A SYSTEM FOR DETERMINING CAVITATION PRODUCTION BY ACOUSTIC MONITORING IN TURBINES

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INTRODUCTION

Elimination or nullification of the effects of lethal agents on fingerling salmon migrants within Kaplan turbines is one of the approaches to the problem of protecting young migrants at low-head dams in the Columbia and Snake Rivers. Some of the agents suspected of being lethal are turbulence, sudden pressure changes, mechanical obstructions in the form of wicket gates and blades, and cavitation. One of the objective of the Bureau's program of research in prototype Kaplan turbines is to define the specific agents involved and the relative importance of each.

Cavitation is suspected by many investigators to be a major factor in causing injury or death to fish in turbines (Muir, 1959; Cramer and Oligher, 1964; Lucas, 1962). Cavitation may be described as a "breaking" or "rupture" of the water mass to form a pocket or cavity containing water vapor and possibly a small quantity of air. It generally begins when the local pressure drops to the vapor pressure corresponding to the temperature of the water, and thus is common in those areas of a turbine where low pressures occur. The collapse or implosion of a cavity produces a violent mechanical blow (Osborne, 1957), and also intense sound waves (Harrison, 1952; Benjamin, 1958; Jorgensen, 1961; Song and Silberman, 1961) either of which may be a cause of injury to fish. Mechanical blows from the implosion of cavities in contact with blades and other parts of the turbine are of sufficient force to cause damage by pitting metal and concrete structures at Bonneville and other dams. The magnitude of the forces exerted by a collapsing cavity has been calculated to be in the order of tens of tons (Silver, 1942), and measurements by Parsons and Cook (1919) placed the force of the water hammer following collapse of a cavity at about 140 tons per square inch.

The acoustic noise produced by cavitation provides a suitable method for its measurement. Although several investigators (Osborns, 1947; Song and Silberman, 1961; Harrison, 1952; Mellen, 1954) have studied cavitation noise, none have made detailed studies of cavitation noise in turbines. Benjamin (1958) mentions ". . . . . the spectral properties of noise from severe propeller cavitation make it quite distinct from other forms of underwater noise", and Jorgensen (1961) has established certain characteristics of cavitation noise in the 125 to 8,000 cycle range which provide a useful guide. Jorgensen states that, "The first evidence of cavitation is indicated by the rather sudden increase of noise level in the high frequency bands. Here cavitation is heard as infrequent, randomly intermittent bursts of noise. Further reduction of the cavitation index brings lower frequency components of cavitation noise into prominence over the noise of turbulence . . . . . In addition, the separate bursts occur more frequently until . . . their intermittent character is no longer discernible and the noise is heard as a steady, dull roar."

As these noise characteristics may be related to cavitation production in turbines, equipment was developed to identify and measure acoustic properties within a turbine. The equipment, described in this report, is being employed to investigate cavitation phenomena in turbine No. 9 at Bonneville Dam.

EQUIPMENT

In general, the noise signals are detected by a hydrophone within the turbine or by an accelerometer mounted outside the draft tube liner. The signals are transmitted through recording devices, to electronic analyzers and an electronic counter. An oscilloscope is provided in the system for visual observation of bursts of noise. A diagram showing the general arrangement and nomenclature of the electronic equipment used in studying the acoustic noise in the turbines is shown in figure 1.

The hydrophones for detecting the noise signals were inserted into the turbine through special valve assemblies in the draft tube liner (fig. 2). These assemblies were constructed so that the hydrophones or any similar equipment could be inserted or removed without interfering with the turbine operation. Noise signals were also detected by an accelerometer mounted outside the turbine draft tube. When sufficient data have been accumulated it may be possible to calibrate the accelerometer with the hydrophone and the necessity of installing valve assemblies for hydrophones in all turbines to be examined can be eliminated.

The frequency pattern of noise signals between 2.5 cycles and 25 kilocycles, received by the hydrophone or by the accelerometer, was analyzed with a sound and vibration analyzer coupled to the analyzer by a drive system. A paper-strip-chart recorder provided a permanent record of amplitude vs. frequency. Although the frequency range of cavitation noise extends well above the range of the 25 kc. capacity of this equipment, the noise produced at the lower frequencies is of higher amplitudes (Osborne, 1947) and is less subject to attenuation factors than are the higher frequencies (Laird and Kendig, 1952). It was felt that use of the 2.5 cycle to 25 kilocycle range would provide an index of the noise produced in the turbines that would be adequate for the present turbine studies.

A filter, amplitude discriminator, and electronic counter provide a means of studying the bursts of cavitation noise. The filter has a variable band-pass feature which permits a study of discreet frequency bands to determine whether any frequency differences are found in bursts produced under various operational conditions.

From the filter, the signal is transmitted to an amplitude discriminator. This can be adjusted to permit only those bursts of noise above a desired amplitude level to pass through. By this means, bursts associated with cavitation may be separated from background noise, counted, and analyzed to determine the amplitude of the noise frequencies contained in the bursts. In addition, the total noise level may be measured for any set of operational conditions of the turbine.

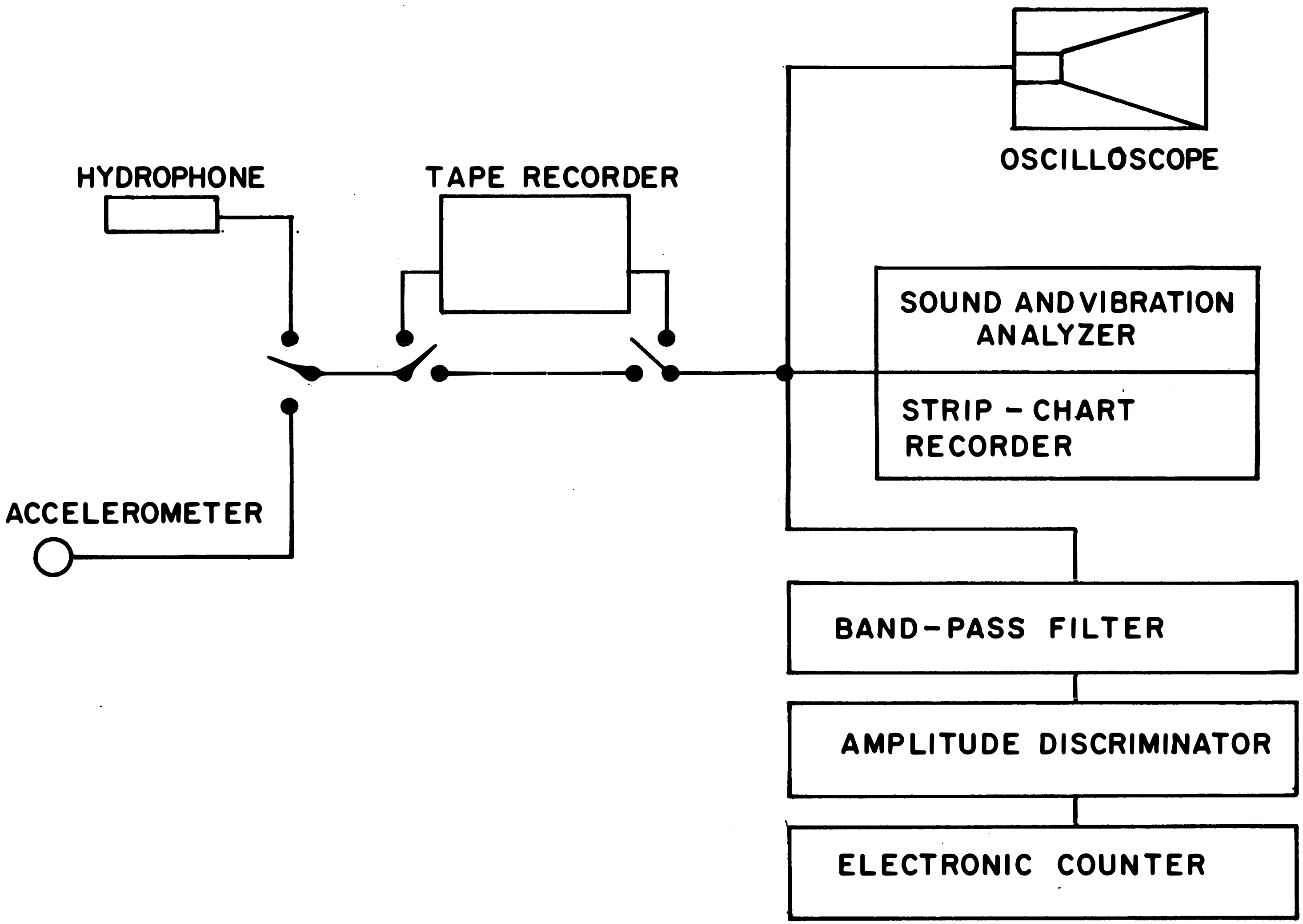

Figure 1.--Diagrammatic arrangement of equipment used for studying acoustic noise in turbines.

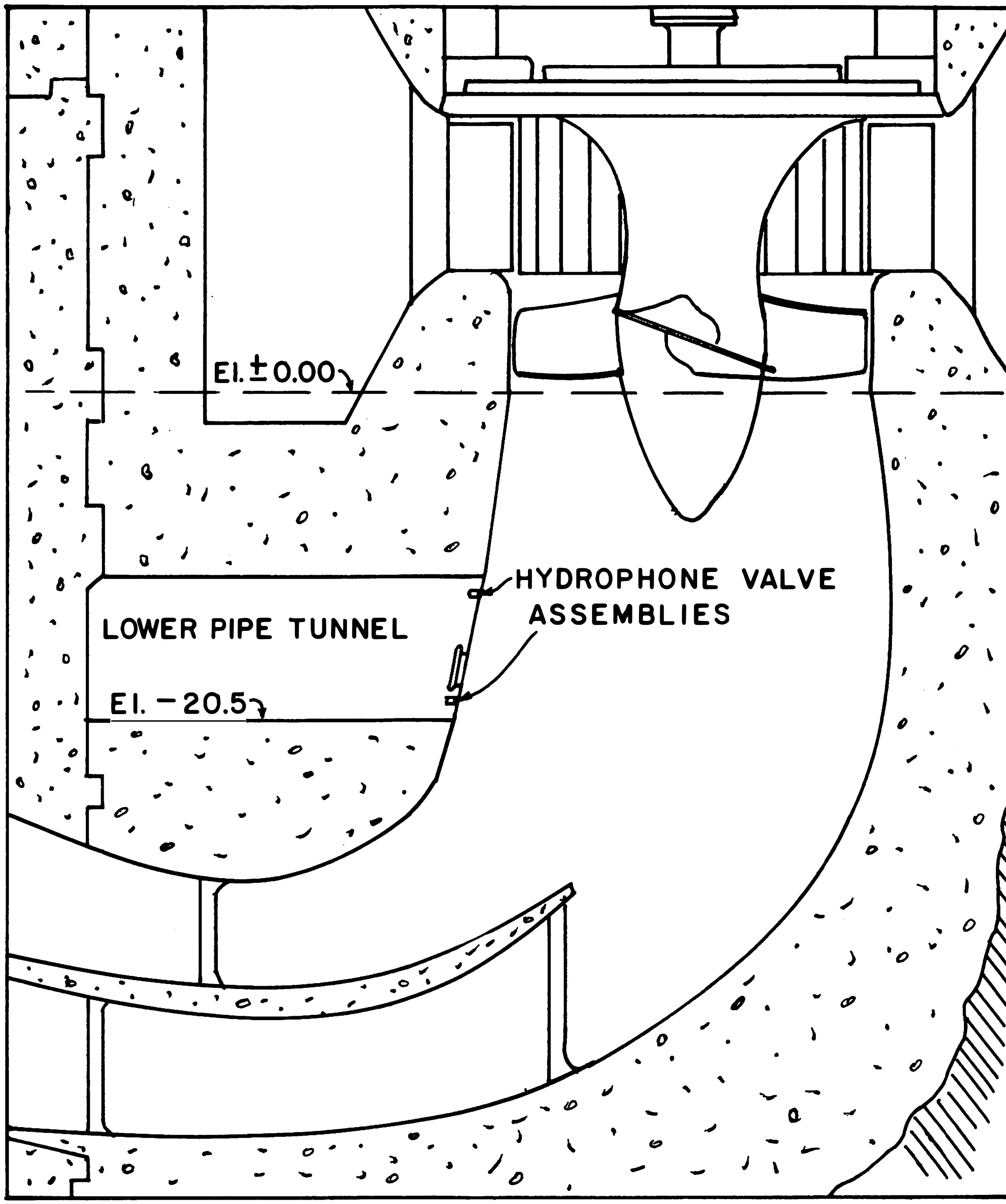

Figure 2.--Location of valve assemblies for inserting hydrophones into water flow of draft tube of turbine #9 at Bonneville Dam.

The oscilloscope provides a means of visually observing the noise pattern at various stages of analysis. A dual-trace feature permits a comparative observation of two signals, such as the total noise pattern and a filtered portion of the noise signal.

By using a tape recorder, the noise signal may be retained for later playback and analysis. A recording made at the time that fish are passing through the turbine would provide a permanent record of the prevailing acoustic conditions. For detailed analyses of a transient noise pattern or burst, a continuous closed loop can be made from the tape. The loop can then be played back and the transient studied as though it were a steady signal.

RESEARCH STUDIES

Preliminary evaluation of equipment and techniques has been carried out. These tests have indicated that "bursts" similar to those described by Jorgensen (1961) exist under operational conditions of the turbine which are known to produce cavitation. A burst pattern from turbine noise as viewed on the oscilloscope screen is shown in figure 3.

Current work at Bonneville Dam includes the cataloging of the frequency patterns of noise produced within turbine No. 9 under a wide range of operational conditions. This information will provide the background for determining correlations that may exist between specific noise characteristics and injury or mortality of fish passed through the turbines.

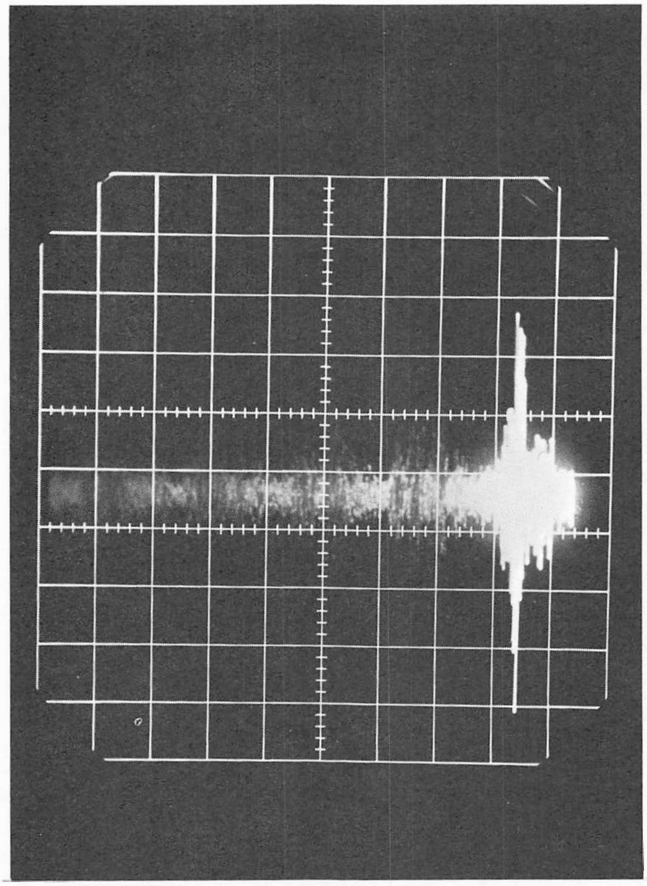

Figure 3.--Burst of turbine noise as presented on oscilloscope screen.

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