MASTER

PATHFINDER ATOMIC POWER PLANT

PILE OSCILLATOR ROD ASSEMBLY, AND
MEASUREMENTS OF REACTOR TRANSFER
FUNCTIONS (432)

Submitted to
U. S. ATOMIC ENERGY COMMISSION
NORTHERN STATES POWER COMPANY
and
CENTRAL UTILITIES ATOMIC POWER ASSOCIATES

by

ALLIS-CHALMERS MANUFACTURING COMPANY
ATOMIC ENERGY DIVISION
Bethesda, Maryland

Ref: AEC Contract No. AT(11-1)-589

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by G. C. Rudy and J. T. Stone

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CENTRAL UTILITIES ATOMIC POWER ASSOCIATES

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ALLIS-CHALMERS MANUFACTURING COMPANY

under

**Agreement dated 2nd Day of May 1957, as Amended
between**

**Allis-Chalmers Manufacturing Company and Northern States Power Company
under**

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PATHFINDER ATOMIC POWER PLANT
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AND MEASUREMENTS OF REACTOR TRANSFER FUNCTIONS (432)

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FOREWORD

One of a series of reports on research and development carried out in connection with the Pathfinder Atomic Power Plant, this report deals with the design, development and fabrication of a special oscillator rod assembly. It also includes certain stability and dynamic performance tests (432) carried out at the plant utilizing the oscillator rod. The Pathfinder plant is located at a site near Sioux Falls, South Dakota and reached criticality early in 1964. Owner and operator of the plant is Northern States Power Company of Minneapolis, Minnesota. Allis-Chalmers is performing the research, development and design, and is also responsible for plant construction.

The U.S. Atomic Energy Commission, through Contract No. AT(11-1)-589 with Northern States Power Company and Central Utilities Atomic Power Associates (CUAPA), are sponsors of the research and development program. The plant's reactor is of the controlled-recirculation boiling-water type, with integral nuclear superheater.

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1. INTRODUCTION

A special oscillator rod assembly was fabricated for the Pathfinder plant as part of the research and development program associated with the project. The fabrication was preceded by an extensive development program leading to the final design of the assembly and its components, which include the oscillator rod and drive mechanism and the associated instrumentation and recording equipment. The objectives of the reactor test program were to conduct oscillator tests, to measure and record the resulting variations in the neutron flux in order to verify dynamic performance calculations, and to experimentally determine the stability of the reactor system.

This report includes descriptions of the mechanism and related equipment, a summary of the test procedures used, and the results of the initial calibration tests performed at low power. Due to the curtailment of the program, testing at higher power levels was not performed. The detailed testing program and procedures for higher power level testing were prepared and are included as part of this report.

2. EQUIPMENT DESCRIPTION

The oscillator rod and drive assembly, together with major subassemblies, are shown in Figs. 2.1 through 2.6. Figures 2.1, 2.2, and 2.3 show the complete oscillator rod assembly, from the top of the shield pool to the grid plate. Figure 2.4 is a photograph of the oscillator drive assembly. Figures 2.5 and 2.6 are photographs of the oscillator rod internal assembly and the external support tower, respectively. The oscillator rod internal handling tool used to install and remove the internals from the core is shown in Fig. 2.7.

The oscillator mechanism was designed to be inserted into a core position normally occupied by a boiler control rod. The position selected for testing was control rod position No. 8. In order to accommodate the oscillator assembly into the reactor, four modified fuel elements were used in the core positions surrounding the oscillator position. Each of the modified fuel element boxes contain 75, rather than 81, fuel pins. This number allows room, at the innermost corner of each box, to pull the element wall back from the center of the four-element array. Thus an approximately square, water-filled hole is formed. The oscillator assembly is inserted into this space. A schematic of this arrangement is presented in Fig. 2.8.

The oscillator assembly proper consists of three major units. They are the concentrically placed rotor and stator (located in the center) and, outside of these, four stainless "fins" which partially fill the control channels of the four-element cell. The innermost element, or rotor, is a hollow tube 2.49 in. ID which extends the full length of the reactor core. The wall of the tube is a three-layer sandwich consisting of a 0.065 in. stainless steel supporting tube, 0.015 in. of cadmium and steel, and 0.025 in. of stainless steel cladding. The middle layer is cadmium for two diametrically opposed quarters of the rotor periphery. The other two quarters have a middle layer of stainless steel complementary in area to the cadmium. All quarter segments extend uniformly along the full length of the rotor.

The rotor can is enclosed in the stator can, which is similar to the rotor in construction except that the inner structural steel wall is 0.070 in. thick, 2.86 in. ID; and the cadmium portion of the middle layer is shaped so that, with the rotor fitted into the stator, the fraction of the stator surface which covers at least one thickness of (either rotor or stator) cadmium is expressed by $A + B \sin 2\theta$, where θ is the angular location of the stator poison relative to that of the rotor. The rotor is driven by a motor with a variable speed transmission which is supported by the same support as is the stator. The motor housing is supported by a flange on the vessel cover. A tower supported by the base plate of the motor housing supports a mounting plate. The mounting plate serves as a connection interface for the required oscillator electrical cables and coolant-lubricate tubing. The desired reactivity signal is generated when the rotor is turned, causing cadmium exposure to follow the above sinusoidal expression for each 360° of mechanical rotation. The fraction of stator surface exposing cadmium will vary between upper and lower limits of 0.50 and 0.82. The interior of the rotor and the clearance between the rotor and the stators are water-filled.

The stainless steel fins (Fig. 2.8) complete the oscillator assembly. Their configuration is similar to a cruciform control rod. The fins are primarily used to assure that no excessive flux peaking will occur in the oscillator cell area; secondarily, they provide a location for control material should an increase in shutdown margin be necessary.

The operation, control, and monitoring of the oscillator system are performed remotely from a control cabinet located in the control room. Figure 2.9 is a photograph of the completed pile oscillator instrumentation system. The components, from top to bottom, are: (a) computer patchup problem board and potentiometer strip, (b) computer, (c) digital voltmeter, (d) micromicroammeter, (e) strip chart recorder, (f) recorder amplifier, (g) oscillator and instrumentation operating console, (h) electronic multiplier, and (i) fan unit. Figure 2.10 is a circuit block diagram of the instrumentation system. Figure 2.11 is a closeup photograph of the operating console from which the entire oscillator mechanism and instrumentation system is operated.

The ability of the correlation equipment to accept and digest reactor transfer function data was verified by injecting theoretical perturbations and neutron flux signals into the correlation computer from the Pathfinder analog computer model. The output of the correlation equipment duplicated reactor system closed loop transfer functions previously obtained for the analog computer simulator.

OSCILLATOR ROD ASSEMBLY

OSCILLATOR DRIVE ASSEMBLY

FIG. 2.4

OSCILLATOR INTERNAL ASSEMBLY

FIG. 2.5

EXTERNAL SUPPORT TOWER

FIG. 2.7

SKETCH OF OSCILLATOR SUPERCELL, WITH ROD IN POSITION

FIG. 2.8

PILE OSCILLATOR AND MONITOR SYSTEM

FIG. 2.9

PATHFINDER PILE OSCILLATOR INSTRUMENTATION SCHEMATIC DIAGRAM

FIG. 2.10

CLOSEUP OF OPERATING CONSOLE

FIG. 2.11

3. INITIAL ASSEMBLY AND LABORATORY CHECKOUT

Prior to shipment to the reactor site, the completed assembly and control cabinet were tested individually and as a system in the laboratory. The tests were performed in order to assure that the oscillator rod assembly functioned properly, to verify the controllability of the system, to insure that all components met design and performance specifications, to demonstrate the correlation equipment's ability to analyze data signals, and to identify and correct possible malfunctions or problem areas.

The system test was run in cold, demineralized water in a 40-ft deep tank. The test setup, as originally assembled in air, is illustrated in Figs. 3.1, 3.2, and 3.3. The setup outside of the tank was made in order to set the sine-cosine potentiometer to give a signal which would be in phase with the actual reactivity input signal. This was accomplished by placing the rotor-stator poison configuration in the least reactive position. The reference potentiometer was then adjusted to obtain maximum output. Small angular displacement errors between the poison alignment and the potentiometer signal were identified and accounted for during the low-power testing performed in the reactor. (See Sec. 5 of this report.)

The test setup was disassembled and reassembled in the tank, which was filled with demineralized water. The tower was not mounted on the drive assembly but was submerged in the tank with the tubing assembled on the tower. The test was run for a total of 25 hr, including operation of the rotor at 350 rpm for 20 hr. During the remaining time, the rotor was run at speeds varying between 0.3 and 350 rpm.

The following observations were made during the in-tank testing.

- a. The natural frequency of the bearings was outside the 0.3 to 350 rpm range.
- b. Motor current increased during the testing. This was attributed to an oil leak which permitted motor oil to enter the transmission.
- c. Electrical contacts, set with a 0.005 in. gap, did not arc in the oil.

NOTE: Subsequent field tests indicated that electrical contacts did not give accurate and repeatable indications of rotor position. The contacts were replaced with a solid-state control device controlled by monitoring a reference sine wave.

Upon completion of the test, the test setup was dismantled and the internals of the oscillator rod assembly were taken apart for checking and inspection. Results of the inspection showed:

- a. There was no measurable wear on any of the graphite bearing surfaces. No pitting of the graphite bearing or chromeplated bearing surfaces was evident.

b. Inspection of the chromeplated bushing and the 17-4 PH drive shaft showed no galling on either bearing surface.

c. A check of the connection between the lower and upper drive shafts revealed several scratches at the lead-in surface of the connection which is pinned to the lower drive shaft. These scratches were anticipated, however, since the key on the upper drive shaft had a heavy chromeplate which was much harder than the material from which the connection was made. Other than the scratches, the connection and the key showed no sign of wear or damage.

d. The rotor and the stator showed no evidence of rubbing or other distress.

e. The breaker points, gapped at 0.005 in., did not pit.

f. The Amphenol submersion-proof connectors did not leak either oil or water.

g. Close inspection of all components for indications of corrosion showed slight rust formation at some welds. This rust was attributed to improper cleaning.

The following preventive measures were taken: The drive motor unit was returned to the manufacturer for replacement of all the gaskets (to ensure proper sealing of the unit); the welds which exhibited rust were cleaned.

Based on these tests, it was concluded that oscillator rod assembly and associated instrumentation were ready for assembly and use at the Pathfinder reactor site with assurance of satisfactory operation, and that all components were compatible and met design and performance specifications. The equipment was shipped to the site for installation in the reactor.

OSCILLATOR ROD ON TEST ASSEMBLY

FIG. 3.1

OSCILLATOR ROD INTERNALS ON TEST ASSEMBLY

FIG. 3.2

OSCILLATOR ROD DRIVE UNIT ON TEST ASSEMBLY

FIG. 3.3

4. TEST METHOD AND PROCEDURES

Test procedures utilizing the oscillator rod to measure reactor transfer functions and to evaluate reactor dynamic stability and performance were prepared in two parts. Part 1, designated test procedure 432.1 "Zero Power Transfer Function and Oscillator Rod Worth Evaluation," deals with the initial installation of the oscillator rod assembly into the reactor. In Part 1, initial base-line measurements and calibration are performed at low reactor power levels. These measurements include differential rod worth and shutdown margin measurements, determination of peak-to-peak reactivity worth of the oscillator, and zero power determination of reactor transfer function. This test procedure is included herein as Appendix A.

Part 2, designated test procedure 432.2 "Reactor Transfer Function Test, Reactor Operation," deals with reactor transfer function measurements at elevated reactor power levels up to and including 75 percent of full design power (190 Mwt). This procedure is included herein as Appendix B.

5. ZERO POWER TEST RESULTS

This section presents the methods and results of the Pathfinder Zero Power Transfer Function Test, Test 432.1.

Test 432.1 was conducted as a preliminary test to verify the satisfactory performance of electronic and mechanical systems and to obtain base-line data prior to performing the transfer function test specified under Test 432.2. The areas evaluated during 432.1 testing were:

- a. the ability of the system to meet the Technical Specification requirements with the Most Reactive Rod Out (MRRO) and with the pile oscillator and its special fuel elements in the core,
- b. the ability of the oscillator to generate a reactivity change suitable for the transfer function tests,
- c. the proper operation of the pile oscillator associated instrumentation, and
- d. the ability to obtain the Zero Power Transfer Function.

5.1 MRRO AND OSCILLATOR PEAK-PEAK WORTH

Considerable effort was devoted to meeting the MRRO criteria and to obtain a core with a satisfactory oscillator peak-peak worth. Table 5-1 lists the various core conditions evaluated to obtain a configuration which would meet the Technical Specification MRRO criterion and which would yield an acceptable peak-peak oscillator rod reactivity worth.

The initial conditions for the MRRO and peak-peak tests were as follows: (Refer to Figs. 5.1 and 5.2.)

- a. a 48-shim, borated, cold core, (8 extra oscillator shim locations were 036, 037, 052, 053, 044, 045, 068, 069; refer to Fig. 5.2.)
- b. pile oscillator in CRD position No. 8, and
- c. pile oscillator fuel assemblies in BG-2, BG-3, BF-2, BF-3 core locations.

Using the above conditions, the Technical Specification requirements on the MRRO test were met (Case 1 of Table 5-1.). However, the reactivity perturbation was suppressed to such a degree that no significant flux variation existed. Then the boron solution was removed in an attempt to increase the worth of the oscillator rod, and it was determined that the MRRO criterion was met (Case 2 of Table 5-1.).

TABLE 5-1

CORE CONDITIONS FOR TEST 432.1

Case No.	Core Condition	Estimated Worth of Boron, $\% \Delta k$	Rod Configurations	Shutdown Margin $\% \Delta k$ No Fission Products	Estimated Reactivity, Peak-Peak Worth
1	48 Shim + Oscillator + Boron	0.70	Most reactive rod all out	1.45	2.5¢
2	48 Shim + Oscillator	Unborated	Most reactive rod all out	0.75	4.7¢
3	48 Shim + Oscillator	Unborated	Groups IV and V at 45 in.	0.75	0.7¢
4	44 Shim + Oscillator	Unborated	Most reactive rod being withdrawn, criticality indicated at 67 in.	--	5.6¢
5	44 Shim + Oscillator + Boron	0.45	Groups IV and V at 46 in.	0.72	8.1¢

With this core condition (48-shim, nonborated core), and when control rod Groups IV and V were banked at normal positions (as they would be during the transfer function test), an oscillator reactivity worth of 0.7¢ peak-to-peak was obtained (Case 3 of Table 5-1.).

In order to obtain a more significant reactivity perturbation, the four shims around the oscillator rod location (044, 045, 060, and 061) were removed, and an unborated core was tested. For this test a compensated ion chamber was placed inside the reactor opposite control rod position No. 3 on the steam separator shelf. Preliminary results indicated that this configuration would not meet the MRRO criterion (Case 4 of Table 5-1.). Boron solution was added to the core, and the test was rerun (Case 5 of Table 5-1.). The results of this test were considered satisfactory. The peak-peak oscillator reactivity worth was determined to be 8.1¢, and the MRRO test was successfully completed. Case 5 of Table 5-1 represented the core condition that was eventually used during the zero power transfer function test.

The technique used to obtain the peak-peak worth consisted of establishing criticality with the oscillator in its least reactive position, jogging the oscillator to its most reactive position, and recording the reactor period. During the peak-peak evaluation, a misalignment error of approximately 20 degrees was noted between the reference sine-cosine potentiometer and the oscillator poison sine waves. Subsequent testing verified this misalignment error.

A review of Table 5-1 indicates the following:

- a. The presence of 0.7 percent Δk boron solution in the core reduces the peak-peak reactivity worth by about a factor of 2 (Comparison of Cases 1 and 2.).
- b. The removal of the four shims resulted in an increase in the peak-peak reactivity worth of the oscillator rod by a factor of ~ 23 . (Comparison of Cases 3 and 5.).

5.2 MEASUREMENT OF OSCILLATOR REACTIVITY WORTH VS. ANGULAR POSITION

One of the objectives of Test 432.1 was to measure the shape of the reactivity function generated by the revolving oscillator rod. The oscillator mechanism was designed to produce a sinusoidal shape with two complete sine waves for each 360° of mechanical motion of the rod. The reactivity pattern was obtained by placing a thin cadmium foil cut in the shape of axially recurrent sine waves on the oscillator stator; straight strips of cadmium foil were placed along the oscillator rotor. As the rotor revolves, the area of cadmium foil exposed to the neutron population varies sinusoidally in time and causes k_{eff} to vary in the same fashion. Estimates of the reactivity change produced by the oscillator indicated that about 10¢ peak-peak variation in reactivity could be expected.

Rotor position was indicated by the output of a sine-cosine potentiometer fastened to the rotor through a 2:1 speed increaser. This sine potentiometer was previously aligned visually so that a maximum output voltage from the potentiometer would correspond to

a minimum Cd foil exposure. Possible errors in this alignment were investigated by rotating the oscillator in both forward and reverse directions at the same frequency. The period difference method was utilized to determine Δk vs. oscillator rotor position. The period difference measurements were made with seven rods in Groups IV and V at 37 in., Groups I, II, and III at 0 in., and Rod No. 3 at 73 in. Rod No. 3 was used to control the reactor. The results shown in Fig. 5.3 were obtained by the period difference method. Also plotted on Fig. 5.3 is a true sine wave, to be used for visual comparison. A detail of the computer circuit is presented in Fig. 5.4.

Results of this test indicate the following:

a. The maximum Δk does not coincide with the maximum voltage from the sine potentiometer, thus indicating that a misalignment between potentiometer position and reactivity shape exists. This misalignment was determined to be 20 degrees.

b. There is no noticeable backlash in position measurement since the reverse rotation and forward rotation yield the same results.

c. There is a slight difference in shape between the two sine waves that are generated by each mechanical 360° turn of the rotor. The peak-peak worth of the first sine wave is 12.1¢, whereas the peak-peak worth of the second sine wave was measured to be 10.6¢. This difference may have been caused by the existing rod bank configuration of Groups IV and V and Rod No. 3.

5.3 ZERO POWER TRANSFER FUNCTION TEST

After verifying that the MRRO criterion was met and that a sufficient peak-peak worth existed, the zero power transfer function test was performed with the 44-shim, borated core (Case 5 of Table 5-1.).

The first transfer function correlations were obtained with the oscillator rotating in the reverse direction and with frequency varied from 11.7 to 0.0142 cps. The highest frequency correlation was run first so as to minimize power drift; the reactor operator established the steady-state condition with the oscillator rotating. The higher frequencies of this run were not too successful in duplicating or generating accurate data because of improper micromicroammeter and analog computer gain settings. However, by the time that 0.162 cps and the lower frequencies were tried, a higher degree of proficiency had been obtained for instrument operation; and the resulting data yielded good comparison with the expected gain and phase profiles.

The oscillator was then rotated in the forward direction for frequencies varying from 0.049 cps to 11.7 cps. No difficulties were encountered during this run, and the measured data compared favorably with calculations.

Both cross-correlation data from the analog analyzer and data from the Brush recorder were obtained during the forward and reverse runs. Using this information, it was

possible to generate phase and gain profiles from two independent data sources, thereby giving a good cross-check of the results and system performance. The reactor power response from the CIC was recorded on one channel of the high-speed Brush recorder; the output of the sine potentiometer was recorded on the remaining channel. The data were reduced manually and also digitally to obtain the required correlations. Manual reduction consisted of measuring gain and phase relations directly from the Brush recorder charts. Digital data reduction was accomplished using the IBM-1620 Program described in Sec. 5.6.

The results are presented in Fig. 5.5 and are compared with the pretest calculations represented in Fig. 432.1.9.1 of Test Procedure 432.1 (Appendix A of this report). The deviation above 3 cps was attributed to an actual β/ℓ^* different from the value used to generate the information presented as Fig. 432.1.9.1. The actual β/ℓ^* evaluation is discussed in Sec. 5.5.

The value of ℓ^* obtained from the test (ℓ^* was found to be 6.1×10^{-5} sec) and the kinetics parameters listed in Table 5-2 were introduced into a kinetics transfer function code to obtain gain and phase profiles. The calculated results are presented in Fig. 5.5 and are compared to the two sources of experimental results.

TABLE 5-2

PARAMETERS OF DELAYED NEUTRON GROUPS

<u>i</u>	<u>β_i/β</u>	<u>$\lambda_i \text{ Sec}^{-1}$</u>
1	0.0380	0.0127
2	0.2130	0.0317
3	0.1880	0.1150
4	0.4068	0.3110
5	0.1280	1.40
6	0.0260	3.87

$\beta = 0.007228$ (cold, zero power)

Since it is not possible to maintain an in-core CIC during high power testing (432.2), it was decided to rerun Test 432.1 with the monitoring CIC in the channel 5 external instrument port. This was done to determine if there would be any difficulty in duplicating the established test results when monitoring the attenuated oscillator signal on a more sensitive micromicroammeter scale.

The oscillator signal was detectable utilizing the out-of-core CIC. However, the recorder trace showed a strong 7 cps interference in addition to the basic harmonic being studied. Due to this interference, it was impossible to obtain reliable analog data.

It was later established that due to micromicroammeter component aging, the more sensitive micromicroammeter input and feedback range resistors were no longer in calibration, thereby causing the micromicroammeter output to oscillate at 7 cps. This condition was later rectified.

5.4 CONCLUSION

The techniques utilized and the results obtained in this test have proven the pile oscillator system to be completely operational. In addition, the testing has demonstrated that Test 432.2, the Power Transfer Function Test, can be safely performed with the resulting data producing very reliable gain and phase profiles and stability margins. (Note: Group II withdrawal limits would be specified prior to conducting Test 432.2.)

The zero power experimental data and the calculated reference transfer function profiles as shown on Fig. 5.3 compared favorably. The gain as calculated with the analog computer cross-correlation equipment was, compared with the calculations, within ± 0.25 db at frequencies above 0.2 cps and within ± 0.75 db for frequencies less than 0.2 cps. The phase experimental band was always within ± 3 degrees of the calculated values, although at below 0.5 cps the experimental band was wider than expected (about 10 degrees in phase lag). This rather large experimental phase band at low frequencies is attributed to short experimental run times. Any future rerun of the zero power transfer function should utilize longer correlation times at low frequencies and should result in data with less spread.

Since a borated core will not be used in Test 432.2, a physics evaluation of the Test 432.1 MRRO data has shown that Test 432.2 could be conducted with a 47-shim non-borated core. Six of the seven additional B-s.s. shims would be located in positions 036, 037, 052, 053, 068, and 069. The seventh shim would be a special double shim between BG-1 and BF-1. A peak-peak oscillator signal of about 5¢ and a shutdown margin of 0.4 to 0.5 percent Δk would be expected with the above configuration. These values will be reviewed prior to performance of Test 432.2.

5.5 ℓ^* EVALUATION

ℓ^* is evaluated by determining the high frequency break frequency of the transfer function,

$$\frac{\delta n(s)}{\delta k(s)} = \frac{no}{\ell^* s} \cdot \frac{1}{1 + \sum_i \frac{\beta_i}{\ell^* (s + \lambda_i)}} \quad (1)$$

Since λ_i is small compared to s as s goes to infinity, one can rewrite Equation (1) as

$$\frac{\delta n(s)}{\delta k(s)} = \frac{n_0}{\ell^*} \frac{1}{s + \sum_i \frac{\beta_i}{\ell^*}} = \frac{1}{s \ell^* + \beta} \quad (2)$$

The gain of Equation (2) can be approximated as

$$db = 20 \log \left(\frac{s \ell^*}{\beta} + 1 \right) = 0 \quad \frac{s \ell^*}{\beta} < 1 \quad (3)$$

$$\text{and } db = -20 \log \left(\frac{s \ell^*}{\beta} + 1 \right) = -20 \log \left(\frac{s \ell^*}{\beta} \right) \quad \frac{s \ell^*}{\beta} > 1 \quad (4)$$

The evaluation of Equation (4) for $s > \beta/\ell^*$ shows that the gain will change -6 db/octave.

Utilizing Equation (4) in conjunction with the extrapolated Brush recorder and analog computer gain profiles, it is noted that a 6 db loss occurs at approximately 2π (38 cps), thereby establishing the value of β/ℓ^* as 2π (19 cps). Since $\beta = 0.007228$ for cold, zero power conditions, ℓ^* is evaluated as 6.1×10^{-5} sec.

5.6 ZERO POWER TRANSFER FUNCTION DATA ANALYZER

The Zero Power Transfer Function Data Analyzer code accepts as input all μ ammeter and analog computer gain settings and outputs. The input parameters are itemized at the beginning of the code.

The code evaluates for each test case the total integrating real time,

$$\text{Time} = A1/GA1 \quad (6)$$

frequency,

$$\text{cps} = A4/\text{Time} \quad (7)$$

transfer function phase,

$$\text{deg} = \arctan \left[\frac{A2 (GA3)}{A3 (GA2)} \right]; \text{ and} \quad (8)$$

transfer function gain,

$$db = 20 \log_{10} \left[\frac{2 (RA)}{(\text{Time}) (RRA) (GA8)} \left[\frac{A2^2}{GA2^2} + \frac{A3^2}{GA3^2} \right]^{1/2} \right] \quad (9)$$

The RA/RRA term in Equation (9) takes into account the gain changes when the μ ammeter range sensitivity is switched. RRA and RA represent the range sensitivities for the first test and n th test cases, respectively.

In addition to the results of Equations (6) through (9), the program prints as output the case number, the μ ammeter range, the μ ammeter suppression and the total number of cycles integrated.

```

C   DIRECT TRANSFER FUNTION SOLUTION FOR SIX DELAY GROUP KINETICS
C   DECAY CONSTANTS - A1,A2,A3,A4,A5,A6
C   FRACTION OF TOTAL NEUTRONS - B1,B2,B3,B4,B5,B6
C   BETA - BETA
C   NEUTRON LIFETIME - T
C   FREQUENCY (CPS) - WCPS
PRINT 100
100 FORMAT(27HSW1-ON-IF B(1)/BETA ENTERED/23HSW1-OFF-IF B(1) ENTERED/)
    PAUSE
    READ 1,A1,A2,A3
    READ 1,A4,A5,A6
    READ 1,B1,B2,B3
    READ 1,B4,B5,B6
    READ 1,T,BETA
    IF(SENSE SWITCH 1)50,60
50  B1=B1*BETA
    B2=B2*BETA
    B3=B3*BETA
    B4=B4*BETA
    B5=B5*BETA
    B6=B6*BETA
60  PRINT 3
    PRINT 11,A1,A2,A3
    PRINT 111,A4,A5,A6
    PRINT 9
    PRINT 21,B1,B2,B3
    PRINT 211,B4,B5,B6
    PRINT 15,T,BETA
    EXECUTE PROCEDURE 2000
    PRINT 10
40  READ 1,WCPS
    EXECUTE PROCEDURE 1000
    GAIN=GAIN-GNORM
    PRINT 4,WCPS,PHASE,GAIN
    GO TO 40
    BEGIN PROCEDURE 1000
    W=2.*3.1415926*WCPS
    C1=B1/(T*(A1*A1+W*W))
    C2=B2/(T*(A2*A2+W*W))
    C3=B3/(T*(A3*A3+W*W))
    C4=B4/(T*(A4*A4+W*W))
    C5=B5/(T*(A5*A5+W*W))
    C6=B6/(T*(A6*A6+W*W))
    EI=W*(C1*A1+C2*A2+C3*A3+C4*A4+C5*A5+C6*A6+1.)
    ER=W*W*(C1+C2+C3+C4+C5+C6)
    PHASE=ATAN(-EI/ER)*57.295779
    GAIN=20.*LOG(1./(T*(ER*ER+EI*EI)**.5)))/2.302585
    END PROCEDURE 1000

```

5.7 DIRECT TRANSFER FUNCTION SOLUTION FOR SIX DELAY GROUP KINETICS

The kinetics transfer function code solves the general kinetics equation,

$$\frac{\delta n(s)}{\delta k(s) n_0} = \frac{1}{\ell^* s} \left[\frac{-1}{1 + \frac{1}{\ell^*} \sum_i \frac{\beta_i}{s + \lambda_i}} \right] \quad (10)$$

utilizing as inputs the neutron parameters, β , ℓ^* , and any desired frequency. The code determines the real, $R(s)$, and imaginary, $I(s)$, portions of Equation (10) which it then uses to determine the normalized gain in db, Equation (11); phase in degrees, Equation (12); and the zero power gain normalization factor, Equation (13) evaluated at 1 cps.

$$\text{Gain} = 20 \log_{10} \left[\left(R(s)^2 + I(s)^2 \right)^{1/2} \right] - \text{Gain (norm)} \quad (11)$$

$$\text{Phase} = \arctan \left[\frac{I(s)}{R(s)} \right] \quad (12)$$

$$\text{Gain (norm)} = 20 \log_{10} \left[\left(R(2\pi)^2 + I(2\pi)^2 \right)^{1/2} \right] \quad (13)$$

All of the inputs and the results of Equations (11) through (13) are presented as code output. All tabulated data is identified by titles.

```

C   ZERO POWER TRANSFER FUNCTION DATA ANALYZER
C   KASE = CASE NUMBER
C   GA1 = GAIN OF AMPLIFIER 1 (VOLTS/SEC)
C   GA2 = GAIN OF AMPLIFIER 2
C   GA3 = GAIN OF AMPLIFIER 3
C   GA8 = GAIN OF AMPLIFIER 8
C   A1 = OUTPUT OF AMPLIFIER 1 (VOLTS)
C   A2 = OUTPUT OF AMPLIFIER 2 (VOLTS)
C   A3 = OUTPUT OF AMPLIFIER 3 (VOLTS)
C   A4 = NUMBER OF REVOLUTIONS
C   SU = SUPPRESSION CURRENT IN AMPERES
C   RA = MONITORING RANGE SENSITIVITY
      N=1
      PRINT 9
6    READ 2,KASE,GA1,GA2,GA3,GA8,A1,A2,A3,A4,SU,RA
      NA4=A4
      TIME=A1/GA1
      CPS=A4/TIME
      GO TO(3,5),N
3    N=2
      RRA=RA
5    GA2=GA2*GA8*RRA/RA
      GA3=GA3*GA8*RRA/RA
      A2=A2/GA2
      A3=A3/GA3
      PHUC=ATAN(A2/A3)*57.295779
      GUC=20.*LOG(SQRT(A2*A2+A3*A3)*2./TIME)/2.302585
      PRINT 4, KASE,CPS,GUC,PHUC,S1,RA,NA4,TIME
      GO TO 6
1    FORMAT(F8.1F8.1)
2    FORMAT(14F4.0F4.0F4.0F7.0F7.0F7.0F7.0E8.4E8.4)
4    FORMAT(14,F7.3F8.3F7.1E10.3E7.114F6.1)
9    FORMAT(6HCASE 3HCPS3X4HGAIN4X5HPHASE2X8HSUPPRESS2X5HRANGE2X4HREV
14HTIME)
      STOP
      END

```

```

BEGIN PROCEDURE 2000
WCPS =1.
EXECUTE PROCEDURE 1000
GNORM=GAIN
PRINT 200,GNORM
200 FORMAT(6X27HGAIN NORMALIZATION FACTOR =E10.4,8HDECIBELS)
END PROCEDURE 2000
1 FORMAT(E14.8,E14.8,E14.8)
3 FORMAT(6X,15HDECAY CONSTANTS/)
4 FORMAT(E14.3,F10.2,E12.4)
9 FORMAT(/6X,26HFRACTION OF TOTAL NEUTRONS/)
10 FORMAT(/8X3HCPS8X5HPHASE5X4HGAIN)
11 FORMAT(6X,3HA1=F10.6,7X,3HA2=F10.6,7X,3HA3=F10.6)
15 FORMAT(/6X,17HNEUTRON LIFETIME=,E8.2,5X5HBETA=F10.8//)
21 FORMAT(6X,3HB1=E11.5,3X,3HB2=E11.5,3X,3HB3=E11.5)
111 FORMAT(6X,3HA4=F10.6,7X,3HA5=F10.6,7X,3HA6=F10.6)
211 FORMAT(6X,3HB4=E11.5,3X,3HB5=E11.5,3X,3HB6=E11.5)
STOP
END

```

PATHFINDER BOILER CORE LOADING

FIG. 5.1

shim locations

rod groups

I
II
III

IV or V

SHIM AND CONTROL ROD LOCATION

FIG. 5.2

PATHFINDER PILE OSCILLATOR REACTIVITY VS. ANGULAR POSITION

TIMING CIRCUIT

REFERENCE SUPPLY

DETAILED PILE OSCILLATOR COMPUTER CIRCUIT

FIG. 5.4

PATHFINDER ZERO POWER TRANSFER FUNCTION (COLD)

FIG. 5.5

6. HIGHER POWER TESTING

The oscillator rod method for determining reactor transfer function was continued through the zero power phase of testing, at which time the program was terminated due to the curtailment of R&D projects. As a result, no measurements were performed at higher power levels. Should the program be resumed at a later date, the detailed procedures outlined in Appendix B could be utilized for the tests.

APPENDIX A

Test Procedure 432.1

ZERO POWER TRANSFER FUNCTION AND
OSCILLATOR ROD WORTH EVALUATION

Test 432.1

Zero Power Transfer Function and

Oscillator Rod Worth Evaluation

November 29, 1965

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432.1.1 Purpose

The purpose of this test is to verify the shutdown margin of the core with the oscillator and special fuel elements installed, to evaluate the worth of the oscillator rod, and to obtain a zero power transfer function.

432.1.2 General Test Method

432.1.2.1 Personnel and Administrative Requirements

The organization of the personnel required to perform these experiments and their respective duties is described in the Pathfinder Program and Organization for Preoperational and Nuclear Testing (ACNP 6112-Rev. 2). Differences of opinion among these persons which cannot be otherwise resolved, will be referred to higher management. Any opinion which requires reactor shutdown will override all others until the issue is settled.

Personnel will not be permitted in the reactor building during positive periods when the reactor is in the non-boiling condition.

The NSP Operations Supervisor has overall operations responsibility. All Pathfinder Technical Specifications requirements shall be maintained. Administrative control of operations shall be specified to limit operations in a conservative manner to minimize incidence of inadvertent automatic safety actions.

Changes in these procedures will be permitted as long as they are not contrary to the scope of intent of the General Test Method or Technical Specifications and do not introduce an unreviewed operating or safety question. Such changes must be approved by the NSP Operations Supervisor and the A-C Operations Engineer. Details of change and reasons therefore shall be recorded in both the reactor log and on master copy of this procedure, with signature of approving parties. A change will be referred to the Operations Committee for approval upon request of any member. In the event that a condition is discovered which is significantly beyond the expected limits of the test, the matter will be referred to the Safety Committee.

Radiation protection standards and radiation procedures as described in E.1 and E.2 of the Operations Manual shall be adhered to.

The NSP Cognizant Engineer shall be responsible for insuring that all the data required by the procedure are recorded on appropriate logs and for the preparation of these logs.

Operations shall be conducted in accordance with the applicable sections of the Operations Manual, unless specifically stated in the test procedure. Any changes in routine, integrated plant operation shall be given widest possible dissemination to all operating personnel.

432.1.2.2 Summary of Test Procedure

To ensure sufficient margin is available for loading the oscillator rod and 4 special fuel elements, the reactor water will be borated by approximately 0.5 percent Δk . Criticalities before and after the boration will be made on the reference core to obtain an accurate measurement of the boron worth. Though the superheater region will not be borated during this test, it will remain flooded.

After the boration, four boiler fuel elements, #8 control rod and its associated quad box will be removed from the core. Additional shims will be added to the core, then the oscillator rod and its 4 special fuel elements will be installed. A special BF3 detector will be located in-core to monitor core response and the elements will be loaded incrementally. Because of the borated moderator the loading will be done with the shield pool dry.

Upon completion of the installation of the oscillator rod and fuel, the shutdown margin will be verified for both rods #3 and 10 with the oscillator in its supposedly most reactive (maximum contribution to overall core k) position. Also the oscillator rod will be rotated to ensure that it was in the most reactive position for this verification. Then, if the measurements show that the boron in the moderator is not necessary to meet the one-rod-out criterion, the boron will be removed and the shutdown margin verified using the same procedure. If the results are marginal, some dilution will be made in an attempt to make a concrete determination. However, if the results show that the boron cannot be removed, the test will be continued with borated moderator.

Either with or without boron, another criticality and differential rod worths using the 14 rod bank will be performed with the oscillator rod in the least reactive position to determine the actual peak-to-peak Δk worth of the oscillator with the one-rod-out configuration. Then, after a rod interchange to obtain the normal startup rod configuration, a set of period measurements will be performed to obtain the peak-to-peak Δk under these conditions.

When the oscillator rod worth has been evaluated, reactor power will be raised to the 10^{-9} or 10^{-10} amp range on the special CIC connected to the oscillator cabinet. The power level shall be restricted to less than 200 kw. Depending upon the results of criticals performed before this test, the special CIC detector may be placed in-vessel to obtain desired signal strength while the reactor is still at low powers.

With the reactor stable at the midpoint of the desired CIC range, the oscillator rod will be rotated at various frequencies to obtain the zero power transfer function. These frequencies range from .01 to 12 cps. With a maximum expected peak-to-peak Δk of 10¢ expected (8.5¢ nominal), the maximum power swing would be 28 percent of range.

After the test is complete, the oscillator and special fuel will be removed and the core returned to the reference condition. If it is still borated, the boron will be removed.

432.1.3 Prerequisites

432.1.3.1 Special Equipment

1. Oscillator rod, oscillator rod drive and associated control and monitoring circuitry.
2. Four special fuel elements.
3. Crane control circuit has been modified to limit lowering speed to not more than one inch/6 seconds.

432.1.3.2 Reactor Conditions

1. Reactor is shut down with rods latched at ambient temperature and pressure.
2. Criticality measurement previously performed for one-rod-out condition for rods #3 and #10 on reference core using 15 rod bank with the superheater flooded.
3. Superheater flooded with "clean" water to top of chimney during loading.
4. Boiler region flooded to normal operating level.

432.1.3.3 Instrumentation

1. Main Steam Interlock Switch (RMC-159) in OPERATE for critical operations.
2. All nuclear instrumentation is on and operable in accordance with Technical Specifications.
3. Spare BF3 detector on separator shelf next to rod #8 during loading with audio indication in reactor building.

432.1.3.4 System Conditions

1. At least one recirculation pump running while critical.
2. Regulating dump valve 2 percent open.
3. Purification Header Stop Valve (CV-1038) and drain valves PR1-1, 1-2 and 1-3 are shut.
4. Shield pool will be drained.

432.1.3.5 Prerequisite Checks

All prerequisites must be checked by the NSP Cognizant Engineer prior to start of test.

432.1.4 Hazards and Precautions

1. All pertinent steps in the loading process have been previously analyzed in Tests 314 and 318.
2. The oscillator rod, rod drive and special fuel elements have already been dry-loaded and no difficulty in handling had been experienced.
3. The oscillator will be initially loaded in its most reactive condition. This will be verified visually prior to loading. When the oscillator drive is latched to the rod, it may move as much as 20° but all positions will be checked during the shut-down margin verification.
4. The expected peak-to-peak oscillator rod worth is 8.5% with a ± 20 percent uncertainty factor or from 7.0 to 10.0% with the normal startup rod configuration. The one-rod-out peak to peak worth will be higher. If the measured worth for the normal startup configuration is 10% or greater, the test will be halted due to Tech Spec limitations. It is expected that a change to the Tech Specs would be requested to allow testing to continue as peak-to-peak worths of even 30% are still not excessive.
5. With rod #8 and its adjacent four fuel elements removed and with the oscillator rod and its four special fuel elements installed, eight additional shims will be added around rods #3 and #10 in addition to the expected 40 already installed. With this loading, it is calculated that with either rod #3 or #10 completely withdrawn, the shut-down margin will be 0.4 percent Δk (± 0.4 percent Δk). With the uncertainty factor as large as it is, the core will be initially borated to ensure adequate safety margin. If the boron is not needed, it will be removed. If it is needed, it will remain for this test and a solution will be found for future oscillator tests.
6. The superheater region will be drained during the conduct of the test when the head is installed. If excessive radiation levels are experienced in the area of the bridge crane or operating floor, the shield pool will be flooded to a height sufficient to reduce the radiation levels to tolerable levels as determined by the Radiological Control Engineer. If the pool is flooded, the stud seal ring will be installed and a drainage path established in case of seal leakage to avoid in-leakage of pool water to the borated core.
7. For the boration, borax and boric acid will be used as previously done in Test 313, Flux Mapping. The site has experience in measurement of this boron solution and accurate estimates can be made. The actual boron worth as sampled is not as

important as the reactivity difference (at least 0.5 percent Δk) that must be measured due to the boron concentration.

8. Detailed procedures for the maintenance and operation of oscillator drive equipment are contained in a separately issued set of instructions called Auxiliary Procedures To Test 432.

432.1.5 Test Procedure

432.1.5.1 Boron Worth Measurement

Step 1 Using the same mixing and filling procedure as in Test 313, mix 12 lb of borax and 8 lb of boric acid to preheated 100 F water in a 55 gallon drum. Add this boron solution to the reactor core through the liquid level column using the previously installed poly hose. Run each recirculation pump for 5 minutes to ensure good mixing. The superheater is flooded to the top of the chimney with non-borated water and is isolated from the boiler.

NOTE: Throughout the test while the moderator is borated, run at least one pump for 5 minutes twice a normal shift if possible.

Step 2 Obtain criticality by completely withdrawing rod #3 and raising the 15 rod bank as necessary. Measure the differential worth of the bank. Compare this data to the previously measured data obtained with the non-borated reference core and determine the reactivity worth of the boron.

Step 3 Shut down the reactor.

432.1.5.2 Loading of the Oscillator Rod

Step 1 Remove the reactor head, dryer and holddown. Remove CRD #8 from the head.

Step 2 Ensure the crane control speed has been revised to limit lowering speed to 1 inch/6 seconds.

Step 3 Install a BF3 detector on the separator shelf on the north side of the core with audio indication available in the reactor building.

Step 4 Add shims to the following locations:

036	052	068
037	053	069

Step 5 Remove boiler fuel elements from positions BG-2, BG-3, BF-2 and BF-3. Store them in a fuel transfer box in the shield pool.

Step 6 Remove control rod #8. Store the rod vertically in the shield pool.

Step 7 Remove shims from the following locations:

060 061

Step 8 Remove the associated quad box and store it in the equipment transfer box. Transfer rod #8 to the component transfer box and store it in its quad box. Transfer the four fuel elements from the fuel element transfer box to the equipment transfer box.

Step 9 Install oscillator rod in rod #8 position. Ensure the oscillator rod is in its most reactive position.

Step 10 Install the four special fuel elements in the following locations:

MO-4	BG-2
MO-2	BG-3
MO-1	BF-2
MO-3	BF-3

After each element is fully inserted, install a shim in positions 044, 045, 061 or 060 as appropriate.

Insert each element incrementally into the core in 25% steps. Limit the insertion rate to 1 inch per 6 seconds. Monitor count rate after each increment of insertion. The audio count rate indicator is to be monitored by the Chief Loader throughout the whole insertion. He will order the fuel handling crane to be stopped or operated as the change in count rate indicates. He will also be in direct communication with the Control Room and can request scaler counts at his discretion.

Step 11 Remove the in-vessel BF3 and return nuclear instrumentation to normal.

Step 12 Reinstall the holddown assembly, dryer and head.

Step 13 Install and latch the oscillator rod drive in place of CRD #8.

Step 14 Latch and test the remaining control rod drives. Limit any rod raising to 6 inches.

Step 15 Drain the superheater for the shutdown margin verification. If the radiation level is excessive in the reactor building, flood the shield pool to a height that will reduce the level to that specified by the Radiological Control Engineer.

432.1.5.3 Shutdown Margin Verification

Step 1 Bank 14 boiler control rods, excluding rod #3, at 6.4 inches. It is estimated that this bank will be worth 0.2% Δk .

Step 2 Withdraw rod #3 to 73 inches. If criticality is imminent during the withdrawal, insert all rods immediately.

Step 3 The estimated height for 0.33% Δk is 7.55 inches. Withdraw the bank to criticality. Measure the differential rod worth and verify that the 0.33% Δk criterion had been met.

Step 4 Bring the reactor 0.5% Δk subcritical. Connect up the oscillator and jog it very slowly at least 180° with a set frequency of 1 cycle per second. Ensure $k < 1$ for every position and determine where the most reactive position is. If no change in reactivity can be seen, increase the k of the core (while still remaining subcritical) and jog the oscillator rod again. If the shutdown margin had been verified with the oscillator in other than the most reactive, reverify it with a critical and differential rod worth measurement.

Step 5 Interchange rods #3 and 10 and again verify the shutdown margin with a criticality and differential rod worth with the oscillator in its most reactive position.

Step 6 At this point, determine whether or not the boron is necessary to meet the one rod out criterion.

a) If the boron is necessary, proceed with the test leaving the moderator borated.

b) If the boron is not necessary, shut down and drain and flush the reactor to remove the boron. Then verify the shutdown margin with either rods #3 or 10 (whichever was the most worthy) with the oscillator rod in its most reactive position. Then proceed with the test.

c) If the boron need is marginal, shut down and dilute the reactor moderator to approximately half the boron concentration. Reverify the shutdown margin with either rods #3 or 10 (whichever was the most worthy) with the oscillator in its most reactive position. If it can be determined that the boron can be removed, proceed in

accordance with subparagraph (b) above. If it is determined that the boron is necessary, or if its need is still marginal, proceed in accordance with subparagraph (a) above.

432.1.5.4 Oscillator Rod Worth Evaluation

Step 1 Regardless of whether or not the moderator is borated, a critical and 14 rod bank differential worth has been measured with the oscillator rod in its most reactive position with either rod #3 or 10 completely withdrawn. Bring the reactor subcritical and jog the oscillator rod to its least reactive position.

Step 2 With either rod #3 or 10 completely withdrawn, measure a 14 rod bank critical and differential rod worth. Determine the peak-to-peak oscillator rod Δk for the one-rod-out configuration.

Step 3 Leaving the oscillator rod in its least reactive position, interchange the control rods to the normal startup configuration, i.e., Group V rods completely withdrawn, Group IV controlling. Obtain a criticality and differential rod worth for this configuration.

Step 4 With the reactor critical, jog the oscillator rod slowly to its most reactive position. If the period is not excessive (i.e., shorter than 30 seconds), measure the period. If the period is excessive, insert rods as necessary.

Step 5 Obtain a criticality and differential rod worth with this configuration.

Step 6 Determine the peak-to-peak oscillator rod Δk . If it is less than 10¢, proceed with the next step. If it is 10¢ or greater, shut down the reactor and halt the test.

Step 7 Measure several other positions of the oscillator rod by observing periods received when moved from the least reactive position.

432.1.5.5 Zero Power Transfer Function

Step 1 Maintaining the reactor critical, place the oscillator rod in its neutral position.

Step 2 Raise the power level to the midrange of the 10^{-9} amp range if possible. If this power is unattainable, staying below 200 kw, go to the midrange of the 10^{-10} amp range.

NOTE: If an in-vessel CIC is used, raise the power level only to that necessary to obtain midrange of the decade above critical power level or to avoid operational difficulties if in the last decade of the BF3 region.

- Step 3 Bias out d-c effects per the auxiliary procedures.
- Step 4 Establish the desired test frequency. For this test, the desired range is 0.01 to 12 cps. Have the oscillator rotating in the "FOR" direction and set the counter and frequency per the auxiliary procedures.
- Step 5 Establish the proper analog computer gains per the auxiliary procedures.
- Step 6 Adjust the chart of the Brush recorder to obtain a ratio of chart speed to oscillator frequency of about 20.
- Step 7 Place computer control in "REMOTE" position.
- Step 8 Record the system parameter per Data Sheet 432.1.6.
- Step 9 Push the computer "COMPUTE" button.
- Step 10 During the computing, record a short span of cycles on the Brush recorder.
- Step 11 When the computer "HOLD" light comes "ON", turn the power switch of the Digital Voltmeter from "STAND BY" to "ON".
- Step 12 Take a set of readings per Data Sheet 432.1.6 with " V_t ", " V_A ", and " V_B " being read on the Digital Voltmeter, having the amplifier selector knob of Donner Analog Computer in No. 1, No. 2 and No. 3 positions, respectively.
- NOTE: If zero reading is indicated on the Digital Voltmeter, turn the polarity switch on the Digital Voltmeter from + to - or, vice versa.
- Step 13 Turn the oscillator rod off by pushing the "STOP" button on the oscillator control panel.
- Step 14 Reset the computer system by pushing the "RESET" button on the revolution counter and the computer "RESET" button of the oscillator control panel.
- Step 15 Push the "REV" button on the oscillator control panel and repeat items 8 through item 12.
- Step 16 Repeat items 3 through 12 for frequencies ranging from approximately 12 cps to the lowest practicable frequency (expected 0.01 cps).
- Step 17 Calculate the transfer function as follows:

a) For detailed analysis, evaluate the data from 432.1.6, utilizing the Digital Transfer Function Analyzer. This code evaluates:

- 1) open loop, closed loop and feedback gain and phase;
- 2) reference potentiometer and oscillator rotor phase error; and
- 3) gain and phase margins.

b) For on-the-spot transfer function checks, hand-calculate the gain and phase per the auxiliary procedures.

Step 18 Establish normalization factor according to M A Schultz, "Control of Nuclear Reactor and Power Plants," Sections 4-6.

Step 19 When all data has been recorded, shut down the reactor by inserting all rods.

432.1.5.6 Unloading of Oscillator Rod

Step 1 Fill the superheater to the top of the chimney with unborated water. Drain the shield pool if necessary.

Step 2 Unlatch all control rod and oscillator rod drives.

Step 3 Remove the oscillator rod drive and tower from the reactor head and reinstall CRD #8. Store the oscillator drive in the reactor building.

Step 4 Remove the reactor head, dryer and holddown.

Step 5 Remove shims from locations:

060	044
061	045

Step 6 Remove the four special fuel elements from positions:

BG-2	BF-2
BG-3	BF-3

Store them in a grid installed in the second equipment transfer box in the shield pool. Store the transfer box in the fuel transfer mechanism tray.

Step 7 Transfer the four regular fuel elements from the first equipment transfer box to a fuel transfer box.

Step 8 Remove #8 control rod from the equipment storage box and store it in a vertical position in the shield pool.

Step 9 Install the quad box, then #8 control rod. Install shims in locations 060 and 061.

Step 10 Install the four normal fuel elements in their previous locations in:

BG-2	BF-2
BG-3	BF-3

Step 11 Remove shims from positions:

036	052	068
037	053	069

Step 12 If boron is in the moderator, drain and flush the boiler region twice. Then after reinstalling all components and latching rods, perform one-rod-out criticality and compare it to a previous "Clean" reference critical. If the difference in 15 rod bank heights is less than 1 inch, consider the boron removed. Place the purification system on cleanup to remove all residual boron.

432.1.6 Transfer Function Data Sheet

NOTE: The Form "Transfer Function Data Sheet" may be found in Appendix B: "Test Procedure 432.2: Reactor Transfer Function Test."

APPENDIX B

Test Procedure 432.2

REACTOR TRANSFER FUNCTION TEST
REACTOR OPERATION

Test Procedure 432.2

PATHFINDER ATOMIC POWER PLANT

PROCEDURE FOR TEST 432.2

REACTOR TRANSFER FUNCTION TEST

REACTOR OPERATION

Prepared by

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Test Procedure Approval Sheet

Test 432.2

Allis-Chalmers

Prepared by: *L. E. Cuddy* Date: 7/20/66

Approved by: *J. T. Stone* Date: 7/20/66
Section Head

Reviewed by: _____ Date: _____
Site Operations Engineer

Approved by: _____ Date: _____
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Assistant Project Manager

Northern States Power Company

Approved by: Operations Committee Date: _____

Reviewed by: Safety Committee Date: _____

For Approval July 20, 1966

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PATHFINDER TRANSFER FUNCTION TESTS

432.2.1 Purpose

The purpose of Test 432.2 is to obtain experimental reactor transfer function data. This data will be used as follows:

- (1) In determining actual reactor stability margin at each test power level by predicting reactor stability at the new level based on items #1 and #2 and correlating this information with the results of Test 433;
- (2) in predicting the power level where instability occurs;
- (3) in verifying core parameters;
- (4) in determining actual reactor open loop, closed loop and feedback phase and gain for various frequencies of a sinusoidally varying reactivity at numerous power levels; and
- (5) in verifying the Pathfinder analog simulation model.

432.2.2 General Test Method

Prior to reactor startup, the pile oscillator assembly and four special fuel bundles will be placed in the reactor core in positions normally occupied by control rod #8, and fuel bundles BF-2, BF-3, BG-2 and BG-3, respectively.

Following the special equipment installation, normal reactor startup procedures (Tests 277 & 278) will be performed,

432.2.2 General Test Method (Continued)

thereby establishing steady-state reactor operation at various power levels as required by this test.

432.2.2.1 Personnel and Administrative Requirements

The organization of the personnel required to perform these experiments and their respective duties is described in the Pathfinder Program and Organization for Preoperational and Nuclear Testing (ACNP 6112-Rev. 2). Differences of opinion among these persons which cannot be otherwise resolved, will be referred to higher management. Any opinion which requires reactor shutdown will override all others until the issue is settled.

Personnel will not be permitted in the reactor building during positive periods when the reactor is in the non-boiling condition.

The NSP Operations Supervisor has overall operations responsibility. All Pathfinder Technical Specifications requirements shall be maintained. Administrative control of operations shall be specified to limit operations in a conservative manner to minimize incidence of inadvertent automatic safety actions.

Changes in these procedures will be permitted as long as they are not contrary to the scope or intent of the General Test Method or Technical Specifications and do not

432.2.2.1 Personnel and Administrative Requirements (Cont'd)

introduce an unreviewed operating or safety question.

Such changes must be approved by the NSP Operations Supervisor and the A-C Operations Engineer. Details of change and reasons therefore shall be recorded in both the reactor log and on master copy of this procedure, with signature of approving parties. A change will be referred to Operations Committee for approval, upon request of any member. In the event that a condition is discovered which is significantly beyond the expected limits of the test, the matter will be referred to the Safety Committee.

Radiation protection standards and radiation procedures as described in E.1 and E.2 of the Operations Manual shall be adhered to.

The NSP Cognizant Engineer shall be responsible for insuring that all the data required by the procedure is recorded on appropriate logs and for the preparation of these logs.

Operations shall be conducted in accordance with the applicable sections of the Operations Manual, unless specifically stated in the test procedure. Any changes in routine, integrated plant operation shall be given widest possible dissemination to all operating personnel.

432.2.2.1 Personnel and Administrative Requirements (Cont'd)

Routine water chemistry samples shall be taken in accordance with the NSP operating requirements as established by the Radiation & Chemical Engineer. Corrective actions shall be taken to ensure that the limits as specified in the Technical Specifications are not reached.

432.2.2.2 Summary of Test Procedure

The four boiler fuel elements, #8 control rod and its associated quad box will be removed from the core.

Additional shims will be added to make a 47 shim core, then the oscillator rod and its 4 special fuel elements will be installed. A special BF_3 detector will be located in-core to monitor core response and the elements will be loaded incrementally.

Upon completion of the installation of the oscillator rod and fuel, the shutdown margin will be verified for both rods #3 and #10 with the oscillator in its supposedly most reactive (maximum contribution to overall core k) position. Also, the oscillator rod will be rotated to ensure that it was in the most reactive position for this verification. If the MRRO results are marginal, the shim valves and locations will be reevaluated.

Another criticality and differential rod worths, using the 14 rod bank, will be performed with the oscillator rod in the least reactive position to determine the actual peak-to-peak Δk worth of the oscillator with the one-rod-out configuration. Then, after a rod interchange to obtain the normal startup rod configuration, a set of period measurements will be performed to obtain the peak-to-peak Δk under these conditions.

432.2.2.2 Summary of Test Procedure

When the oscillator rod worth has been evaluated, reactor power will be raised to the 10^{-9} or 10^{-10} amp range on the special out of core CIC connected to the oscillator cabinet. The power level shall be approximately 200 Kw for the zero power studies. However, the actual zero power level will be dependent on the ability of the special CIC to see a good signal to noise ratio.

With the reactor stable at the midpoint of the desired CIC range, the oscillator rod will be rotated at various frequencies to obtain the zero power transfer function. These frequencies range from .01 to 12 cps. With a maximum expected peak-to-peak Δk of 10¢ expected (8.5¢ nominal), the maximum power swing would be 28% of range. After the zero power run, the transfer function will be established for each of the following conditions:

<u>Power</u>	<u>Temp</u>	<u>Flow</u>	<u>$\frac{P}{F}$</u>	<u>Remarks</u>
Zero (200KW)	90F	3 pump (full)	<1	
5 Mwt	420 F	3 pump (full)	<1	Nuclear warmup
38 Mwt	475 F	3 pump (full)	<1	20% power
76 Mwt	475 F	3 pump (full)	<1	40% power
114 Mwt	475 F	3 pump (full)	<1	60% power

432.2.2.2 Summary of Test Procedure Continued)

<u>Power</u>	<u>Temp</u>	<u>Flow</u>	<u>P</u> <u>F</u>	<u>Remarks</u>
142.5 Mwt	475 F	3 pump (full)	<1	75% power
142.5 Mwt	475 F	2 pump (full)	<1	75% power 79% flow
142.5 Mwt	475 F	2 pump (th)	=1	75% power 75% flow
142.5 Mwt	475 F	2 pump (th)	>1	75% power 60% flow
114 Mwt	475 F	2 pump (th)	=1	60% power 60% flow
114 Mwt	475 F	2 pump (th)	>1	60% power 45% flow
76 Mwt	475	1 pump (full)	<1	40% power 45% flow
76 Mwt	475	1 pump (th)	=1	40% power 40% flow
76 Mwt	475	1 pump (th)	>1	40% power 35% flow

Note: Should the decision be made to go to 100% power prior to doing Test 432.2, the above test profile will be altered so that the 75% cases will be done first. If Test 432.2 is conducted following 40% power, the above test ^{schedule} will be in effect.

432.2.2.2 Summary of Test Procedure (Continued)

These reactor conditions will be established in accordance with Test 277 and/or 278, Initial Plant Startup Procedure.

On reaching each power level, a series of pile oscillator tests will be conducted by varying the frequency of the sinusodial reactivity input from .01 to 12 cps.

The data from the test will then be used to calculate the acutal transfer funcation and reactor stability at that power level. From these results and the results of other tests (such as Test 433) run at the same power levels, the reactor stability margin will be predicted for the next higher power level.

The increasing of power to the next higher power level will not be allowed unless stable operation is predicted by Test 432 or inferrred by Test 433.

Prior to the execution of 432.2, detailed rod configurations and the expected operable power band based on as much reactor power history as possible will be ^{calculated.} ~~issued by physics.~~

432.2.3 APPLICABLE THEORY

In control theory, the transfer function of a ~~system~~ element can be obtained by evaluating the output relative to the input when the input is a sinusoidal perturbation. Since a reactor is a system element, it is adaptable to this method of transfer function evaluation.

The device utilized as the Pathfinder perturbation generator is a ~~poisonous~~ pile oscillator which has a frequency range of zero to 12 cps. This perturbation introduces a ripple on the steady-state neutron flux which is monitored and re-transmitted by CIC-micro microammeter circuitry as a d-c current with a superimposed a-c ripple. The d-c level is biased out and the a-c portion is amplified. The final signal has the following form:

$$f(t) = A \cos \left(\frac{2\pi t}{T} - \theta \right) + \Psi(t) \quad (1)$$

where

A = signal amplitude

T = the period of the oscillating δk

θ = phase shift

$\Psi(t)$ = noise signal

Utilizing Fourier Analysis, the function is multiplied by both $\sin \frac{2\pi t}{T}$ and $\cos \frac{2\pi t}{T}$ and integrated over n complete cycles, thereby giving the following results:

432.2.3 APPLICABLE THEORY (Continued)

$$R = \frac{2}{nT} \int_0^{nT} f(t) \cos \frac{2\pi t}{T} dt \quad (2)$$

$$I = \frac{2}{nT} \int_0^{nT} f(t) \sin \frac{2\pi t}{T} dt \quad (3)$$

letting

$$f(t) = A \cos \frac{2\pi t}{T} \cos \theta + \sin \frac{2\pi t}{T} \sin \theta + \Psi(t) \quad (4)$$

one can readily evaluate

$$R = A \cos \theta + \frac{2}{nT} \int_0^{nT} \Psi(t) \cos \frac{2\pi t}{T} dt \quad (5)$$

$$I = A \sin \theta + \frac{2}{nT} \int_0^{nT} \Psi(t) \sin \frac{2\pi t}{T} dt \quad (6)$$

Noting that $f(t)$ is the random noise term, it is assumed that the value of its total integral is zero and that the term can be deleted from any future consideration.

Hence, Equations 5 and 6 reduce to

$$R = A \cos \theta \quad (7)$$

$$I = A \sin \theta \quad (8)$$

from which one can evaluate the power disturbance (output) amplitude as

$$A = \sqrt{R^2 + I^2} \quad (9)$$

432.2.3 APPLICABLE THEORY (Continued)

and the phase, θ , as

$$\theta = \tan^{-1} \frac{I}{R} \quad (10)$$

The transfer function gain can be obtained by relating the above results to the reactor kinetics equation, considering six groups of delayed neutrons.

The basic kinetics equations are

$$\frac{dn}{dt} = \frac{\delta_k}{l^*} n - \sum_{i=1}^6 \frac{dC_i}{dt} \quad (11)$$

$$\frac{dC_1}{dt} = \frac{\beta_1}{l^*} n - \lambda_1 C_1 \quad (12)$$

Expanding the Equations 11 and 12 into steady-state and perturbed state terms, one obtains

$$\frac{dn}{dt} = \frac{d\delta n}{dt} = \frac{\delta_k}{l^*} n_0 + \frac{\delta_k \delta n}{l^*} - \sum_{i=1}^6 \frac{d\delta C_i}{dt} \quad (13)$$

and

$$\frac{dC_1}{dt} = \frac{d\delta C_1}{dt} = \frac{\beta_1}{l^*} (n_0 + \delta n) - \lambda_1 (C_{10} + \delta C_1) \quad (14)$$

Noting that δk is the perturbation and δn is the result of the perturbation, one need consider only the time varying portions of Equations 13 and 14.

432.2.3 APPLICABLE THEORY (Continued)

These portions are then transformed to the frequency domain utilizing the Laplace transform. Hence, Equations 13 and 14 can be modified and rewritten as:

$$s \delta n(s) = \frac{n_0}{l^*} \delta k(s) - s \sum_{l=1}^6 \delta c_l(s) \quad (15)$$

and

$$s \delta c_1(s) = \frac{\beta_1 \delta n(s)}{l^*} - \lambda_1 \delta c_1(s) \quad (16)$$

Combining Equations 15 and 16 gives

$$\frac{\delta n(s)}{n_0 \delta k(s)} = \frac{1}{l^* \left[s + s \sum \frac{\beta_1}{l^*(s + \lambda_1)} \right]} \quad (17)$$

Relating this to Equation 9, one notes that

1. $\delta n(s) = A$
2. $\delta k(s) = \text{oscillator reactivity worth}$
3. $n_0 = \text{d-c flux level (steady-state power)}$

Hence, Equation 9 can be rewritten as

$$\frac{\delta n}{n_0 \delta k} = \frac{A}{n_0 \delta k} = \frac{1}{n_0 \delta k} \sqrt{R^2 + I^2}, \quad (18)$$

thereby defining the reactor gain.

The phase is defined by Equation 10.

432.2.3 APPLICABLE THEORY (Continued)

Equation 10 and 18 represent the gain and phase of the closed loop transfer function

$$G = \frac{G_o}{1 + G_o H}$$

where G_o is the reactor Zero Power transfer function without feedback, and

H is the feedback transfer function

The closed loop transfer function data once obtained is placed in an IBM 1620 transfer function analyzer program which evaluates the open loop and feedback transfer functions, $G_o H$ and H , respectively. By plotting the gain and phase of $G_o H$ vs. frequency, one can readily evaluate the minimum gain and phase margins at each power level relative to where the gain and its argument depict instability. The system becomes unstable in the frequency domain when

$$\begin{aligned} |G_o(j\omega)H(j\omega)| &= 1 & \text{and} \\ \angle G_o(j\omega)H(j\omega) &= -180^\circ \end{aligned}$$

Linearly plotting the phase and gain margins versus power and extrapolating the curve to the next higher power level allows one to predict the stability margins at that new power level. Refer to the auxiliary procedures for a hypothetical case.

432.2.4 PREREQUISITES

432.2.4.1 Special Equipment

- (1) For Pile Oscillator Installation into the Core.
 - A) Four special 2.2 w/o fuel assemblies for boiler core positions BF-2, BF-3, Bg-2 and BG-3.
 - B) Pile oscillator internals (Refer to Dwg. 43-501-092).
 - C) Pile oscillator drive mechanism (Refer to Dwg. 43-500-999).
 - D) Pile oscillator tower (Refer to Dwg. 43-401-258).
 - E) Three bundles of in-core ion chambers (three chambers per bundle).
 - F) Pile oscillator rod assembly Drawing 43-501-096.
 - G) Pile oscillator position Drawing 43-501-106.
 - H) Crane control circuit modified to limit lowering speed to not more than one inch/6 seconds.
- (2) For Pile Oscillator Operation (transfer function data generation).
 - A) Section 432.4.1 (1) is established.
 - B) Pile oscillator control cabinet and associated system wired per dwgs. 43-501-124, 43-401-309-MK502, and 43-501-108.
 - C) The Donner 3400 problem board wired per the auxiliary procedures.
 - D) The in-core ion chambers and associated monitor circuits wired per Dwg 43-302-090.

432.2.4.2 Reactor Conditions

(1) For Pile Oscillator Installation into the Core.

- A) The reactor is flooded to bolt ring. Pool flooding will be a function of the radiation level and health physics.
- B) The reactor vessel head, the steam dryers and the hold-down mechanism are removed from the vessel.
- C) Criticality measurement previously performed for one-rod-out condition for rods #3 and 10 on reference core using 15 rod bank with the superheater flooded.
- D) Fuel bundles BF-2, BF-3, BG-2, and BG-3 are removed from the boiler core.
- E) Control rod #8 is removed from the boiler core.
- F) The BF-2, BF-3, BG-2 and BG-3 quad boxes are removed.

(2) For Pile Oscillator Operation (transfer function data generation).

- A) Pile oscillator internals (rotor and stator) are mounted in the #8 control rod position.
- B) The four special fuel bundles are located in the BF-2, BF-3, BG-2 and BG-3 core positions.
- C) The pile oscillator drive mechanism is mounted on the vessel head in place of control rod drive #8.
- D) The in-core ion chambers are inserted into the superheater ion chamber tubes.
- E) The reactor vessel head, steam dryers and hold-down mechanism are in place.

432.2.4.2 Reactor Conditions (Continued)

- F) The reactor is at a steady-state power level as a result of the Reactor Startup Procedures 277 and 278.

432.2.4.3 System Conditions

- (1) For Pile Oscillator Installation into the Core.
 - A) All nuclear and process instrumentation systems are checked and are operational.
 - B) Nuclear instrument channels 1, 2 and 3 are explicitly monitoring the core during the manipulation of the fuel bundles, control rod #8 and pile oscillator internals.
- (2) For Pile Oscillator Operation (transfer function data generation).
 - A) All nuclear and process systems are operating in accordance with the power level of operation.

432.2.4.4 Instrumentation Check

- (1) For Pile Oscillator Installation into the Core.
 - A) Pile oscillator internals operable.
 - B) Spare BF_3 detector on separator shelf next to rod #8 during loading with audio indication in reactor building.
- (2) For Pile Oscillator Operation (transfer function data generation).
 - A) Normal nuclear and process instrumentation pre-startup checks are completed according to Reactor Startup Procedures 277 and 278.

432.2.4.4. Instrumentation Check (Continued)

- B) Instrument initial conditions for each power level are as described in Procedure 278 and Tech Specs.
- C) Pile oscillator instrument checkout per the auxiliary procedures.

432.2.4.5 Prerequisite Check

All of the above prerequisites must be checked prior to starting each set of power level tests.

432.2.5 HAZARDS AND PRECAUTIONS

432.2.5.1 Criticality Considerations

(1) For Pile Oscillator Installation into the Core.

A) During Test 432.2, the pile oscillator and the four special fuel bundles will replace control rod #8 and fuel bundles BF-2, BF-3, BG-2, and BG-3, respectively. This core change constitutes a difference in the core shutdown capabilities for the pile oscillator cell versus the control rod cell as reported in Physics Memo #162, dated June 13, 1961.

The memo describes a detailed study comparing the two cells and utilizing statistical weight factors and how these factors figure into the conclusion that the differential shutdown capability is $.4\% \Delta k/k$; where $\beta = .007$. This shutdown capability was based on the cold case where the typical cell weighting factor is close to the boiler average. This average is conservatively evaluated as .04 vs. .011 for the hot and hot-voided cases, respectively.

The study also gives all peaking values for the oscillator cell as less than those for the reference cell. In addition, the gross reactor power

432.2.5.1 Criticality Considerations (Continued)

as shown by the core weighting factors will be depressed around the oscillator. Thus, oscillator power peaking should not present any adverse reactor flux condition.

- B) The neutron population of the core will be continuously monitored while altering the core internals and the count rate will be recorded at each significant step.
- C) Control rod #8 will be removed only after the four surrounding fuel elements BF-2, BF-3, BG-2 and BG-3 have been removed from the core.
- D) When reactivity is being added to the core, such as by removing control rod #8 or adding the four special fuel assemblies, count rate will be recorded every 18 inches of rod withdrawal or fuel insertion. If any significant change should be noted, negative reactivity should be introduced and the test halted.

432.2.5.2 Hazards and Precautions

1. All pertinent steps in the loading and operating procedures have been previously analyzed in Tests 314, 318, and 432.1.
2. The oscillator rod, rod drive and special fuel elements have been loaded and operated and no difficulty in handling had been experienced.
3. The oscillator will be initially loaded in its most reactive condition. This will be verified visually prior to loading. When the oscillator drive is latched to the rod, Test 432.1 has verified that there exists ^{a 20°} ~~an 18°~~ misalignment between the reference potentiometer and the stator-rotor since configuration.
4. The expected peak-to-peak oscillator rod worth is 5¢ with the normal startup rod configuration. Test 432.1 demonstrated a peak to peak worth of 8.5¢. The one-rod-out peak to peak worth will be higher. If the measured worth for the normal startup configuration is 10¢ or greater, the test will be halted due to Tech Spec limitations. It is expected that a change to the Tech Specs would be requested to allow testing to continue as peak-to-peak worths of even 30¢ are still not excessive.

432.2.5.2 Hazards and Precautions (Continued)

5. With rod #8 and its adjacent four fuel elements removed and with the oscillator rod and its four special fuel elements installed, seven additional shims will be added around rods #3 and 10 in addition to the expected 40 already installed. With this loading, it is calculated that with either rod #3 or #10 completely withdrawn, the shutdown margin will be $0.4\% \Delta k$ ($\pm 0.5\% \Delta k$).
6. Detailed procedures for the maintenance and operation of oscillator drive equipment are contained in a separately issued set of instructions called Auxiliary Procedures To Test 432.2.

432.2.6 TEST PROCEDURE EQUIPMENT ASSEMBLY

432.2.6.1 Loading of the Oscillator Rod

- (1) Remove the reactor head, dryer and holddown. Remove CRD #8 from the head.
- (2) Ensure the crane control speed has been revised to limit lowering speed to 1 inch/6 seconds.
- (3) Install a BF3 detector on the separator shelf on the north side of the core with audio indication available in the reactor building.
- (4) Add shims to the following locations:

Single B-SS:	036	053	Double between
	037	068	BG-1 and BF-1
	052	069	
- (5) Remove boiler fuel elements from positions BG-2, BG-3, BF-2 and BF-3. Store them in a fuel transfer box in the shield pool.
- (6) Remove control rod #8. Store the rod vertically in the shield pool.
- (7) Remove shims from the following locations:

060	061
-----	-----
- (8) Remove the associated quad box and store it in the equipment transfer box. Transfer rod #8 to the component transfer box and store it in its quad box.

432.2.6.1 Loading of the Oscillator Rod (Continued)

(8) Continued

Transfer the four fuel elements from the fuel element transfer box to the equipment transfer box.

(9) Install oscillator rod in rod #8 position. Ensure the oscillator rod is in its most reactive position.

(10) Install the four special fuel elements in the following locations:

MO-4	BG-2
MO-2	BG-3
MO-1	BF-2
MO-3	BF-3

Insert each element incrementally into the core in 25% steps. Limit the insertion rate to 1 inch per 6 seconds. Monitor count rate after each increment of insertion. The audio count rate indicator is to be monitored by the Chief Loader throughout the whole insertion. He will order the fuel handling crane to be stopped or operated as the change in count rate indicates.

432.2.6.1 Loading of the Oscillator Rod (Continued)

(10) Continued

He will also be in direct communication with the Control Room and can request scaler counts at his discretion.

(11) Remove the in-vessel BF3 and return nuclear instrumentation to normal.

(12) Reinstall the holddown assembly, dryer and head.

(13) Install and latch the oscillator rod drive in place of CRD #8.

(14) Latch and test the remaining control rod drives. Limit any rod raising to 6 inches.

(15) Drain the superheater for the shutdown margin verification. If the radiation level is excessive in the reactor building, flood the shield pool to a height that will reduce the level to that specified by the Radiological Control Engineer.

432.2.7 TEST PROCEDURE PROGRAM

432.2.7.1 Shutdown Margin Verification

- (1) Bank 14 boiler control rods, excluding rod #3, at 6.4 inches. It is estimated that this bank will be worth $0.2\% \Delta k$.
- (2) Withdraw rod #3 to 73 inches. If criticality is imminent during the withdrawal, insert all rods immediately.
- (3) The estimated height for $0.33\% \Delta k$ is 7.55 inches. Withdraw the bank to criticality. Measure the differential rod worth and verify that the $0.33\% \Delta k$ criterion had been met.
- (4) Bring the reactor $.5\% \Delta k$ subcritical. Connect up the oscillator and jog it very slowly at least 180° with a set frequent of 1 cycle per second. Ensure $k < 1$ for every position and determine where the most reactive position is. If no change in reactivity can be seen, increase the k of the core (while still remaining subcritical) and jog the oscillator rod again. If the shutdown margin had been verified with the oscillator in other than the most reactive, reverify it with a critical and differential rod worth measurement.

432.2.7.1 Shutdown Margin Verification (Continued)

- (5) Interchange rods #3 and 10 and again verify the shutdown margin with a criticality and differential rod worth with the oscillator in its most reactive position.

432.2.7.2 Oscillator Rod Worth Evaluation

- (1) A critical and 14 rod bank differential worth will be measured with the oscillator rod in its most reactive position with either rod #3 or 10 completely withdrawn. Bring the reactor subcritical and jog the oscillator rod to its least reactive position.
- (2) With either rod #3 or 10 completely withdrawn, measure a 14 rod bank critical and differential rod worth. Determine the peak-to-peak oscillator rod Δk for the one-rod out configuration.
- (3) Leaving the oscillator rod in its least reactive position, interchange the control rods to the normal startup configuration, i.e., Group V rods completely withdrawn, Group IV controlling. Obtain a criticality and differential rod worth for this configuration.
- (4) With the reactor critical, jog the oscillator rod slowly to its most reactive position. If the period is not excessive, (i.e., shorter than 30 seconds), measure the period. If the period is excessive, insert rods as necessary.
- (5) Obtain a criticality and differential rod worth with this configuration.

432.2.7.2 Oscillator Rod Worth Evaluation (Continued)

- (6) Determine the peak-to-peak oscillator rod Δk . If it is less than 10ϕ , proceed with the next step. If it is 10ϕ or greater, shutdown the reactor and halt the test.
- (7) Measure several other positions of the oscillator rod by observing periods received when moved from the least reactive position.

432.2.7.3 Transfer Function Procedure

NOTE: When the oscillator is not being used, place it in a neutral position.

- (1) Check all prerequisites and calibrations.
- (2) Establish steady-state conditions at zero power with the controlling rod group, and with the oscillator rotating in the forward direction, at approximately its maximum frequency.
NOTE: Note Section 432.2.2 for allowable rod withdrawal.
- (3) Bias out d-c effects per the auxiliary procedures.
- (4) Establish the desired test frequency. Have the oscillator rotating in the "FOR" direction and set the counter and frequency per the auxiliary procedures.
- (5) Establish the proper analog computer gains per the auxiliary procedures.
- (6) Adjust the chart of the Brush recorder to obtain a ratio of chart speed to oscillator frequency of about 20.
- (7) Place computer control in "REMOTE" position.
- (8) Record the system parameter per Data Sheet 432.9.4.
- (9) Push the computer "COMPUTE" button.
- (10) During the computing, record a short span of cycles on the Brush recorder.
- (11) When the computer "HOLD" light comes "ON", turn the power switch of the Digital Voltmeter from "STAND BY" to "ON".

432.2.7.3 Transfer Function Procedure (Continued)

- (12) Take a set of readings per Data Sheet 432.9.4 with " V_t ", " V_A ", and " V_B " being read on the Digital Voltmeter, having the amplifier selector knob of Donner Analog Computer in No. 1, No. 2 and No. 3 positions, respectively.

NOTE: If zero reading is indicated on the Digital Voltmeter, turn the polarity switch on the Digital Voltmeter from + to - or vice versa.

- (13) Turn the oscillator rod off by pushing the "STOP" button on the oscillator control panel.
- (14) Reset the computer system by pushing the "RESET" button on the revolution counter and the computer "RESET" button of the oscillator control panel.
- (15) Push the "REV" button on the oscillator control panel and repeat items 8 through item 12.
- (16) Repeat items 3 through 12 for frequencies ranging from approximately 12 cps. to .001 cps.
- (17) Calculate the transfer function as follows:
- A) For detailed analysis; evaluate the data from 432.9.4, utilizing the Digital Transfer Function Analyzer. This code evaluates:
 - 1) open loop, closed loop and feedback gain and phase;
 - 2) reference potentiometer and oscillator rotor phase error; and
 - 3) gain and phase margins.

432.2.7.3 Transfer Function Procedure (Continued)

(17) (Continued)

B) For on-the-spot transfer function checks, hand-calculate the gain and phase per the auxiliary procedures.

(18) Establish normalization factor according to M. A. Schultz "Control of Nuclear Reactor and Power Plants," Sections 4-6.

(19) Based on the established margins, predict the gain and phase margins for the next suggested power level. Correlate these margins with Test 433 in order to determine the safety of increasing to the next power level.

(20) Repeat items 1 through 19 for the power levels and conditions defined by Section 432.2.2

432.2.8 TEST PROCEDURE EQUIPMENT DISASSEMBLY

432.2.8.1 Unloading of Oscillator Rod

- (1) Fill the superheater to the top of the chimney with unborated water. Drain the shield pool if necessary.
- (2) Unlatch all control rod and oscillator rod drives.
- (3) Remove the oscillator rod drive and tower from the reactor head and reinstall CRD #8. Store the oscillator drive in the reactor building.
- (4) Remove the reactor head, dryer, and holddown.
- (5) Remove the four special fuel elements from positions:

BG-2

BF-2

BG-3

BF-3

Store them in a grid installed in the second equipment transfer box in the shield pool. Store the transfer box in the fuel transfer mechanism tray.

- (6) Transfer the four regular fuel elements from the first equipment transfer box to a fuel transfer box.
- (7) Remove #8 control rod from the equipment storage box and store it in a vertical position in the shield pool.

432.3.8.1 Unloading of Oscillator Rod (Continued)

(8) Install the qual box, then #8 control rod. Install shims in locations 060 and 061.

(9) Install the four normal fuel elements in their previous locations in:

BG-2

BF-2

BG-3

BF-3

(10) Remove shims from positions:

Single B-SS: 036 053

037 068

052 069

Double between BG-1 and BF-1

ZERO POWER FREQUENCY RESPONSE

— $\lambda = 10^{-4}$ SEC. - SCHULTZ, CONTROL OF
NUCLEAR REACTORS AND POWER PLANTS, PP 115
□ PATHFINDER TRANSIENT SIMULATOR -
LISSAJOUS FIG.

NOTE:

THE VALUE OF NEUTRON
LIFETIME USED ON THE
PATHFINDER TRANSIENT
SIMULATOR IS $9(10^{-5})$ SEC.

432.2.9.1.1

PATHFINDER
OPEN LOOP FREQUENCY RESPONSE

LISSAJOUS FIGURE METHOD

- $N_0 = 100\%$, $W_{VO} = 100\%$
- - - $N_0 = 80\%$, $W_{VO} = 100\%$
— $N_0 = 80\%$, $W_{VO} = 77\%$

PATHFINDER TRANSIENT
SIMULATOR - LISSAJOUS FIG.
(n)_{iv} 100% (w_v)_{iv} 100%

GRAPHICAL TECHNIQUE
—— (n)_{iv} = 100% (w_v)_{iv} = 100%
- - - (n)_{iv} = 80% (w_v)_{iv} = 100%
- · - (n)_{iv} = 80% (w_v)_{iv} = 77%

shim locations

rod groups

I
II
III
IV or V

SHIM AND CONTROL ROD LOCATION

432.2.9.3

432.6.7.

[illegible]

TEST PROCEDURE 432.2

Supplement 1

PATHFINDER ATOMIC POWER PLANT

SUPPLEMENT 1

TO

TEST PROCEDURE 432.2

REACTOR TRANSFER FUNCTION TEST

July 20, 1966

Prepared by
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TEST PROCEDURE 432.2

Supplement 1

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APPROVED JULY 20, 1966

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432.2.10 Pile Oscillator Assembly and Preliminary Check
(Mechanical Detail)

- (1) When the oscillator rod is ready to be used in the core, the major sub-assemblies of Dwg. 43-501-096 will be uncrated. Immediately after uncrating, all pieces will be inspected for shipping damages. One of these checks will be manual rotation of the rotor inside the stator by turning the shaft from the upper end using the internal turning device, Dwg. 43-202-918, Serial No. 43-0293-8. Refer to Dwg. 43-501-092 for this operation. It will rotate freely if the graphite bearing is undamaged. To remove the internals from their crate, place the bolt and nut, Dwg. 43-101-892, Serial No. 43-0293-7, in the J notches in the sleeve at the top of the internals and tighten down. Using a standard hitch arrangement, the internals will be raised to the vertical position and then placed on the oscillator rod internals stand, Dwg. 43-302-057, Serial No. 43-0293-4, which will be on the bottom of the shield pool. Secure the internals against tipping. The internals will remain there until they are ready to be loaded into the core.

Once inspection is complete, the drive unit will be placed on the control rod drive test stand. Next, the oil shipped with the drive unit will be put into the Graham transmission through the oil fill hole in the

432.2.10 Pile Oscillator Assembly and Preliminary Check
(Mechanical Detail) (Continued)

upper end of the transmission. To do this, the motor cover will be removed and then replaced after the oiling is complete. When the oil is in the transmission, the drive unit may be placed on its side opposite the oil fill hole. This side is marked with an A-C name plate.

After replacing the motor cover, tighten down the bolts with the gasket in place and fill the motor housing with VELOCITE 6 oil. Pressure test at 15 psig for one hour to check for leaks. After this test is complete, drain the VELOCITE 6 oil from the motor housing. The tower and its tubing and lead cable will be assembled to the oscillator drive in accordance with Dwg. 43-501-096.

The assembly is now complete and it will remain on the CRD test stand until it is ready to be installed on the reactor head.

432.2.11 Pile Oscillator Control Cabinet Chassis Power On Check
and Warm-up

- (1) The computer control switch on the Donner Analog Computer is in the "LOCAL" position, thereby allowing the computer to be controlled by the "LOCAL RESET-COMPUTE-HOLD" switch instead of the remote "RESET-COMPUTE-HOLD" pushbuttons.

432.2.11 Pile Oscillator Control Cabinet Chassis Power On Check and Warm-Up (Continued)

- (2) Turn cabinet power switch on the oscillator control panel to the "ON" position. This will result in the following:
 - A) Light the "CABINET INSTRUMENT POWER ON" lamp on the oscillator control panel.
 - B) Light the "CABINET MOTOR POWER ON" lamp on the oscillator control panel.
 - C) Light the "COMPUTER RESET" lamp on the oscillator control panel.
 - D) Start the fan in the Donner Cooling unit.
- (3) To turn "ON" the Donner Analog Computer, put a feedback resistor across all amplifiers and turn the:
 - A) Computer master control to "BAL".
 - B) "POWER" knob clockwise. The red neon power lamp should be "ON".
- (4) To turn "ON" the digital voltmeter, turn the:
 - A) "OFF-STD-BY-ON" switch from "OFF" to "STD BY". The digital readout panel should be illuminated.
- (5) To turn "ON" the Keithley $\mu\mu$ ammeter, turn the:
 - A) "AMPERES FULL SCALE" switch to the 10^{-3} position;
 - B) "METER" switch "OFF";

432.2.11 Pile Oscillator Control Cabinet Chassis Power On Check and Warm-up (Continued)

- C) "CURRENT SUPPRESS AMPERES" switch
"OFF"; and
 - D) "ON" switch to "ON" position. The red indicator should be illuminated.
- (6) To turn "ON" the oscillograph, turn the:
- A) "MASTER" control to "STANDBY" and the
 - B) "POWER" switch "ON". The red indicator lamp should be illuminated.
- (7) To turn "ON" the Dual Channel DC Amplifier, turn the:
- A) #1 "VOLTS/CHART LINE" switch to the
"OFF" position;
 - B) #2 "VOLTS/CHART LINE" switch to the "OFF" position; and
 - C) "POWER" switch "ON". The red indicator lamp should be illuminated.
- (8) To turn "ON" the Donner Function Multiplier, turn the:
- A) "MASTER" control switch to "OPERATE";
 - B) "POWER" switch "ON". The "ON" light should be illuminated.

432.2.11 Pile Oscillator Control Cabinet Chassis Power On Check and Warm-up (Continued)

(9) To energize the 208 VAC 3 ϕ circuits:

- A) Turn "PILE OSCILLATOR 208 VAC 3 ϕ circuit breaker in cabinet "J" on the mezzanine floor "ON". The motor control power "ON" lamp should be illuminated and the "MOTOR CURRENT" meter should read zero amperes.

(10) To turn "ON" the Diatrol Servo Amplifier:

- A) Because of the possible mismatch between the "OSC. FREQ. CONTROL" potentiometer and the servo-driven matching potentiometer, one must turn "ON" the pile oscillator mechanism by pushing either "OSCILLATOR MOTOR CONTROL" "FOR" or "REV" pushbuttons. This will result in a motor (oscillator drive motor) current indication and the illumination of a white oscillator direction indication, either "OSCILLATOR ROTATION FORWARD" or "OSCILLATOR ROTATION REVERSE", respectively. The purpose of turning the pile oscillator "ON" is to allow the servo-driven matching potentiometer to match the frequency demand potentiometer, "OSC. FREQ. CONTROL" under the most favorable mechanical transmission

432.2.11 File Oscillator Control Cabinet Chassis Power On Check and Warm-up (Continued)

conditions, when the servo amplifier is turned "ON". Should the above dynamic matching procedure be accidentally violated, there would be no catastrophic results. Reduced transmission and servo life could be expected if the procedure is violated a high percentage of the time.

- B) Turn the "DIATROL" switch "ON". This should result in a clicking sound as the servo matches the demand and signal potentiometer. Movement of the "OSC. FREQ. CONTROL" demand potentiometer should cause servo action.
- C) Once the match is obtained, the oscillator may be turned "OFF" by pushing the "OSCILLATOR MOTOR CONTROL" "STOP" pushbutton.

NOTE 1: Once the match is accomplished, the "OSC. FREQ. CONTROL" potentiometer should be manipulated only when the servo is "ON" and the oscillator is rotating.

NOTE 2: Turn the DIATROL "OFF" once the desired frequency has been established in order that there is no frequency drift due to amplifier drift.

432.2.11 Pile Oscillator Control Cabinet Chassis Power On Check and Warm-up (Continued)

- (11) The energizing of the cabinet is complete.

432.2.12 Calibration and Balancing of Chassis Circuits

(1) Donner Analog Computer

- A) Test all tubes
- B) Check the Donner Analog Computer Power Supply Voltage according to the Analog Computer Instr. Manual, ACIM, Page 5, Section 5.1. If voltage is in error, refer to Page 22, Section 1.
- C) Balance the amplifiers according to ACIM, Page 7, Section 5.2.

(2) Digital Voltmeter

- A) Test all tubes
- B) Gain settings - Refer to Digital Voltmeter Manual, DVM, Section 5.A.
- C) Hum Control Adjustment - Refer to DVM, Section 5.B.
- D) Standardization Adjustment - Refer to DVM, Section 5.C.
- E) Feedback Voltage Linearity Test - Refer to DVM, Section 5.D.

432.2.12 Calibration and Balancing of Chassis Circuits (Continued)

- F) Range Unit Adjustment - Refer to DVM, Section 5.E.
- G) General Test. Place input jacks across a standard cell. Readout should indicate cell rating.

(3) Keithley $\mu\mu$ ammeter

- A) DC, Refer to $\mu\mu$ AIM, Section 5.A.
- B) Calibration of Buck-Out Supply - Refer to $\mu\mu$ AIM, Section 5.C.
- C) Zero Check
 - a) turn meter "ON",
 - b) push and lock "ZERO CHECK",
 - c) bias meter to desired position with lower right hand potentiometer,
 - d) release "ZERO CHECK".

(4) Brush Oscillograph

- A) Clean pens and inkwells. Refer to BOIM, Section VI, Page 23.
- B) Fill inkwells. Refer to BOIM, Section III, Page 9.
- C) To measure and adjust paper tension, refer to BOIM, Section IV, Pages 23 and 24.
- D) Align Pennotors. Refer to Section IV, Page 24.
- E) Adjust pen pressure. Refer to Section III, Page 15.

432.2.12 Calibration and Balancing of Chassis Circuits (Continued)

(5) Brush Amplifier

- A) Balancing. Refer to BAIM, Section III, Page 8.
- B) Calibration. Refer to BAIM, Section III, Page 10.

(6) Donner Electronic Multiplier

- A) Power supply check. Refer to DEMIM, Page 17.
- B) Multiplier balance. Refer to DEMIM, Page 4.

(7) Presen counter accuracy

- A) Push counter "RESET".
- B) Set desired number of test counts on present counter dial.
 - a) open dial door;
 - b) push digit dials to lift along axis and rotate until desired digits appear; and
 - c) close dial door.
- C) Place a test recorder across points #9 and #12 on TB-5. Refer to Dwg. 43-501-124. Pulse height is 110 VDC.

NOTE: Turn counter "ON".

- D) Place "COMPUTER CONTROL" in "REMOTE" position.
- E) Push either "OSCILLATOR MOTOR CONTROL" "FOR" or "REV".
- F) Turn "OSC. FREQ. CONTROL" potentiometer to high frequency. See 432.2.26 for position.

432.2.12 Calibration and Balancing of Chassis Circuits (Continued)

- G) Turn recorder "ON".
- H) Push "COMPUTER COMP" pushbutton and wait until the system goes from "COMPUTER COMP" TO "COMPUTER HOLD".
- I) Turn recorder "OFF".
- J) Compare the number of pulses on the recorder to the number indicated on the counter. If the two numbers are the same, the counter is operating correctly. If the counter number is less than the number of pulses recorded on the recorder:
 - a) check pulse height; if correct;
 - b) increase pulse width by adjusting the "PULSE WIDTH" potentiometer on the "SINE WAVE ANALYZER".
- K) Repeat adjustments until no more counter error exists.
- L) Turn oscillator "OFF" by pushing the "OSCILLATOR MOTOR CONTROL" "STOP" pushbutton.
- M) Reset the computer by pushing "COMPUTER RESET".

(8) Diatrol Servo Amplifier

- A) Push oscillator "FOR" or "REV" button.
- B) Adjust the servo dead band with the "SENSITIVITY" control. Refer to Van Special Drive, Jordan Controls, Inc.

432.2.12 Calibration and Balancing of Chassis Circuits (Continued)

- C) Adjust the servo overshoot by the
"ANTICIPATION" control.
- D) Push the "OSCILLATOR MOTOR CONTROL" "STOP"
pushbutton.

432.2.13 Correlation Circuit Check

- (1) Modify the computer circuit in 432.2.23 to that in 432.2.24 by replacing the potentiometer No. 2 and amplifier No. 8 with the indicated "TEST CIRCUIT".
- (2) Place the "COMP. CONTROL" switch on the Donner Analog Computer to "REMOTE".
- (3) Turn the "COUNTER" toggle switch on the oscillator control panel to the "ON" position.
- (4) Establish integrating time constant for amplifier No. 1 per procedure in 432.2.16 assuming 1.0 volt per second.
- (5) Set the revolution counter on the oscillator control panel to read "RA" = 100 revolutions per procedure in 432.2.14.
- (6) Connect the "INPUT" of the Digital Voltmeter to "AMP" of the analog computer.
- (7) Establish oscillator rod speed of 12 cps. per procedure in 432.2.17 with the oscillator rod rotating in forward "FOR" direction.
- (8) Adjust the Brush recorder pen sweep gains on dual channel DC amplifier to the same "VOLTS/CHART LINE"; i.e., one to one ratio of channel 1 to channel 2.
- (9) Adjust the chart speed of the Brush recorder to obtain a

432.2.13 Correlation Circuit Check (Continued)

ratio of chart speed to oscillator frequency of about 20.
In this case, set the chart speed at 250.

- (10) Turn the master control switch to the Brush recorder from "STAND BY" to "REMOTE".
- (11) Turn the pen "BIAS" to the dual channel amplifier and adjust the Brush recorder pens to center line of chart.
- (12) Turn the master control switch to "STAND BY".
- (13) Push the computer "COMPUTE" button on the oscillator control panel.
- (14) During the computing cycle, turn the Brush recorder master control switch from "STAND BY" to "mm/sec" and record a short span of cycles (about 5) on the chart.
NOTE: There should be no DC component in the traces, and if one is observed, turn the master control switch to "REMOTE" and "BIAS" the amplifier. If DC component still persists on repeat of item 14, stop the test and determine its cause.
- (15) When the computer "HOLD" light on oscillator control panel comes on, turn the power switch of the Digital Voltmeter from "STD BY" to "ON".

432.2.13 Correlation Circuit Check (Continued)

- (16) With the amplifier selector knob of the Donner Analog Computer in No. 1 position, read "V MINUS" on the Digital Voltmeter, in No. 2 position, read " V_A ", in No. 3 position, read " V_B ", and record the values.
NOTE: If zero reading is indicated on any of the above, change polarity on the Digital Voltmeter.
- (17) Turn the oscillator rod off by pushing the "STOP" button on the oscillator control panel.
- (18) Reset the computer system by pushing the "RESET" button on revolution counter and the computer "RESET" button of the oscillator control panel.
- (19) Turn the power switch of the Digital Voltmeter to "STD BY".
- (20) Calculate the gain and phase shift per instructions in the auxiliary procedures.
- (21) Compare the results with those in 432.2.25.
- (22) If the results do not compare well with 432.2.25, notify the supervisor and locate the faulty circuit component.
- (23) Repeat item 7 through item 22 for the oscillator drive, rotating in reverse, "REV", direction.
- (24) Repeat item 2 through item 23 for frequencies ranging from zero to 12 cps.

432.2.14 Setting of the Revolution Counters

- (1) The setting on the revolution counter establishes the number of cycles over which the computer integrates.

The number of cycles selected should be such that:

- A) the number of complete integration cycles be large so that the probable correlation error would be small; and
- B) the integrating amplifier results are within the range of 25 to 90 volts DC.

- (2) To obtain the desired number of integration cycles "RA" set $RA + 1$ on the revolution counter, in order to allow for the initial pulse. Thus, when $RA=100$ is desired, set the revolution counter to read 101. The value of $RA + 1$ is set on the revolution counter as follows:

- A) Push the counter reset button in the upper left corner of the revolution counter.
- B) Open the door of the revolution counter and push the respective wheel for units, tens, hundreds, etc; to the left, along the shaft and rotate the disc until the desired number appears.
- C) Close the door and push the reset button to make sure that $RA + 1$ does indeed appear on the counter.

432.2.15 Analog Computer Amplifier Gains

- (1) The gains of the system should be such that the outputs of amplifiers #2 and #3 at the end of an integrating cycle are between 25 and 90 VDC.
- (2) The input resistors, R_1 and R_3 , of amplifiers #9 and #10 should not be less than 1 megohm because of the required load characteristics of the sine-cosine potentiometer.
- (3) The input and feedback resistors of amplifiers #6 and #7 must be the same for circuit balance across the sine-cosine potentiometer.
- (4) $\bar{E}$ should not exceed 50 VDC. For long integrating times, the $\bar{E}$ should be 10 VDC.
- (5) The gains of amplifiers #8, #9 and #10 should be adjusted such that their outputs have the same relative amplitude of approximately 10 VDC for optimum electronic multiplier operation.

432.2.16 Establishment of Integrating Time Rate Constant, Volts/sec,
for the Analog Computer Clock

- (1) The rate constant should be adjusted to a value that will produce an analog clock (integrating amplifier-output) between 25 and 90 VDC.
- (2) The constant is established as follows:
 - A) Connect the "INPUT" of the Digital Voltmeter to "ARM" of potentiometer #9.
 - B) Connect the ground lead to any computer ground.
 - C) Place the amplifier selector knob of the Donner Analog Computer in the No. 1 position.
 - D) Turn the power switch of the Digital Voltmeter to "STD BY".
 - E) Set the range selector switch of the Digital Voltmeter to "1000 VDC".
 - F) Turn the power switch of the Digital Voltmeter to "ON" and read the indicator.
 - G) If the indicator reads + 000.0, turn the polarity switch from + to - or vice versa.
 - H) If the indicator reads other than + 010.0, turn the power switch to "STD BY" and adjust potentiometer #9.
 - I) Repeat item F and item H until the Digital Voltmeter indicator reads + 010.0.

432.2.16 . Establishment of Integrating Time Rate Constant, Volts/sec,
for the Analog Computer Clock (Continued)

(2) Continued

J) Change the range selector of the Digital Voltmeter
to "100 VDC".

K) The Digital Voltmeter indicator should read + 10.00.

432.2.17 Oscillator Frequency Determination

- (1) Start the oscillator drive by pushing either "FOR" or "REV" pushbutton. Appropriate lamp will indicate in which direction the drive rotates.
- (2) Adjust the "OSC. FREQ. CONTROL" to the desired frequency per 432.2.26.

Caution: The oscillator drive motor must be rotating before adjusting the frequency.

- (3) Check that the "INPUT" to the Digital Voltmeter is connected to "AMP" of the Analog Computer.
- (4) Push the computer "COMPUTE" button on the oscillator control panel and allow the system to compute. The "COMPUTE" light will be on. When computation is complete, the "HOLD" light will turn on and the "COMPUTE" light will go off.
- (5) Turn the power switch of the Digital Voltmeter from "STD BY" to "ON" and read " V_t " on the indicator.

NOTE: If zero reading is indicated, turn the polarity switch from - to + or vice versa.

- (6) Reset the computer system by pushing the reset button on revolution counter and the computer "RESET" button.
- (7) Turn the power switch of the Digital Voltmeter back to "STD BY".

432.2.17 Oscillator Frequency Determination (Continued)

- (8) Obtain integrating time by the following formula:

$$T = \frac{A10}{V/\text{sec}}$$

- (9) Divide RA, the revolution counter setting minus 1, by T, obtaining the oscillator rod speed in cycles per second.
- (10) If a definite speed is desired, repeat item 2 through item 10 until the desired frequency is attained.

432.2.18 Biasing out of the Steady-State Power Level

- (1) Depress and lock by turning one quarter turn the "ZERO CHECK" button.
- (2) Set the "CURRENT SUPPRESS" controls as follows:
 - A) Multiplier: set to "0"
 - B) Amperes: set to "OFF"
 - C) Fine: set to most counter-clockwise position
 - D) Meter: turn to + position.
- (3) Using the "ZERO ADJUST" knob, set the needle, i.e., to read .0 on the indicator scale.
- (4) Turn the "AMPERES FULL SCALE" switch to 10^{-3} , the most insensitive scale.
- (5) Unlock the "ZERO CHECK" button.
- (6) Turn the Brush recorder master control switch from "STAND BY" to "mm/sec".
- (7) Turn the "AMPERES FULL SCALE" switch until the indicator gives a full scale deflection. There will be a DC level with AC ripple indicated on the $\mu\mu$ ammeter and the Brush recorder.

432.2.18 Biasing Out of the Steady-State Power Level (Continued)

- (8) Adjust the "CURRENT SUPPRESS MULTIPLIER" and "AMPERES" dials until the DC level is removed and the needle approaches as near zero (.0) as possible. Use the "FINE" control as necessary to bring the needle to oscillate about vertical, leaving only the AC ripple signal on $\mu\mu$ ammeter and Brush recorder. This represents the sinusoidal power deviation caused by the oscillator rod rotation.
- (9) Repeat items 7 and 8 as necessary until the indicator shows full scale oscillation without any DC level.
NOTE: The indicator (meter) deflection may be distorted; hence, monitor the Brush recorder for full scale indication.
- (10) If the Brush recorder should indicate any DC component, turn the Brush recorder master control switch to "REMOTE" and bring the pen-to-center of chart with "PEN BIAS" on the amplifier.

432.2.19 File Oscillator Rod Worth Evaluation

Refer to Section 432.2.7.2.

432.2.20 Transfer Function Calculation

Utilizing correlator data from both forward and reverse direction cases, the reactor transfer function is hand calculated as follows:

(1) Phase

$$\theta (\text{For}) = \tan^{-1} \frac{S_A V_A (\text{For})}{S_B V_B (\text{For})}$$

$$\theta (\text{Rev}) = \tan^{-1} \frac{S_A V_A (\text{Rev})}{S_B V_B (\text{Rev})}$$

$$\theta (\text{Actual}) = \theta_{\min} + \frac{\theta_{\max} - \theta_{\min}}{2}$$

The phase correction allows for rotor-potentiometer misalignment.

(2) Gain

$$V_A (\text{Actual}) = \frac{\sin \theta (\text{actual}) \cdot V_A (\text{For})}{\sin \theta (\text{For})}$$

432.2.20 Transfer Function Calculation (Continued)

$$V_B \text{ (Actual)} = \frac{\cos \theta \text{ (actual)} \cdot V_B \text{ (For)}}{V_B \text{ (For)}}$$

$$A = \frac{2}{A_{10}} \sqrt{\frac{V_A^2}{S_A^2} + \frac{V_B^2}{S_B^2}}$$

$$\text{Gain} = 20 \log \frac{2}{O.K. \cdot T \cdot E_B} \cdot \sqrt{\frac{V_A^2}{S_A^2} + \frac{V_B^2}{S_B^2}}$$

K - Oscillator rod worth

E_B - $\mu\mu$ ammeter bucking voltage

T - Total Integrating time

S_A^* - Composite scale factor

S_B^* - Composite scale factor

*The composite scale factors take into account the gains and potentiometer settings of each circuit path.

432.2.21 Stability Determination

Definitions:

(1) Gain Margin: The amount of gain that $|G_o H|$ at $\angle -180$ can be multiplied by in order to reach unity gain. Gain margin can be expressed in decibels.

(2) Phase Margin: The amount of phase shift that can be added to $|G_o (j\omega) H| = 1$ to result in a total phase shift of -180° .

At each power level the gains and phase margins as determined from the Bode Plots are linearly plotted and the stability is predicted at the next higher power level by extrapolating the established data as shown by 432.2.22.

Gain and Phase Margins of Open Loop ($G_o H$) Vs. Power

TIMING CIRCUIT

REFERENCE SUPPLY

NOTES

1- $\bar{E}$ SHOULD NOT EXCEED 50V DC

2-.1% RESISTOR SHOULD BE USED IN ALL CIRCUITS

3- RESISTORS IN MEGOHMS DETAILED PILE OSCILLATOR COMPUTER CIRCUIT

4- CAPACITORS IN $\mu\mu F$

5- R1 & R3 MUST BE 1 MEG

TIMING CIRCUIT

REFERENCE SUPPLY

NOTES

1- $\bar{E}$ SHOULD NOT EXCEED 50 VDC

2- RESISTORS IN MEGOHMS

3- CAPACITORS IN μF

DETAILED OSCILLATOR COMPUTER TEST CIRCUIT

432.2.24

μ μ AMMETER BUCKING CURRENT VS. BUCKING VOLTAGE

432.2.26