DATA ACQUISITION SYSTEM WITH HYDROPHONE SENSOR IN PIPELINE LEAK DETECTION

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Abstract - This paper describes in detail, a data acquisition system and the measurement results for pipeline leak detection. The data acquisition system hasa software platform to perform signal analytics; hardware for acquiring sensor data and perform signal processing; and a hydrophone sensor for acquiring acoustic signals. The data acquisition system was used to acquire data from packaged hydrophone sensors which were deployed to monitor the acoustic ina water pipeline under a laboratory condition. Data analysis using both transient and spectral interrogation methods showed thatfrom captured data, it was possible to clearly identify water flow disturbances due to leakages.

Keywords - Data Acquisition, Signal processing, background noise cancellation, water leak, acoustic.

I. INTRODUCTION

Pipeline leakagesin portable water delivery are a major concern for the sustainability to a country's economic development. In developing countries or old cities, it is reported that the amount of potable water loss due to pipeline leakages is more than 30% and reaches as high as 50% in some cases [1][2][3][4]. There is an urgent need to develop methods to monitor pipeline for leakages. Water leakages in pipelines are mainly caused by structural damageslike cracks. Such kind of defect can be determined through a variety of methods such as pressure gauge, flow meter, optical, acoustics [5][6] etc. Water leaking from cracks can create hissing noise by means of friction between water leaving cracks at high velocity. Smaller cracks tend to produce higher frequency signature than larger cracks thus makes it possible to use acoustics as a means to detect the presence of water leaks. In this paper, we explore the use of acoustics to determine the presence of a water leak.

II. ARCHITECTURE AND DESIGN

To pick up acoustics in water, we are using hydrophone sensors (which are similar to microphones but used in water instead of in air). To acquire data from hydrophone sensors, we custom-built a data acquisition system with both software interface and hardware.

2.1 Data Acquisition System

A hydrophone can be connected to the data acquisition system shown in Figure 1to measure and analyze acoustic data. The data acquisition system is based on the Texas Instruments reference design PCM 2906C chip for "Stereo Audio Codec with USB interface".

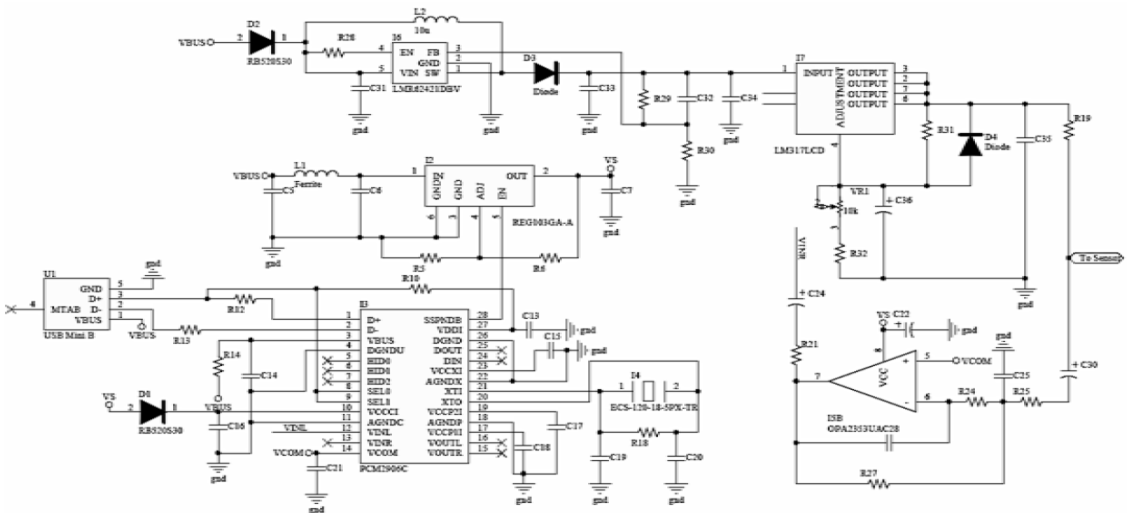


Figure 1 Data Acquisition System for hydrophone sensor in water pipeline leak detection

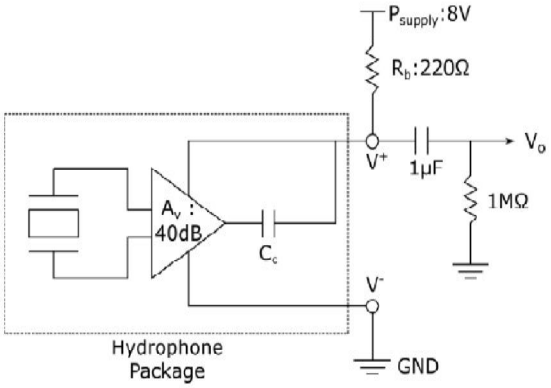


Figure 2: Hydrophone sensor using 2-wire interface where the power supply and the output from the active buffer circuit shares the same connection node.

The PCM 2906C chipset takes in an ac-coupled analog buffer signal VIN from the operational amplifier OPA2353. The operational amplifier is configured as a 2nd order multi-feedback low pass filter with bandwidth in the audio band. The input to the operational amplifier comes directly from the hydrophone sensor via an ac-coupling capacitor. The hydrophone sensor in our design uses a 2-wire interface with an active circuit configured with "phantom power configuration, i.e. power supply and the output signal from the active buffer circuit shares the same connection. More details on the packaged hydrophone sensor are presented in the next section.
The power supply required for the hydrophone sensor is between 8-12V, and it is generated directly from the USB supply using a dc-dc booster LMR62421DBV chipset and the voltage regulator LM317 chip. This data acquisition system is meant to be connected directly to a PC via usb and its power is also supplied directly from the PC via the usb connection, thus reducing the need for additional hardware to supply power to the different systems.

2.2 Active hydrophone sensor

The hydrophone sensor used in our design is a CMOS-compatible piezoelectric type sensor [7].The piezoelectric material senses a change in localized pressure caused by acoustic waves and translates that to electrical charges which can then be measured by an electrical sensor interface.

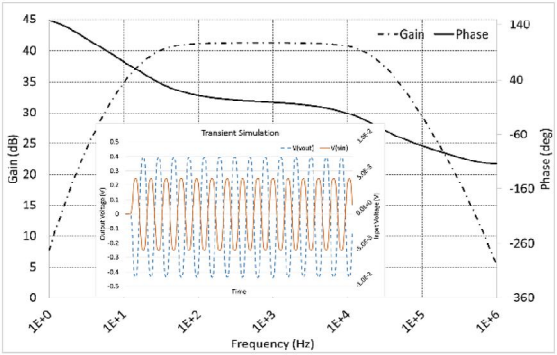


Figure 3: Simulation results for the active amplifier showing both the ac and transient response.

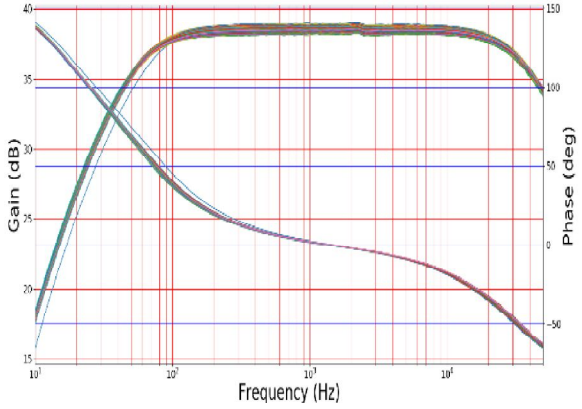


Figure 4: Batch testing of hydrophone package sensors.

In our design, we built an analog voltage amplifier circuit to measure the change in charges on the piezoelectric sensor. As depicted in Figure 2our hydrophone package has a piezoelectric sensor attached to an active amplifier circuit. This active amplifier circuit is configured to use 'phantom power' (2-wire) which allows us to share the power supply line with the voltage output on a single connection node denoted as V+. Power to the active amplifier is supplied via the bias resistor Rb to isolate output signal from the power supply Psupply. The output signal from the active amplifier is ac-coupled to V+via Cc where Rb and Cc form the high pass corner for the output signal. The transient and ac simulation results for the active amplifier is shown in Figure 3. The high pass corner frequency as determined by Rb and Ccin the same connection. is about 30 Hz. To improve the low-frequency response for the active amplifier, the value of Rb can be increased at the expense of high supply voltage (above 8V) to keep the active amplifier in operation. The active amplifier circuit is tolerable from 8-20V operation. The active amplifier circuit has a voltage gain of 40dB across a wide band of 30Hz to 20kHz which covers the entire audio band.

III. RESULTS AND DISCUSSION

3.1 Characterization of the active amplifier

Characterization of the active amplifier circuit was done using the Agilent 35670A dynamic signal analyzer. The ac response of the amplifier circuit was measured and the response of 50 units are shown in Figure 4.

The mean value for the gain is 38.5dB with a standard deviation of 0.21dB and a very tight spread of ±0.5dB only across the 50 units. Equally, the distribution of the phase response has a tight spread of only ±0.5° across the entire spectrum. The measurement results from the batches of amplifier circuits closely match the simulation results in terms of the phase and corner frequency characteristics. The mean gain value is slightly degraded due to the

imperfect matching of the gain determining resistors chosen in our design.

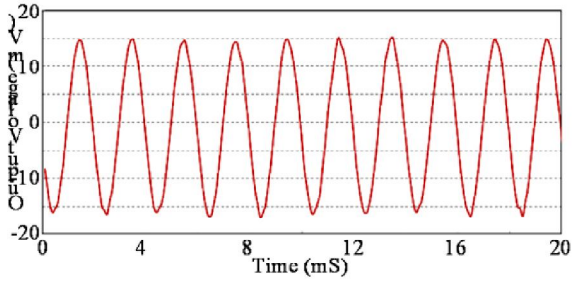


Figure 5: Transient output response of the hydrophone package sensor tested with SEAMAP Verification and Re-Calibration Unit: Part #02-94-2418.

This discrepancy can be easily compensated in the software domain as the spread of the gain data is tight.

3.2 Characterization of hydrophone sensor

Characterization of the packaged hydrophone sensor was done using SEAMAP near field verification and calibration unit (Part #02-94-2418). The hydrophone was exposed to 500Hz sound wavesata sound pressure of 25Pa. The measured results of the packaged hydrophone sensor are shown inFigure 5.The measured result shows a 30 mVppk implying that our package hydrophone sensor has a sensitivity of -187.4 dB (ref 1V/µPA). With the active amplifier circuit having a mean gain value of 38.5dB, the base sensitivity of the piezoelectric sensor is -225.9 dB (ref 1V/µPA).

3.3 Testing of the hydrophone sensor in water pipeline

The hydrophone sensor was placed in a special purpose-built 30m long cast-iron pipeline.

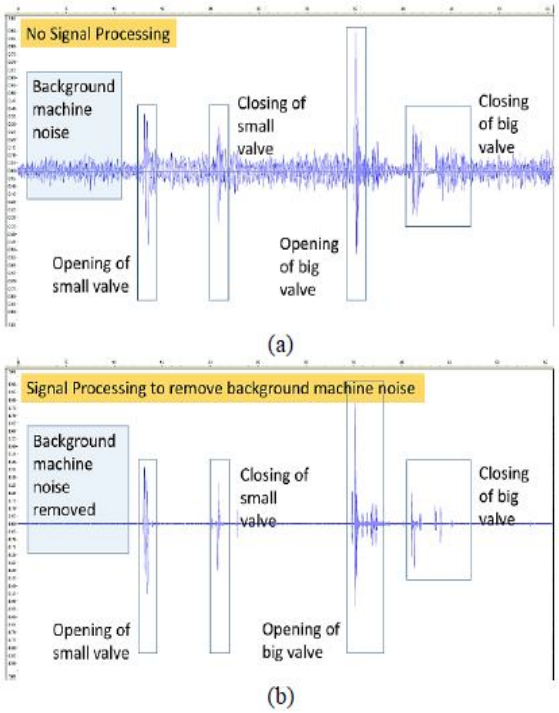


Figure 6: Transient recording of the hydrophone sensor in water pipeline (a) without and (b) with signal processing.

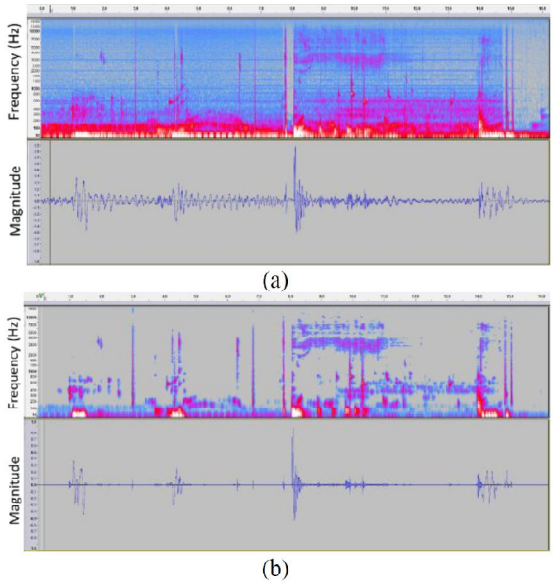


Figure 7: Transient and spectrogram of the recording from the hydrophone packaged sensor in water.

A pump was attached to one end of the pipeline to circulate water flow thus simulating water delivery whilst maintaining an internal static pressure of 3 – 5 bar. Water leak valves of various sizes were installed at various lengths along the pipeline to simulate leaks. A hydrophone sensor was attached to the data acquisition card shown in Figure 1 which in turn was connected directly to a PC via usb connection for data connection. The power for the data hydrophone sensor was provided by the dc-dc booster and voltage regulator on the data acquisition card which in turn gets power directly for the PC via the usb connection. To record the response from the data acquisition system, the Audacity® software was used. This software is able to take in usb audio inputs and perform post-processing on the raw data. Figure 6: shows a clip of a transient recording from a hydrophone sensor tested in the water pipeline. To simulate leaks or water supply disturbances, different valves at different locations from the hydrophone sensors were opened and closed. It is evident from the results shown that events triggered by the opening and closing of valves created large transient. In terms of signal magnitude, smaller valves tend to generate smaller perturbation than larger valves. In addition to transient spikes which were caused by the opening/closing of valves, there was also a constant background humming across the entire clip of the recording. The humming signal was caused by the action of pump that was circulating water in the pipeline and also maintaining the static pressure in the water pipeline. This signal is considered as background noise that could interfere with the sensing of leak event although in actual situation of water delivery pipeline, background noise could vary in magnitude depending on the distance of sensors to the pump. In addition, background noise could also

come from other sources that could conduct through the outer surface of pipelines. To remove background noise from the recordings, we employed the spectral subtraction method. This is done by selecting a section of the time recording which has the background noise and uses it as a reference. With this reference spectral signature,signalssimilar to the reference across the entire recording can be removed as shown in Figure 6:

Spectral information is an important source which allows insights into the data that are otherwise difficult to interpret in the time domain. Figure 7shows the spectrogram of another recording of the packaged hydrophone sensor in the water pipeline. The spectral information shown in the spectrogram shows much richer information with high level and low level detailsof spectral content, such as the low frequency humming from the pump and high frequency spikes due to the opening/closing of the leaking valves. Figure 7 (a) shows the raw data without background noise removal while Figure 7 (b) shows the end results with background noise removal.

CONCLUSIONS

We have presented a paper on the design of a data acquisition system for water pipeline leak monitoring using packaged hydrophone sensors. Our data acquisition is a custom-built using commercially off the shelf electronics and software with proprietary hydrophone sensor technology to measure acoustics of water flow in a pipeline environment. Simulated leaks using different sizes of valves were tested in laboratory condition and the results showed that the system was able to record events caused by simulated leakage using both transient and spectral analysis. The system can be used as a basis for developing a solution for monitoring leakage in water pipeline.

ACKNOWLEDGMENTS

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