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AN ADVANCED DESIGN MAIN COOLANT PUMP FOR BWR PLANTS

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ABSTRACT

The Byron Jackson® nuclear reactor recirculation pumps have experienced cracking in the shaft and cover. Even though these cracks have not caused safety concerns for the power plants, their potential to lead to shaft failure, as has happened in a few cases, motivated a consortium of Japanese plant owners and manufacturers to develop a crack-free design. The design was fully tested in the Japanese manufacturer's facility and later demonstrated in a new operating power plant in Japan. This paper describes field experience with the original design, the new concept, and its successful demonstration.

INTRODUCTION

Byron Jackson® Boiling Water Reactor recirculation pumps have provided years of trouble-free service. In the early 1980s, however, significant shallow cracks were observed on the shaft and cover of some of these units. A great deal of analysis was conducted by Byron Jackson, Japanese utilities and manufacturers to understand the cause of these cracks and to assess their impact on continuing operation of these pumps.

It was rapidly realized that the initiation of cracks was due to thermal cyclic fatigue caused by the mixing of a stream of cold injection water and the hot system water at a location above the impeller. The injection water is necessary to keep the seal area cool and clean. The early analyses indicated that cracks will tend to grow with time because of thermal effects, but will arrest with crack depths about 0.3". It was deemed that this depth will not compromise the structural integrity of the shaft within the design life of the plant viz. 40 years.

A tremendous effort was initiated by G.E., Byron Jackson, and a consortium of Japanese utilities and manufacturers to solve the thermal cracking problem. This activity produced a two-phase approach. In the first phase, all pumps considered to be at-risk were provided with upgraded components (viz. shafts, covers, and hydrostatic bearings) of substantially same design but with improved safety margins against serious failure. In the second phase, a new concept which totally eliminates thermal cracking was developed and installed in a few plants. After differing amounts of service, two of these installations were disassembled for inspection and found to be crack-free. With this demonstrated success, we now expect introduction of the new design into existing plants.

Cracks found in the cover bore area are typically less than 0.3" deep. While these cracks have a potential for eventual seepage of radio active water into the component cooling system, there has been no clear evidence that such a situation has occurred in the field.

This paper begins with a brief analysis of observed shaft cracks. The new design concept and its demonstration through extensive testing are then described. The paper concludes with the results of the inspection of the plant pump components.

Shaft Cracking

Field Observations. (Figure 1) shows a schematic of the Byron Jackson® BWR recirculation pump. Thermal fatigue cracks occur both on the threaded region within the thermal barrier and on the smooth portion of the shaft immediately below the threads. Figure 2 shows a typical crack pattern. In the groove region the orientation of the cracks is axial. On the smooth portion, cracks occur in a random "turtle back" pattern.

The severity of the cracks is governed by the interacting effects of the rate and temperature of seal injection flow (or absence of injection), the presence of pressure oscillations, and the particular pump geometry. For this reason, there is considerable variation from one pump to another.

i. Flow Visualization Test: A full-size model of the heater was tested in a loop to measure the flow rate through the heater for different rotating speeds. It was determined that at 1395 rpm, total heater flow is 800 ℓ/min, which is quite adequate for heating the purge water to the desired temperature. Also, the flow pattern around the heater was visualized using an oil film method. No undesirable vortices or other flow anomalies were observed.

ii. Mock-Up Test: To determine the actual fluctuating temperatures under different operating conditions, a full-scale mock-up pump facility was built. In this rig, the environment of the heater and the internal heat exchanger were accurately reproduced. Flow into the hydrostatic bearing was driven by an external pump. Temperatures on stationary and rotating parts were measured by using thermocouples with high frequency response. Tests were conducted for various speeds and purge flow rates. Key results from the sequence of these tests are shown in Figure 6. This figure shows the temperature fluctuation ΔT on the shaft surface as a function of flow rate and speed. It can be seen that low values of ΔT are achieved for the range of speeds and flow. It can also be noticed that as expected, the heater effectiveness increases with speed. It is believed that potential for crack initiation exists when ΔT exceeds about 75°C or so. Hence to provide sufficient margin, the maximum limit for purge flow was conservatively established to be 7.5 ℓ/min. over the operating speed range of 280 to 1680 rpm.

Dynamic tests were also performed in this facility to demonstrate the capability of this concept against plant transients. These included fluctuations in purge flow, pump loop flow, etc. The heater performed satisfactorily under all conditions. A total of 1800 hours was accumulated during these tests.

iii. Full-Scale Pump Test: To confirm the performance on an actual full-scale pump, components were installed in the 6000 kW pump. Once again thermocouples were installed and temperature measurements were made. The measured mean and fluctuation temperatures were quite similar to the mock up test results. A total of 500 hours were accumulated in this test. Parts were dye checked after test, and no cracks were observed.

iv. Field Verification: After the successful completion of the tests described above, the new design components were installed in a new nuclear power plant in Japan in the spring of 1992. After about nearly two years of flawless performance, the pump was disassembled and the components were examined by dye penetrant testing. No cracks were found demonstrating the effectiveness of the new design.

CONCLUSIONS

The thermal cracking problem that has plagued the Byron Jackson reactor recirculation pumps has now been solved. A patented concept that greatly reduces the temperature differential which resulted in alternating cyclic stresses has been developed. This concept was fully tested in a mock-up test facility as well as a full-scale pump. Then it was installed in a new operating power plant in Japan. The components were examined after two years of service and found to be crack-free, thereby paving the way for installation of this design worldwide.

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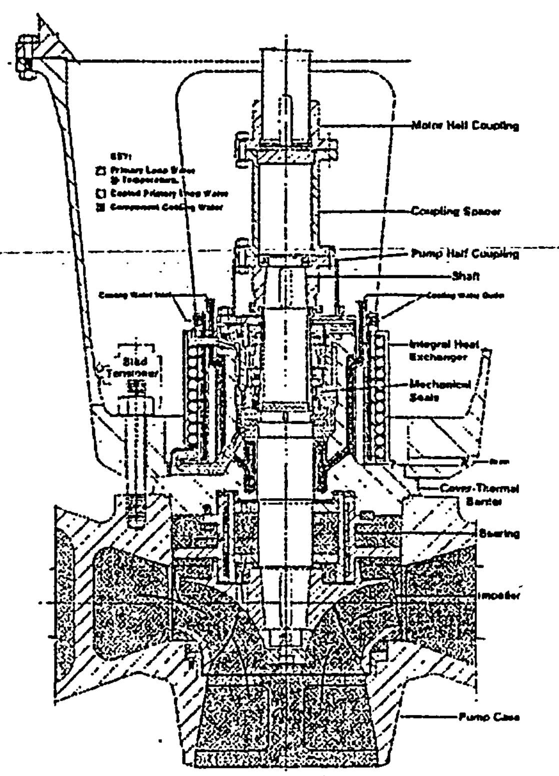

REACTOR RECIRCULATION PUMP

Figure 1

Summary of Temp. Fluct. measurement

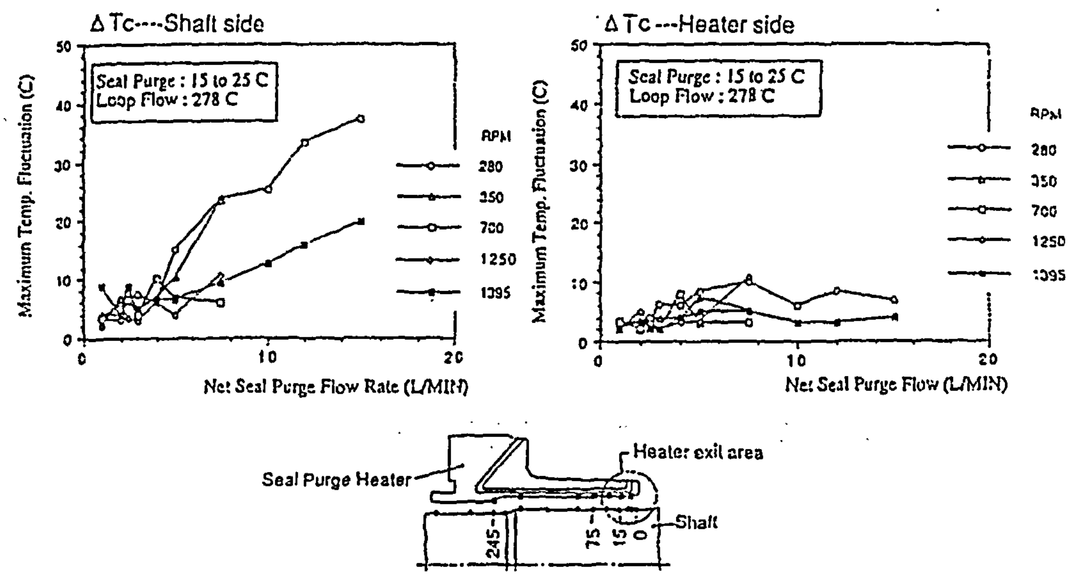

Figure 6