1985

CHICKAMAUGA HYDRO PLANT UNIT REALIGNMENT

AS A RESULT OF CONCRETE GROWTH

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ABSTRACT

The Chickamauga Hydro Plant has been plagued with numerous occurences of foundation cracking and unit misalignment problems. Studies have proven that the primary cause for these problems is concrete expansion (concrete growth) resulting from an alkali-aggregate reaction. Over the years it has been necessary to grind the throat rings to provide adequate blade-to-throat ring clearance for all the units. On several occasions it has been found that the wicket gates could not be completely closed because of misalignment between the head cover and distributor ring. In 1980, unit 4 was disassembled and realigned because the wicket gates could not be completely closed. This paper presents a brief background on the concrete problem at Chickamauga and the results of the realignment of unit 4.

NOMENCLATURE

Below is a list of the terms used in this paper.[1] An identification number is given by each item which also appears on Figure 1 to assist in identifying the component.

1. Distributor Ring - the stationary ring attached to the stay ring which contains the lower wicket gate bushings, sometimes called bottom ring.

2. Draft Tube - the water passage which carries water away from the turbine runner and regains the residual velocity energy.

3. Draft Tube Liner - the steel lining used in the draft tube to protect the concrete.

4. Excitor Bridge - the structural member used to support the main and pilot excitors.

5. Generator stator - it contains the armature in conventional ac generators.

6. Inner head cover - the inner section of the head cover which supports the turbine guide bearing and packing box.

7. Nose vane - the junction of the small and large ends of the spiral case.

8. Outer Head Cover - the outer portion of the head cover that supports the upper wicket gate journals.

9. Runner - the rotating part of the turbine or water wheel that transforms hydraulic energy into mechanical energy.

10. Runner Blades - the parts of a propeller runner which transfer energy to the hub from flowing water.

11. Runner Hub - the main body of the runner to which the runner blades are attached.

12. Semi-spiral case - the water passage around the turbine which provides uniform flow through the wicket gates and has direct flow from the head water to its upstream portion.

13. Stay Ring - the support frame consisting of upper and lower rings connected by a number of fixed guide vanes surrounding the wicket gates.

14. Stay Vanes - fixed guide vanes attached to the upper and lower sections of the stay ring which provides support. It also guides the water to the wicket gates.

15. Throat Ring - the band which surrounds the blades on a propeller turbine runner.

16. Thrust Bearing Support Bridge - the structural member used to support the dead weight of the turbine and the hydraulic thrust, sometimes called main bridge.

17. Turbine Shaft - the shaft which connects the runner hub to the generator shaft.

18. Wheel Pit - the open area in a vertical unit between the generator and the top of the turbine.

19. Wicket Gates - the adjustable guide vanes which regulate the flow of water to the turbine.

20. Wicket Gate Servomotors - the hydraulic actuators which operate the wicket gates.

INTRODUCTION

The Chickamauga Hydro Plant was constructed by the Tennessee Valley Authority (TVA) during the period 1936-1940 as part of a program to control and develop the Tennessee River. The plant is located seven miles above the City of Chattanooga, Tennessee, and is one of nine TVA dams on the Tennessee River that help regulate the river's flow for flood control, navigation, and electric power production.

Units 1, 2, and 3 were initially installed and began operation in 1940. Unit 4 was placed in operation in 1952. All four vertical units utilize Kaplan adjustable-blade propeller turbines with a rated capacity of 36,000 horsepower (each) at 36 feet net head as shown in Figures 1 and 2. The generators are rated at 30,000 kilowatts resulting in a total plant capacity of 120,000 kilowatts.

Throughout the history of the plant, there has been numerous occurrences of foundation cracking and unit alignment problems which have led to much concern over the quality and structural condition of the concrete used during its construction. Consequently, a considerable amount of research has been done over the years attempting to determine the quality of the concrete, identify problems, and determine the cause and effect of the problems. Studies have shown that the primary cause for the structural problems at the plant is concrete expansion (concrete growth) resulting from an alkali-aggregate reaction.

Although the progressively more serious structural problems have occurred in the navigation lock, since the early 1950's intermittent problems have been encountered with the misalignment of the units in the powerhouse due to the affects of concrete growth. It has been necessary on all four units (some more than once) to completely disassemble the units and realign the head cover with the distributor ring. This paper presents a brief background on the concrete growth problem at Chickamauga and the results of the realignment of unit 4 which occurred in 1980.

CONCRETE GROWTH

Petrographic examinations have been performed by the Corps of Engineers Waterways Experiment Station on concrete cores removed from Chickamauga. The first examination was performed in 1963 on cores removed from the powerhouse. It was initiated by the many unit alignment problems which have occurred over the years. The second examination was performed in 1966 on cores removed from the lock. It resulted from a sudden joint opening in a lock wall. According to the petrographic examinations, an expansive alkali-aggregate reaction has occurred involving the dolomitic limestone coarse aggregate and alkalies in the concrete.

Concrete cores were removed from three areas in the powerhouse. The first core was removed from the semi-spiral case which is constantly wet. The second core was removed from the draft tube access gallery which is usually damp. The third core was removed from the pipe gallery which is constantly dry. Expansion tests on the cores showed expansion from the dry areas was twice those from the damp and wet areas. These tests were confirmed with tests performed on cores removed from wet and dry areas on the lock. These expansion tests imply that the dry concrete may have not yet realized its expansive potential and the presence of moisture affects the expansive reactions.[2]

RESULTS OF CONCRETE GROWTH

Concrete deterioration caused by a chemical reaction between high alkalies in cement and alkali-reactive aggregates, is characterized by the following observable conditions: <u>(1) excessive expansion or growth</u>; (2) large scale and random cracking; (3) wide surface cracks which may only extend a short distance into the concrete; (4) gelantinous and chalky deposits on the surface of the concrete.[3]

All of the above characteristics can be of concern not only from their appearance but also from implications of structural problems. Primarily, the one characteristic which affects the operation of the powerhouse is the concrete expansion or growth. As the concrete expands the embedded parts of the generating units (i.e., throat ring, distributing ring, and stay ring) shift or move resulting in misalignment of parts. These embedded parts are encased in concrete which is continually wet and confined with drier concrete (concrete at a greater depth which has not expanded significantly). As this confined concrete expands, it presses in and deforms these parts.

The 263.625-inch diameter Kaplan turbine runner at Chickamauga, runs with an Original Equipment Manufacturer (O.E.M.) design radial clearance of 0.1875 inch. As the concrete around the throat ring expands, it closes in on the runner and reduces this clearance. Thoughout the history of these units, it has been necessary, periodically, to air-arc and grind the throat rings to maintain adequate blade-to-throat ring clearance. Movement of the embedded parts not only closes the blade-to-throat ring clearance but it also causes havoc with the wicket gate assembly. On several occasions it has been found that the wicket gates of each unit could not be completely closed because of misalignment between the head cover and distributor ring. In 1980, unit 4 was disassembled and realigned because the wicket gates could not be completely closed.

REALIGNMENT AND REPAIR OF UNIT 4

<u>Realignment</u>

On July 18, 1980, it was discovered that unit 4 would not completely stop because the wicket gates could only be closed to 1.5 percent gate. The wicket gate servomotors had to be externally assisted with jacks in order to completely close the wicket gates and shut down the unit. The unit was then removed from service and the wicket gates were inspected for problems. It was found that the wicket gates would start rubbing at approximately 60 percent gate and they would close no further than 1.5 percent gate. An attempt was made to free the gates up to enable the unit to return to service. After three days of measuring and cleaning, the gates were still tight and could not be closed any further than 1.5 percent gate. The throat ring in this unit had been ground numerous times in the past to maintain adequate blade-to-throat ring clearance. Through our past experience, with the misalignments of the other three units at Chickamauga, a decision was made to disassemble the entire unit and realign all of the components.

The unit was completely disassembled (utilizing in house personnel) and all of the components were removed except for the outer head cover. Because of its size and the configuration of the wheel pit, it is impossible to remove the outer head cover. In order to remove the wicket gates, the outer head cover was raised up and placed on pipe stands. The draft tube scaffold was installed immediately below the throat ring at the top of the draft tube liner. Since the throat ring is embedded in concrete and cannot be moved, the whole unit must be centered with the throat ring. The exciter bridge was installed back in place from which a 55 foot long plumb wire was suspended and centered in the throat ring. A 50 pound plumb bob in a container of oil was used to stabilize the wire. Measurements were taken from the throat ring, distributor ring bushing holes, and outer head cover to the plumb wire.

Figure 4 is a plot of the distance from the plumb wire to the throat ring wall. Figure 6 is a plot of the distance from the plumb wire to the center of the wicket gate bushing holes in the distributor ring. It is interesting to note that both of these plots are eggshaped and the axis of the major diameters coincide with the location of the nose vane as shown in Figure 3. Since the nose vane is located where the semi-spiral case has its minimum cross-sectional area, this would be where the embedded parts have their greatest structural support. The support of the embedded parts gradually decreases as the cross-sectional area of the semi-spiral case increases and approaches the intake as shown in Figures 2 and 3. We believe this explains the shape of the throat ring shown in Figure 4 and the direction of movement for the embedded parts.

Figure 5 is a plot of the distance from the plumb wire to the inner head cover-to-outer head cover fit on the outer head cover. The plot shows that the head cover is misaligned with the center of the throat ring by approximately 0.500 inch 20 degrees counterclockwise with the axis of the powerhouse. We believe that most, if not all, of this misalignment resulted from the movement of the lower part of the stay ring (including the throat ring and distributor ring) due to the shape of the throat ring shown in Figure 4. This means that the center of the throat ring has moved rather than the center of the outer head cover.

The wicket gates at Chickamauga are designed to operate with 0.040 inch end clearance. Calculations reveal that if the head cover is moved 0.250 inch out of line with the distributor ring, the end clearance will be exhausted and the gates will rub the head cover and distributor ring. Since a misalignment of 0.500 inch was found in unit 4, this explains why the wicket gates could not be completely close.

In order to realign the unit, the outer head cover, thrust bearing support bridge, and generator stator had to be moved and centered with the throat ring.

The outer head cover was removed from the stands and lowered back into place. Four aluminum plates were fabricated and installed in the wicket gate thrust bushing holes of gate numbers 3, 8, 14 and 20. A plumb wire was suspended through the center of each plate with a small plumb-bob attached and located in the corresponding bushing holes in the distributor ring. Measurements were taken and a move was plotted for the outer head cover. A small amount of metal had to be removed from the inside of the stay ring and the outer head cover flange bolt holes had to be elongated in order to move the outer head cover. The outer head cover was shifted to attain a compromise of all twenty-four wicket gate bushing holes and the center of the throat ring.

Before attempting to realign the generator stator, it was discovered that the clearance around the hold down bolts was limited due to previous moves (for rounding). The stator was raised up and the bolt holes were elongated. It was then lowered back into place and initially moved 0.400 inch. Final adjustments were made after the rotor was installed and the stator was then redowelled.

During reassembly, the thrust bearing support bridge was shifted a corresponding amount in relation to the head cover and redowelled to the sole plates.

Repair

In the past, as a temporary fix, areas on the throat ring were air-arced and ground smooth to maintain some blade clearance. This was corrected by building up the shallow areas with 308 stainless steel. Deep areas were built up with mild steel and then capped with 308 stainless steel. The throat ring was then ground to the proper diameter and contour.

All of the wicket gate bushings and journals were subjected to excessive wear because of the misalignment and 28 years of service. The bushings were replaced with new bushings manufactured from a C 864 bronze alloy. Upper and lower bushing journals were undercut, welded with 308-16 stainless steel, and machined to dimensions of O.E.M. The gate vanes were blasted and painted with a vinyl water immersion system: Corps of Engineers V766B - base, Corps of Engineers V1206 - top coat.

The unit outage and disassembly provided an opportunity to perform maintenance on the entire unit. Generator thrust and guide bearing shoes were cleaned, inspected and ultrasonically tested. Thrust oil coolers and generator air coolers were cleaned and tested. Wicket gate servomotors were cleaned and inspected. New turbine guide bearing and packing sleeves were installed on the turbine shaft and runouts were checked in a lathe. One blade was removed from the runner hub to check for excessive wear in the bushings and linkage; none was found.

The unit was reassembled with the turbine runner centered in the throat ring. A plumb and rotation check was performed to check verticality and straightness of the shafts and the built-in throw of the unit; all were satisfactory.

A total of 29,000 man-hours and 113 working days was required to realign and repair Unit 4. The unit was returned to service on December 30, 1980.

Since 1980, we have noticed that the shifting of the throat rings in all four units has subsided. The expansive reaction in the concrete around the embedded parts may be depleted or decelerating.

FUTURE THROAT RING REPAIR

No matter how much time and care is used to recontour a throat ring deformed to the extent as found at Chickamauga, there is a limit to the quality of work which can be performed by hand welding and grinding. The surface can still be irregular enough to encourage cavitation.

We have successfully tried a method at our Nickajack Hydro Plant in which a portion of the throat ring was overlaid with stainless steel and machined semiautomatically by a contractor using his patented process. The runner is rotated with equipment mounted on the blades which performs the welding and machining processes. The equipment consists of a remote control friction drive (drive wheel on generator rotor brake band), welding machines with automatic wire feeds, a slide/compound assembly for holding tools for the machining and welding processes, and a collector ring for transmitting power to the welding machines and other tools fixed to the runner. The stainless steel band reduced the throat ring cavitation by approximately 75 percent.

This process may have to be applied to the Chickamauga units in the future in order to accurately true and recontour the throat rings.

CONCLUSION

Investigations into the unit misalignment problem at Chickamauga revealed that the throat rings and other embedded parts were shifting because of concrete expansion (concrete growth). This expansion is caused by an alkali-aggregate reaction that is accelerated by the presence of moisture. Concrete growth has caused the embedded parts of the turbines to shift resulting in tight blade and wicket gate clearances. Most of this shifting has occurred in the lower part of the stay ring and the throat ring. In 1980, Unit 4 was disassembled and realigned because the wicket gates could not be completely closed. Since then, the shifting of the throat rings in all four units has subsided indicating that the expansive reaction around the embedded parts may be depleted or decelerating.

REFERENCE

1. Allis-Chalmers Hydro - Turbine Division, "Standard Definitions and Nomenclature for Hydraulic Trubines and Pump/Turbines", brochure 54X10084-01, pp. 2-5.

2. Tennessee Valley Authority, "Chickamauga Project - Lock Repairs - Concrete Investigations", Appendix B, Nov. 29, 1983, pp. 1, 2.

3. U. S. Department of Interior, Water and Power Resources Service, "Concrete Manual", Eighth Edition, U. S. Government Printing Office, Washington, 1975, pp. 8, 9.

4. Tennessee Valley Authority, "Chickamauga Hydro Plant - Unit 4 - Outage Report", Mar. 12, 1981.

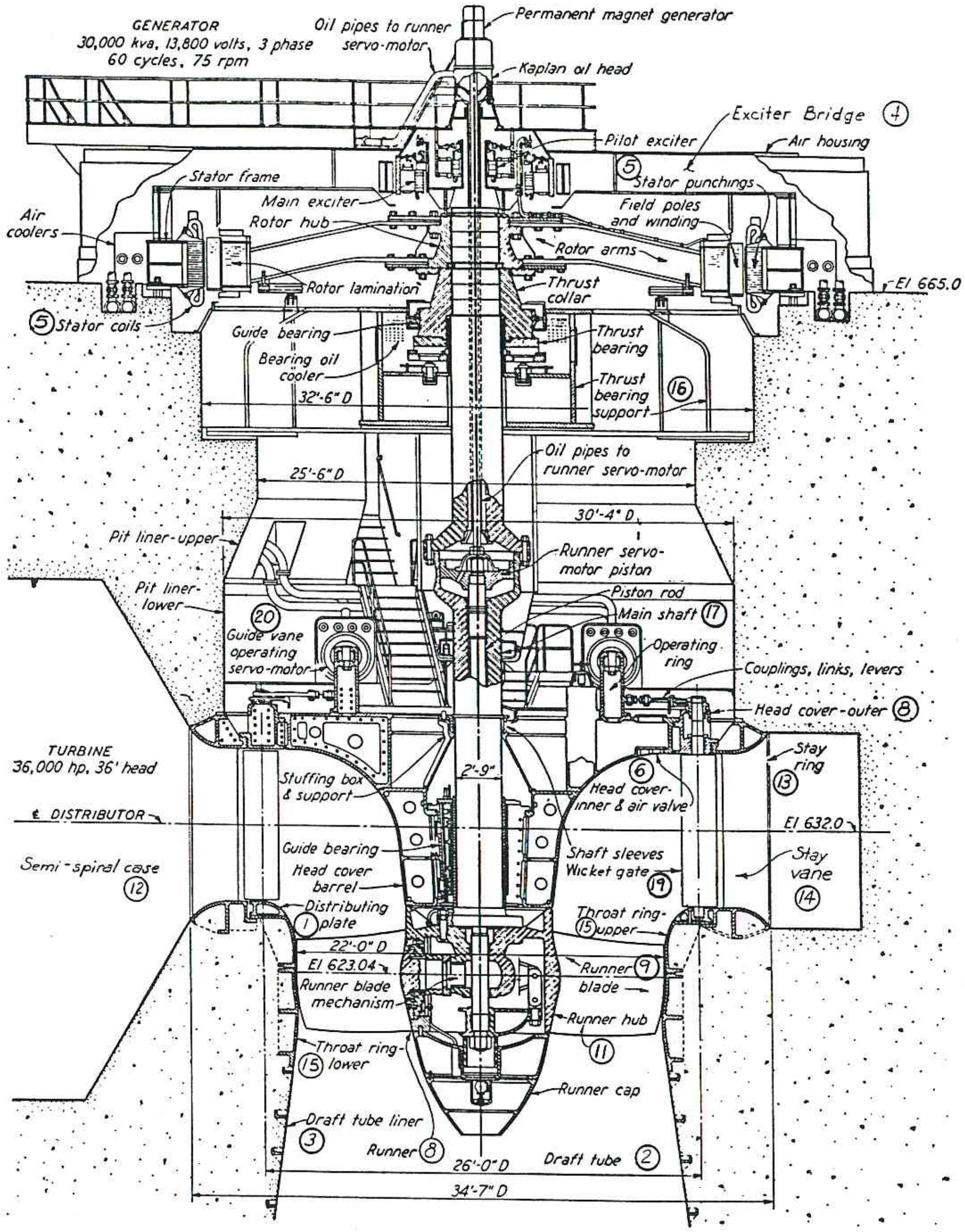

FIGURE I - SECTION THROUGH TURBINE - GENERATOR UNIT

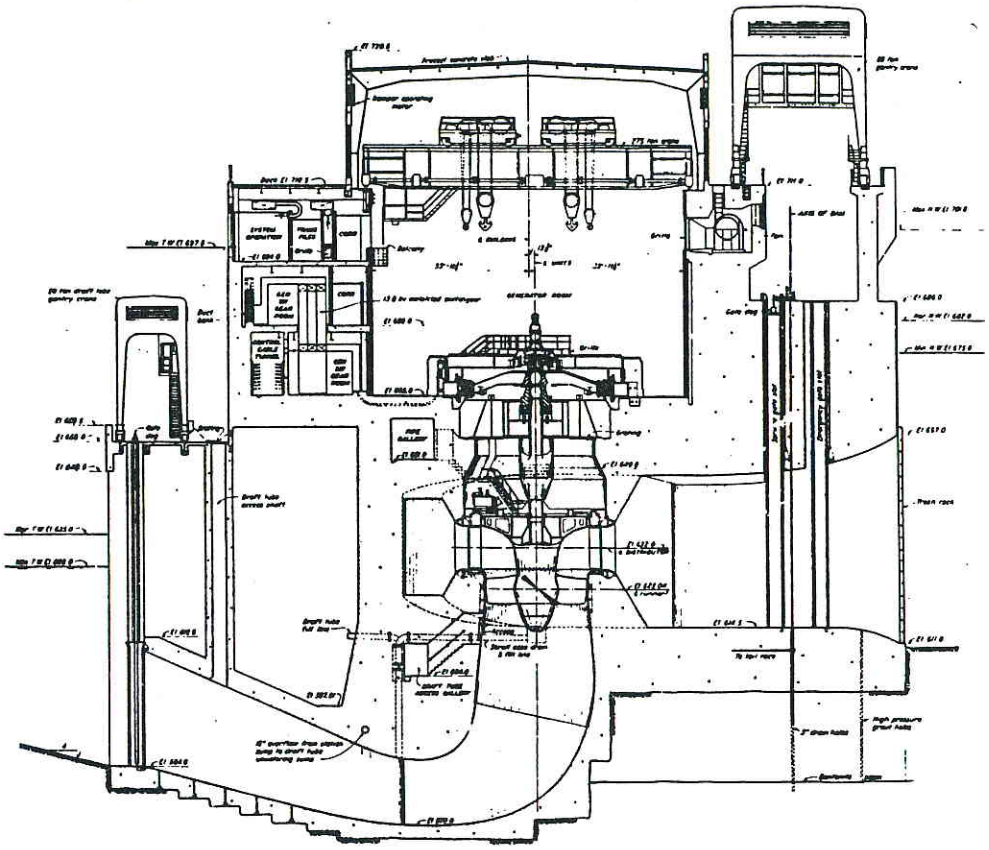

FIGURE 2- SECTION THROUGH POWERHOUSE (UNIT I)

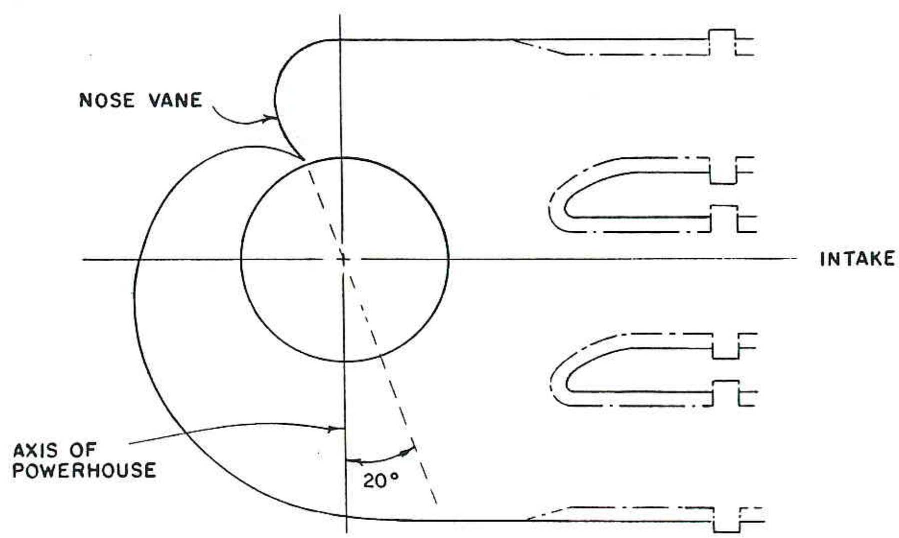

FIGURE 3- SECTION THROUGH SEMI-SPIRAL CASE AT CENTERLINE OF DISTRIBUTOR

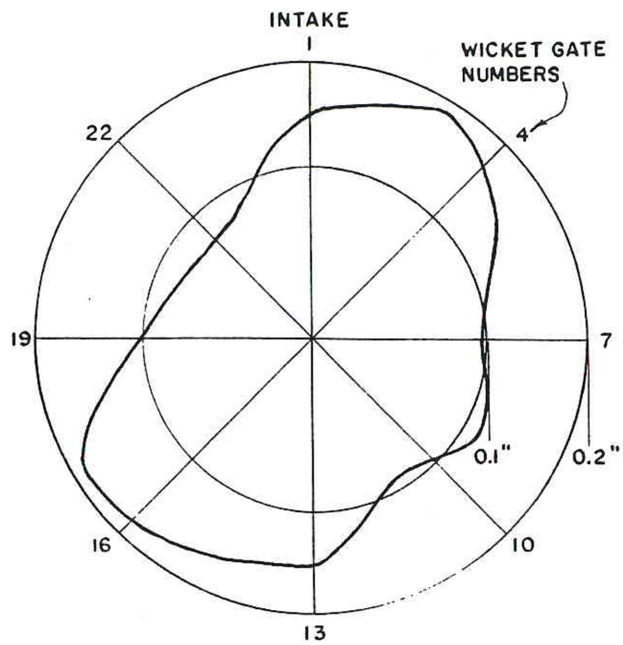

FIGURE 4 - PLOT OF THROAT RING

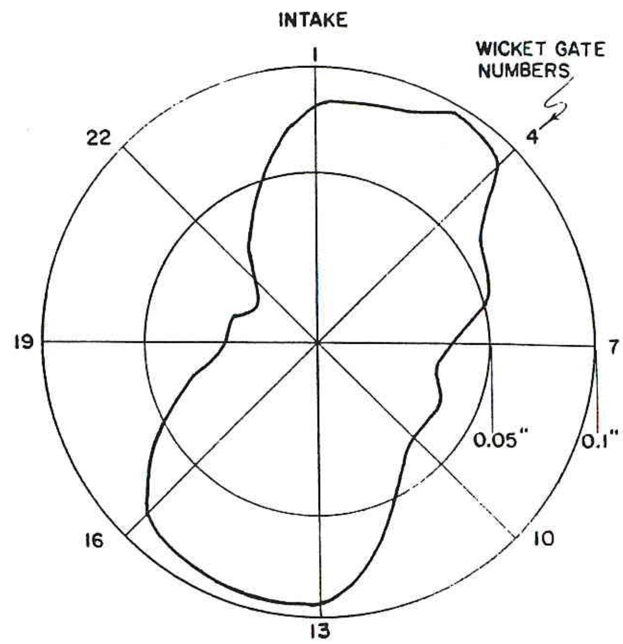

FIGURE 6 - PLOT OF DISTRIBUTOR RING BUSHING HOLES

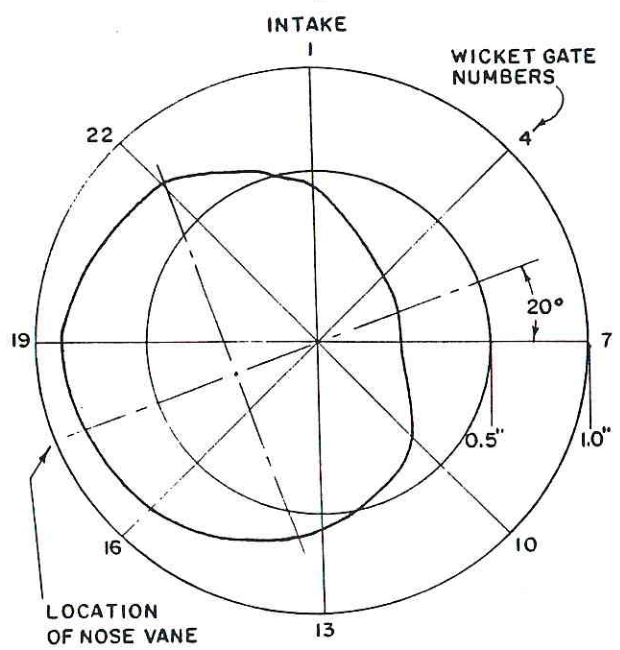

FIGURE 5 - PLOT OF OUTER HEAD COVER