# From Reactive to Proactive: A Power Plant Pipeline Owner's Change in Philosophy

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## ABSTRACT

Pipeline systems in power plants have a unique set of factors quite different from pipeline systems in municipalities. Typical municipalities have hundreds of miles of pipelines and focus on the inspection of this underground infrastructure has historically been a regular practice of the maintenance of this system. In contrast, a typical power plant may have less than a mile of large diameter circulating water pipelines. Since large diameter pipelines comprise only one component of many systems managed within a power plant, in many generating stations regular inspection of these pipelines has not been a standard practice. While power plants have historically taken a reactive approach to management of their pipelines, the recent increase in leaks and failures in their large diameter circulating water pipelines is highlighting a need for proactive approach to pipeline management.

## INTRODUCTION

A primary focus for power plants is operating safely while maximizing days of continuous service, avoiding any unplanned shut downs – called forced outages. To this end, many fossil fuel power plants schedule between one and two planned shut downs, or outages, a year for the purpose of general operations, maintenance and repair. It is during the outage and start-up process that the greatest distress occurs on the large diameter pipelines due to changes in loading conditions within the pipe. The increased distress is demonstrated in statistics reported on the failure rate of pre-stressed concrete circulating pipe (PCCP) in service at power plants. While the typical distress rate for PCCP in a municipal water pipeline is approximately 3%, the same type of pipe has approximately 12% distress rate within industrial and power generation facilities [Higgins et al., 2012].

A recent example of this shift from reactive to proactive occurred at a power plant which experienced a rupture of a 102-inch diameter PCCP circulating water line. The failure of this pipeline caused a plant wide shut down costing the plant nearly a million dollars a day in lost revenue. The ruptured pipe segment was removed and replaced. During this forced outage, the owner performed an inspection on the remainder of the pipeline. The results of this assessment indicated that several additional segments of pipe had significant distress, which in this case was broken pre-stressing wires. These segments were identified to be at risk of near term failure. Based on these findings, the owner contacted rehabilitation contractors and scheduled immediate repairs on the most severely distressed pipe segments. Emergency structural upgrades were completed within two weeks from initial contact.

During the next scheduled outage, structural rehabilitation took place on additional segments that had been identified as distressed but with enough structural integrity to remain in place until the next scheduled outage. As part of the scheduled outage activities, additional inspections were performed on other pipelines within the plant's circulating water system. Severe distress was identified on several 90-inch carbon steel pipe segments. Structural repairs to these pipe segments were also completed within the same shutdown.

## BACKGROUND

The majority of electricity in the United States is generated in thermoelectric power plants which boil water to create steam to spin turbines to generate electricity. These types of power plants are fueled by various means including coal, natural gas, oil and nuclear. The heat used to boil water can come from burning of a fuel, from nuclear reactions, or directly from the sun or geothermal heat sources underground. Once steam has passed through a turbine, it must be cooled back into water before it can be reused to produce more electricity. Colder water cools the steam more effectively and allows more efficient electricity generation. Given the large volume of water needed to create the necessary cooling, the water used to cool the steam is most often transmitted through large diameter pipelines.

Circulating water pipeline systems within large power plants have a wide range in diameters from 36-inches to as much as 144-inches, and typically range from 1,000 to 3,000 lineal feet in length. The material of these pipelines also varies greatly including metallic, plastic and concrete piping. This paper will focus on metallic and concrete pipeline systems.

## POWER PLANT CIRCULATING WATER PIPELINES AND PLANT LIFE CYCLES

Just as there is a wide range in types and sizes of pipeline systems which make up circulating water systems, the management of these pipeline systems also varies greatly. In many cases, *out of sight, out of mind* is a saying which would accurately describe the approach power generation plants use for management of buried pipeline assets. While ignoring their buried infrastructure may have worked for many power plants until recently, the majority of the systems were installed prior to 1980 and are beginning to show their age, making this approach is no longer viable.

Over 50% of all generating capacity in the US is being produced by plants which were at least 30 years old at the end of 2010. A majority of coal-fired plants, 73%, were over 30 years into production by 2010 (See Figure 1).

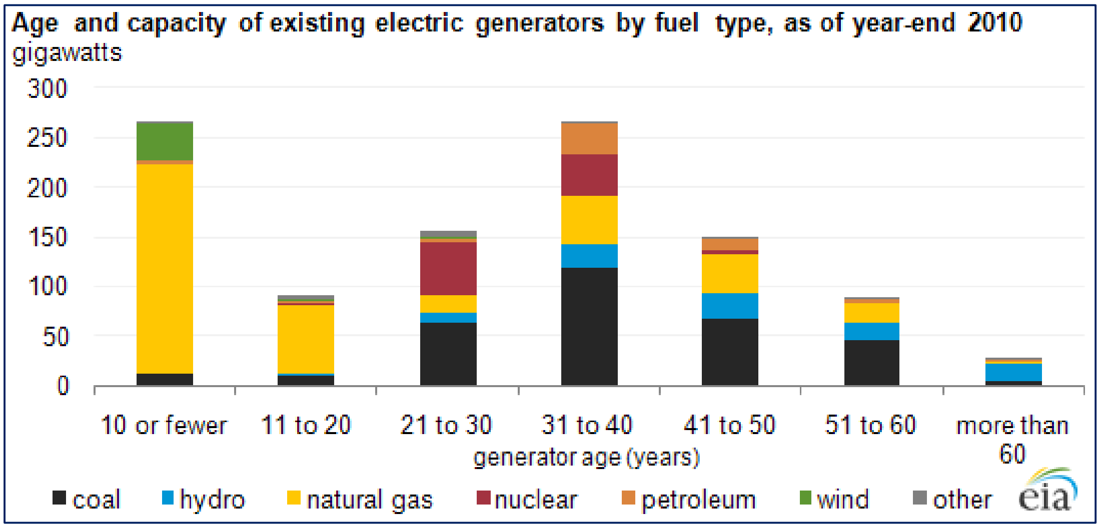


**Figure 1. Aging US Power Plant Fleet [US Energy Information Administration, 2011]**

The U.S. Energy Information data as of 2014 reported 1,172 gigawatts of power being produced by operating units across the United States, with an average start-up year of 1983. This same report showed only a total of 109 gigawatts of newly proposed units to be constructed.

Given these statistics, and the life cycle position of the US fleet, an emphasis has been placed on maintenance and extending the operability of these plants. The circulating water pipeline system is a critical component to keeping these plants on-line, and as such managing these large infrastructure assets has increased in importance.

## REACTIVE TO PROACTIVE

Over the past several years the development of asset management programs for large diameter pipeline systems in power plants has often been initiated by failure events. A typical scenario includes catastrophic failure of a single spool section of large diameter PCCP, as shown in Figure 2, followed by immediate inspection of the entire circulating water pipeline system.

**Figure 2. Failed section of PCCP**

Through the inspection of the pipeline system, distressed segments or areas are identified. and replaced or repaired. The replacement or repair of the distressed segments can take place during this same outage, or depending on the severity of the identified distress, can be postponed to a future outage. The inspection results can be used for analysis, risk ranking and prioritization in long term budgeting and planning for future outages. This process is how some plants initiate their asset management programs.

Through similar operator experience, plants with common ownership sometimes adapt a proactive approach to buried pipeline asset management. When owners share best practices among plants, an increase in the implementation of pipeline asset management plans has been observed.

One sector of power generation which is leading in a proactive approach is nuclear generators. Originating with a Nuclear Energy Institute (NEI) initiative in 2009, NEI 09-14, a guideline was put in place to manage the integrity of buried pipelines and tanks within nuclear plants. The goals are stated as:

> ***3.2 INITIATIVE GOAL*** *The goal of the Underground Piping and Tanks Integrity Initiative is to provide reasonable assurance of structural and leakage integrity of in-scope underground piping and tanks with special emphasis on piping and tanks that contain licensed materials.*
>
> *The Underground Piping and Tanks Integrity Initiative will:*
>
> - *Drive proactive assessment and management of the condition of piping and tanks that fall within the Initiative scope.*
> - *Ensure sharing of industry experience.*
> - *Drive technology development to improve available techniques for inspecting and analyzing underground piping and tanks.*
> - *Improve regulatory and public confidence in the industry's management of the material condition of its underground tanks and piping systems.*

Nuclear energy plants, under regulation of the NRC, lead the power industry in knowledge, best practices and in establishing operating standards. As the buried pipeline initiative becomes common practice within the nuclear industry other sectors within the power generation industry will begin to adapt its practices.

## IMPLEMENTING A PROACTIVE ASSET MANAGEMENT PROGRAM

An effective asset management program for power plant circulating water systems begins with recognition that the condition of buried pipelines should be monitored on a regular basis. Elementary as it may seem, simply walking the system and observing the state of the pipelines is an effective first step. Documenting and monitoring abnormalities, along with addressing cracks, areas of distress and/or section loss in all types of pipelines, as they are identified as problematic, can assist in avoiding forced outages due to pipeline failures.

Beyond observation, an effective program designed to maximize the life of pipelines will include engineering analysis, advanced or enhanced inspection methods, failure risk analysis, prioritization of identified repairs, and replacement or repair as necessary.

Many power generation plants utilize pre-stressed concrete cylinder pipe (PCCP) as the main piping type for their circulating water lines. Following is an overview of inspection methods which have proven effective for PCCP circulating water systems:

- <u>Visual & sounding</u> – Combines visual with hammer sounding of the pipeline interior to identify cracks, degradation, corrosion and anomalies such as hollow spots
- <u>In-line acoustics</u> – Determines leaks in the pipe
- <u>Electromagnetics</u> – Determines pre-stressing wire breaks in PCCP. Specialized equipment measures anomalies identified in the pipe segments.
- <u>Impact echo</u> – Determines concrete integrity (or metallic wall thickness).

Walking the pipeline, engineering analysis and utilization of enhanced inspection techniques, on a periodic basis are primary building blocks of an asset management program. Collecting and evaluating data to determine risk level and replacement or repair strategies are the important next steps.

Consequence of failure is a phrase often used to describe the methodology by which risk is assigned to pipeline systems or segments which have been evaluated. In the case of a power plant circulating water system, a pipe failure can often lead to a forced shutdown, or outage, of a unit and/or the plant, leading to considerable loss of revenue for the owner. In addition, the consequence of failure could include damaging nearby critical systems within the plant which require significant lead time to replace. The repair of the pipeline segment(s) may be incidental in cost when compared to lost revenue from forced outages or the expense of incidental damage to major parts and/or equipment.

In the case of PCCP, collection, cataloging, and evaluation of the circulating water pipeline system can be broken down segment-by-segment. Likewise, as determinations are made to address the pipeline system, repairs or replacement can be carried out on a segmental, or precision, basis.

Power plant pipeline systems are different from municipal systems in several ways including being subject to more transient pressure events. Circulating water systems are shut down and started up much more often than typical municipal systems. This leads to more stress being put on the overall system and in some cases premature failure of the lines. Statistics show that PCCP, for instance, demonstrates significantly higher distress rates in power plants. All factors considered typical distress rates in PCCP as part of a municipal water system is 3% or less, and the same type of pipe demonstrates a 12% distress rate in power plant environments.

Given all these factors, including the age of plant, criticality of the circulating water systems, and stressful operating conditions, the case for implementing proactive asset management programs within power generation plants is clear.

## TEXAS POWER PLANT CASE STUDY

A recent example of a power plant where the shift from reactive to proactive occurred this past year was in a fossil plant in Texas. A 102-inch diameter PCCP circulating water line catastrophically failed, causing a forced outage at nearly a million dollars a day in lost revenue. The failed pipe segment was removed and replaced, and there was an immediate inspection of the balance of the circulating water system using electromagnetic equipment. This included inspection of approximately 5,000 LF of 102-inch PCCP.

The results of this electromagnetic inspection indicated eight (8) additional pipe segments with a level of broken pre-stressing wires to be at risk for near-term failure. Based on these findings, the owner began to explore the best methods to address these segments, including cost and other options analysis. The eight (8) segments, 16 lineal feet each with an operating plus transient pressure of 75 psi, were spread out within the circulating water system. Given this, replacement of the pipes would require excavation in multiple locations along the pipeline. In addition, there was a significant lead time associated with manufacturing and shipping of replacement pipe sections, which would have cause substantial additional loss of revenue due to additional time out of service. This was deemed cost prohibitive due to the invasiveness of replacement locations and the time needed for replacement, so accelerated trenchless rehabilitation methods were sought out.

As stated previously, owners often reach out within their own fleet to determine best operator experience. In this case the Texas facility reached out to a sister plant in Maryland who had experience utilizing carbon fiber-reinforced polymer (CFRP) as an internally applied, fully structural repair system. After evaluation it was determined that CFRP was the best method to repair the 102-inch PCCP segments.

## CFRP REPAIRS AS PART OF ASSET MANAGEMENT PROGRAM

CFRP repair of large diameter pipelines is an effective alternative repair method to have available as part of a proactive asset management program. CFRP repairs entail the installation of layers of unidirectional carbon fiber fabric in a pipe longitudinally and circumferentially. In areas with steel substrate such as the joints, a layer of glass fabric was used as a dielectric barrier between the steel and the carbon fiber. Both the carbon fiber and glass fabrics are saturated in a two-part 100% solids epoxy using a mechanical saturator, as shown in Figure 3.

**Figure 3. Glass fabric being saturated with a two-part 100% solid epoxy using a mechanical saturator**

Prior to application of the CFRP repair system, the concrete substrate is prepared to a minimum of ICRI CSP-3 using abrasive blasting, per project drawings. To verify surface preparation, adhesion tests are performed on adjacent substrate per ASTM D4541 to 300 psi minimum, as shown in Figure 4 below.

**Figure 4. Preparation of test dollies for performing a pull test to verify surface preparation**

Once surface preparation is completed, the pipe substrate is covered by a prime coat of epoxy and a layer of thickened epoxy, as shown in Figure 5.

**Figure 5. Primer epoxy being applied to concrete substrate of PCCP line**

Saturated layers of CFRP are then manually applied onto the interior of the pipe per the project drawings. See Figure 6 for an example of a completed installation.

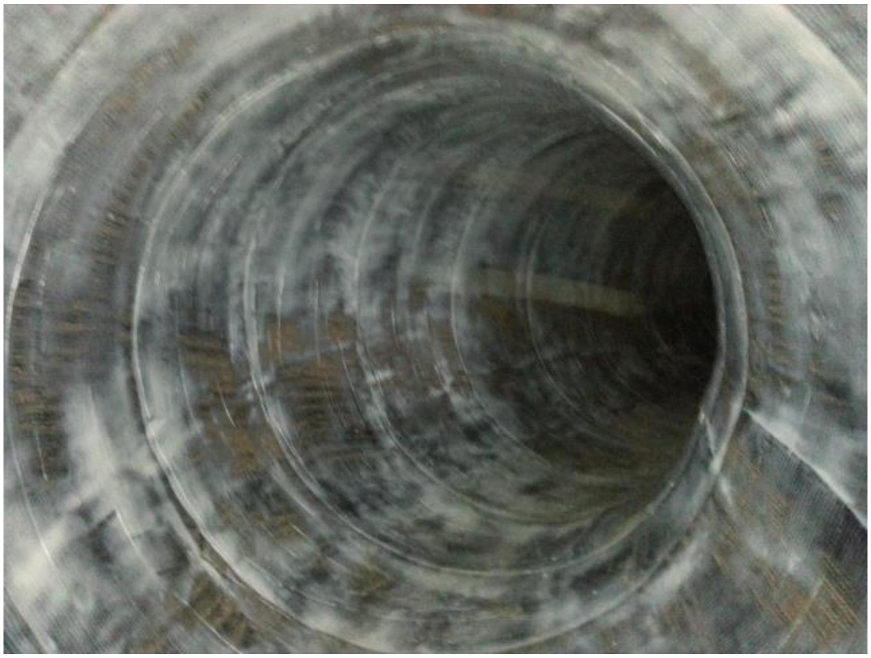

**Figure 6. Competed CFRP installation**

CFRP repairs are performed using a 100% trenchless approach, with no excavation necessary to complete implementation of the pipeline upgrade. As described in the overview of the installation process above, the layers of CFRP are installed on the interior surface of the pipeline to provide structural repair and upgrade.

When considering their usefulness for power plants, CFRP repairs are a viable option in many cases because they can be installed for segmental, repairs and the operating pressures in power plants (typically 30-80psi) is well within the design limits of the material. In some cases CFRP is used for spot repairs on an as-needed basis to upgrade just the distressed segments of concrete or metallic pipelines. In other cases, power facilities have lined their entire circulating water systems in an effort to proactively upgrade the pipelines and effectively renew the pipelines extending their service life for 50 years.

Renewal or replacement of the pipeline system is a wholesale approach, and given the age of some plants, if they are to remain operational the circulating water systems are a consideration. In situations where the circulating water pipelines run under critical equipment and/or buildings replacement can be cost prohibitive.

Another advantage of CFRP for proactive asset management programs, when compared to other methods to address distressed pipelines, is its speed of installation. Power plants typically only shut down one to two times per year, for 3-4 weeks each time. After implementing a proactive approach to power plants, regularly scheduled inspections of the circ water piping will take place. Many plants set up contingency repair plans so that any severely distressed pipelines can be addressed during the same outage. CFRP is one of the options which can be included in contingency repair plans because it can be installed rapidly. Similar to the power plant in Texas, many plants either experience or identify situations which must be responded to rapidly. When a trenchless option is necessary to perform rapid structural repairs, CFRP provides a viable option for pipeline owners as part of executing a proactive asset management program.

## CONCLUSION

As the owner of the power plant in Texas learned through the pipe failure, a proactive asset management approach to circulating water systems helps to avoid turning a single forced outage situation into similar future occurrences. Given the age of the US power plant fleet it would be beneficial for owners to adopt a proactive program to inspect, assess and manage their pipeline systems. While many owners do, in fact, inspect their water lines, utilization of advanced and enhanced inspection and repair methods can help to extend the life of the these valuable assets.

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