N86-30182

VERTICAL REACTOR COOLANT PUMP INSTABILITIES

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This paper describes the investigation conducted at the Tennessee Valley Authority's Sequoyah Nuclear Power Plant to determine and correct increasing vibrations in the vertical reactor coolant pumps. Diagnostic procedures to determine the vibration causes and evaluate the corrective measures taken are described.

INTRODUCTION

Of the myriad pumps, motors, fans and other rotating equipment in a nuclear power plant, by far the largest and most powerful are the vertical reactor coolant pumps (RCP's). Sequoyah Nuclear Plant comprises two pressurized water reactor units (Westinghouse, 4 loop) generating 1180 megawatts each at full power. The two independent units are in operation at the site in Soddy, Tennessee. Unit 1 began commercial operation in 1981 and Unit 2 started up 1 year later. By the end of fuel cycle 2 of Unit 1, vibration trends on the RCP's were showing an unexplained increase. The investigation of this increase and the solution to the problem are the basis for this paper.

The opinions and interpretations described in this paper are based on the author's personal experience and do not necessarily represent official Tennessee Valley Authority policy.

SYMPTOMS

At a vibration seminar, Dr. Elemer Makay said in reference to vibration analysis of vertical pumps, "All bets are off". The meaning of this statement becomes clear when you attempt to directly apply the knowledge and experience gained from solutions to horizontal pump problems to a set of vertical pump problems. Even the common factor, gravity, doesn't seem to act properly. The familiar horizontal and vertical force components, are now "x" and "y" while the influences of temperature, pressure, flow, and bearing seal clearances on these components assume different and sometimes unexpected magnitudes.

Our investigation began in the fall of 1983 when trend data began to show a gradual increase in vibrations from the desired level of 3-4 mils P-P displacement. At that time, vibration levels were indicating between 6 and 10 mils for no apparent reason. (Fig 1) Fig 2 illustrates a typical RCP with bearing locations and Fig 3 shows the Bently-Nevada proximity probe location on the pump shaft.

INVESTIGATIONS

Bearing Clearances--Since the rate of vibration increase had increased after the implementation of new maintenance procedures for the setting of bearing clearances, we began our investigation by analyzing the procedure changes. Previously, bearing clearances for the 7-segment lower motor bearing were set during the "swingcheck" when the motor shaft was forced to one quadrant with sufficient force that no more shaft movement was detected. The new procedure limited the swing force to 25 ft-lbs. We immediately suspected that the bearing clearances were being set larger than the .004" to .006" listed in the pump specifications, leading to increased sensitivity of the rotating elements.

The installation location of the proximity probes and the geometry of the pump support structure (Fig 4) allowed us to make some judgements on bearing clearance without disassembly of the unit. The following procedure was used:

1) Gap voltage measurements were taken for the probe opposite the discharge or intake of the pump while the system was at normal operating temperature and pressure.

2) Immediately after pump shutdown, the voltage gap was recorded again.

3) The stainless pump shaft response is 283 mv/mil.

4) Subtracting (1) from (2) and dividing by (3) gave us the lateral shaft movement from running position to the at rest position.

5) Assuming that the shaft had been running in the center of the bearing, the movement in excess of the specified bearing clearance could be interpreted as excessive bearing clearance.

For example:
1) Running gap 8.1V
2) At rest gap 12.9V
3) Difference 4.8V
4) 4.8/283 = .017"
5) Max movement if bearings properly set, .012", therefore, clearance is .005"

The geometric configuration of the pump results in shaft movement at the probe being 2X the movement at the bearing (Fig 3). Therefore the bearing clearance is .0085" and the excessive clearance at the bearing is .0025". (Assuming the shaft was rotating in the center of the bearing.) The accuracy of this analysis was confirmed later when a teardown revealed a bearing clearance of .008".

Balance--The second area of investigation was to determine the cause of the increased sensitivity to balance weights. During initial start-up, the observed sensitivity was in the range of 90-100 gm/mil. At the time of the investigation this sensitivity had changed to a range of 30-40 gm/mil (Fig 5,6). The first thought that this data suggests is an increased sensitivity due to reduced bearing support, i.e., excessive clearance in the motor bearings. In the arrangement of the bearings, the lower motor bearing "carries the load" and is the most susceptible to problems. One area that needs additional study under controlled conditions is the relationship between this increased sensitivity and the critical speed of the pump. During normal operations the pump exhibits 3 critical speeds, 300, 800, and 1500 rpm. It appears that as the bearings provide less support, the third critical is moving down from 1500 rpm toward the operational speed of 1200 rpm.

Spectral Analysis--The third area we examined was the spectrum analysis in the 0-200 Hz range. Two points of interest were observed. Although the lower motor bearing is a 7-shoe segmented bearing designed to reduce oil whip, a 1/2 harmonic of over 3 mils was observed on some pumps (Fig 7). In conversations with other utilities, an incident was discussed where the entire shoe support harness had become detached allowing excessive bearing clearance and a resulting 15 mil vibration at 1/2X. The other point noted was the variation in the 2X component, the usual interpretation being possible misalignment. During the maintenance teardown of this pump, the pump/motor misalignment was found to be .014".

CORRECTIVE ACTION

Correlation of the interaction of these four items, voltage gap measurements, increased sensitivity to balance weights, possible oil whip and misalignment pointed to the need for an evaluation and revision of our local procedures for RCP maintenance to incorporate these latest observations.

A review of the maintenance procedures was conducted with the Westinghouse representative. Although this study is still in progress, general recommendations were implemented during the last Unit 2 cycle 2 outage.

These dealt with three main areas:

1) The motor shaft must be centered in the bearing. Swing check methods were refined to insure this point.

2) Seal clearances must be equal at all points on the shaft.

3) Only after the shaft is centered in the seal and centered in the bearing will the bearing shoes be gauged. Clearances are set at .005" and if there is any give, it is toward .004".

CONCLUSION

When maintenance is performed on large vertical pumps, extreme care must be exercised to observe all conditions during disassembly and return the unit to the manufacturers specifications. Any deviations appear to have a much greater effect than with a comparable sized horizontal pump/motor set and under certain conditions, failure to follow these specifications could have catastrophic results.

GENERAL DATA FOR REACTOR COOLING PUMPS

Model	W11007-A1
Type	Single-Stage, Centrifugal
Head	277 feet
Flow	88,500 gpm
Impeller	Seven-vane single suction
Rotating Inertia	82,000 lb-ft.2
Rated Horsepower	6,000 hp
Voltage	6,600 volts
Starting Current	3,000 amps
Flywheel	13,200 lbs
Nominal Temperature	545 F.
Nominal Pressure	2,250 psia

Frequency Analysis of Pump Vibrations

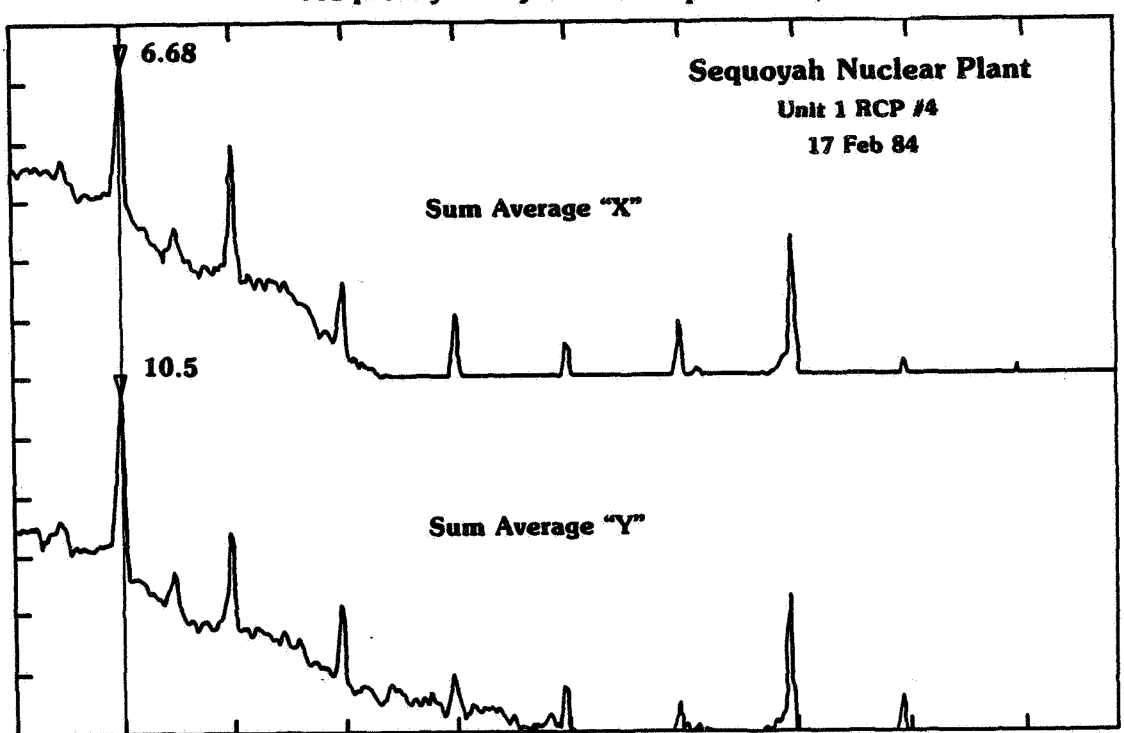

Figure 1

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Reactor Coolant Pump

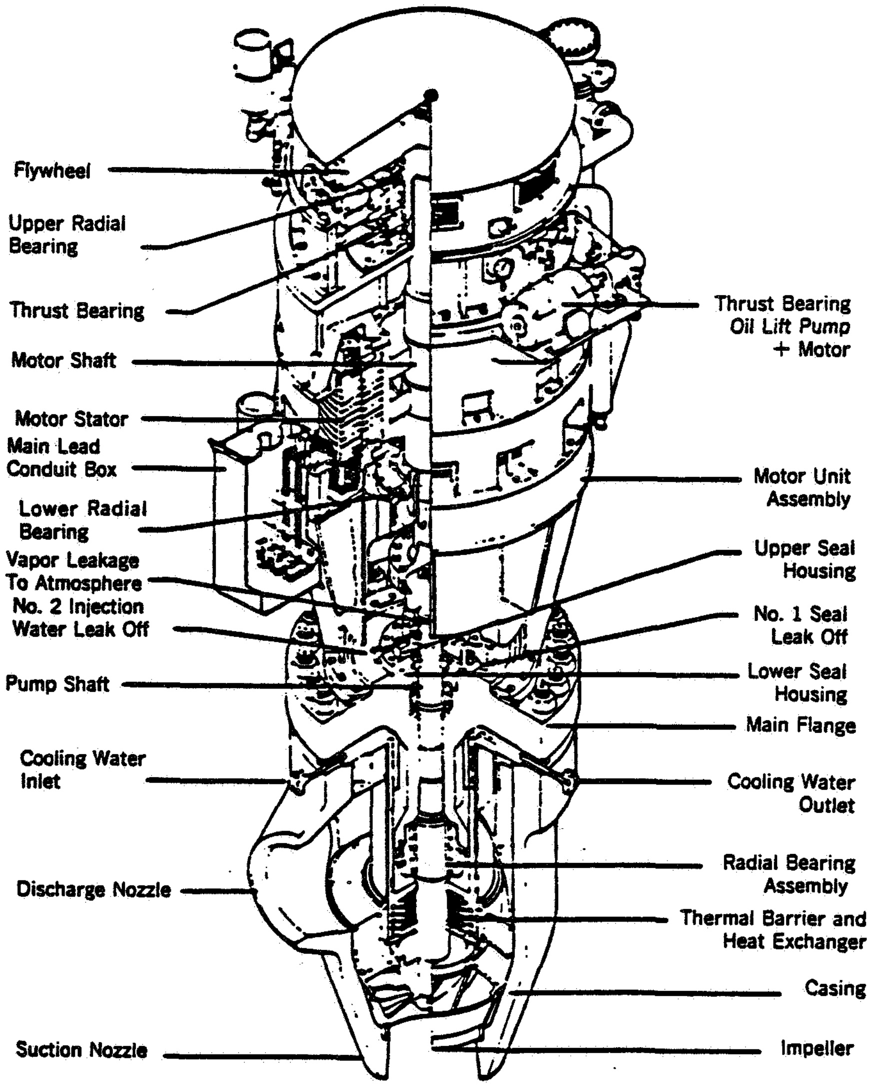
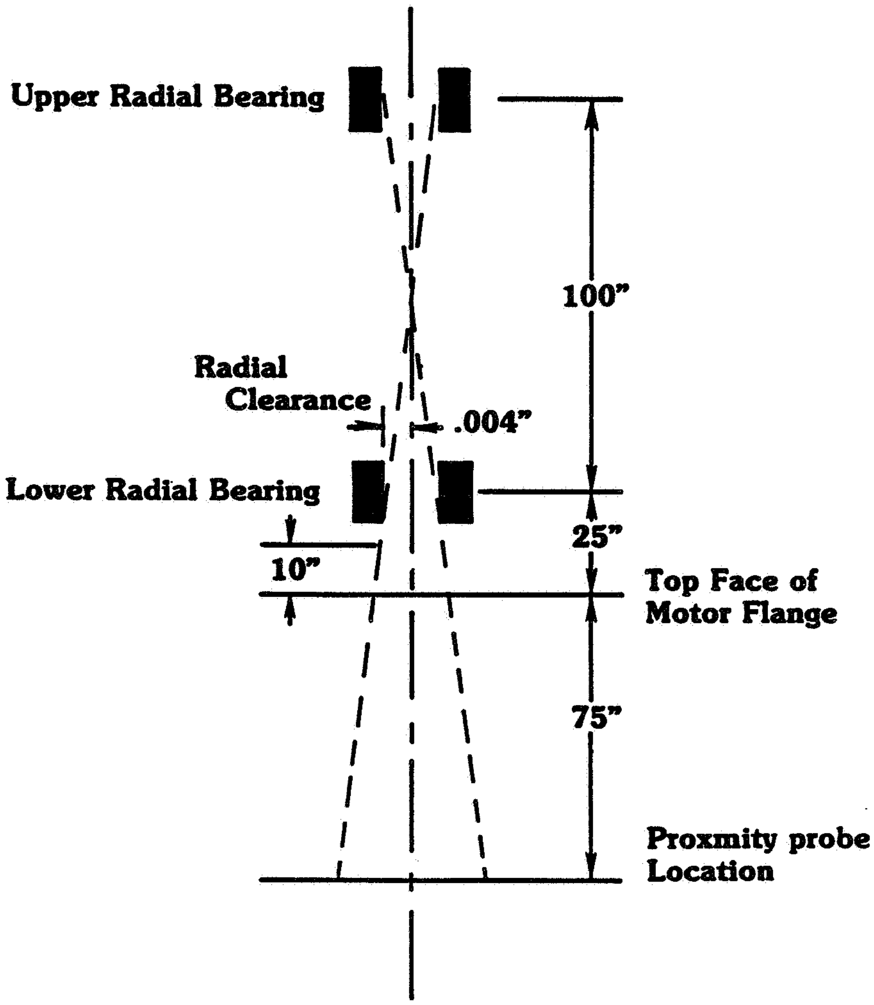


Figure 2

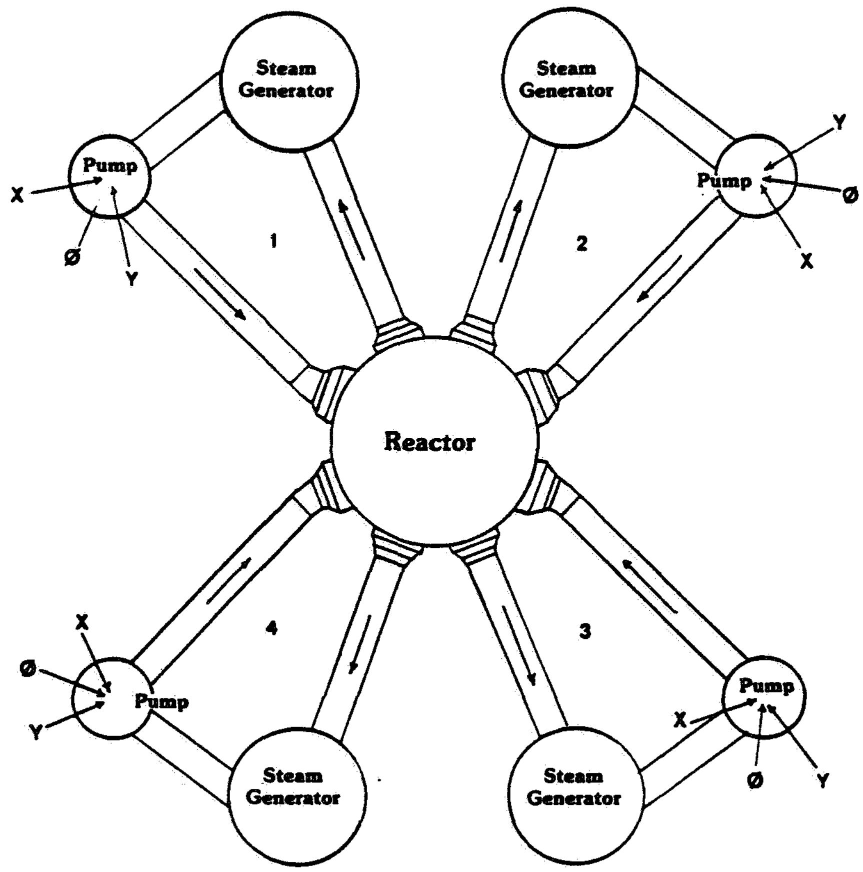
Sequoyah RCP's Physical Arrangement of Bearings and Displacement Probes



From Westinghouse instruction letter, June 1976

Figure 3

Physical Arrangement of Reactor, Pumps, Steam Generators



Sequoyah Nuclear Plant

Figure 4

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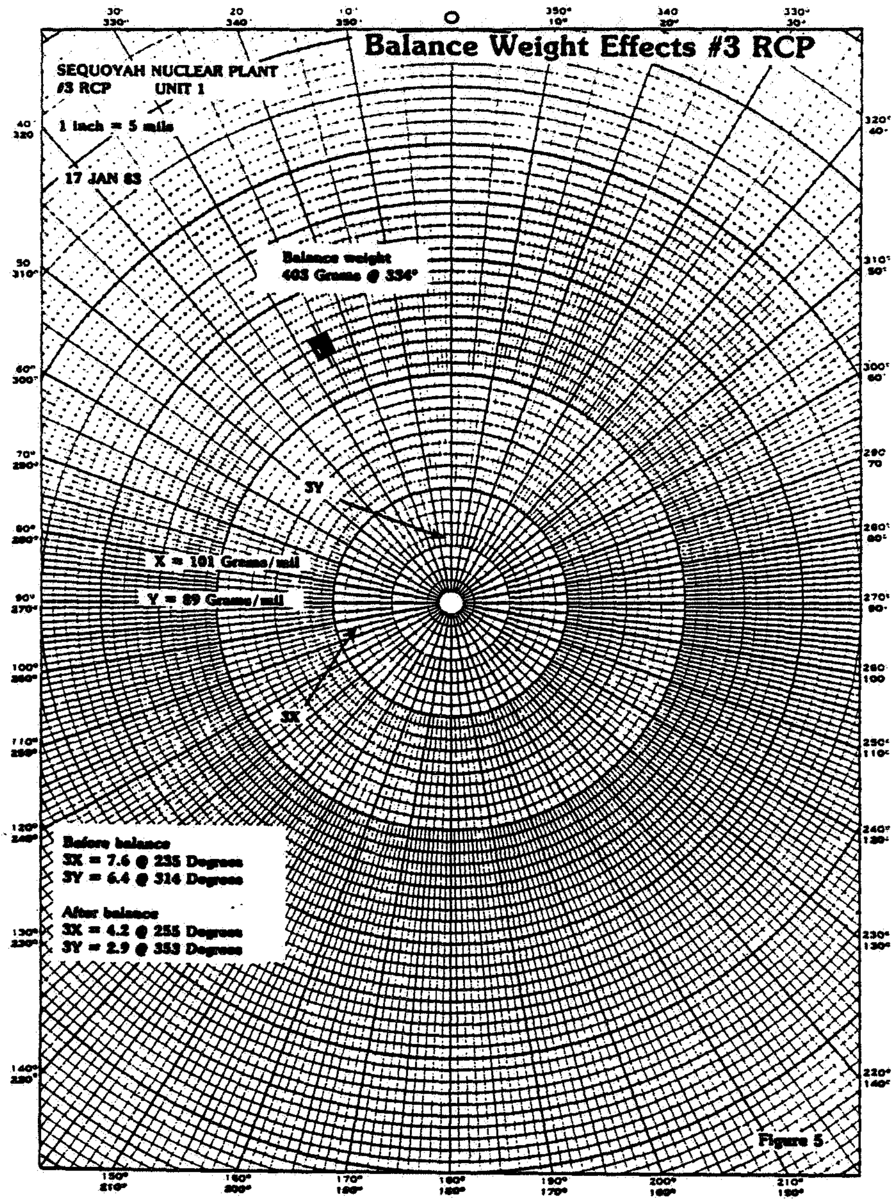
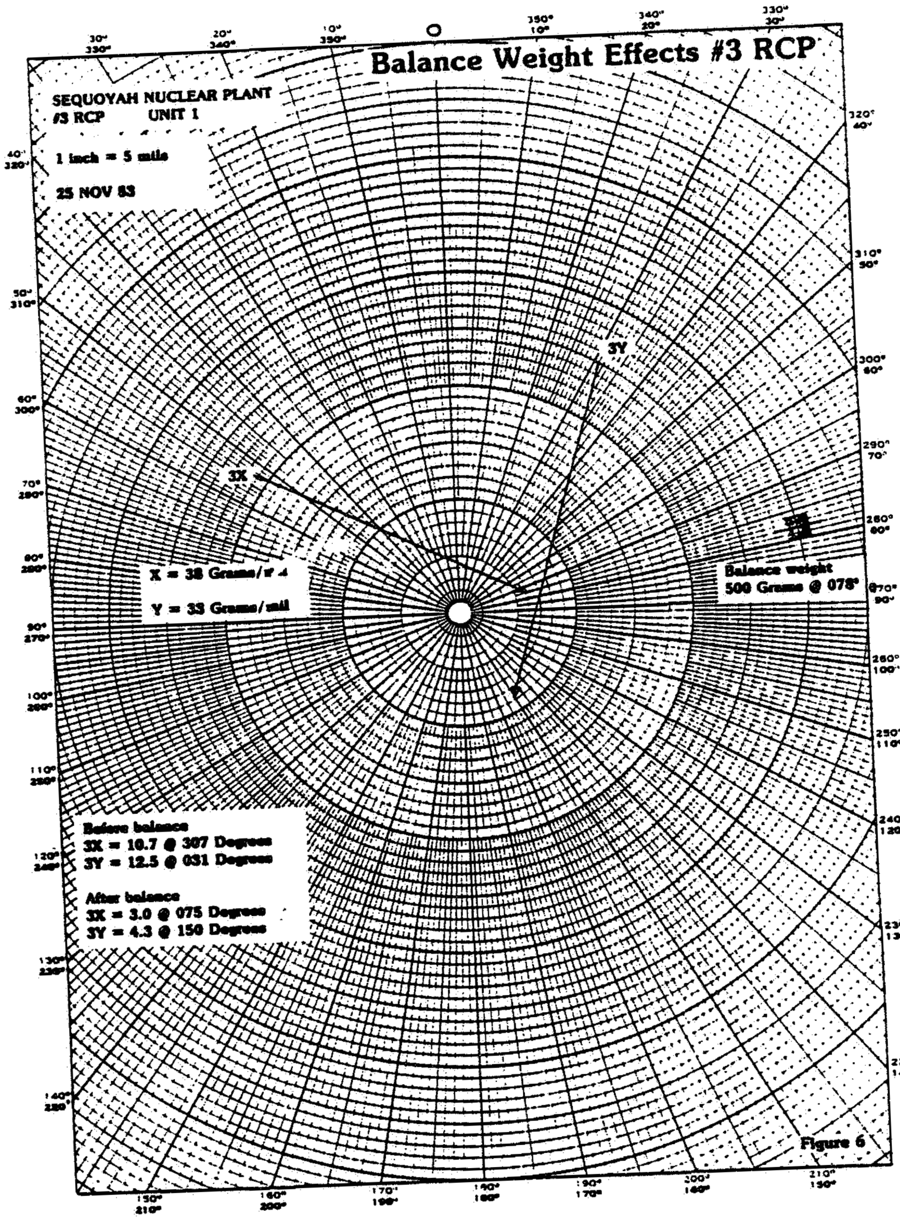


Figure 5


Balance Weight Effects #3 RCP
SEQUOYAH NUCLEAR PLANT
#3 RCP UNIT 1
1 inch = 5 mils
25 NOV 83
3Y
3X
X = 38 Grams/mil
Y = 33 Grams/mil
Balance weight
500 Grams @ 078°
Before balance
3X = 10.7 @ 307 Degrees
3Y = 12.5 @ 031 Degrees
After balance
3X = 3.0 @ 075 Degrees
3Y = 4.3 @ 150 Degrees
Figure 6

Frequency Analysis During Operation

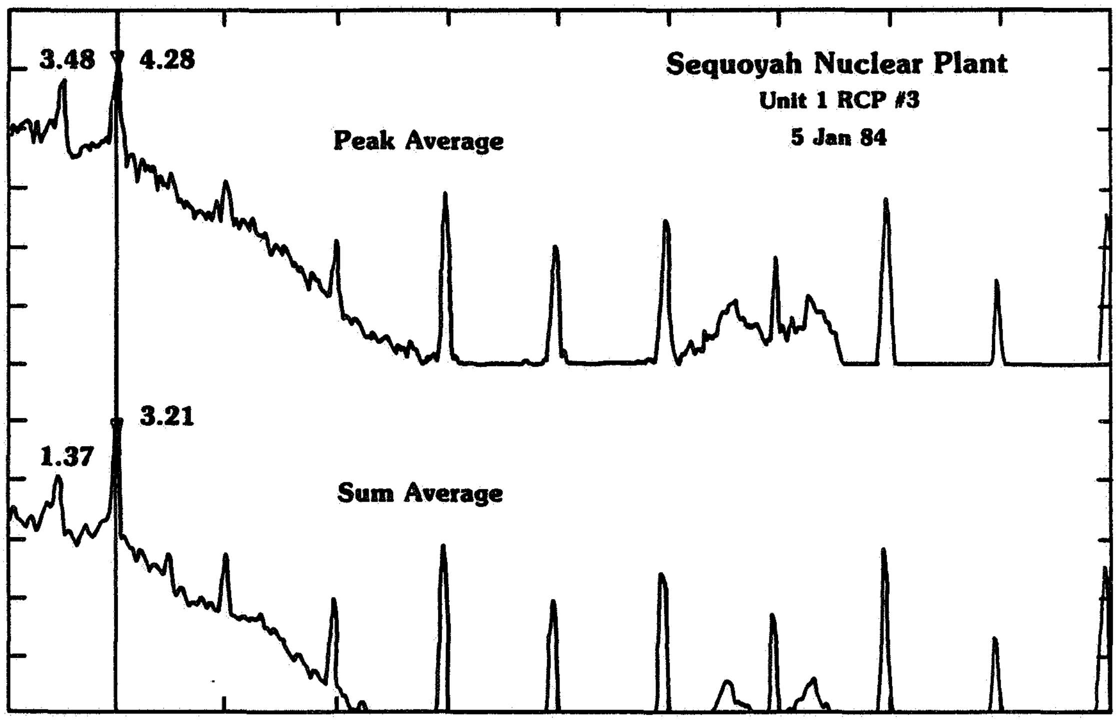


Figure 7