Vol. 99 ◆ No. 12 ◆ December 1995

*A PennWell Publication*

# POWER Engineering

THE MAGAZINE OF POWER GENERATION TECHNOLOGY

## Saving money with maintenance

*page 21*

## Steam turbine control retrofit improves reliability

*page 41*

## 1995 Project of the Year Awards

*page 45*

## Award-winning $NO_x$ control at Bridgeport Harbor

*page 51*

OFFICIAL SPONSOR OF
**POWER-GEN**

By Timothy B. DeMoss,
Associate Editor

PART
1

# Finding lost megawatts

**Saving money is not something one generally associates with maintenance. Industry literature often lumps maintenance into the "operation and maintenance costs" column as if cost is the only applicable label. What many at power plants are discovering, however, is that the return on a plant's maintenance investment can be substantial. Ignoring preventive maintenance or using outdated maintenance technology can rob plant owners of millions in potential generation revenue. The plants highlighted in this month's feature on maintenance are using the latest technology and methods to recapture money and power lost to normal wear and tear.**

The importance of maintaining a power plant's water systems cannot be overstated, especially by a plant manager who has replaced expensive components and tubing due to neglect or insufficient monitoring. However, inadequate maintenance can also be costly when it negatively impacts plant performance.

**Water system diagnostic methods and maintenance technologies are helping plant engineers save millions**

## Ultrasonic testing

At the recent Electric Power Research Institute (EPRI)-sponsored Nuclear Plant Performance Improvement Seminar, several participants talked about accurate water system testing and monitoring using ultrasonic flow measurement, a concept applicable at almost any power plant. In the past, installing an ultrasonic flow measurement transducer required intrusive measures to place transducers in the flow stream. For nuclear plants, this technique was not practical if measurements were necessary on the reactor's coolant system. Recent advances in the technology are allowing plant personnel to track flow and temperature characteristics using externally mounted transducers.

In their paper, "Development of an Ultrasonic Flow and Temperature Measurement System for Pressurized Water Reactors," authors T. Lubnow and E. Miller, MPR Associates, R.W. James, EPRI, and D. Ravetti, Caldon Inc., described the concepts behind the external transducer technology. The transducers measure the elapsed time between ultrasonic pulses which travel a diagonal path along the pipe axis. Because fluid flow affects the acoustic wave velocity's axial component, the transit times can be related to the average fluid velocity along the pipe's center line (Figure 1). By calculating velocity profiles in a scale model test, engineers can convert the fluid's velocity to a volumetric flow rate.

To measure temperature, engineers measure the ultrasonic pulse's transit time directly across the pipe's diameter. Then, knowing the speed of sound in the fluid, and the fluid's pressure, engineers can calculate the fluid's temperature.

Although ultrasonic flow measurement has been used for many years in nuclear power plants, transducer reliability and signal measuring uncertainty have prevented accurate measurements. Precisely measuring pulse flight times and accounting for non-fluid acoustic and electronics time delays are keys to achieving high accuracy, said the authors.

## Transducer development

The project to develop a reliable transducer with strong, well-formed acoustic signals required original, clean-paper designs when early testing revealed that commercially available transducers violated the necessary design criteria. In addition to selecting piezoelectric crystals that would optimize acoustic transmission, the designers had a specific objective to avoid materials which might degrade when exposed to the high temperatures and radiation in a reactor's coolant system.

After selecting suitable design materials, the project team built and tested the prototypes with good results in a fossil-fired power plant feedwater system. The team then installed a system in Ginna, a two-loop Westinghouse pressurized water reactor, owned and operated by Rochester Gas & Electric Co. Early during plant heat up, the temperature signals were very strong and well formed (the system was not configured to take flow measurements until the plant reached nearly full load). However, above 355 F thermal streaming from upstream flow systems degraded the signal's strength and quality. When the plant reached standby conditions and flow measurement commenced, the flow measurement signals also degraded due to thermal streaming and turbulence.

Because the signals continued to degrade up to full power, project engineers used data post-processing to clean up transducer readings. Algorithms to post-process flow data were not yet available, but corrected temperature measurements were very near the values recorded by resistance temperature devices already installed in the plant. Engineers calcu-

Reprinted from the December 1995 edition of **POWER ENGINEERING**

lated the uncertainties in the measurements at Ginna as approximately ±2 percent for flow and ±1.5 F for temperature. Refining post-processing algorithms could bring those values down to ±1 percent and ±1 F respectively.

## Hydraulic testing

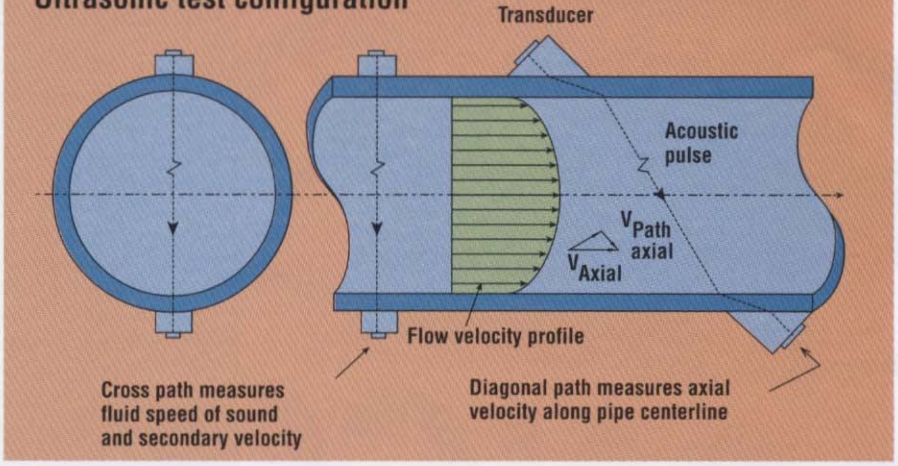
As mentioned previously, engineers conducted scale-model plant pipe configuration tests to accurately predict flow velocity profiles. In their paper, "Hydraulic Testing of External Mount Ultrasonic Flowmeters," D.E. Mazzola, MPR Associates Inc., and D.R. Augenstein, Caldon Inc., discussed these tests and their importance.

Because externally mounted transducers measure the average velocity along a pipe's centerline, an engineer must have proper knowledge of the relationship between this measured average velocity and the overall average axial velocity in the pipe to accurately calculate volume flow. According to Mazzola and Augenstein, without knowing this relationship, engineers could use a high-accuracy instrument to measure average centerline velocity and still have errors as large as 5 percent in volumetric flow rate.

To correct for such errors, a flow calculation should include a profile factor (*PF*). The PF, determined experimentally, is defined as the ratio of average axial velocity in the pipe to the average centerline velocity.

**Figure 1**

**Ultrasonic test configuration**



The volume flow can then be calculated from:

$$Q = PF \cdot A \cdot \overline{V}_{CL}$$

where:

$\overline{V}_{CL}$=average axial velocity in the measurement plane,

$A$=pipe cross-sectional area and

$Q$=volumetric flow rate.

By using a carefully calibrated weigh tank for model testing, the *PF* is calculated from:

$$PF = \frac{Q_{WT}}{Q_{CALC}}$$

where:

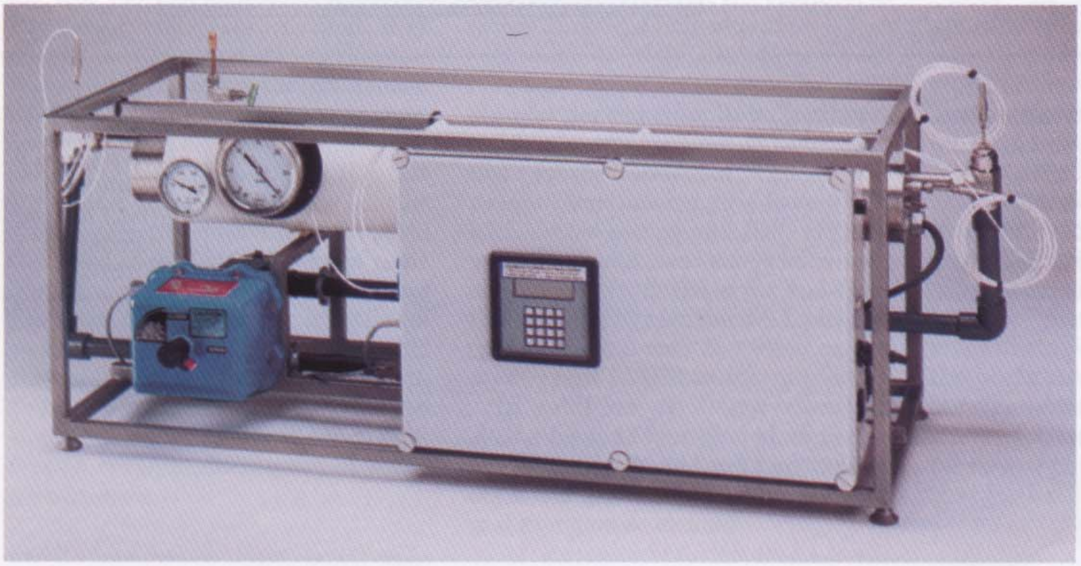
$Q_{WT}$=actual flow rate based on weight tank and

$Q_{CALC}$=flow rate calculated using ultrasonic centerline velocity measurement

Mazzola and Augenstein listed the principal factors which influence the profile factor at a given location in the piping system:

- the piping configuration upstream from the measurement location (elbows, headers, etc.),
- the instrument's proximity to upstream hydraulic disturbance,
- the relative roughness of the inside pipe surface, and
- the Reynolds number.

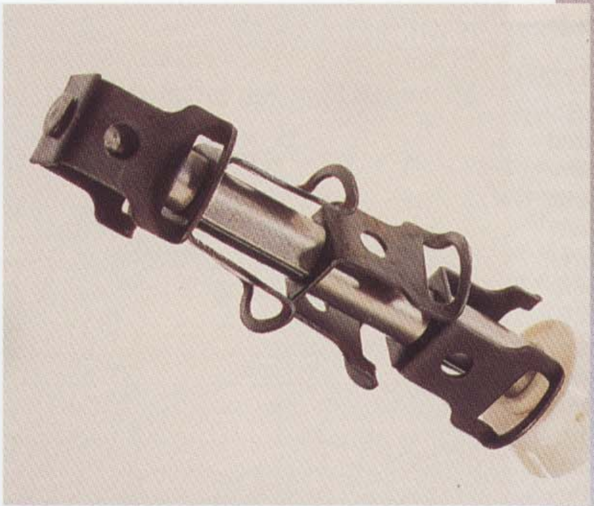
By conducting a series of tests incorporating varying combinations of these factors based on different configurations in a plant, plant engineers can build a PF database for ultrasonic testing. In tests cited by the authors, when measurements were taken downstream from a header or elbow, the conditions present upon entering those flow discontinuities had little effect on the measured PF, a fact that



*A portable test condenser can help track fouling and the nature and quantity of deposits without disturbing the main condenser unit.*

might simplify testing in some configurations.

It was also apparent in the authors' research that it is important in scale-model testing to account carefully for pipe friction influence. In straight-pipe tests, Mazzola and Augenstein found that locating transducers too far downstream from a hydraulic disturbance may permit axial velocity profile development to the point that the pipe's relative roughness becomes the controlling variable in determining the profile factor. This is a problem because, unlike a piping system's physical configuration, the roughness of a pipe in use may be difficult or impossible to determine.



*Advanced tube cleaners can help recover megawatts and millions in lost revenue.*

Despite precautions to account for all variables, there is still some uncertainty in PF measurement. The authors listed the following principal contributors to this uncertainty:

- uncertainties in weight tank measurements,
- observation errors,
- uncertainties in extrapolating test results to plant Reynolds numbers (if test results indicate PF sensitivity to Reynolds number),
- differences in relative roughness between test lines and plant lines, and
- uncertainties inherent in the test equipment (e.g., metering section dimensions, pipe acoustic properties, time measurement, etc.)

Combining the uncertainty in the PF, approximately ±0.7 percent, with the flow meter uncertainty, typically ±0.6 percent to ±0.7 percent, yields a plant flow measurement uncertainty in the range of ±0.9 percent to ±1.0 percent. These small uncertainties should provide high confidence in ultrasonic flow testing.

## Condenser performance

With improved measurement techniques for feedwater flow, operators can push plants closer to their licensed power rating. With increased thermal energy available to the turbine, a thermal engineer's task is to maximize this energy's conversion to power-generated revenue by minimizing cycle losses, according to George Saxon Jr. and Richard E. Putman in their paper, "Improved Condenser Performance Can Recover up to 25 MW Capacity in a Nuclear Plant."

The largest cycle loss, said the authors, is the energy rejected to the environment through the condenser. The loss increases as the back pressure rises above its expected value. Such deviations in back pressure can be caused by tube fouling (inside or outside), air inleakage, insufficient or improper air removal, turbine blade erosion or any number of complicating factors.

By combining existing performance standards based on cleanliness factor, cooling-water temperature difference, etc., which indicate the condenser's present condition, with new computer-based methods for continuous monitoring, engineers can more accurately determine optimum condenser cleaning frequency and can establish a fouling signature. Plant engineers can also use a fouling monitor or portable test condenser to monitor fouling progress and deposit quantity and nature.

## Monitoring equipment

Saxon and Putman referred to a monitor which incorporates a single-tube heat exchanger, with steam under vacuum on the shell side and cooling water on the tube side, drawn from the condenser's cooling water supply. A small computer reads temperature and flow data and trends the results.

Since the monitor collects deposit samples without disturbing the main unit, a load reduction is not necessary for sample collection. The tubing in the monitor can be removed or replaced at any time for cleaning, evaluation and heat transfer testing. According to the authors, deposits in the monitor are the same as those in the condenser.

Using data from deposit sample analysis with results from the tube and condenser performance analysis, engineers can compare the degree and nature of fouling in different condenser compartments or locations. They can then use this information to adjust water treatment programs and tube cleaning methods.

While past condenser analysis yielded only total costs associated with fouling, the advanced diagnostic methods and tools mentioned here can accurately identify fouling onset and predict its effect on performance, said the authors. Furthermore, depending on deposit type and quantity, engineers can use these diagnostic tools to evaluate removal methods or develop new removal techniques for more difficult applications.

There is an important result to using this approach. "The use of sound and comprehensive diagnostic techniques," stated Saxon and Putman, "can allow an expeditious recovery plan for unit capacity to be developed before an outage and implemented on schedule and within budget."

## 80 tons removed

Saxon and Putman cited two case studies where applying these diagnostic methods proved effective.

At the Clinton Power Station, a 985-MW boiling water reactor (BWR) in Illinois, operators had experienced degraded performance over four operation cycles. A performance evaluation program at Clinton identified condenser thermal deficiencies as the main performance culprit. The deficiencies increased over time, eventually resulting in seasonal generation output reductions as high as 15 MW due to elevated back pressure. When back pressure reached 0.8 in. Hg higher than expected, plant personnel became concerned, only to see the deviation reach 1.3 in. Hg two years later. Table 1 shows the expected generation output losses resulting from operation above design back pressure.

Dramatic pH swings in lake water fed to the condenser made managing the scale inhibitor feed rate extremely difficult. Previous cleanings had removed soft deposits, but using the aforementioned diagnostic methods and tools operators discovered hard scale deposits approximately 20-mils thick in the condenser's 53,160 stainless steel tubes. Further analysis proved the scale to be calcium carbonate.

Attempts to clean the scale from the test monitor's tubes were futile and plant engineers realized they needed a new type of mechanical scale cutter to clean the condenser. Operators acquired a new scraper more suited to cleaning the ceramic-like deposit and tried it on the test monitor's tubes. The new cutter proved effective and Clinton operators used it to clean 80 tons of scale from the condenser's tubes during the next outage, saving 20 MW of generating capacity. An economic analysis revealed that, had the condenser not been cleaned, Clinton would have lost $2.6 million in generation revenue during the next operation cycle.

### Table 1

**Megawatt loss due to operating above design back pressure**

| | | MW loss due to operation at | |
|---|---|---|---|
| Month | Design | 0.6 in. Hg above design | 1.3 in. Hg above design |
| January | 0.00 | 0.00 | 2.41 |
| February | 0.00 | 0.00 | 2.66 |
| March | 0.00 | 0.00 | 3.35 |
| April | 0.00 | 1.12 | 6.05 |
| May | 0.00 | 1.56 | 7.60 |
| June | 1.74 | 6.66 | 14.47 |
| July | 3.20 | 9.53 | 19.96 |
| August | 3.49 | 10.04 | 20.56 |
| September | 1.06 | 5.39 | 14.45 |
| October | 0.00 | 1.39 | 7.46 |
| November | 0.00 | 0.14 | 4.12 |
| December | 0.00 | 0.00 | 2.26 |

## 25 MW recovered

Operators at the 1,152-MW BWR Peach Bottom plant in Pennsylvania also experienced the effectiveness of a thorough diagnostic approach in evaluating performance deficiencies. At Peach Bottom, which draws its cooling water from the Susquehanna River, thermal performance engineers observed over several months a degradation in cleanliness factor, their primary criterion for determining condenser tube fouling. Tube blockage was thought to be contributing to a performance degradation in Peach Bottom's Unit 2. However, observed degradation during the winter months, when fouling should cause little or no megawatt loss, was a cause for concern. Operators did manage to clean the water boxes during a load drop in February, recovering 6 MW, but the cleanliness factor improved only slightly.

Similar to the Clinton analysis, operators at Peach Bottom devised a plan for deposit sampling. Engineers collected samples from various locations in the condenser with deposit weight densities ranging from 0.4 to 17.5 grams per square foot. Deposit analysis confirmed suspicions that manganese from the river and from the plant's hyperchlorite biological control system was deposited on the condenser's 55,080 titanium tubes.

In addition to using standard spring-loaded, four-bladed cleaners, engineers conducted tests on various blade designs in a search for the optimal manganese cleaner.

A new cleaner developed through Conco Consulting Corp. increased the blade surface contact area and proved to be very effective at removing the tenacious manganese. As a result of Peach Bottom operators' thorough diagnosis and using the new cleaner, PECO Energy Co. realized a 25-MW capacity increase, equivalent to more than $4.3 million per year. Maintenance workers cleaned the 55,000 tubes in 90 hours, removing 7,000 pounds of deposits.

## Making money

Clinton and Peach Bottom are good examples of how a well-maintained plant can mean millions of dollars in savings. The maintenance analysis methods and new technologies presented at the EPRI nuclear conference were a result of direct experience in maintaining nuclear plants at peak efficiency and capacity. All power plant operators can transfer knowledge from the lessons learned by the nuclear power community to achieve similar results. At the EPRI conference, David Eder, Commonwealth Edison, summarized well the changing role of thermal engineers in today's power generation industry: "We are no longer just finders of lost megawatts. We need to try not to be the plant with the lowest heat rate, but the plant that makes the most money." Continuing innovation in performance analysis should make that goal attainable. ∎

## Conco Systems, Inc.
### Absolutely the Best!

Long recognized throughout the power industry for quality cleaning of condensers and heat exchangers, Conco has both integrated systems and service capabilities. Applications of technology exclusive to Conco add value to your cleaning, inspection, and monitoring programs for cooling and service water systems.

The company is comprised of three divisions: (1) **Systems**, providing the manufacture and sale of products, (2) **Services**, field services employing qualified personnel for supervision of turnkey project work at your site, and (3) **Consulting**, applied technology, equipment and software for the resolution of deposition, corrosion, failure and performance concerns which you may incur.

Conco offers exclusive technology for:

- Tube Cleaning
- Deposit Sampling
- Leak Detection
- Eddy Current Testing
- Tube Failure Analysis
- Tube Plugging
- Deposition Monitoring
- Corrosion Testing
- Performance Software
- Process Modeling
- Optimization Studies

Contact us for more information or a demonstration in your plant.

CONCO
ESTABLISHED 1923

**Conco Systems, Inc.**
530 Jones Street
Verona, PA 15147 USA
**1-800-345-3476**
**Fax: 412-826-8255**
E-mail: info@concosystems.com
www.concosystems.com

---

CONCO
ESTABLISHED 1923

**Conco Systems, Inc.**
530 Jones Street
Verona, PA 15147 USA
1-800-345-3476
Fax: 412-826-8255
E-mail: info@concosystems.com
www.concosystems.com

BULK RATE
U.S. Postage
PAID
PERMIT NO. 36
Verona, PA
15147