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COLLECTION OF FIELD DATA USING WIRELESS INSTRUMENTATION FOR PUMP AND SYSTEM EVALUATION

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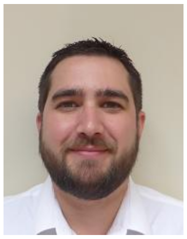

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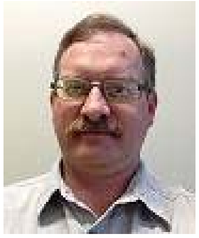

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ABSTRACT

This paper outlines the benefits of utilizing a temporary data acquisition system with wireless instrumentation to collect field data for analysis and troubleshooting of pumps and pumping systems. It also discusses the basics of signal transmission with wireless system architecture and associated equipment. Two studies are given where a portable wireless data acquisition system was employed to support an analysis of a pumping system.

INTRODUCTION

Pump system problems can be a challenge to diagnose and understand. Actual field installations can be dated, with modifications that were not fully documented, and may suffer from degradation. In order to diagnose problems or analyze a pumping system, it is very important to have accurate data to ensure that cost effective and accurate upgrades or repairs are made. However, field measurement can often be a challenge in many ways: regulation updates, physical access, and expense often contribute to the difficulty. Various ways to meet these challenges have been developed. One that shows particular promise is the use of wireless technology.

Most large industrial sites have some form of a central DCS (Distributed Control System). The DCS performs many functions, including monitoring the critical operating parameters of the plant. Selected parameters are stored at defined sampling intervals in a historian system. Often times, the stored data is not sufficient for troubleshooting a pump or pumping system issue. During these times, supplemental data collection is required to perform more in-depth analysis.

Traditionally, hardwire sensors and/or local gauges (hand logging) are used for data collection, but a new and growing method is the use of a wireless DAS (Data Acquisition System). This method of data collection is convenient, reduces material requirements, and enhances an engineer’s ability to analyze pumping systems.

BACKGROUND

When troubleshooting a pump, it is often not clear if the source of the problem is the pump itself, a single, or multiple system components. A logical starting point is to measure pump flow, as the operating range of a pump is an excellent indicator of potential issues. For example, a pump running back on its curve can lead to excessive thrust while one running out on its curve can suffer from cavitation due to insufficient NPSH (Net Positive Suction Head). Virtually all pump analyses will require measurement of suction pressure, discharge pressure, and fluid temperature to determine TDH (Total Developed Head) of the pump. Flow, TDH, and operating speed are parameters necessary to plot a pump curve and compare it with its as-designed curve. Power measurements may also be needed to determine BHP (Brake Horsepower) and efficiency.

When it is unclear that the pump itself is the problem, an analysis of the system may need to be completed. Often times, this is done in conjunction with an analysis of the pump. System parameters that have a bearing on pump performance include all sources of upstream and downstream pressure loss. Most notably, a regulating valve position can have a dramatic effect on flow and TDH of the pump. Other important sources of pressure loss are of course heavily dependent on the type of system but can include heaters, orifices, condensers, etc. All may need to be monitored.

These pump and system parameters should at a minimum be monitored during all normal system conditions. During special cases, transient conditions may also need to be monitored, though these can be much more difficult to capture and usually require very high sample rates.

BENEFITS OF A WIRELESS DAS

A wireless DAS can be easily deployed to collect system and component data necessary for troubleshooting and analysis. Wireless systems are most beneficial when simultaneous steady state or quasi-steady state data is required and when it is deployed in situations where instrumentation is spread out, in a remote location, or where there are area classification restrictions that prevent data collection with a traditional DAS.

When collection points are spread over a large area or multiple elevations, collecting data with wired systems causes several complications. Transmission cables may take a long time to install and may block access to areas or components and create potential safety hazards. It may be problematic to route cables near high temperature piping or components. With a wireless DAS, instrumentation can be installed with the same effort that is required to install local indicating instruments. The lack of data transmission cables removes safety hazards and does not interfere with access to components. An example of this is collecting data for a flow distribution study on a system that has multiple pumps operating in parallel. In such an example, pump discharge flow, recirculation flow, discharge header pressure, pump speed, and regulating valve position need to be collected over a period of several days or weeks. Transmitting data from the sensors to a temporary DAS using cable would require running the cables across walkways, around components, through overhead cableways, or along piping runs. Any case can be a logistical challenge. The use of a wireless DAS makes data collection a simpler and less intrusive task.

When the data that needs to be collected is in a remote location, such as a pumping station or tank farm, instrument users may be hesitant to leave acquisition equipment unattended or unprotected, especially if the data needs to be collected over several days or weeks. With the use of a wireless DAS and signal repeaters (a device that boosts and re-broadcasts a signal, increasing the distance of which a signal can be transmitted), data can easily be received and monitored from a central location, such as an office building or control room. This can be accomplished by bringing all of the data from a remote area to a central node and then relaying the data to the DAS at a desired location. This method has been highly effective for permanently installed wireless systems that monitor remote locations and can easily be adapted for temporary DAS applications. This technique can also be used to monitor temporary equipment that is installed for abnormal operations or procedures. With a wireless system, the DAS can easily be installed in a control room where the temporary equipment can be monitored without additional operators. This is useful for situations such as transitioning to and / or maintaining temporary system configurations, such as piping temporally filled with Nitrogen, or setting up / maintaining freeze plugs in a system.

Most temporary data loggers are not designed for locations where area classification restrictions apply. This can pose a major challenge for collecting data. A DAS can be moved to a general classification area (an area that does not have classification restrictions), but this increases the amount of cable that is required and any connections located in the restricted area must still meet compliance requirements. By using wireless sensors, transmitters, and repeaters that are certified to operate with restrictions in hazardous areas (10 CFR 1910.307, 2007), data collection can occur without the need for hot work permits by transmitting the data to a DAS that is located outside the hazardous area.

Another benefit is that it is easy to add instrumentation into a wireless DAS. With mesh architecture (discussed in the *Wireless System Architecture* section of this paper), additional sensors or transmitters can be installed into a system and can be recorded by a DAS with minimal programming. Furthermore, since the number of sensors that can be installed is not limited by the number of physical ports available, a wireless DAS is capable of recording a larger number of sensors than a wired DAS.

Due to the ease of instrument installation and data collection with a wireless DAS, it can also be used in place of manual logs of local data. For example, when troubleshooting a mechanical seal cooling system or bearing lubrication system, it may be beneficial to trend component pressures over time. This is often accomplished by manually logging data from local gauges (since these systems are rarely instrumented into a DCS). Temporarily replacing these gauges (or connecting to a tee) with wireless gauges allows these parameters to be logged at a regular interval without burdening operators or engineers.

WIRELESS SYSTEMS

There are many different types of wireless platforms available. Each type of platform is tailored for a specific use. Variations in platform specification include sample rate, security protocol, network type, transmission band, output power, and transmission distance. For most pumping system troubleshooting and analysis using a wireless DAS, it is ideal to be able to transmit long distances (without obstruction), not require a site license, and have a sample rate sufficient enough to measure quasi-steady state events taking place. An instrument user should understand that no system will be ideal for every situation and should be aware of the requirements and limitations prior to obtaining and using a portable wireless DAS system.

Data collection with Wireless DAS

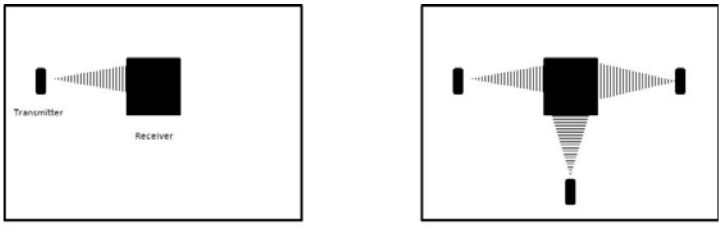
Data collection via a wireless DAS can be accomplished with almost any type of sensor. Typical parameters that can be collected are pressure, temperature, flow, speed, overall vibration, and power. Any instrument that has a mA, VDC, or pulse output can be connected to a wireless transmitter for collection with a wireless DAS. Some sensors, such as pressure sensors and thermocouples/RTDs, can be incorporated with a mA or VDC output from the sensor using a transmitter/sensor packed as a single battery powered unit. This single unit can easily be installed and can be certified for operation in locations with area classification restrictions.

The frequency that data can be recorded via a wireless receiver is variable, with different systems providing varying degrees of sample rates. Even though a high sample rate is possible (sample rates greater than 100 kS/s (kilo-samples per second)) from a wireless system, a sample rate between 5 seconds and 15 seconds is acceptable for the majority of system analyses. This frequency is generally sufficient to record steady state data while capturing sufficient data to analyze the effect of quasi-steady state events, which, for example, may be observed when changing the load of a power plant. Unless short transient cycles are being captured, any resolution less than 5 seconds will generally cause an unnecessary drain on transmitter batteries and provide large data files that can be difficult to manipulate. In general, this will not provide any additional insight into what is being studied. For cases where a high sample rate is required, such as measuring pressure pulsation, piping strain, or component displacement, a wired DAS system is generally the best option. This is mainly due to the capability of a wired DAS to collect data at sample rates greater than 1 MS/s (NI PXI-5124 Data sheet Rev. 16:18:45.0, 2012) (Dewetron, 2013).

Data transmission hardware will typically have a published range of 0.5-5 miles. These published ratings are generally for ideal conditions with line of sight transmission, minimal obstructions, and a dry environment. For the typical industrial data collection scenario, there is often interference from piping, equipment tanks, and walls/floors between a transmitter and the receiver / data logger. These obstacles reduce the transmitted signal strength through attenuation and scatter. Typical data transmitters have a power from 15 to 25 dBm (where Power (dBm) = 10 $\log_{10}$ (P(mW)/1mW) (Rappaport, 2002). General machinery (floor area of 10-20 sqft) typically has an attenuation between 5-10 dB at 1300 MHz and light machinery (floor area <10 sqft) typically has an attenuation between 1-4dB at 1300 MHz (Rappaport, 2002). With the proper placement of the signal receiver / logger, signals from across a site can be transmitted successfully. When there are multiple large pieces of equipment (floor area > 20 sqft) or large volumes of water (such as a condenser or deaerator) between a transmitter and receiver, properly placed repeaters will allow the data to be collected. Ideally a portable DAS will have several repeaters that can be deployed as necessary during installation.

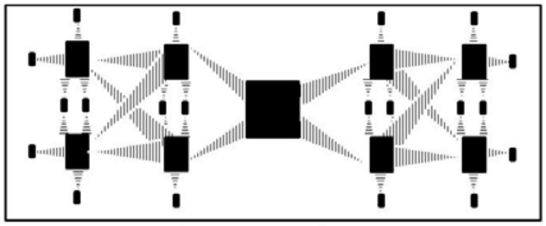
Wireless System Architecture

There are multiple different types of wireless networks. The most prominent types for a local DAS are a point to point, point to multi-point, and a mesh network system, as illustrated in Figure 1. A point to point system is one where a receiver and transmitter are paired together. An example of this type of connection is a blue tooth headset linked with a cell phone. A point to multi-point system is a receiver paired with multiple transmitters. An example of this is a home Wi-Fi network where multiple computers are paired with a single router. Both of these types of systems are sometimes used with permanently installed wireless DAS systems, and large networks can be created by nodes of point to multi-point connections. If each node is treated as a point, then each point can be brought into a DAS through an overlaying point to multi-point system. This type of network can be difficult to set up. Also, if the receiver in a node loses power, none of the sensors connected to that node will be seen by the DAS (IJIS Institute, 2005).



Point to Point

Point to Multi-Point



Multi-Point to Multi-Point

Figure 1. Examples of Different Types of Wireless Networks.

A mesh network, which is a multi-point to multi-point system, does not have paired receivers and transmitters. Instead any transmitter with proper security protocols can be connected through any receiver with the same security protocols. An example of this type of system is a cell phone and tower network. A cell phone is not paired with a single cell tower. Rather it connects to whichever tower receives its signal (Rappaport, 2002). This type of system is relatively easy to set up and can be thought of as self-healing in that if a signal repeater loses power, then the transmitters that were near that repeater will be picked up by the next nearest repeater.

For a portable DAS network, mesh architecture provides the most flexibility and can be easily implemented in a field environment with little to no planning. For example, a data logger can be set up in an area with low traffic volume and outside any area classification restrictions. The use of battery powered transmitters can be installed on the output of temporary or permanent instrumentation to provide further ease of implementation. To complete the circuit, repeaters can be placed as necessary to transmit signals to the logger.

SUMMARY

Temporary wireless DAS provides numerous benefits over temporary wired DAS for troubleshooting and analysis of pumps and pumping systems. The lack of cables needed to connect instrumentation to a DAS allows a wireless system to be easily and quickly installed without blocking access to equipment or walkways. It also allows the DAS to be easily placed in a remote location such as an empty work area, control room, or a location outside a hazardous area with classification restrictions. The ability to record multiple instruments simultaneously is often a key aspect of any analysis. This is made easier if data from all of the instruments is collected in a central location.

There are multiple types of wireless DAS and associated equipment. An instrument user or operator should understand that no system will be ideal for every situation and should be aware of requirements, needs, and limitations prior to obtaining and using a portable wireless DAS system.

CASE #1

A system assessment was performed on the boiler feed system of a power station in a refinery in Alberta, Canada. The station generates both electrical power and steam for the refinery. The boiler feed system utilizes five between-bearing, horizontal, axially-split, 5-stage BFPs (boiler feed pumps). The purpose of the system assessment was to perform a flow distribution study to determine what would be required to operate four of the five BFPs at full load (new desired operating condition) and to determine the current operational performance of the BFPs (full load operation required operation of all five BFPs). In order to collect the required data, temporary instrumentation was installed along with a temporary wireless DAS. This was necessary due to the fact that the required system parameter monitoring locations were spread out over a large area as well as multiple floors.

Two of the pumps are motor-driven and three are turbine-driven, and the pumps operate in parallel. The boiler feed pumps take suction from a common header that is supplied by three DA (deaeration) units and discharge into a common header that supplies multiple boilers (Figure 2). Each pump has a dedicated recirculation line located between the discharge nozzle and isolation valve going back to the DA. The rated capacity of each boiler feed pump is 2250 gpm at 2600 ft-head at 3570 rpm. The demand of the boiler feed system, at average operating feed water temperature, is 9457 gpm at full rated system load.

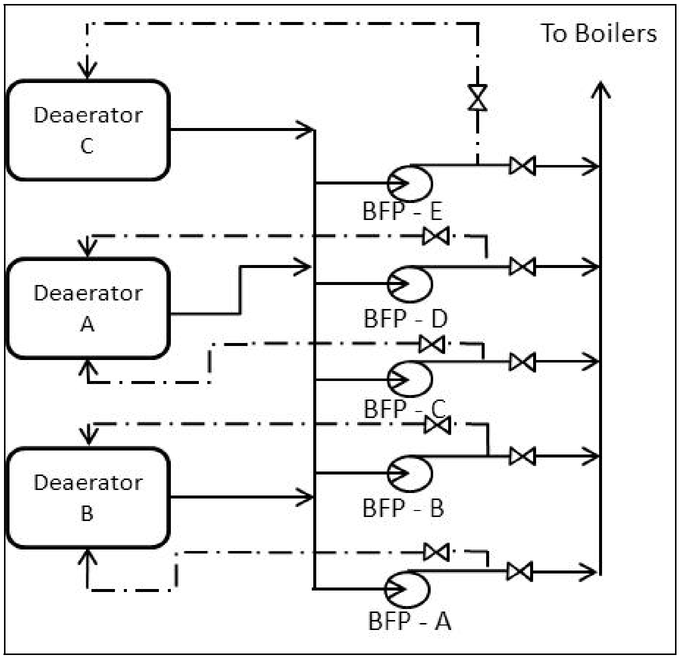


Figure 2. Boiler Feed System Line Diagram.

The layout of the boiler feed system was such that connecting all of the temporary instrumentation to a single DAS would require a significant amount of cable and would block primary walking paths and egress routes. To avoid this, 30 mW wireless instrumentation with a spread spectrum transmission frequency of 902-928 MHz was used with a mesh architecture. The DAS was set up in a location that was non-intrusive to operators, and repeaters were placed as needed to capture all instruments without any change in equipment programming. This use of wireless instrumentation allowed site operators to access all equipment. Furthermore, no additional safety requirements, such as sectioned work areas or temporary changes to emergency access routes, were necessary.

Additionally, the installation of the cable would have required a significant amount of time, especially due to the fact that instrumentation was installed on multiple floors. The use of a wireless DAS allowed all of the instrumentation to be installed and data collection to begin within a day.

Temporarily installed instrument locations included suction and discharge pressure, discharge flow, recirculation flow, and driver speed for each of the BFPs along with each DA discharge flow. Data from these 27 instruments was recorded every 15 seconds for a period of one week. The pressure instruments were solid state piezoresistor transducers integrated with self-contained, battery powered, sensor-transmitter units. As shown in Figure 3, the sensors were installed at tee connections where local pressure gauges were installed (this allowed operators to maintain a local indication of system parameters). Individual pump discharge and recirculation flow data was collected with non-intrusive ultrasonic flow meters. The flow meters were programmed to output an analog 4 to 20 mA signal that was wired into a loop-powered analog transmitter (Figures 4 and 5). Pump speed was measured with a laser tachometer configured for a pulse output. The pulse output was connected to a battery powered digital counter and transmitter combination (Figure 6). Due to the lack of open thermal wells, DCS data was used for process flow temperature. To supplement the DCS temperature reading and verify that all transients were recorded, the suction piping was instrumented with surface thermocouples connected to an analog transmitter.

Figure 3. Tee Connection with Local Pressure Gauge (Vertical- Left) and Wireless Pressure Sensor with Battery Powered Transmitter (Horizontal-Blue).

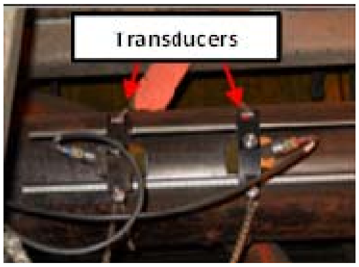


Figure 4. Ultrasonic Flow Meter Transducers on Discharge Piping.

Figure 5. Ultrasonic Flow Meter With Loop Powered Transmitter.

Figure 6. Battery Powered Transmitter with Pulse Input for Pump Rotational Speed.

The results of the data collection (covering five days of 24 hour monitoring) allowed analysis of the flow distribution of the BFPs and DA units. The analysis also provided pump performance curves that were based solely on collected data (Figures 7 and 8). Figure 7 shows performance data for one of the BFPs over a wide range of flow conditions. This data was collected during several hours of testing where the associated discharge isolation valve was manually throttled and was accomplished for each of the BFPs. Figure 8 shows flow distribution versus percent time at a given flow over the five day collection period (excluding instances where pump performance testing caused abnormal testing conditions) for the same pump as in Figure 7. In Figure 8 it can be seen from the distribution of operating time versus flow that the pump spent the majority of its operational period (88.2 percent) between 45 and 63 percent of BEP (best efficiency point).

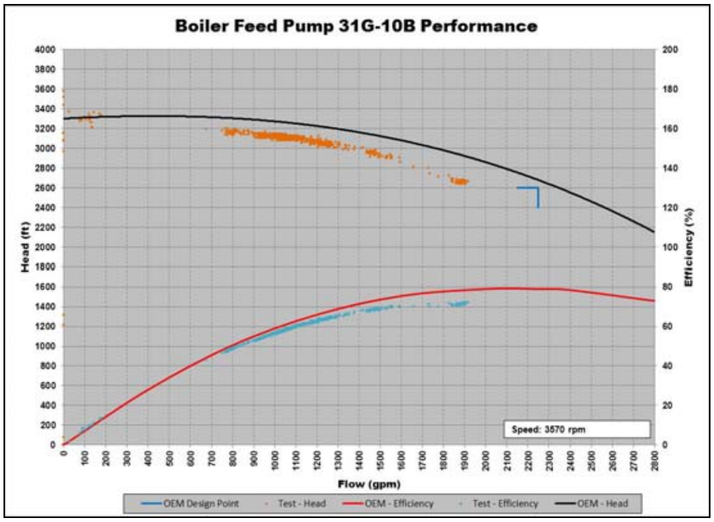


Figure 7. BFP 31-G10B Performance.

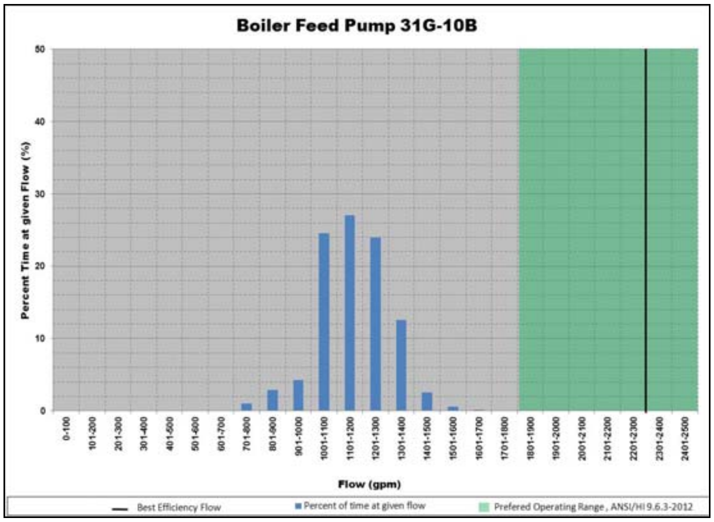


Figure 8. BFP 31-G10B Flow Distribution Over 5 Days of Normal Operation with Preferred Operating Range per ANSI/HI 9.6.3-2012.

The final recommendations included conditions that would allow the plant to operate with four of the five BFPs at full load. Permitting the pumps to operate closer to BEP would result in considerable power saving (due to higher efficiency) and less wear on the pump (due to undesired hydraulic conditions). The system study also uncovered unanticipated deficiencies with the recirculation lines, which allowed changes to be made that would provide proper flow protection for the pumps. The data that supported the final recommendations could not have been collected without temporary instrumentation. The use a wireless DAS allowed data from all of the temporary instrumentation to be collected simultaneously without extensive cabling and disruption to site personnel.

CASE #2

A municipal wastewater collection plant in Michigan, USA has a reported history of TDSSCD (Time Dependent Steady State Capacity Drift) with its RSPs (Raw Sewage Pumps). This reduction in flow during steady state conditions occurred with no evidence of clogged passages due to solids accumulation. To document and determine the cause of the TDSSCD, two of the RSPs were instrumented and monitored with a wireless DAS. Both RSPs were single stage volute type from different manufacturers (different hydraulic designs) and each pump had different suction piping geometry.

The TDSSCD phenomenon (here after referred to as “capacity drift”) has become more prevalent over the last few years. There have been reported cases at multiple municipal plants with RSPs from a variety of manufactures and suction piping geometries.

The pump station handles unscreened sewage that is gravity-fed into a wet well. Each wet well has four RSPs that take suction from the base of the wet well. Also, each pump discharges through a dedicated vertical header into a vented channel at ground level (Figure 9). The elevation rise between the RSP and ground level is 43 feet through three re-enforced concrete floors. The rated capacity of the RSPs is 74,500 gpm and 35 ft-head at 397 rpm. The reported capacity drift was approximately 10 to 15 percent of rated flow with discharge flow returning to rated conditions following a pump shut down and restart. The unique aspect of this phenomenon is that it occurs with no significant change in TDH.

In order to document the occurrence of the capacity drift and determine the cause, data was collected on two pumps for one month each. It was necessary to collect suction and discharge pressures, discharge flow, pump speed, and electrical horsepower for each pump. Additionally, to determine if the physical configuration of the pumps and inlet piping were causing the capacity drift, a ring of four suction pressure instruments were needed around the inlet nozzle of each pump (Figure 10). Permanently installed instrumentation measured wet well level, motor amperage, and discharge flow through site DCS along with a local discharge pressure gauge. Temporary instrumentation was required in order to collect the necessary data.

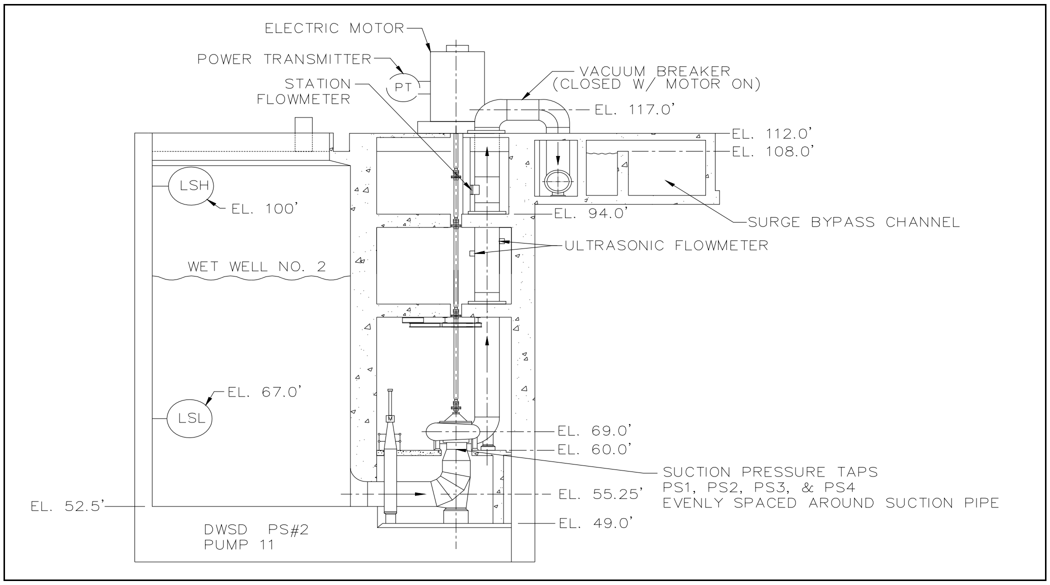


Figure 9. RSP Elevation Drawing.

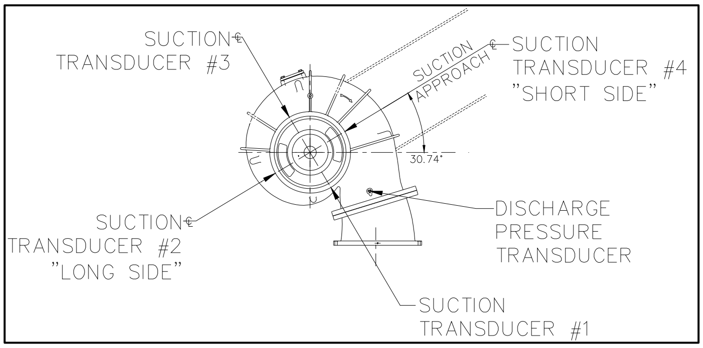


Figure 10. Suction Pressure Location.

Figure 11. Pressure Instruments Around Suction Nozzle Spaced 90 Degrees Apart.

Figure 12. Ultrasonic Flow Meter with 4-20mA Transmitter and Signal Repeater (Black Box).

Figure 13. Laser Tachometer with Battery Powered Transmitter (Red) with Pulse Input for Pump Rotational Speed.

The temporary instrumentation included suction and discharge pressures on the lower level, flow and speed on the middle level, and electrical horsepower on the motor level (Figure 9). A wireless DAS was chosen because instrumentation was spread over several levels, data collection was to occur for several months, and instrumentation would be moved between two pumps all while leaving the DAS in a secure location. The wireless system consisted of a DAS receiver on the motor level equipped with a cell phone card to transmit data to a remote viewing portal with a sample rate of 0.033 S/s. The pressure instruments were solid state piezoresistor transducers integrated with self-contained, battery powered, sensor-transmitter units (Figure 11). Flow data was collected with non-intrusive ultrasonic flow meters. The flow meters were programmed to output an analog 4 to 20 mA signal that was wired into a loop powered analog transmitter (Figure 12). Pump speed was measured with a laser tachometer configured for a TTL pulse output (Figure 13). The pulse output was connected to a battery powered digital counter and transmitter combination. Electrical horsepower was measured with a power meter installed in the pumps switchgear and programed to output an analog 4-20mA signal that was wired into a battery powered analog transmitter. Due to the signal attenuation through the re-enforced concrete floor (estimated to be approximately 10 to 15 dB (Rappaport, 2002)), a signal repeater was utilized at the gap between the floor and discharge piping on each level (Figure 12). The wireless system utilized 30 mW wireless instrumentation with a spread spectrum transmission frequency of 902-928 MHz with a mesh architecture. Due to the long data collection period and remote location of the system, data from the DAS was sent to a remote server via a cellular card. This allowed for remote monitoring of measured parameters through an Internet connection.

The analysis of the data from pump F9P0011 showed strong evidence of capacity drift. Figure 14 shows the pump discharge pressure and the average of the four suction pressures plotted against time. A slight, unequal distribution was noted between the individual suction pressure instruments. The pump is driven by a constant speed motor so all data is at 100 percent speed. The 100 percent speed assumption was confirmed by means of a laser tachometer with variation in speed less than 1 rpm. During the measurement time period, following pump start up, the pump was shut down and restarted three times.

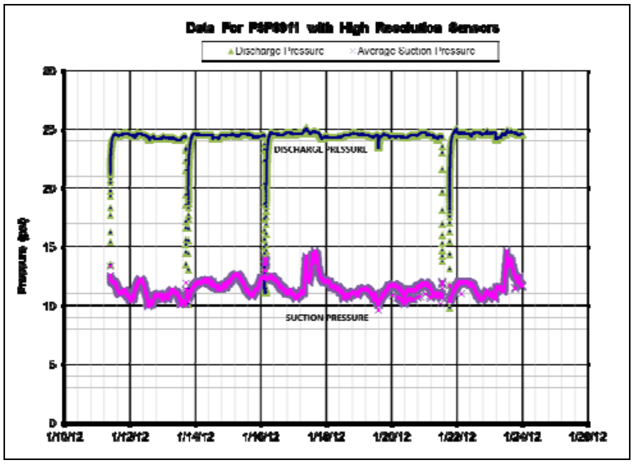


Figure 14. F9P0011 Discharge Pressure and Average Suction Pressure of the Four Suction Pressure Instruments Around the Inlet Nozzle.

Of particular interest is the time period that began early on 1/16/12 and continued through 1/21/12. Figure 15 shows the pump flow and the pump motor input power plotted against time. When the pump was started early on 1/16/12 the flow was on the order of 70,000 gpm. For the next 40 hours, the flow fluctuated between 70,000 gpm and 55,000 gpm. By the early hours of 1/18/12 the flow drifted to about 50,000 gpm and did not recover until the pump was shut down and restarted late on 1/21/12. The increase in driver input power during the time of significant capacity drift can be explained by the fact that the pump's power increases with decreasing flow due to its specific speed. Given the small changes in pump head and the slope of the pump curve, these flow reductions were initially unexplainable. The shop test of the F9P0011 did not have any indicated symptoms of the capacity drift phenomenon.

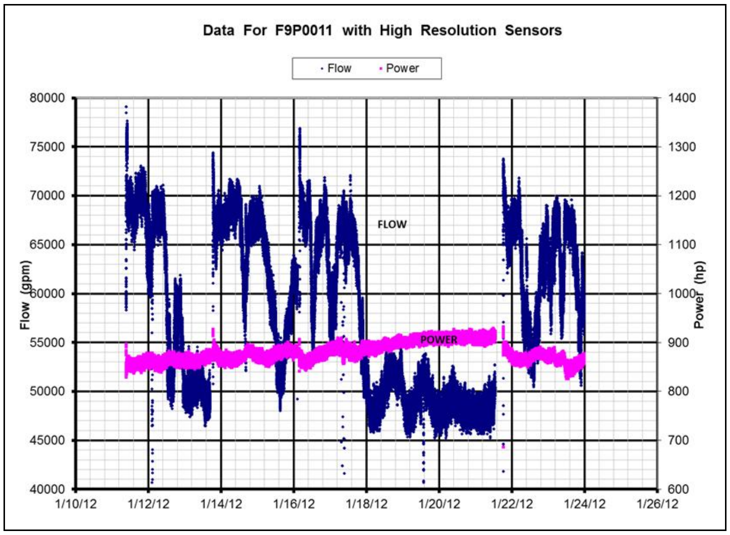


Figure 15. F9P0011 Discharge Flow and Power.

Pump F9P 0010 employs a different hydraulic design to meet the same design conditions. Reports from the station operators indicated that this pump did not experience capacity drift. By means of the same instrumentation arrangement, the capacity drift testing was conducted on this hydraulic design. Figure 16 shows the discharge and suction pressures plotted against time starting early on 1/27/12 until 3/7/12. These plots tell us that the average pump head is close to the static head between the suction free water level in the wet well and the discharge free water (vertical) level (Figure 9). Figure 17 concentrates on the time period beginning with a pump start early on 1/27/12 and ending with a pump shutdown on 2/1/12. Again, pump flow and input power are plotted against time while maintaining constant pump speed (397 rpm) and head. This chart clearly shows that this design reacts differently than that shown previously. In this case the average pump flow is in the order of 70,000 gpm at start-up but the capacity drift begins shortly after startup and continues to an average of 62,000 gpm. Interestingly, after 12 hours of reduced capacity, the pump recovers the original flow without a pump shutdown. Early on 1/29/12 the capacity drift restarts and the flow drops to an average of 60,000 gpm over the next four days. As we saw on pump F9P0011, the motor input power increases as the flow reduces with a similar specific speed hydraulic.

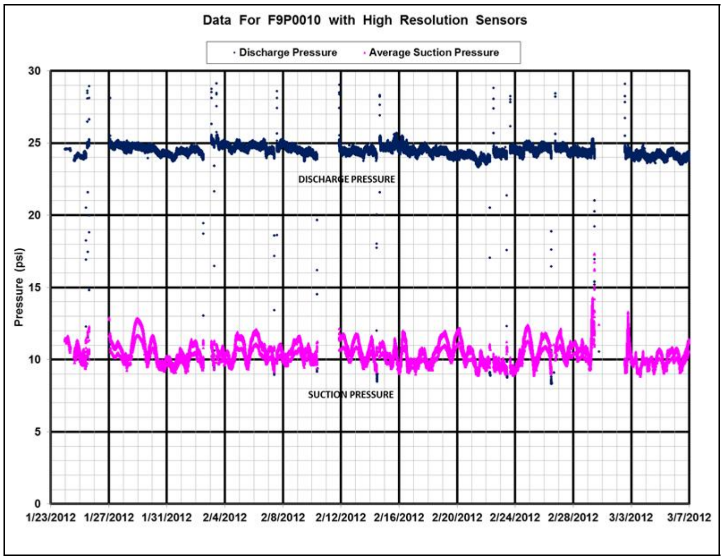


Figure 16. F9P0010 Discharge and Average Suction Pressure

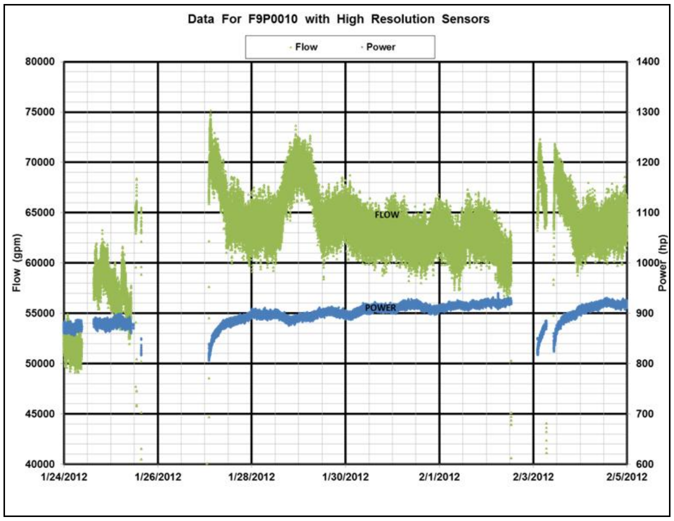


Figure 17. F9P0010 Discharge Flow and Power

The result of the analysis is that the capacity drift is occurring on both pumps in the wet well. That data collected from the wireless instrumentation is currently being used to aid in the development of a CFD model of the complete pumping system, including the wet well, suction piping, and one pump from suction to discharge flange. The CFD simulation (in progress) suggests that the amount of capacity drift is likely related to the pump design, suction piping geometry, and position of the pump around the wet well , and likely presence of suspended solids (sewage medium) .

CONCLUSIONS

A temporary wireless DAS has numerous benefits for troubleshooting and analysis of pumps and pumping systems. As shown in the first case study, a wireless DAS can aid in pump and system testing by allowing the information from the temporary instrumentation to be collected simultaneously without extensive cabling and disruption to site personnel.

The second case study shows an example of using wireless instrumentation and a DAS to record field data to give insight into a phenomenon pertaining to Raw Sewage Pumps. This data has become the basis for a resolution to the capacity drift that uses CFD simulation of the existing system configuration to provide features of a new pump system (suction piping and pump) design that will be less sensitive to capacity drift.

Due to the multiple types of wireless DAS and associated equipment, an equipment user or operator should understand that no system will be ideal for every situation and should be aware of requirements, and limitations prior to obtaining and using a portable wireless DAS system. A portable wireless DAS allows an equipment user or operator to accomplish all of this and should be a key component of any plant's "tool box."

NOMENCLATURE

BEP = Best Efficiency Point
BFP = Boiler Feed Pump
BHP = Break Horsepower
CFD = Computational Fluid Dynamics
DA = Deaerator
DAS = Data Acquisition System
dB = Decibel
dBm = Decibels referenced to one milliwatt
DCS = Distributed Control System
NPSH = Net Positive Suction Head
P = Power
RSP = Raw Sewage Pump
RTD = Resistance Temperature Detector
S/s = Samples per Second
TDH = Total Developed Head
TDSSCD = Time Dependent Steady State Capacity Drift
TTL = Transistor-Transistor Logic

APPENDIX A

Description of instrumentation used in case studies.

Ultrasonic Flow Meters (GE Sensing, 2004)

- Range: 0.1 to 40 ft/s
- Accuracy: +/-1% to 2% of reading
- Power Supply: 24 VDC
- Output: Isolated 4 to 20 mA
- Transducer Mount: External chain clamp

Tachometer (Monarch Instrument, 2013)

- Type: Optical (laser)
- Range: 1 to 250,000 rpm
- Power Supply: 12 VDC
- Output: TTL pulse (0-5 VDC)

Electrical Horsepower (Load Controls Inc, 2007) (Load Controls Inc, 2008)

- Range: 0 to 50 HP (with 1:1 transformer)

- Accuracy: +/-1% of reading
- Response Time: 500 mS
- Power Supply: 120 VAC
- Output: 4 to 20 mA

Combined Pressure Sensor and Wireless Transmitter (FEDD Wireless, 2013)

- Range: -30 inmg to 30 psig, 0 to 200 psig, 0 to 1000 psig, and 0 to 5000 psig
- Element: Solid state piezoresistor
- Sensor Accuracy: +/- 0.1 % of full scale
- Power Supply: Battery
- Battery Life: 1 year (battery life is dependent on transmission rate)
- Transmission Rate: 15 seconds
- Power Output: 30 mW
- Transmission range: 0.75 miles
- Transmission Frequency: 902 MHz to 928 MHz

4 to 20 mA Wireless Transmitter (FEDD Wireless, 2013)

- Input: 4 to 20 mA
- Power Supply: Battery
- Battery Life: 1 year (battery life is dependent on transmission rate)
- Transmission Rate: 15 seconds
- Power Output: 30 mW
- Transmission range: 0.75 miles
- Transmission Frequency: 902 MHz to 928 MHz

TTL Pulse Wireless Transmitter (FEDD Wireless, 2013)

- Input: TTL Pulse
- Power Supply: Battery
- Battery Life: 1 year (battery life is dependent on transmission rate)
- Transmission Rate: 15 seconds
- Power Output: 30 mW
- Transmission range: 0.75 miles
- Transmission Frequency: 902 MHz to 928 MHz

Signal Repeater (FEDD Wireless, 2013)

- Power Supply: 120 VAC
- Power Output: 60 mW
- Transmission range: 1.5 miles
- Transmission Frequency: 902 MHz to 928 MHz

Data Receiver (FEDD Wireless, 2013)

- Power Supply: 120 VAC
- Maximum Number of Inputs: 2500
- Data Output:
    - External hard drive
    - Cell card to remote server

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