil temperature, air pressure, and wind. Therefore, the model is probably only good to within $\pm 5\%$ of a set velocity value. To overcome this problem with the model, an error routine is used when the arm gets within $\pm 5\%$ of the set value.

A block diagram of the Computer Control System is shown in Figure C. The Centrifuge Control Computer is an HP 2112A minicomputer with 32K of solid-state memory. It has 128 standard instructions, 4 general-purpose registers, and the power fail/auto-restart option. There are 14 input/output channels in the main frame, which may be increased with HP 12979 I/O Extenders.

A Texas Instrument Model 733 terminal is used as the system console. It is a portable, hard-copy terminal which is used either locally for most tests or, in conjunction with the Vadic series 300 modem, for remote tests.

The RPM Counter gives a direct angular velocity reading to the computer. It is a programmable, 12-bit binary counter; which operates from a 600 tooth gear attached to the centrifuge arm.

An HP 91000A Analog-to-Digital Interface Subsystem converts inlet and outlet pressure voltages to binary data. The pressure voltages originate from bridge transducers and BLH Model 450A transducer amplifiers.

The Mode Control governs the mode of operation the system is operating in. It senses which centrifuge is selected, which console is selected, number of fluid motors on the 8.8 metre (29 foot) centrifuge, if the KILL circuit is energized, and which pumps are on. Also, it controls the brake and overall computer control power.

The Pump Volume Control controls the variable displacement pumps. It senses the fractional setting of each pump and allows either increase or decrease of these settings.

The Pump Pressurize Control allows the computer to pressurize any of the 13 pumps. Also, it monitors which pumps are pressurized. Normally, the electric motors driving each pump are started before each run, but to send its flow to the main line a hydraulic valve must be energized. When this valve is energized, the pump is pressurized. When the valve is not energized its flow is cycled back to the reservoir.

The Pump Start Control allows remote starting, of the electric motors driving the pumps, from the computer. Verification of which pumps are on is accomplished by the Mode Control. Also, in the Pump Start Control, the power supplying the motors is monitored; should the voltage drop, an emergency shut-down would be initiated.

FIGURE A ORIGINAL CENTRIFUGE CONTROL SYSTEM

FIGURE B . MAIN CENTRIFUGE DRIVE SYSTEM

FIGURE C . CENTRIFUGE COMPUTER CONTROL SYSTEM

· APPENDIX 11

Digital Data Acquisition & Analysis System
for the
8.8- and 10.7-Metre Centrifuge Facilities
System Capabilities Report

APPENDIX 11

SAND77-1502
Unlimited Release
Printed January 1978

DIGITAL DATA ACQUISITION & ANALYSIS SYSTEM
FOR THE
8.8 AND 10.7 METRE CENTRIFUGE FACILITIES
SYSTEM CAPABILITIES REPORT

Robert N. Tomlinson
Facility and Digital System
Design and Development Division 9344
Sandia Laboratories
Albuquerque, New Mexico 87115

ABSTRACT

This report describes the capabilities of a minicomputer controlled data acquisition and analysis system for the Area III centrifuge facility at Sandia Laboratories. The system utilizes a PCM encoder for on-board signal digitizing and a magnetic disc for data storage. Report quality plots are available immediately at the conclusion of a test from the CRT graphics terminal and hardcopy unit. Program software is written in Fortran and assembly language.

CONTENTS

	<u>Page</u>
General Description	5
Basic System Capabilities	5
Data Acquisition System Components Description	6
PCM Encoder	7
PCM Bit Synchronizer, Decommutator and Interface	8
Telemetry Equipment	9
Analog to Digital Converter - HP 2313	9
Minicomputer Controller	10
Magnetic Disc	10
Operator's Console and Graphics Plotter	11
Remote Terminal	11
Magnetic Tape Recorder/Reproducer	12
Line Printer	12
Paper Tape Equipment	12
Centrifuge System Software Capabilities	12
Software Operating System	12
Plotting Software	12
Test Program Software	13
Test Data Acquisition Programs	14
Program CENT	14
Program SPEED	15
Program TIMSR	15
Data Analysis and Plotting Programs	17
Program PLOTH	17
Program DLIST	17
Program GTIME	17
Program PTIM	17
Program PSD	18
Program DXFER	18

CONTENTS (cont)

	<u>Page</u>
Summary	18

Illustrations

Figure 1. Centrifuge Minicomputer System	19
Figure 2. PCM Encoder and Telemetry Transmitter	21
Figure 3. Centrifuge Data Acquisition and Analysis System	23
Figure 4. System Operator's Console and Plotter	25
APPENDIX A. Sample Interactive Operator/System Dialog for Program CENT	27
APPENDIX B. Sample Data Plot of Strain Data Stored by Program CENT	33
APPENDIX C. Sample Test Verification Plot of G versus Time as Stored by Program CENT	37

DIGITAL DATA ACQUISITION & ANALYSIS SYSTEM
FOR THE
8.8 AND 10.7METRE CENTRIFUGE FACILITIES
SYSTEM CAPABILITIES REPORT

General Description

The minicomputer based data acquisition system described in this manual was designed to become a permanent part of the 8.8metre and 10.7metre centrifuge test facilities located at Sandia Laboratories, Albuquerque, Area III. It has modernized and greatly improved the data acquisition and handling capabilities at this installation.

In addition to the minicomputer, major system components consist of a magnetic disc for data and program storage; a CRT graphics terminal used as the system operator's console and plotter; an airborne type pulse code modulated (PCM) multiplexer/encoder for low level data input to the system; a telemetry link consisting of an S-band transmitter and receiver; a PCM bit synchronizer and decommutator for serial to word-parallel conversion of the PCM bit stream; a medium speed A to D (analog to digital) converter for acquisition of vibration data and other higher level signals; an electronic counter coupled to a magnetic speed sensor for measurement of the centrifuge RPM/G; and peripheral line printer, magnetic tape and paper tape equipment. Figure 1 pictures the minicomputer and associated equipment. Figure 2 shows the PCM encoder and telemetry transmitter. The system is functionally depicted in the block diagram (Figure 3).

Basic System Capabilities

There are important advantages to this new data system. Foremost among these is the ability to obtain some information about a test while it is in progress and to obtain data plots immediately afterward.

Computer System

Figure 2. PCM Encoder and Telemetry Transmitter

Figure 3. Centrifuge Data Acquisition and Analysis System

The test operator may establish alarm levels for critical data channels. A warning message will be printed on the system console any time during the test that the alarm level for that channel is exceeded. This is accomplished by on-line reduction of the raw data to scaled strain or voltage values. Report quality, "quick look" plots of all or selected channels may be made after the test to insure that all test requirements have been met at the time of the test or to determine if it is appropriate to continue with follow-on testing. Additionally, a listing may be printed of the scaled data values for all channels at the recorded G intervals selected by the operator.

The use of the PCM encoder has eliminated the electrical noise problems associated with the use of slip rings for the low level strain data channels. Now this data is digitized near the transducers and only a single good data path is required. This path may be via a telemetry link or by a good slip ring pair. The encoder has also increased the number of low level strain channels that may be handled to 96 and, in addition, 64 channels of higher level data signals may be digitized. The PCM encoder is not intended to replace specialized PCM data acquisition equipment already incorporated into some flight test units, nor is the computer hardware or software intended to accept data from other PCM encoders because of the variability of data rates and formats found in that type of equipment. Where critical channels are of concern it is recommended that duplicate channels be set up and connected to the centrifuge system PCM. In this way the trend of the data may be followed during the test by establishing alarm limits for these channels. Monitoring the control console printout will insure that design limits are not exceeded.

Data Acquisition System Components Description

The following descriptive information gives pertinent specifications for the system components as used in the centrifuge data acquisition system. More detailed information may be found in the reference manuals for the various equipment.

PCM Encoder

The PCM encoders are 7000 series airborne type units manufactured by Gulton Industries. They are intended primarily to handle the acquisition of the low level strain data from the centrifuge arm at relatively low sampling rates. There are four different gain ranges associated with the low level differential inputs as noted in the specifications below. In addition to the low level channels there is a group of high-level, single-ended input channels which may be used for general data recording. The encoder is designed to operate near the source of data signals at the end of the centrifuge arm and as such is rated for operation at 200 linear G. Output of the encoder goes to an airborne type S-band telemetry transmitter. Alternately the encoder output may be directed through a differential line driver, incorporated in the encoder, and then through the centrifuge slip rings to a differential line receiver.

1. Encoder Specifications

Number of bits per data word	- 9 (8 bits + Sign)
Bit range	- 0 to 511 full scale (± 255.5)
Number of data channels	- 160 (all are always scanned)
Number of frame ID bits	- 36 (9 bit frame ID word + 27 bit frame sync word)
Bit rate	- 93,035 K bits per second
Data rate	- 63 data words per second per channel
Maximum frequency response per channel	- 31.5 Hz
Output codes	- BI PHASE L & NRZ-L (Pre-modulation filtered and unfiltered)

2. PCM Encoder Low-Level Channels

Number of channels	- 96 (channels #1-#96)
Amplifier gain ranges	- 62.5, 125, 250, 500

NOTE: Only one range may be programmed for a given test.

The sensitivity and full scale ranges in terms of voltage and nominal micro-strain are tabulated below, together with maximum error experienced at ambient temperature (25°C).

The nominal micro-strain values assume a bridge voltage of 5 Vdc with a 350 ohm, 4 arm strain gage bridge. Actual strain range and sensitivity will vary with individual gages and with actual bridge voltage.

Gain Range	Voltage	Sensi- tivity (μ V/Bit)	Strain		Error at 25°C (% of F.S.)	Bit Swing (Bits)
	Input Range (mV)		Input Range (μ ϵ)	Sensi- tivity (μ ϵ /Bit)		
62.5	±40.88	160.	±15024	58.8	+0, - .4	±255.5
125	±20.44	80.	±7512	29.4	+.2, - .58	±255.5
* 250	±10.22	40.	±3756	14.7	+.78, - .58	±255.5
500	±5.11	20.	±1878	7.35	+.78, - .58	±255.5

*The 40 μ V per bit range (Gain = 250) will be the most frequently used range for centrifuge tests due to the strain levels encountered in normal test operations at this facility. The A to D converter step size will therefore provide a resolution of approximately 14.7 micro-strain.

3. PCM Encoder High-Level Channels

Number of channels - 64 (channels #97 - #160)
 Full scale range - ±2.555 volts
 Sensitivity - 10 millivolts per bit
 Error - less than .7% of full scale
 Bit swing - ±255.5 bits

PCM Bit Synchronizer, Decommutator and Interface

This equipment takes the serialized bit stream from the telemetry receiver or differential line receiver, establishes reference clocks and a synchronized bit stream which the decommutator then reforms into parallel data words with word strobe pulses. The decommutator simultaneously puts out a BCD coded channel number with each data word. The PCM-computer interface, custom designed for this project, accepts the first and last channel number information from the computer together with channel number information, frame and word strobe pulses and data words from the decommutator. It allows only those channels selected to be strobed into the computer, thus limiting the data transfer to active PCM data channels and permitting direct memory access (DMA) hardware transfers rather than program controlled transfers. Multiple successive samples of selected

channels may be made and stored with one call to the interface.

Bit Synchronizer - EMR Model 2726 with Model 2727 fixed frequency,
fixed code selector

Bit rate - 93,000 bits per second

Code - Bi Phase L

Other bit rates or code types would require a separate plug-in
selector module

Decommutator - EMR Model 2746

This is a manually programmable unit capable of accepting a wide
range of bit rates and frame and word lengths. The following
settings are required for use with the Gulton PCM encoders.

Frame length (words) - 162 (160 data + 1 frame sync + 1 ID counter)

Data word length - 9 bits

Frame sync word length - 27 bits

Frame sync word (binary) - 111110101101001100110000000

Telemetry Equipment

The telemetry link from the centrifuge arm consists of a Conic CTS 702P S-band transmitter and a Microdyne Model 1100 AR receiver. The transmitter operates on a frequency assigned to the facility. It is a ruggedized, airborne type unit capable of operating in an environment of 100 linear G.

Analog to Digital Converter - HP 2313

In addition to the PCM encoder for on-the-arm, low-level, relatively low speed digitizing, an HP 2313 A to D system has been incorporated into the data acquisition system. Input signals from the centrifuge arm will necessarily come through the slip ring assembly and should therefore be from higher voltage level, low output impedance devices. The converter will operate at programmable data rates of up to 45 kHz. It is intended to be used to monitor vibration signals for combined linear acceleration and vibration tests and to monitor switch closures and other parameters of systems under test that require the higher frequency capability. At present this converter is equipped with a programmable pacer and high-level multiplexer card. It could be expanded to include additional channels of A to D converter inputs, both high and low level, and digital to analog outputs for analog control applications.

HP 2313 capabilities available at the facility include:

Analog to Digital Converter

Number of channels	- 32 single ended input or 16 differential input channels (any number may be sampled under program control)
Input voltage range	- ± 10.24 volts
Number of bits per data word	- 12 (11 + sign)
Bit range	- ± 2048
Voltage sensitivity	- 5 millivolts per bit

Programmable Sample Pacer

Data sample rates	- programmed as a product of a variable integer microsecond time base (1 to 255) times 10 to a variable integer power (0 - 7)
Data rate	- 2550 seconds per sample through 45,000 samples per second

Minicomputer Controller

The system computer is an HP 2100A core memory unit with Direct Memory Access and floating point arithmetic hardware. In conjunction with the magnetic disc (described below), the system uses Hewlett-Packard's Disc Operating System (DOS) for system control.

Computer Information

Word size	- 16 bits
Memory size	- 32,767 words
Memory cycle time	- 980 nanoseconds
Number of DMA channels	- 2
DMA operating speed	- up to 1 MHz word rate shared by 2 channels
Input/Output channels available	- 14

Magnetic Disc

The system disc is an HP 7905 moving head disc containing one fixed and one removable disc platters. Each surface of the platters will hold up to 2.5 million 16-bit computer words (5 million 8-bit bytes). One surface of the fixed platter is

devoted to disc control. There are 7.5 million words of storage available at any given time on the three remaining surfaces. Each surface is divided into 203 tracks. A track is subdivided into 96 sectors with a sector containing 128 words, 16 bits in length. Average access time to a particular track and sector is 25 milliseconds. A single disc surface could store approximately 75 full 32K coreloads or 1220 blocks of data containing 2048 integer words each.

Operator's Console and Graphics Plotter (Figure 4)

The operator's console is a Tektronix 4014-1 CRT terminal which has with it a Tektronix 4631 hardcopy unit. The terminal allows normal keyboard/operator interaction with output from the computer to the CRT at a nominal rate of 9600 baud in the alpha-numeric mode. In the graphics mode the terminal becomes a high-speed, high-resolution plotter with viewable resolution of 1024 in the horizontal axis and 780 in the vertical axis. Report quality plots may be copied from the screen by the hardcopy unit. The Tektronix PLOT 10 software packages have been modified for use with the HP DOS. These provide automatic linear or log plot scaling and grid line generation. The PLOT 10 vector character generator has been modified and included to enable the use of rotatable, variable sized characters for attractive plot labeling and annotation.

Remote Terminal

A remote terminal has been included in the system for those tests that require that the centrifuge facility be evacuated and that the test be controlled from the remote console located in Building 6540. At present this terminal is really a remote input/output device. Test control programs have been written to communicate with the terminal where the need exists; however, it does not now have the system capabilities of starting or terminating a program.

A Texas Instruments Model 730 terminal operating at 30 characters per second is used in conjunction with a set of Vadic modems operating over shielded data lines between the buildings.

Magnetic Tape Recorder/Reproducer

A digital magnetic tape has been included with the system for data portability to other computer systems. Formatted tapes may be written on the system for transfer to the CDC 6600 or for archiving of test data where it seems advisable. The PERTEC recorder produces a 7 track, 556 bit per inch, even parity tape in standard computer industry compatible format. Records may also be written in Hewlett-Packard binary format where the tape will be used locally, or with a decode program if used on a different type computer system. This recorder cannot be used as a high-speed I/O device. It is a relatively slow software driven unit intended for post-test data storage only.

Line Printer

The system printer is an electrostatic type unit with 600 lines per minute speed in continuous print operation. It has an 80 character line width. The printer is used for data listing and for program preparation and printout.

Paper Tape Equipment

A paper tape reader and punch are available for operating system generation from the tape masters and for program portability between minicomputer systems.

Centrifuge System Software Capabilities

Software Operating System

The software operating system chosen for this data system was Hewlett-Packard's DOS III. This was selected because of the large data arrays that would be handled by the system and because of the need to be able to plot from these arrays. All plot software packages require a sizable block of memory to function. DOS combines the features of (1) a large user program area (nearly 24,000 words of memory), (2) a comparatively simple set of operating system control instructions, and (3) a powerful disc based, file oriented system. A good Fortran IV compiler is also available with DOS III.

Plotting Software

Tektronix PLOT 10 software has been modified for use with the HP DOS III operating system. An input/output routine was written to interface the Tektronix graphics routines

to the DOS operating system. Changes were made in the graphics routines to make them compatible with the minicomputer Fortran IV compiler which is more restrictive than the compilers on large computer systems. Some plotting capabilities, such as bar chart and calendar type graphs, were eliminated to make the package small enough to load in the limited memory of the minicomputer. Those PLOT 10 packages available in the modified form include the Terminal Control System (TCS), Advanced Graphics II (AG II), the Character Generator System, and the Preview Routines for Calcomp Plotters. A separate paper on the modified PLOT 10 software has been published.

Test Program Software

Test programs are written in Fortran IV for ease in programming, clarity in understanding and ease of modification. Software drivers or handlers for peripheral devices, and data scaling and conversion routines, are written in Hewlett-Packard assembly language for compatibility with the operating system or for speed.

Programs are written so that they interface interactively with the operator at the keyboard console. Test parameters are entered in response to program requests. Where possible, operator replies are checked to determine that they are reasonable; if not, the operator is asked to re-enter the parameter. These techniques save time by minimizing program re-starts and post-test corrections of stored parameters.

Test readings from the PCM encoder and A to D converter are organized into data files and stored in raw form on the system disc. When there are questions about test results, calibrate levels or scaling information, it is a simple task to go back and examine those items and make corrections if required. The raw, unscaled test data stored on the disc would remain unchanged.

Test data are logically organized and stored in files on the magnetic disc. For example, all PCM data pertaining to one linear G load are stored in a single file.

In order to uniquely identify each data file on the disc, one sector (128 computer words) has been added at the beginning of each file. The contents of this sector are:

1. a 72 character title block

2. the test R-number
3. the channel number of the first data channel
4. the number of sequentially scanned channels in the record
5. the number of complete scans of selected channels contained in one file
6. the type of record (zeroes, calibrates, scaling data, test data, G/Time data)
7. the test radius
8. the RPM counter reading (from which the linear G may be calculated)
9. the RPM counter time base setting
10. counters to preserve the number of data points included in the complete test record

Where a series of data files will be generated during one program execution, an automatic file name convention has been set up for data acquisition and analysis programs. The name for the first file is requested from the operator. A four or five character name is suggested with the fourth character set at "A". As a file is used, a new one is established by incrementing the fourth character (A becomes B, etc.). When the "Z" file has been used, the fourth character is reset to "A" and the second character of the name is incremented. In this manner RANA becomes RANB...RANZ, RBNA...RBNZ, RCNA, etc.

Test Data Acquisition Programs

Program CENT

This program allows the sampling of up to 96 low-level strain gage channels and up to 64 high-level channels via the PCM encoder. In order to limit the amount of data stored on the disc, the operator enters the first and last data channel numbers and the number of PCM scans to be averaged for one set of data points (4-20). The PCM data values are scaled and compared against pre-set alarm limits. If these are exceeded, a message is routed to the operator's console giving the current reading and the limit reading, for each channel beyond the limit, so that the operator may take appropriate action. At operator determined G increments, the PCM output data is stored on magnetic disc files from which plots can be made immediately after the test run. As each G level reading is taken, the corresponding clock time is taken from the computer system time base. These

values are stored in a separate file for a post-test plot of G versus time for verification of the test environment seen by the unit under test. All data files are identified by means of an ID sector set up in the course of program execution. The 72 character test identification block from the ID sector is used as the title for the plotted test data. Program GTIME is used to plot the G versus time curve.

PCM data channels are plotted by program PLOTH. Where a line printer listing of the plotted values is required, program DLIST may be used.

Program SPEED

This program is used to display a plot of G versus time on the CRT terminal while the test is in progress. At the same time, the data for the plot is stored in a disc file for replot after the test. This program can only be used for those tests where the test consultant supplies his own data equipment and therefore does not require any data handling by the PCM encoder or A to D systems.

Test identification information is stored in the first sector of the data file in the same format as that used for program CENT. The stored G versus time data may be replotted after the test by using program GTIME.

Program TIMSR

TIMSR is used to sample vibration signals in combined vibration and linear acceleration environment tests. In particular the program is used to obtain a series of consecutive data samples so that the power spectral density (PSD) of a random vibration signal may be calculated. For vibration analysis each data record must consist of a "power of 2" samples per channel (usually 1024 or 2048). The maximum frequency component in the sampled data must not be greater than one half of the sample rate per channel. The input to the A to D converter must be low pass filtered at this frequency on each data channel.

This routine allows the operator to program the number of channels sampled, the A to D sample rate, and the number of consecutive files (blocks) of data to be recorded. Normally 32 data blocks will be adequate.

Factors to consider in using TIMSR and subsequent reduction programs are:

- (1) The maximum frequency of interest in the sampled data must not be greater than one half the sample rate per channel (the Nyquist frequency).

$$F_{\max} = SR/2$$

- (2) In any frequency analysis of the sampled data, the frequency resolution equals the sample rate per channel divided by the data block size (N).

$$DELTF = SR/N$$

- (3) The time interval over which the data is sampled equals the number of samples divided by the sample rate.

$$T = \frac{N}{SR} \quad \text{also} \quad T = 1/DELTF$$

- (4) The maximum data block size imposed by the system and this program is 8192 data samples per file.

- (5) The maximum sampling rate of the A to D converter system is 45 kHz.

For example, if the test required information to 5 kHz for each channel and there were a need for four data channels, the resulting A to D sample rate would be $2 * 5 \text{ kHz} * 4 \text{ channels}$, or 40 kHz (10 kHz per channel), which is just within the capability of the system. In addition the maximum data block size per channel for four channels is $8192/4$ or 2048 words; consequently, the frequency resolution would be SR/N , or $10 \text{ kHz}/2048 = 4.88 \text{ Hz}$. The time for a single sample block would be

$$N/SR$$

or

$$2048 \text{ samples}/10 \text{ kHz} = .2048 \text{ seconds}$$

Program TIMSR also establishes a file of G versus operating system-time values for a G versus time plot. These values are stored for the entire centrifuge run and may be plotted after the test by using program GTIME.

Data Analysis and Plotting Programs

Program PLOTH

PCM data stored by program CENT is sorted, scaled, plotted and labeled by PLOTH. Since large data arrays may be involved and since the plotting routines require a large program area, it was necessary to segment the program. It consists of a main program and three segments.

The operator selects the block of channels requiring similar X and Y axis labeling, selects the proper label or enters a new one, and enters the data file name of the first data file and the number of data files in the record. The program sorts through the files one channel at a time, selects the appropriate data, scales it, and saves it for the plot segment. The plot is drawn and copied under program control. The process is repeated until all data channels requested have been plotted. After initialization of the program, the batch operation is automatic for all channels selected.

Program DLIST

The PCM data plotted by program PLOTH may also be listed on the system line printer by DLIST. The first data file name and number of files in the record are entered by the operator. The raw data from the disc file is scaled and block lists of all active channels where data was recorded during the test are printed. The individual readings are the mean of from 4 to 20 successive scans of each data channel. The standard deviation from the mean is also calculated and included in the listing.

Program GTIME

The G versus time data stored by programs SPEED, CENT and TIMSR can be plotted by this program. If desired the values of G and elapsed time can be listed on the line printer at the time that the plot is made. As an alternative, an expanded scale plot of the points within an operator selected G and time range may be plotted.

Program PTIM

This program makes time series plots of data recorded by program TIMSR. This is data stored by the HP 2313 analog-to-digital converter and is primarily vibration type

data from combined linear and vibration acceleration tests.

Program PSD

This program accepts random vibration data which has been sampled and stored on the magnetic disc by program TIMSR. From a number of such samples, usually 32, the average power spectral density is calculated using a set of discrete fast Fourier routines. The results of this analysis are then stored in a disc file for subsequent plotting by program PPSD.

Program DXFER

This program is intended to facilitate the long term retention of test data files on magnetic tape. In order to keep the system disc file storage area from being overloaded, data files must be purged from the disc after a reasonable period of time. This program allows the data to be stored on tape from which it may be loaded back on disc if necessary.

Summary

The data acquisition and analysis system discussed in this report has enhanced the testing capabilities at the centrifuge facility. As a matter of course the test consultant can expect to have plots of important data channels immediately at the conclusion of a test run. This information can be used as the basis for further testing. Where questions about individual data channels occur, they may be resolved while the test setup is intact. Consequently, the loss of important data can be minimized.

Since the data system is minicomputer controlled, it will be relatively easy to provide new test capabilities for the facility as the need arises. It is anticipated that test control and data analysis programs will be expanded to satisfy new testing requirements.

Figure 4. System Operator's Console and Plotter

APPENDIX A
SAMPLE INTERACTIVE OPERATOR/SYSTEM DIALOG
FOR PROGRAM CENT

IPR,CENT
CENTRIFUGE DATA ACQUISITION PROGRAM 3.5
AUTOMATIC SCAN AND CONTINUOUS Q/TIME STORAGE VERSION

THE SYMBOL > IS USED AS A PROMPT
TO INITIATE A DATA SCAN STRIKE ANY KEY (NOT!) & CR-LF AFTER THE >
ENTER TEST DATE(10 CHARS.) 02-15-1977
FIRST PCM CHAN= 1
LAST PCM CHAN= 10
ENTER THE NO. OF PCM SCANS AVERAGED FOR A DATA POINT?(4 MIN-50 MAX)

10
TEST RADIUS (INCHES)= 318
SET COUNTER TIME BASE & ENTER (.1 OR 1 (SEC)) 1
REMOTE KEYBOARD LU= 1
LIST LU= 1
ENTER TEST ID INFO (UP TO 72 CHARS.)
CENTS,CHECK AFTER MODS THIS DATE
ENTER 6 DIGIT TEST NO. R
1ST DATA FILE NAME
ENTER NAME OF DISC FILE (5 CHARS - 4TH INCREMENTED)

EEEE
ENTER G INCREMENT FOR DATA SCANS 10
ENTER MAX TEST DURATION (MIN.) 10
Q US, TIME PLOT FILE
ENTER NAME OF DISC FILE (5 CHARS - 4TH INCREMENTED)

PLT7
READY FOR ZERO SCAN?

>
1 PRE TEST ZERO READINGS

CH 8	AUE VAL	10 SCAN DELTA
1	29	4
2	76	0
3	-86	4
4	-99	9
5	8	4
6	-128	9
7	38	4
8	-32	9
9	-49	4
10	-62	9

REDO ZEROES? NO
ZEROS,FILE TYPE 0 , FILE NAME= EEEA

READY FOR RESISTOR CALS?

>

1 CALIBRATE READINGS - UNSCALED

CH #	AUE VAL	10 SCAN DELTA
1	28	5
2	76	10
3	-85	33
4	-99	55
5	8	33
6	-127	44
7	38	44
8	-32	22
9	-49	33
10	-62	33

REDO CALS? NO
 CALS, FILE TYPE 1, FILE NAME= EEEB

ENTER SCALING INFO
 CHAN #
 THRU CHAN #
 CAL VAL=
 ALARM VAL=

CHAN # 1
 THRU CHAN # 1
 CAL VAL= 10
 ALARM VAL= 10
 MORE SCALING INFO? YE
 CHAN # 2
 THRU CHAN # 2
 CAL VAL= 14.7
 ALARM VAL= 29.4
 MORE SCALING INFO? YE
 CHAN # 1
 THRU CHAN # 1
 CAL VAL= 10
 ALARM VAL= 10
 MORE SCALING INFO? YE
 CHAN # 3
 THRU CHAN # 4
 CAL VAL= 20
 ALARM VAL= 40
 MORE SCALING INFO? YE
 CHAN # 5
 THRU CHAN # 6
 CAL VAL= 30
 ALARM VAL= 60
 MORE SCALING INFO? YE
 CHAN # 7
 THRU CHAN # 8
 CAL VAL= 100
 ALARM VAL= 20

MORE SCALING INFO? YE
 CHAN # 9
 THRU CHAN # 10
 CAL VAL= 50
 ALARM VAL= 100
 MORE SCALING INFO? NO
 1 CALIBRATE VALUES

CH #	CAL VAL	SENS.(UNITS/BIT)	ALARM VAL
1	1.000000E+01	1.000000E+01	1.000000E+01
2	.147000E+02	.147000E+02	.294000E+02
3	.200000E+02	.200000E+02	.400000E+02
4	.200000E+02	.200000E+02	.400000E+02
5	.300000E+02	.300000E+02	.600000E+02
6	.300000E+02	.300000E+02	.600000E+02
7	.400000E+02	.400000E+02	.800000E+02
8	.400000E+02	.400000E+02	.800000E+02
9	.500000E+02	.500000E+02	1.000000E+02
10	.500000E+02	.500000E+02	1.000000E+02

OK? YE
 SCALING, FILE TYPE 2, FILE NAME= EEEC

TEST SET UP COMPLETE, FURTHER COMMUNICATION THRU REMOTE KEYBOARD LU
 READY FOR ZERO SCAN?

>YE
 .00 G TEST READINGS RPM= .00 RPM DELTA= .00

CH #	U STRAIN	DELTA(BITS)
1	.000000E+00	3
2	-.147000E+02	10
3	.200000E+02	3
4	.000000E+00	3
5	.000000E+00	3
6	.300000E+02	3
7	.000000E+00	3
8	.000000E+00	3
9	.000000E+00	3
10	.000000E+00	3

REDO ZERO? NO
 TEST DATA, FILE TYPE 3, FILE NAME= EEED

START TEST RUN?
 >YE

READY FOR POST TEST ZERO?

>YE
 TIME= 15 HRS, 6 MINS, 33.80 SECS

.00 G TEST READINGS RPM= .00 RPM DELTA= .00

CH #	U STRAIN	DELTA(BITS)
1	-1.000000E+01	5
2	-.147000E+02	11
3	.000000E+00	4
4	.000000E+00	6
5	.000000E+00	2
6	.300000E+02	4
7	-.400000E+02	4
8	.000000E+00	3
9	.000000E+00	3
10	.000000E+00	3

TEST DATA, FILE TYPE 3, FILE NAME= EFEA

THE TOTAL NO. OF TEST FILES USED IS 27
 G/TIME FILE= PLT7 CONTAINING 21 SECTORS
 SCAN REQ'D 8 SECTORS, 149 DATA POINTS

APPENDIX B
SAMPLE DATA PLOT OF STRAIN DATA
STORED BY PROGRAM CENT

SAMPLE STRAIN DATA PLOT - CENTRIFUGE PCM DATA SYSTEM
PCM CHAN.# 3 GAGE#3 RADIUS(IN.)=396. DATE:09-16-1976 R123456

APPENDIX C

SAMPLE TEST VERIFICATION PLOT OF
G VERSUS TIME AS STORED BY PROGRAM CENT

SAMPLE G VS. TIME PLOT
DATE: 08-22-1977 R242424 FILE=GA-1

APPENDIX 12

Denison Hydroilic Pumps

APPENDIX 12

DENISON ENGINEERING DIVISION
AMERICAN BRAKE SHOE COMPANY
COLUMBUS 16, OHIO

Bulletin P-4-6-D

DENISON HYDROILIC PUMPS

Variable Volume, Pressure Compensator with Handwheel Volume Control
600, 700 and 800 Series

The Denison variable volume pumps, controlled by pressure compensator with handwheel, are rated at 10, 20 and 35 gpm for the 600, 700 and 800 series respectively for operating pressures up to 5000 psi. The 600 series pump may be operated at either 1200 or 1800 rpm, the larger 700 and 800 series at 1200 rpm.

The handwheel volume control permits the regulation of the maximum volume delivered by the pump by adjusting the angle of the cam plate through a threaded mechanism within the pump.

The pressure compensator control automatically regulates the volume delivered by changing the length of stroke of the pumping

pistons. Stroke change is controlled by system pressure in such a manner that when the pump is operating at a pressure less than the maximum setting of the compensator, the pump delivers full volume. When the system pressure reaches or exceeds the compensator pressure setting, the delivery is automatically reduced to only that amount of flow required to maintain this pressure throughout the working system. The pressure setting is regulated by a knurled knob adjustment which is similar to a relief valve control.

Clockwise rotation is standard with all pumps but counter clockwise rotation may be obtained if specified at time of order.

OPERATING CHARACTERISTICS

Type	Vol. Ind. Reading	DELIVERY IN GPM					H. P. INPUT				
		1000 PSI	2000 PSI	3000 PSI	4000 PSI	5000 PSI	1000 PSI	2000 PSI	3000 PSI	4000 PSI	5000 PSI
600 Series	Full	7.15	7.1	7.05	7.0	6.9	4.9	9.1	13.3	17.5	21.7
	3/4	5.3	5.3	5.2	5.2	5.1	3.0	7.0	10.3	13.4	16.8
1200 RPM	1/2	3.5	3.5	3.5	3.5	3.4	2.7	5.0	7.3	9.6	11.9
	1/4	1.7	1.7	1.7	1.7	1.7	1.6	2.5	4.3	5.6	7.0
600 Series	Full	10.9	10.8	10.7	10.6	10.5	7.4	13.8	20.2	26.6	33.0
	3/4	8.2	8.2	8.0	8.0	7.9	5.7	10.7	15.6	20.6	25.5
1800 RPM	1/2	5.4	5.4	5.3	5.3	5.2	4.1	7.6	11.1	14.6	18.0
	1/4	2.7	2.7	2.6	2.6	2.6	2.4	4.5	6.5	8.7	10.5
700 Series	Full	20.0	19.9	19.8	19.7	19.6	14.5	26.9	39.3	51.7	64.0
	3/4	15.0	14.9	14.9	14.7	14.7	11.2	20.8	30.4	40.2	49.7
1200 RPM	1/2	10.0	9.9	9.9	9.8	9.8	8.0	14.8	21.6	27.4	35.2
	1/4	5.0	4.9	4.9	4.9	4.9	4.8	8.7	12.7	16.8	20.8
800 Series	Full	34.9	34.8	34.7	34.5	34.4	25.3	47.0	69.7	91.4	113.0
	3/4	26.2	26.0	26.0	25.8	25.8	19.6	36.5	54.0	70.8	87.8
1200 RPM	1/2	17.4	17.3	17.3	17.2	17.2	13.9	25.9	38.2	50.3	62.3
	1/4	8.7	8.6	8.6	8.6	8.6	8.2	15.3	22.7	29.4	36.8

OPERATING CHARACTERISTICS SHOWN ABOVE BASED ON USE OF 300 SSU OIL, FOR OTHER VISCOSITIES CONSULT DENISON ENGINEERING DEPT.

112

DENISON HYDROILIC PUMPS

Constant and Variable Volume
Series 600, 700 and 800

Denison Variable Volume Pumps With Handwheel Control—in 10, 20, and 35 gpm capacities

A few features of these pumps:

A quiet operating pump . . . at all pressures.

A pump that combines high pressure and high volume output.

Fewer parts . . . more compact in size.

Elimination of thrust bearings.

A unique shaft . . . absorbs deflection, and furnishes shaft rigidity to compensate for external load or misalignment of coupling.

Axial piston design for long trouble-free service. Hydraulically balanced throughout.

Operates on oils in a wide viscosity range, and under extremes in temperature conditions.

Choice of controls for regulating volume delivered by the pump.

Three means of mounting the pumps . . . face, flange and foot.

Denison pumps of this series are of axial piston design and available for either constant or variable volume requirements. Rated at 5000 psi, they provide the user with a type and size for many different industrial needs. New principles incorporated in Denison pumps reduce bulk through the elimination of parts. The exploded view of the basic pump on page 2 illustrates the compactness and simplicity of this constant volume pump.

The 600, 700, and 800 series pumps produce a maximum 10, 20 and 35 gpm respectively, and are ruggedly constructed for years of service even under the most extreme conditions. Although built for high pressure systems, their use for requirements less than maximum assures smooth uninterrupted service for even greater periods.

In operation, the electric motor which powers the pump rotates the cylinder and thus causes the axial reciprocation of the pumping pistons confined in the cylinder. Traveling in a circular pattern against a cam plate fixed at an angle, oil is drawn into the pump by suction. As the cylinder rotates toward the high side of the cam plate, the oil is delivered to the pressure outlet port. The quantity of oil delivered is in direct proportion to the angle of this cam plate.

In constant volume pumps this angle remains fixed for each pump and delivers a maximum 10, 20 and 35 gpm. The variable volume pumps incorporate a free swinging hanger to which the cam plate is attached. In this manner, the angle of the cam plate may be varied manually and automatically to change the delivery to the desired volume within a regulative maximum and minimum setting.

The DENISON Engineering Company

Columbus 16, Ohio

VARIABLE VOLUME CONTROLS. Four types of control are available with the Denison pumps for regulating delivery of the pump volume: they are handwheel, pressure compensating, stem and cylinder. Of the four, the handwheel and compensator types are in most popular

demand. As explained previously, the control regulates the position of the cam plate hanger. Each type mounts to a pad on the top of the hanger housing as shown in the installation drawings on the specification sheets covering each model.

HANDWHEEL CONTROL. This control provides a means of manually setting the volume delivered by the pump. It is available with all three sizes of this series. Setting is made by the use of a handwheel which positions the cam plate in the desired volume position. The positions are shown by an indicator on the side of the pump marked in divisions of $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$ and full volume. It is only necessary to know the maximum volume capacity of your pump to determine the volume delivered at each position. Adjustment for minimum delivery is made through a threaded regulator on the side opposite the handwheel control.

PRESSURE COMPENSATING CONTROL. Compensator controls are used for those systems where it is desirable to operate the pump at full volume at low pressures in conjunction with periods of full pressure at minimum volume. Such installations include press operations where it is desired to rapidly close the press and then reduce the pump volume during a holding cycle to just the amount necessary to maintain system pressure. Through use of this unit, the efficiency is greatly increased and the horse power required to drive the pump need only be sufficient to maintain the maximum volume at low pressure or the minimum volume at high pressure—whichever is greater.

Exploded View of Denison Hydraulic Pump.

Denison Constant Volume Pumps—in 10, 20, and 35 gpm capacities

STEM CONTROL. Stem control is similar in action to the handwheel described in a preceding paragraph wherein the adjustment is made by raising or lowering the minimum and maximum stop positions for regulating pump delivery. A short stem protrudes from the control body which may be shifted to change the volume delivery of the pump by a push-pull action. Such controls are usually actuated during the course of an operation by mechanical linkage, timed to synchronize with some other function of the machine. Adjustment for minimum delivery is made through a threaded regulator on the side opposite the handwheel control.

CYLINDER CONTROL. Cylinder control is similar in function to the stem control except that the actuation of the hanger is accomplished hydraulically instead of mechanically. Not to be confused with the compensator control which operates from system pressure, the cylinder control can either be actuated by pilot lines from any part of the hydraulic system or by outside sources. It is not confined to the working pressure of the hydraulic system for its operation. Maximum and minimum adjustment is possible with this control.

OIL SPECIFICATIONS

It is of utmost importance that the oil used in the system incorporating these pumps be of a type recommended below and be kept free of dirt, lint, scale and other foreign matter which can seriously damage the critical surfaces of the parts within the pump. **CLEAN OIL IS ESSENTIAL** if these pumps are to give maximum service. Suitable micronic filtration must be installed on every pump application. Filters should be used at the breather and oil filler openings.

We recommend an oil with the following specifications:

- Viscosity Range - 70 to 300 SSU at 100° F.
- Viscosity Index - 80 or above.
- Pourpoint - 3000 SSU at starting temperature.
- Neutralization Number - .10 or below (when using new oil).
- Demulsibility - 125 or below.

CAUTION: Temperature of oil should never exceed 150° F. for most efficient operation

DIRECTION OF ROTATION: Direction of rotation is shown by arrow on pump housing, and is established as viewed from shaft end. Clockwise rotation is standard unless otherwise specified at time of order.

DRAIN CONNECTIONS. Connect drain line from top of pump to tank. Be sure drain connection is open to atmospheric pressure and pump housing is filled with oil before starting pump.

MOUNTINGS

**FOOT
MOUNTING**

**FLANGE
MOUNTING**

**FACE
MOUNTING**

Two types of mountings, foot and flange, in addition to the face mounting of the pump, are available for the three sizes of these pumps. They provide methods of installation to meet individual preference.

The foot mounting brackets conform to the center line dimension of standard electric motors of the lowest horsepower rating that can successfully be used with these pumps. When larger motors are utilized, the pump is blocked to a comparative level for coupling. A hole in the base of this mounting bracket allows for vertical mounting of the pump's flanges so that, if the pump is mounted directly over the oil reservoir, the suction line may be piped through the bracket to the tank. By this arrangement, it is possible to mount the pump in any of four positions. See accompanying sheet for dimensional data.

Flange mounting plates provide a means for the assembly of pump, motor and necessary piping into a single unit. The installation of the motor and pump over the oil reservoir with the pump suspended within the reservoir necessitates the use of a mounting arrangement of this type. The flange mounting is machined for a tight fit between tank and plate and requires only the use of a gasket and mounting cap screws.

Special mountings using a subplate type foot mounting, provide pipeless installations of the pump. This method of installation is often desirable for high pressure installations where the pressure developed necessitates the use of extra heavy pipe and fittings and requires a special port block to replace the standard block. In such installations, the pump can be removed without the necessity of breaking pipe connections.

OTHER DENISON HYDROILIC EQUIPMENT

Accurate RELIEF SEQUENCE and UNLOADER VALVES For High Pressure Circuits

Denison high pressure, high flow capacity valves are available for use with Denison Pumps, and are offered in three types: with threaded bodies for direct connection of piping, subplate mounted type for panel mounting control systems, and with flange connections for extreme high pressure conditions. All types are available for either direct adjustment at the valve or for remote control. They are designed for accurate pressure regulation within a range of from 100 to 5000 psi. Complete catalog available upon request.

THE DENISON ENGINEERING COMPANY

FLUID MOTORS Versatile Power in Compact Form

Denison Fluid Motors in 3 hp to 160 hp models offer compact rotary drive with stamina to withstand long, hard service beyond the ability of ordinary motors. They may be stopped, started, reversed — used for braking — at full rpm and pressure. Smaller sizes are available with gear reduction attachments and instant speed-up controls for variable speed requirements. Capacities up to 3000 rpm, 5000 psi. Ask for complete catalog.

PUMPING UNITS A Wide Variety of Sizes and Capacities

Denison High Pressure Pumping Units are oil-hydraulic power plants in a compact, self-contained form, providing accurately regulated pressures up to 5000 psi. Basically they consist of electric motor, hydraulic pump and relief valve mounted on an oil reservoir. They are available in a range of sizes and in capacities up to 35 gpm, and for either constant or variable volume control. Write for catalog, giving details and multiple advantages of the complete units.

COLUMBUS 16, OHIO

DISTRIBUTION:

U. S. Department of Energy
Office of Military Application
Attn: MAG GEN William W. Hoover,
Director

DOE/AGMMA, Attn: R. E. Caudle
Research Development and Test
Washington, DC 20545

U. S. Department of Energy
Division of Contracts
Attn: H. G. Dittmar
Washington, DC 20545

The Bendix Corporation
P. O. Box 1159
Kansas City, MO 64141
Attn: M. C. Collins
A. K. Thoeni

E. I. du Pont de Nemours & Company
Savannay River Plant
Aiken, SC 29801
Attn: T. G. Clark
James N. Beatty

General Electric Company
Neutron Devices Department
P. O. Box 11508
St. Petersburg, FL 33733
Attn: B. E. Belnap
R. Rigney

Klaus L. Cappel
Wyle Labs
P. O. Box 1008
Huntsville, AL 35807

University of Michigan
G. G. Brown Lab
Ann Arbor, MI 48104
Attn: F. E. Richard
Richard D. Woods

G. W. Clough
Stanford University
Department of Civil Engineering
Stanford, CA 94305

Ronald F. Scott
Division of Engineering and
Applied Science
California Institute of Technology
Pasadena, CA 91125

R. V. Whitman
Massachusetts Institute of
Technology
Cambridge, MA 02139

Hsi-Ping Lu
U. S. Geological Survey
Menlo Park, CA 94720

F. C. Townsend
Department of Civil Engineering
University of Florida
Gainesville, FL 32611

Professor Hon-Yim Ko
Department of Civil Engineering
University of Colorado
Boulder, CO 80302

Dr. Robert M. Schmidt
Mail Stop: 42-37
Boeing Aerospace Company
P. O. Box 3999
Seattle, WA 98124

Dr. George B. Clark
Earth Mechanics Institute
Colorado School of Mines
Golden, CO 80401

Dr. K. A. Holsapple
Department of Aeronautics and
Astronautics
University of Washington
Seattle, WA 98185

Dr. Paul McWilliams
Spokane Mining Research Center
Bureau of Mines
E. 315 Montgomery Avenue
Spokane, WA 99207

Waterways Experiment Station
P. O. Box 631
Vicksburg, MS 39180
Attn: Dr. Kim Davis
Dr. Ben Carns

University of California
Department of Civil Engineering
Davis, CA 95616
Attn: James A. Cheney
Kandiah Arulanawdaw

DISTRIBUTION: (Cont'd)

Mason & Hangar/Silas Mason Co., Inc.
P. O. Box 30020
Amarillo, TX 79177
Attn: E. D. Laughter
R. E. Taylor

Monsanto Research Corporation
Mound Facility
P. O. Box 32
Miamisburg, OH 45342
Attn: D. A. Homan
D. E. Wendeln

Rockwell International
Energy Systems Group
Rocky Flats Plant
P. O. Box 464
Golden, CO 80401
Attn: S. W. Creager
S. Beitscher

Union Carbide Corporation
Y-12 Plant
P. O. Box Y
Oak Ridge, TN 37830
Attn: F. W. Jones
P. J. Long

Lawrence Livermore Laboratory
P. O. Box 808
Livermore, CA 94550
Attn: R. A. Hawley, L-115
K. W. Volkman, L-115
J. M. Floyd, L-115
J. D. Deligano, L-125

Los Alamos Scientific Laboratory
P. O. Box 1663
Los Alamos, NM 87545
Attn: E. H. Eyster, WX
J. C. Fuller, WX-1
Jesse Aragon, WX-3
N. F. Kernodle, WX-3
J. F. B. Szoo, SD-DO

J. P. Nielsen
Civil Engineering Research Facility
University of New Mexico
Campus P. O. Box 25
Albuquerque, NM 87131

U. S. Department of Energy
Albuquerque Operations Office
Albuquerque, NM 87185
Attn: Contracts Division
Weapons Production Div.
Quality Assurance Div.
Mgmt. Information Sys.
Div.
Weapons Development
Div.
Mr. A. E. Whitman

1426 A. J. Roth
1426 R. E. Baack
1480 J. R. Sublett
1500 W. A. Gardner
1520 T. J. Hoban
1521 J. L. Mortley
1530 W. E. Caldes
1531 P. H. Adams (20)
1531 R. L. Ault (5)
1531 D. L. Fulton (5)
1533 F. H. Mathews
1535 D. C. Bickel
1535 J. E. Bear (10)
1537 N. R. Keltner
1540 R. L. Brin
1541 M. L. Shannon
1542 D. R. Schafer
1543 E. H. Copeland
1543 C. G. Sain
1545 D. Williams, Jr.
1581 A. E. Bentz
1581 R. M. Caster
1582 W. V. Hereford
1713 J. T. Risse
4314 W. R. Hoagland
4321-1 C. L. Page
4335 R. D. Christopher
4344 S. L. Jeffers
4337 W. C. Nickell
4338 W. D. Ulrich
4341 P. A. Longmire
4342 W. R. Reynolds
4363 D. W. Doak
4732 D. A. Northrop
5520 T. B. Lane
5522 T. G. Priddy
5524 R. T. Othmer
5530 W. Hermann

DISTRIBUTION: (Cont'd)

5623 D. J. Rigali
8410 R. A. Baroody
8412 S. G. Cain
8412 L. R. Myers
8413 R. M. Hargreaves
8266 E. A. Aas
3141 T. L. Werner (5)
3151 W. L. Garner (3)
for DOE/TIC (Unlimited Release)
DOE/TIC (25)
(R. P. Campbell, 3154-3)

[illegible]

* Recipient must initial on classified documents.