PAP-661

Final Report
WATER Project NMA3A - Detection of Damaging Cavitation
Tests Conducted at Flatiron Powerplant
February 1994

by
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October 12, 1994

ATTACHMENT 1

(TYPICAL FORM)

PEER REVIEW DOCUMENTATION

PROJECT AND DOCUMENT INFORMATION

Project Name NMA3A - Detection of Damaging Cavitation WOID NMA3A

Document Final Report to client (Eastern Colorado Area Office)

Document Date 10/12/94 Date Transmitted to Client ______

Team Leader Tony Wahl Leadership Team Member ______
(Peer Reviewer of Peer Review/QA Plan)

Peer Reviewer K. Warren Frizell Document Author(s)/Preparer(s) Tony Wahl

Peer Reviewer ______

Peer Reviewer ______

REVIEW REQUIREMENT

Part A: Document Does Not Require Peer Review

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Part B: Document Requires Peer Review: SCOPE OF PEER REVIEW

Peer Review restricted to the following Items/Section(s): ______ Reviewer: ______

REVIEW CERTIFICATION

Peer Reviewer - I have reviewed the assigned Items/Sections(s) noted for the above document and believe them to be in accordance with the project requirements, standards of the profession, and Reclamation policy.

Reviewer: Warren Frizell Review Date: 10/12/94
Signature

Preparer - I have discussed the above document and review requirements with the Peer Reviewer and believe that this review is completed, and that the document will meet the requirements of the project.

Team Member: Tony L. Wahl Date: 10/12/94
Signature

FINAL REPORT

WATER Project NMA3A - Detection of Damaging Cavitation

Tests Conducted at Flatiron Powerplant - February 1994

Objectives

This test was conducted for Quick Response Research Project NMA3A, Detection of Damaging Cavitation. The objective of the project is to test and develop new methods, devices, and procedures for detecting the presence of damaging cavitation, primarily in hydraulic reaction turbines. These tests were conducted at Flatiron Powerplant due to the presence there of a known source of damaging cavitation, namely suspected leakage through the closed wicket gates of turbine unit number 1 under approximately 335 meters (1100 feet) of head. Site-specific goals are to identify the operating conditions that produce cavitation, and determine the root cause of the cavitation problem so that it may be eliminated.

Although Quick Response Funding ceased at the end of FY94, work on this project will continue in FY95 with funding from the Eastern Colorado Area Office and WATER project PS006 (O&M of Hydraulic Machinery). Where appropriate, this report will describe related work to be conducted during FY95.

Background

Severe cavitation damage to the wicket gates on unit 1 was observed in early 1994. Damage was confined to the runner sides of each wicket gate, downstream of the seal point at which the tail of one wicket gate seals against the body of the next gate. The suspected cause of the damage was a leaking bypass valve upstream of the unit which allowed full reservoir head to be placed on the closed gates, thereby causing leakage through the gates that led to the cavitation damage. (The runner and wicket gates remain fully submerged under normal tailwater conditions.) The cavitating condition may have been exacerbated by an offset created by the seal, which had been built up with Nitronic 60 during a previous rehabilitation of the gates and was not ground smooth with the existing gate profile. The time period during which the damage occurred is uncertain, but probably was at least several months. At the time of these tests the bypass valve had been repaired, and further damage was thought to have been stopped. The gates were not repaired.

Late in FY94, reinspection of the wicket gates on unit 1 suggested that damage is continuing to occur on the wicket gates. The source of the continuing cavitation damage is uncertain. The poor surface condition of the gates from the previous damage may be causing cavitation during normal operations.

Description of Tests

The tests conducted on February 23, 1994 were done to evaluate the use of accelerometers and hydrophones for the detection of the wicket gate cavitation. Hydrophones were suspended from the downstream side of the powerplant in the tailrace, approximately even with the exit of the unit 1 draft tube. Accelerometers were installed in the turbine pit on the linkage components of several wicket gates and on the turbine shaft. Participants in the test were Tony Wahl and Ernie Bachman (Denver Office), John Germann (Eastern Colorado Area Office), and Dr. Morris Skinner (Colorado State University).

Accelerometers were mounted using a variety of methods, including hot glue, epoxy adhesives, and magnetic bases. In general, hot glue and epoxy are preferred mounting methods, as the magnetic base provides a linear response only up to about 4 kHz. Good hot glue and epoxy mounts should provide a linear response up to about 10 kHz. We had some difficulty getting good epoxy mountings due to the cold temperature of the mounting surfaces, which retarded the curing of the epoxy.

Signals from the accelerometers were recorded on digital tape for later analysis. Signals from the hydrophones were recorded on tape and were also monitored during the test using a dynamic signal analyzer. Signals from all of the sensors were recorded initially with no flow in the powerplant (all units down). To produce cavitation on the wicket gates, the bypass valve around the shutoff gate upstream of unit 1 was opened. Aside from the leakage through the wicket gates, there was no other flow of water through the powerplant during this phase of the test.

Following the completion of the cavitation testing we removed the accelerometer from the turbine shaft and removed the hydrophones from the tailrace. We then operated the unit from speed-no-load up to about 55 percent wicket gate opening while recording the output from the accelerometers installed on the wicket gate linkages. This was done in an attempt to detect any unusual vibrations that might be associated with draft tube surging and might be related to a history of excessive wicket gate shear pin failures on some gates.

Results

Following the tests, the data recorded on digital tape were analyzed using a dynamic signal analyzer. The signals recorded on tape were limited to a frequency range of 0-6.5 kHz.

Power spectrum density plots (figures 1-4) were constructed for the output from each sensor under cavitating and non-cavitating conditions. In all four figures a 10 dB change in the power spectrum density indicates a change of one order of magnitude in the signal level. In figures 1-3, the accelerometer signals are shown in units of g's. The accelerometers on the wicket gates (figures 3 and 4) show significant increases in signal level throughout the range of 0 to 6.5 kHz, with the largest increases (about 10 dB) being below 4 kHz. The signal from the accelerometer mounted on the shaft (figure 3) was also elevated under cavitating conditions, but only below 4 kHz. The largest increases (about 15 dB) were in the range of 0 to 1.5 kHz.

Comparing the power spectra in figures 1-3 shows that there are substantial differences in the distribution of the signals in the frequency domain and in their reaction to the presence of cavitation. By relocating and interchanging the various sensors we confirmed that both the mounting methods and the location of attachment significantly affect the signal. For each particular location, comparison of signals with and without cavitation is meaningful, but comparisons of signals recorded from different sensors at different locations or using different mounting methods would not be valid.

The recorded hydrophone signal (figure 4) also showed increased noise under cavitating conditions, in the frequency range 0 to 6.5 kHz. The largest increases (about 15 to 25 dB) are at frequencies below 2 kHz. Dr. Skinner also monitored hydrophone signals during the test with a dynamic signal analyzer, using one-third octave analysis. We observed significant reductions in signal level above a frequency of about 80 kHz when cavitation was occurring. Unfortunately, we did not record these one-third octave analyses and could not recreate them from the digital tapes due to the 6.5 kHz upper frequency limit of the recorded signals.

The analysis of the signals recorded from accelerometers during operation of the turbine from speed-no-load to 55 percent wicket gate opening gave no indication of wicket gate vibrations related to draft tube surging. We noted that operation of the turbine was quite smooth with no indication of severe surging in the range in which the unit operated during the test. Figure 5 shows the power spectrum of accelerometer output from the linkage of wicket gate 15 with the turbine operating at 45 percent gate. The signal level is elevated throughout the spectrum in comparison with the signals recorded with the turbine not operating (with and without cavitation of the wicket gates).

Conclusions

- Accelerometers mounted on the wicket gate linkage components and on the turbine shaft produced higher signal levels when we recreated the conditions thought to have caused cavitation damage in the past. We observed increases in power spectrum density of 10-15 dB below frequencies of about 4 kHz. However, we cannot conclude from these tests that the increase is entirely due to cavitation, since normal flow noise may have contributed to the increase.

- The exact location of the accelerometers and the method of attachment substantially affect the signal.

- Data collected with the turbine operating were inconclusive. Further data analysis using demodulation methods may provide additional information concerning the question of whether cavitation is occurring during normal turbine operations.

Additional Testing Planned for FY95

The recent discovery that cavitation damage is continuing has prompted the question of whether cavitation is still occurring due to wicket gate leakage or if cavitation is occurring on the gates during normal operations due to the present extreme surface roughness of the gates. Work will continue on this project during FY95 using Area Office funding and funding from WATER (Water Technology and Environmental Research) project PS006, O&M of Hydraulic Machinery. Work activities during FY95 may include:

1) Creating cavitation conditions on a wicket gate model in the hydraulics laboratory and recording signals from accelerometers and acoustic emission sensors in different locations and mounting arrangements to better determine the "signature" of wicket gate cavitation.

2) Possibly use the results of (1) in an attempt to better analyze the data collected during FY94.

3) Make additional measurements in Flatiron powerplant and analyze using the results of (1).

4) Analyze the data collected in FY94 with the turbine running, using demodulation techniques. These techniques may give some indication of cavitation activity with the unit running.

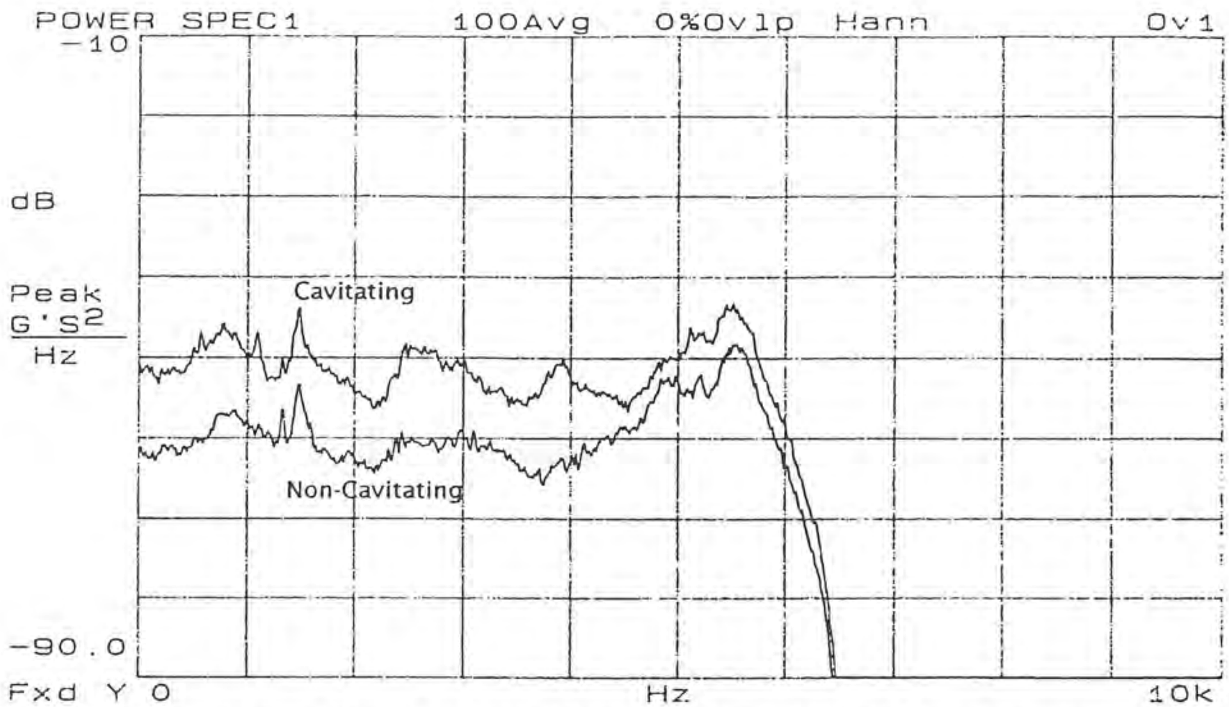

Figure 1. - Power spectrum plots of accelerometer outputs from wicket gate 1 under cavitating and non-cavitating conditions. This accelerometer was mounted on the side of the wicket gate linkage cap using a magnetic base.

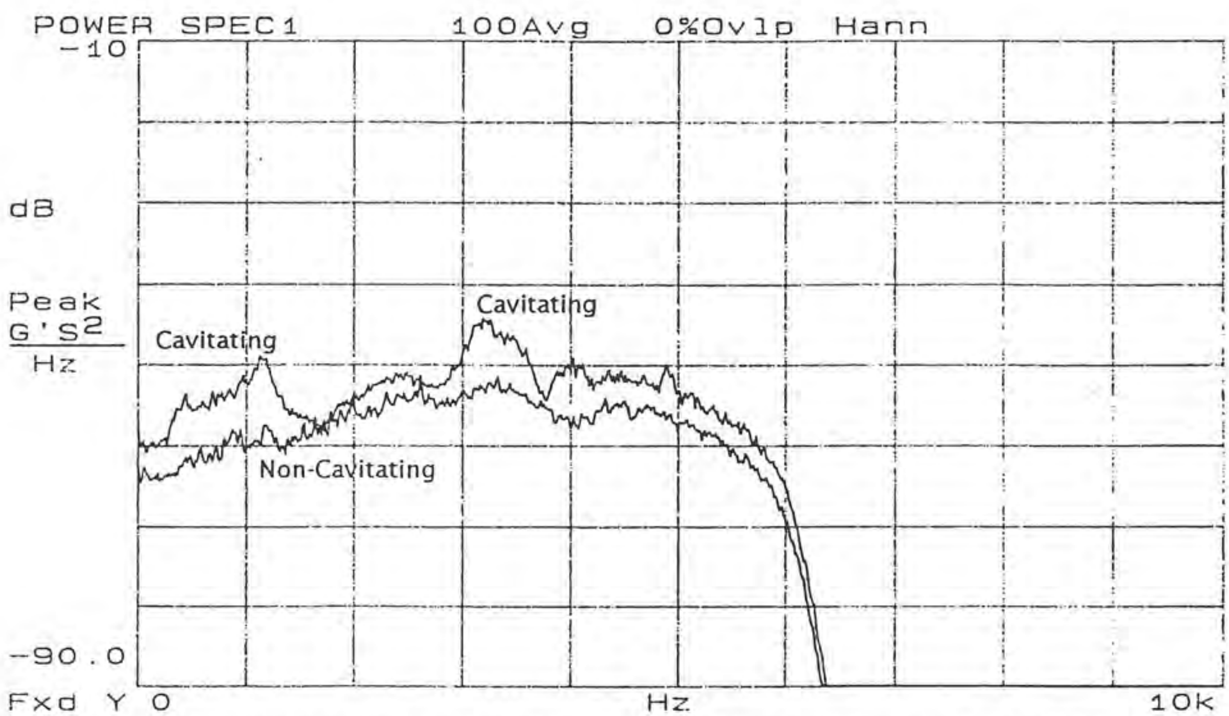

Figure 2. - Power spectrum plots of accelerometer outputs from wicket gate 15 under cavitating and non-cavitating conditions. This accelerometer was mounted on the top of the wicket gate link using epoxy.

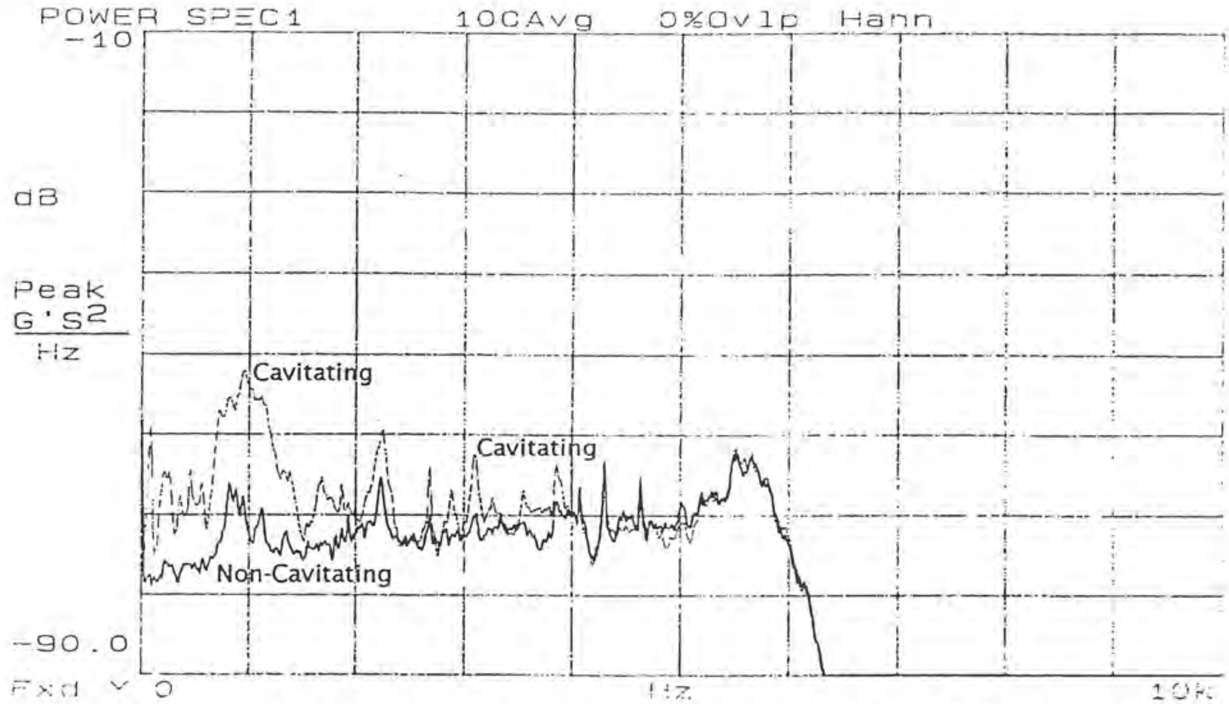

Figure 3. - Power spectrum plots of accelerometer outputs from the turbine shaft, just above the turbine guide bearing. This accelerometer was mounted to the shaft using hot glue.

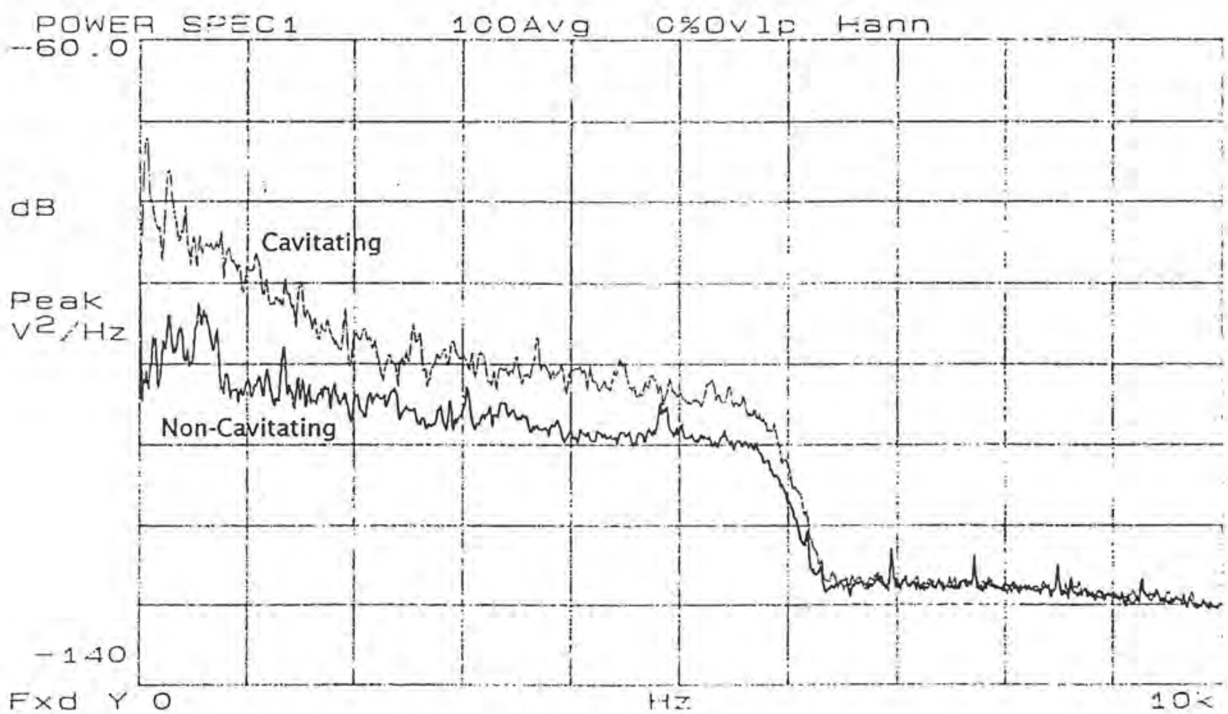

Figure 4. - Hydrophone outputs with and without cavitation.

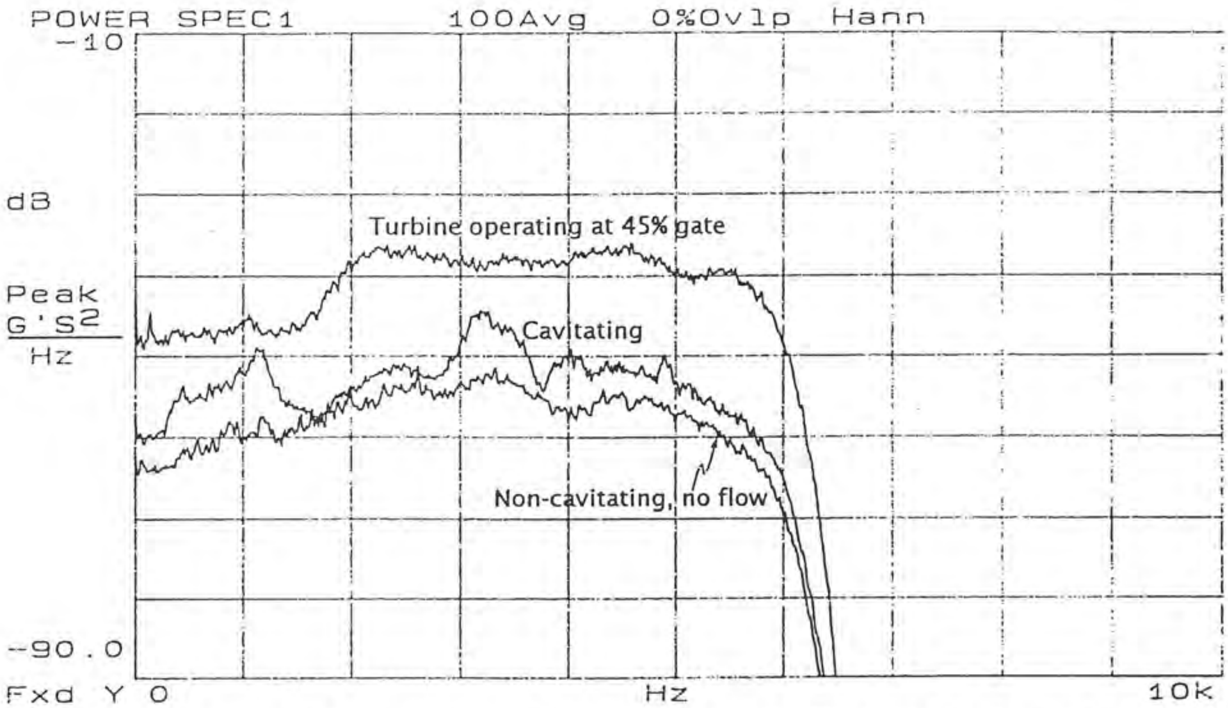

Figure 5. - Power spectra of signals recorded from wicket gate 15. The level of ambient flow noise without cavitation is about 10-15 dB higher than the noise detected during cavitation of the wicket gates without turbine operation.