ASCE Hydraulics Conf. 1991, Nashville, TN.
July 29 - Aug. 2

Detecting the Twin Vortex Draft Tube Surge

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Abstract

Experiments were performed to investigate a twin vortex draft tube surge in a homologous model and the prototype 700-MW turbines installed at the U. S. Bureau of Reclamation's Grand Coulee Third Powerplant. Model tests were conducted on a 1:40.3 scale model turbine located in the new Turbine Research Facility at Colorado State University. Two pressure transducers were mounted 180° apart at the throat of the model draft tube, and pressure fluctuation data were collected with a dynamic signal analyzer and oscilloscope. A BASIC language computer program recorded the operating status of the model turbine. Recent tests have confirmed the presence of the twin vortex in the prototype.

Introduction

The association of a single helical vortex with the phenomenon of draft tube surging has been well known since the earliest model tests in which the draft tube flow could be observed (Dériaz, 1960). Observations of swirling flows in straight ducts (Harvey, 1962; Sarpkaya, 1971) confirmed that the helical vortex was a basic flow structure associated with the breakdown of swirling flows. Work conducted by investigators at the U. S. Bureau of Reclamation (Reclamation) established dimensionless parameters for the amplitude and frequency of pressure fluctuations associated with the draft tube surge, and related these parameters to a dimensionless swirl parameter for the flow through the draft tube (Cassidy 1969; Cassidy and Falvey, 1970; Falvey and Cassidy, 1970).

Although the majority of work has been focused on the single helical vortex, several investigators have also observed a twin vortex in swirling flows (Sarpkaya, 1971; Escudier and Zehnder, 1982). Nishi et al. (1982) and Fanelli (1989) made reference to a twin vortex in turbine draft tubes.

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Recent model tests have defined the characteristics and region of occurrence of the twin vortex for the 700-MW units at Grand Coulee Third Powerplant (Wahl, 1990; Wahl, Skinner, and Falvey, 1991). This paper provides a brief description of those model tests and describes recent tests that confirm the existence of the twin vortex in the prototype units.

Model Tests

Test Equipment and Procedure

The model turbine used for these tests is a homologous 1:40.3 scale model of the 700-MW turbines installed at Reclamation's Grand Coulee Third Powerplant. The test facility was originally installed in a test circuit at Reclamation's Estes Powerplant in the early 1970's, and has recently been moved to the Engineering Research Center at Colorado State University (CSU). The test facility provides geometric similarity with the prototype installation from the penstock intake through the downstream tailrace. At CSU, the model is installed in a once-through flow system drawing water directly from Horsetooth Reservoir, immediately west of the laboratory. The model was designed to operate in the prototype head range of 220-355 ft (67.1-108.2 m). At the current installation, the maximum available head is about 250 ft (76.2 m). A butterfly valve and a 25-ft (7.62-m) standpipe downstream of the model are used to apply back pressure. Load is applied to the turbine by a water-cooled, eddy current absorption dynamometer. Both load and speed control operation are possible.

The operating status of the test facility and model turbine are monitored by a computerized data acquisition system collecting data from pressure transducers, thermocouples, a tachometer, and the dynamometer torque load cell. A computer program written in BASIC controls the collection of data and the required calculations.

Pressure fluctuations due to the draft tube surge were measured with two piezoresistive pressure transducers mounted 180° apart at the throat of the draft tube, in locations that correspond roughly with the mandoor locations on the prototype units. A dynamic signal analyzer was used to obtain frequency spectra for the pressure fluctuations at the upstream transducer location (i.e., corresponding to the inflow side of the powerhouse). An oscilloscope was used to monitor the pressure fluctuations at both locations, to detect changes in their phase relationship.

The model was operated at test points throughout the part-load surging region, with frequency spectra for pressure fluctuations in the draft tube recorded for each test point. Tests were conducted at wicket gate openings of 9°-34°, and net head was maintained in the range of 110-130 ft (33.5-39.6 m) for the majority of the tests; operation at desired points on the turbine hill curve was achieved by varying the runner speed at a given gate setting. The data acquisition system recorded the operating status of the turbine model for each test point. Observation of the flow in the draft tube was made through a clear plastic throat section. The vortex was made visible either by cavitation occurring in the vortex core or by admission of small quantities of air into the draft tube through ports in the runner crown. To minimize the effects of cavitation, pressure fluctuation data were collected with tailwater levels set as high as possible; the cavitation index σ was in the range 0.38-0.42 for most runs.

Test Results

At gate openings greater than 19° (full gate opening = 34°), the part-load draft tube surge in the model was of the typical single vortex variety. The helical vortex was oriented in the form of a left-handed screw, and the vortex precession was in the same direction as the runner rotation. The precession frequency of the vortex was about one-third to one-fourth of the rotational frequency of the runner. Pressure fluctuations in the draft tube occurring at the precession frequency were asynchronous; the signals from the two transducers were 180° out of phase with one another. The amplitude of pressure fluctuations and the size of the cavitated vortex core increased with increasing swirl.

As tests were run at gate settings below 19°, a different pattern of surge development emerged. Cavitation of the vortex core began to decrease at higher swirl values, so that eventually, the single vortex was not visible at high tailwater levels, but could still be seen at low tailwater levels. Despite the loss of cavitation in the vortex core, pressure fluctuations were still detected in the draft tube at frequencies corresponding to the precession of a single helical vortex.

As the swirl value was increased further, the dominant frequency of pressure fluctuations began to shift randomly between two different frequencies. The lower frequency corresponded to the precession of the single vortex observed previously. The higher frequency was generally 2½-3 times the lower frequency. The shifts occurred in a random manner, at intervals ranging from a few seconds to nearly a minute. At gate settings of 17°-19°, the shifting behavior remained random, but at lower gate settings, the higher frequency became well established within a small region of the hill curve. When the tailwater was then lowered, two helical vortices could be seen in the draft tube (Figure 1). Each vortex retained the left-handed orientation of the original single vortex. While the twin vortex was present, the pressure fluctuations at both transducer locations were in phase with one another. A sustained twin vortex was observed at a total of twelve test points, in the range of 9°-15° gate openings (27-45 percent of full gate opening). At a 9° gate setting, the twin vortex region is near maximum prototype head, while at 15° gate, the twin vortex occurs near minimum prototype head.

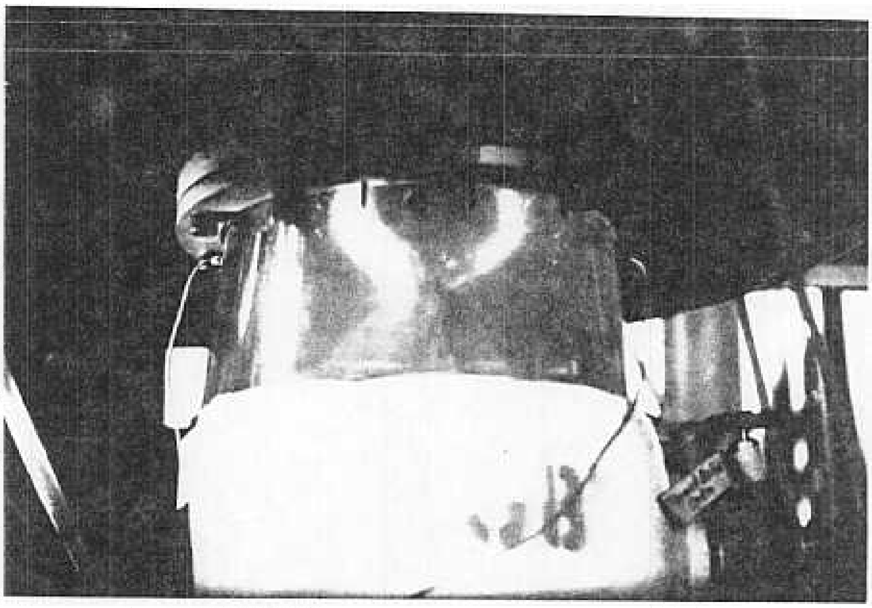

Figure 1. Photograph of twin vortex. The photograph was taken by matching the strobe frequency with the camera shutter speed.

Fisher, Ulith, and Palde (1980) noted similar surge behavior in a review of hydraulic model and prototype tests for the Grand Coulee Third, Marimbondo (Brazil), and Cerron Grande (Brazil) turbines. These installations have similar, but not homologous, turbines and elbow type draft tubes. In tests conducted on a 1:28 scale model of the 700-MW Grand Coulee Third turbines, a random shifting between two dominant frequencies of draft tube pressure pulsations was observed at about 46 percent of the best efficiency gate setting (approximately 12°). The dimensionless frequencies were similar to those observed in the model tests described above. This behavior was also observed in model tests of the Marimbondo turbines at approximately the same gate setting. The vortex was apparently not visible in either test.

Prototype Tests

In December of 1990, Reclamation completed signature tests on Unit G-24 at Grand Coulee Third Powerplant. During these tests, data were collected from numerous instruments, including proximity sensors at the guide and thrust bearings, accelerometers mounted near the draft tube mandoor and on wicket gate stems, and pressure transducers at the draft tube and spiral case mandoors. The test procedure allowed for the collection of data at wicket gate openings of 20-90 percent in 10-percent increments (30-790 MW). Runs at speed-no-load and in synchronous condensing mode completed the test sequence.

The collected data were reviewed following the tests for evidence of the twin vortex draft tube surge. At a 40-percent wicket gate opening (260 MW) the surging frequency, as seen in the pressure pulsations detected at the draft tube mandoor, fluctuated between 0.78 Hz, corresponding to the twin vortex, and 0.29 Hz, corresponding to the single vortex (Figure 2). In addition to the evidence seen in the draft tube pressure records, similar frequencies were seen in the output from the draft tube accelerometer and each of the proximity probes.

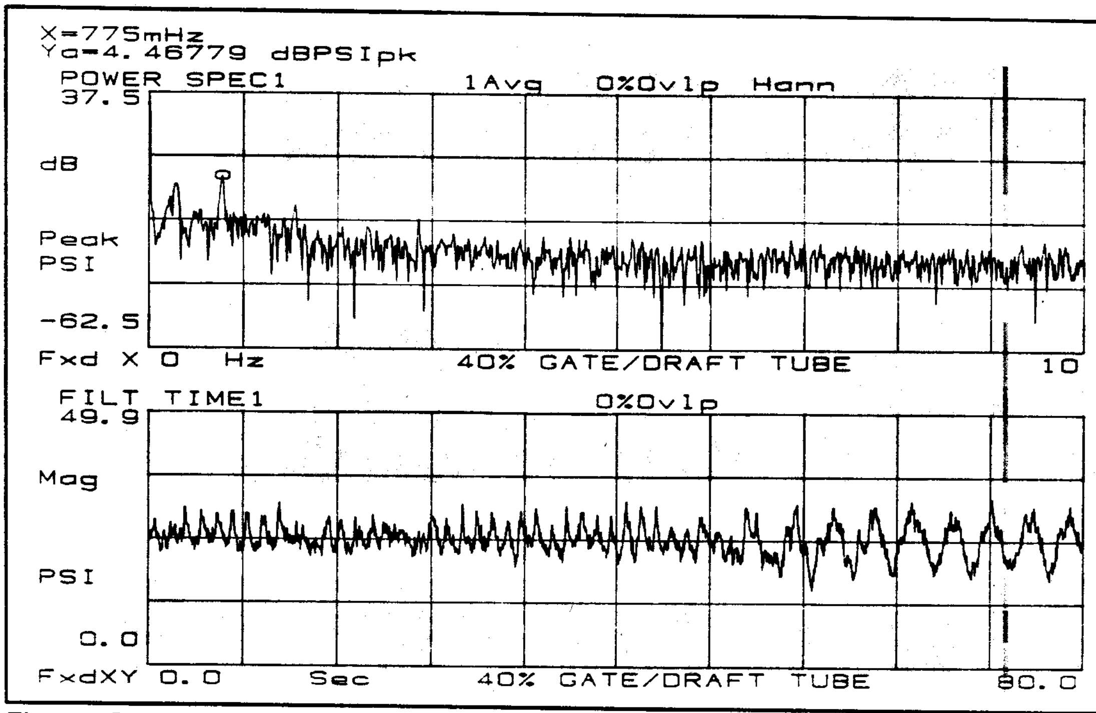

Figure 2. Pressure fluctuations at the draft tube mandoor in the prototype unit. The top trace is the frequency spectrum for the time trace shown at the bottom. A shift from the twin vortex to the single vortex occurs at about 45 seconds on the time trace.

Conclusions

A twin vortex surging mode has been identified in a model of the 700-MW Grand Coulee Third Powerplant turbines, and the characteristics of the twin vortex have been suitably defined so that it may be detected in the prototype units. A simple instrumentation arrangement has been used to confirm the existence of the twin vortex in the prototype units. In addition to pressure fluctuations in the draft tube and vibrations of the draft tube, the twin vortex affected the shaft runout at each of the guide and thrust bearings.

Acknowledgments

The Department of Civil Engineering at Colorado State University, Fort Collins, Colorado, funded the model tests described in this paper.

References

Cassidy, J. J., "Experimental Study and Analysis of Draft Tube Surging," *REC-OCE-69-5, Hyd-591,* U. S. Bureau of Reclamation, Oct. 1969.

Cassidy, J. J., and H. T. Falvey, "Observations of Unsteady Flow Arising After Vortex Breakdown," *Journal of Fluid Mechanics,* Vol. 41, 1970, pp. 727-736.

Dériaz, P., "A Contribution to the Understanding of Flow in Draft Tubes of Francis Turbines," IAHR/AIRH Hydraulic Machinery and Equipment Symposium, Nice, France, Sept. 1960.

Escudier, M. P., and N. Zehnder, "Vortex Flow Regimes," *Journal of Fluid Mechanics,* Vol. 115, 1982, pp. 105-121.

Falvey, H. T., and J. J. Cassidy, "Frequency and Amplitude of Pressure Surges Generated by Swirling Flow," *Proceedings,* 5th Symposium IAHR/AIRH Section for Hydraulic Machinery Equipment and Cavitation, Stockholm, Sweden, 1970.

Fisher, R. K., Jr., U. J. Palde, and P. Ulith, "Comparison of Draft Tube Surging of Homologous Scale Models and Prototype Francis Turbines," *Proceedings,* 10th Symposium IAHR/AIRH Section for Hydraulic Machinery Equipment and Cavitation, Tokyo, Japan, 1980.

Harvey, J. K., "Some Observations of the Vortex Breakdown Phenomenon," *Journal of Fluid Mechanics,* Vol. 14, 1962, pp. 585-592.

Nishi, M., S. Matsunaga, T. Kubota, and Y. Senoo, "Flow Regimes in an Elbow Type Draft Tube," *Proceedings,* 11th Symposium of the IAHR/AIRH Section for Hydraulic Machinery Equipment and Cavitation, Amsterdam, the Netherlands, 1982.

Sarpkaya, T., "On Stationary and Travelling Vortex Breakdowns," *Journal of Fluid Mechanics,* Vol. 45, 1971, pp. 545-559.

Wahl, T. L., "Draft Tube Surging Hydraulic Model Study," *Thesis,* in partial fulfillment of the requirements for the degree of Master of Science, Colorado State University, Summer 1990.

Wahl, T. L., M. M. Skinner, and H. T. Falvey, "The Twin Vortex Draft Tube Surge," *Waterpower '91,* Proceedings of the International Conference on Hydropower, Denver, Colorado, July 1991.

List of Keywords

draft tube
turbines
surge
vortex
swirl
cavitation
hydraulic models
hydroelectric power generation
powerplants