Tennessee Valley Authority, 1101 Market Street, Chattanooga, Tennessee 37402

CNL-15-167

August 7, 2015

10 CFR 50.90

U.S. Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington, D.C. 20555-0001

Watts Bar Nuclear Plant, Unit 1
Facility Operating License No. NFP-90
NRC Docket No. 50-390

Subject: **Watts Bar Nuclear Plant Unit 1 - Response to Request for Flowserve Technical Report on Run-out Flow Operation for a Diesel Generator Frequency above 60 Hertz**

Reference: TVA Letter to NRC, "Application to Modify Watts Bar Nuclear Plant, Unit 1 Technical Specification 3.8.1 Regarding Diesel Generator Steady State Frequency (WBN-TS-13-08)," dated April 6, 2015 [ADAMS Accession No. ML15117A462]

The purpose of this letter is to provide a copy of Flowserve Report GS-8236, Revision 3, "Run-out Flow Operation Capability Analysis," dated March 27, 2013. This submission is being made in response to a July 23, 2015 telephone call from the Nuclear Regulatory Commission staff requesting the report be submitted on the Watts Bar Nuclear Plant (WBN) Unit 1 docket. The report provided information on the impact of a higher allowable diesel generator frequency setting on the safety-related charging and safety injection pumps and was referenced in the Tennessee Valley Authority's application to modify the allowable diesel generator steady state frequency at WBN Unit 1 (referenced letter).

The enclosure to this letter provides the requested report.

There are no regulatory commitments provided in this letter. Please contact Gordon Arent at 423-365-2004 if there are questions regarding this submittal.

Respectfully,

J. W. Shea
Vice President, Nuclear Licensing

Enclosure

cc: See Page 2

Enclosure: Flowserve Report GS-8236, “Run-out Flow Operation Capability Analysis”

cc (Enclosure):

NRC Regional Administrator – Region II
NRC Senior Resident Inspector – Watts Bar Nuclear Plant, Unit 1
NRC Senior Resident Inspector – Watts Bar Nuclear Plant, Unit 2
NRC Project Manager – Watts Bar Nuclear Plant, Unit 1
NRC Project Manager – Watts Bar Nuclear Plant, Unit 2

Enclosure

Tennessee Valley Authority

Flowserve Report GS-8236, “Run-out Flow Operation Capability Analysis”

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RUN-OUT FLOW OPERATION CAPABILITY ANALYSIS

NPO ORDER NUMBER: RLCD00618

CUSTOMER: TENNESSEE VALLEY AUTHORITY

CUSTOMER P.O.: 500688

EQUIPMENT: 2 ½" RLIJ AND 3" JHF

REPORT NUMBER:
GS-8236

FLOWSERVE CORPORATION
NUCLEAR PRODUCTS OPERATIONS
DATE: MARCH 27, 2013

Revision 1:
March 8, 2003 – Editorial corrections and incorporated comments
Revision 2:
March 12, 2013 – Incorporated internal comments
Revision 3:
March 27, 2013 – Final Report

PREPARED BY: REHAN FAROOQI

APPROVED BY: MICHAEL EFTYCHIOU

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BACKGROUND

Due to the requirement of evaluating the impact of allowable tolerances in Emergency Diesel Generator (EDG) frequency and voltage, an evaluation is required to assess continuous operation up to 30 days for the Centrifugal Charging pumps (CCP – Flowserve 2 ½" RLIJ) and Intermediate Head Safety Injection (IHSI – Flowserve 3" JHF) pumps at the maximum flow (run-out) condition.

From attachment D of Westinghouse document WBT-D-3959 NP, the bounding conditions have been developed as follows:

Pump	Maximum Flow (GPM)	NPSHA (Feet)
CCP (2 ½" RLIJ)	561 (~165% of BEP)	298.71
IHSI (3" JHF)	677 (~145% of BEP)	94.50

(Note: Flow rates are rounded to next whole number)

For a conservative analysis the temperature of water is assumed to be 60 F, which would result in maximum rate of material removal in a cavitating condition.

Review of Power Vs Flow curves are essentially flat, therefore, extra power consumption did not seem to be an issue with 0.3% changes in EDG frequency. Assuming a typical system curve shape at the run out flow rates for both the IHSI pump and CCP, the range of change expected in Flow rate, Head and Power is tabulated below.

Pump	Change in Run-out Flow (GPM)	Change in Run-out Head (Feet)	Change in Run-out Power (hp)
CCP (2 ½" RLIJ)	+0.2% - +0.4%	+0.3% – +0.7%	+0.5% to +0.85%
IHSI (3" JHF)	+0.2% - +0.4%	+0.3% – +0.7%	+0.6% to +1.05%

A review of the NPSHR curves, however, indicted that the CCP Pump (2 ½ "RLIJ) will operate at or very close to the asymptotic rise of the NPSHR curve. Given the potential effects of cavitation damage on the first and second stage impeller and possibly in the first stage diffuser, which can limit the pump life and affect performance, a careful analysis is required to assess the probability of damage due to cavitation and in case of damage, the impact on pump overall performance.

SCOPE

This report evaluates the first and second stage impeller design for operation at run-out flow rates for extended durations for the CCP (2 ½" RLIJ) and IHSI (3" JHF) pumps. Flow distortions caused by the suction casing are to be taken into consideration while evaluating the maximum flow performance of the first stage impellers for both pumps, while the pre-swirl introduced by the return guide vanes is considered for the second stage impeller performance at maximum flow. The diffuser cavitation potential for the first stage is also considered at maximum flow rate.

SUMMARY AND RECOMMENDATIONS

Centrifugal Charging pumps – Flowserve 2 ½ " RLIJ

1. The CCP is expected to undergo cavitation damage on the 1st stage diffuser and the second stage impeller while operating at run-out flow condition as specified in table above. The rate of damage would allow continuous operation to 30 days with some pitting and gouging type damage in the first stage diffuser and second stage impeller.

2. Further damage to inlet vane tips of the first stage impeller would occur in 3 to 4 months, however this damage would be 'self-arresting', that is the rate of damage would reduce as the inlet area opens up due to vane material removal. Therefore the pump should be able to operate for up to 1 year. Sudden loss of pump performance is not expected due to this cavitation damage process.

3. There may be an increase of pump vibration due to circumferentially uneven removal of metal from the vanes. Due to variations in metallurgy from vane to vane, the metal removal may be different on each vane hence causing mechanical and possibly minor hydraulic unbalance. The vibration increase is expected to be gradual as the cavitation material removal is not a sudden process.

4. In a worst case scenario the total volume of metal removed due to cavitation from the impeller and the diffuser combined would be approximately 1 cubic inch. The Majority of the material is likely to be removed in the shape of tiny fragments or particles over several months.

5. The first stage diffuser damage would result in opening of diffuser areas, hence flattening the Head vs Flow curve of the first stage only. In a worst case damage scenario this may increase the overall head generated by 1% - 3.5% and the power required by 1% – 3%. This increase in power would be gradual over several weeks.

Intermediate Head Safety Injection – Flowserve 3" JHF

1. The first stage diffuser of the IHSI pump is expected to undergo cavitation damage. There may be minor damage to the first and second stage impellers but the cavitation damage is not expected to be high due to low tip speeds. The pump should be able to run 1 year without sudden loss of performance.

2. Similar to (5) in CCP above, the worst case scenario of diffuser damage may increases the first stage head at the run out flow conditions. Which may increase the overall Head by 1%-2% and power requirement by 1-3% . This change would be gradual over several weeks.

3. The volume of material removed from the diffuser should be less than 0.3 cubic inches. Since material lost from the impeller is limited, increased vibration due to mechanical unbalance is not expected.

DISCUSSION

SUCTION CASING DESIGN

For typical barrel pumps the suction inlet is a symmetric top down design along the centerline of the shaft. This design introduces positive and negative pre-rotation zones on either side of the centerline and affects the inlet velocity triangles of the impeller. Figure 1 below is a representative flow pattern on a typical top down suction casing.

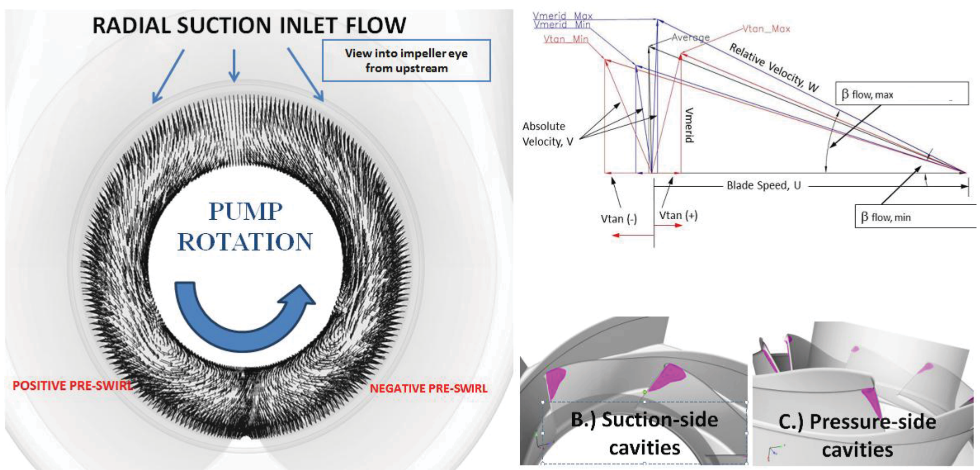

Figure 1. Flow vectors in a typical radial top down suction inlet (Left) – Range of typical inlet velocity triangles at the first stage impeller (top right) – Pressure side and suction side cavitation pulses on the impeller at shockless flow (bottom right)

Area progression in the suction casing was reviewed for the JHF and RLIJ pumps and based on CFD experiences with similar design suction inlets, an estimation was made for the maximum pre-rotations to generate the bounding velocity triangles for the purpose of analysis and an estimate of the corresponding shockless* flow rates.

FIRST STAGE IMPELLER DESIGNS

CCP (2 ½” RLIJ)

The hydraulic design at the impeller inlets can best be categorized as over-designed or oversized. The shockless* flow rate at the impeller inlet for no pre-swirl is even higher than the maximum flow rate (165% -185% of BEP for 2 ½” RLIJ first stage). Normally, impellers are designed for shockless flow rates around 110% of BEP.

Impellers designed for such high flow rates may result in operation with considerable suction recirculation at BEP operation. The damage due to suction recirculation is difficult to ascertain by 1-D analysis. However given the low energy levels and low tip speeds, the rate of damage caused by suction recirculation would be low No major issues

*_ *shockless flow rate is defined as the flow rate at which the flow vectors align best with the shape of the impeller inlet. For a given NPSHA the cavitation bubble / cavity are the smallest at this flow rate.*

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with recirculation related impeller damage have been reported during the operating history of these pumps.

With a high NPSHA at run out conditions (298 feet), the cavity length at run-out conditions is expected to be small; hence, the damage rate due to material erosion is expected to be less than 0.5 mm/year. Even in case of damage, it is estimated that due to blade angle distribution and meridional area increase along the blade the damage would lower the NPSHR at maximum flow rate, thus allowing the pump to continue operation.

IHSI (3” JHF)

The hydraulic design of the 3” JHF suction impeller is unconventional as it has a relatively low inlet vane angle but a sudden increase in vane angle after 10% of vane length. The effective inlet vane angle at the location of the inlet throat is 3 to 5 degrees more than apparent from hydraulic drawings. The JHF first stage impeller is likely to experience significant pulsating or flipping cavitation activity as the impeller rotates 360 degrees and each vane interacts with the flow distortion caused by the suction inlet design. However the tip speed for the 3” JHF is only 66 ft per second, so the damage rate by cavitation is calculated to be 1mm per year in the worst case scenario. As with the RLIJ first stage, any damage to the vane inlet would open up the throat area, increase vane angles and would therefore reduce the NPSHR, hence allowing continued operation of the pump.

1st STAGE DIFFUSER DESIGN:

At run out flow rates, both the CCP and IHSI pumps are expected to experience some diffuser cavitation. There would be 10-20 degrees of incidence at the diffuser and high velocities, and low total pressure rise across the first stage. The damage rate can be appreciable as the collapse energies of the bubbles would be substantial due to high velocities and rapid change in static pressure profile developing in the diffuser. A better estimate of possible cavitation and therefor erosion rate can be made by CFD analysis. However, even in case of heavy damage, the diffuser throat area would open up allowing continued operation at maximum flow rates. Sudden loss of pump performance is not expected. The pump should continue to operate despite damage to 1st stage diffuser vanes.

RETURN GUIDE VANES

For both the IHSI and the CCP pumps the intent of design of the return guide vanes is to remove the swirl from the flow. This is why these vanes are also called de-swirl vanes. From CFD and test experience, we know that some angular momentum is conserved and some residual swirl is passed onto the next stage. Review of the design of the return guide vanes for both the IHSI and CCP pumps indicate that swirl velocity could be 10% of axial velocity. This impacts the second stage NPSHR performance and pushes the shockless flow rate to a lower value and therefore lowers the onset flow-rate of asymptotic point on the NPSHR curve for the second stage.

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SECOND STAGE IMPELLER DESIGN

CCP (2 ½" RLIJ)

The hydraulic drawing of the second stage impeller has steep inlet vane angles, almost 32 degrees at the shroud and 40 degrees at the hub, for zero swirl the design would accommodate up to 600 GPM without asymptotic behavior of NPSHR curve. However the vane angle development for the 2 ½ "RLIJ is heavily loaded, that is, the rate of change of blade angle from very steep at inlet to shallow at exit happens in a relatively short vane length. Also the possibility of residual pre-swirl from the return guide vanes causes lower than expected shockless flow rate. Based on a 15% swirl at the impeller inlet, the shockless flow rate may be as low at 510 GPM. The calculation is based on some assumptions based on experience with CFD of similar configuration and also based on test behavior of the pump.

From NPSHR test data we know that the second stage impeller NPSHR curve starts to asymptote close to 530 -540 GPM. The residual swirl from the return guide vanes also contributes to the lower than expected shockless flow. However high NPSHA and the total head added by the first stage indicate that total pressure available at the second stage inlet is in excess of 450 feet. The cavity length however should be sufficient to block the throat area partly resulting in the asymptotic behavior seen. Assuming the cavity length of 12 mm and using the relation for rate of material removal from the Pump Handbook, 4th Edition, Page 2.90, Table 19:

$$\mathrm{MDPR} = \left[C \times (L_{cav}/10)^n \times \left(\tau_A - \phi_e^2\right)^3 \times U_e^6 \times \rho_L^3 \times A\right] \Big/ \left[8 \times F_{mat} \times (TS)^2\right] \mathrm{mm/h}$$

The leading edge of the vane would lose significant material in 3-4 months.

For operation beyond this stage an analysis of impeller area progression vs. vane development angles and corresponding NPSHR was carried out for a worst case scenario of operation at 565 GPM in which it is assumed that the impeller vane leading edge loses 1" of length. The analysis showed that due to opening up of throat areas, the NPSHR is expected to reduce, therefore the situation should be 'self-arresting', that is, after some damage the rate of damage should reduce. Significant drop in pump performance is not expected if the second stage impeller inlet is damaged by cavitation.

IHSI (3" JHF)

Like the first stage, the 2nd stage impeller of the 3" JHF is also an unconventional design. Although the inlet vane angles are shown to be 18 degrees and 27.5 degrees, they actually jump to 27 degrees and 36 degrees shortly along the vane length. The effective result is a much higher capacity impeller than what would be calculated from the inlet vane angles. The NPSHR test data also supports this analysis. While at the run out flow of 677 GPM,

the NPSHA is around 61 feet. The larger cavity would be on the suction side of the impeller, where damage rate is an order or magnitude lower than on pressure side. It is also expected that while there could be damage on the impeller vane leading edges, the rate would slow enough to allow operation for 1 year.