Online Monitoring of Passive Components and Structures: From Offline Periodic Inspection to Continuous Online Surveillance

Andrei V. Gribok
Plant Modernization Pathway

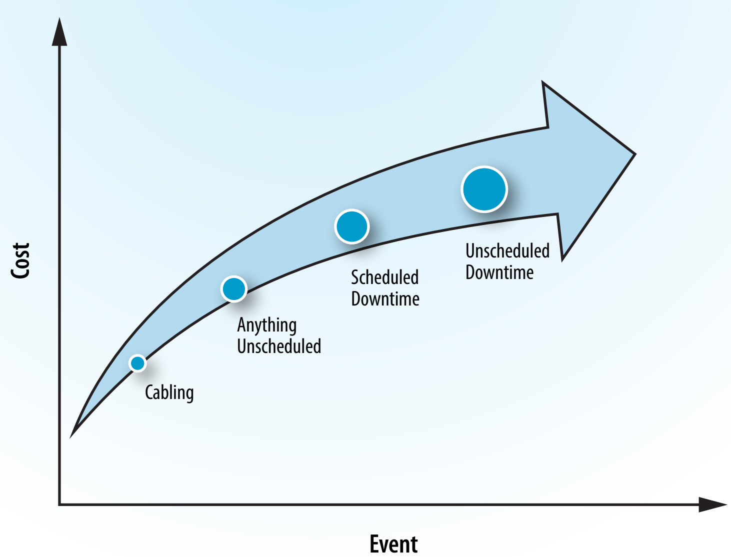
The LWRS Program provides scientific, engineering, and technological foundations to extend the life of operating light water reactors (LWRs). One of the specific areas of research and development (R&D) is developing technology that will reduce the cost to maintain passive components in a nuclear power plant, such as concrete, piping, steam generators, heat exchangers, and cabling [1].

The piping system is one of the most vital assets in nuclear power plants, with inspections performed regularly [2]. The technical basis for an inspection period could be based on predictive analysis or operating experience. However, because of the significant length of the piping systems, the problem of identifying specific piping components that need to be inspected during an outage remains a challenge. Thus, unnecessary inspections may be performed, which adds to planned downtime and costs. As shown in Figure 11, it is widely accepted that the two costliest events—unscheduled downtime and scheduled downtime—are directly related to maintenance. Unscheduled downtime is normally caused by an equipment malfunction or failure, which has not been previously detected during in-service inspections, while planned downtime is mostly spent on performing numerous aging management programs.

The well-established technology of ultrasonic guided waves (UGWs) offers new possibilities in the inspection of large portions of piping systems with few sensors. UGWs are mechanical waves that propagate at low frequencies—either sonically or ultrasonically through the walls of a pipe—and are bounded and guided by those walls. The velocity and wave modes of guided waves are strongly influenced by the geometry of the guiding boundaries. In the pipe, the UGWs exist in three different wave modes—longitudinal, torsional, and flexural. Because the guided waves are mechanical waves, they are generated either through piezoelectric or magnetostrictive transducers that convert electrical magnetic fields into mechanical energy. Once the mechanical wave is generated with a set of piezoelectric or magnetostrictive sensors (MsS) arranged in a collar around the pipe, it is transmitted through the walls of the pipe and reflected from any discontinuities (e.g., flaws) of the surface of the wall. The main advantage of UGW inspections over conventional ultrasonic testing (UT) inspections is shown in Figure 12. In contrast to conventional UT inspections, the UGW technology can cover tens of meters in one inspection session. Traditional UT inspections are highly localized and can only detect flaws within the proximity of the sensor location.

However, for UGW to be a competitive technology in the nuclear industry, it needs to overcome several shortcomings, such as low sensitivity to minor degradation, dependence on geometry, and a low signal-to-noise ratio in a heavily degraded environment. Despite its many benefits, UGW technology is challenged when applied to power plants in general and nuclear power plants in particular. Piping systems in electric power plants come in various configurations and geometries; for example, they have thousands of elbows, bends, tees, valves, nozzles, and flanges. Other secondary components, such as heat exchanger shells, have welds, nozzles, and piping components attached to them. These

Figure 11. The costliest events that affect a plant's economic performance.



geometries are not a friendly media for UGWs. Geometries other than straight pipe attenuate and distort UGWs, making inspections beyond them difficult. Also, while being a perfect tool for locating the damage in pipes, UGWs cannot determine the size of the flaw with acceptable accuracy. In summary, provided the UGW technology can overcome the limitations of complex geometries, it is a perfect tool for answering the question, "Where to inspect?"

Current research aims to address these deficiencies by applying advanced signal processing techniques to extend the detection range and sensitivity of UGW technology. The Plant Modernization Pathway collaborates with the Electric Power Research Institute (EPRI) and the Southwest Research Institute (SwRI) in acquiring data recorded using UGW systems. SwRI was allowed to install its MsS corrosion monitoring system on the shell of a low-pressure feedwater heater at a U.S. commercial nuclear generating station. The system collected daily monitoring data for 747 days between January 27, 2011, and February 12, 2013, from 17 UGWs sensors. The Plant Modernization Pathway is currently developing advanced signal processing and pattern recognition algorithms, which would allow detecting defects with higher confidence over longer ranges of piping.

When ultrasound interacts with a feature, coating, or surface roughness, some of the energy will be converted into different wave modes. If a mode is dispersive, it will contribute to the background signal (noise) as it spreads out in time and space. To increase the defect sensitivity and improve the signal-to-noise of reflection from features, it is important to filter out the noise as much as possible. The background noise produced by dispersion is coherent (non-random) and overlaps in the frequency domain with the signal of interest. Conventional filtering techniques, such as low-pass and high-pass filtering or averaging, are unable to reduce this non-random narrow-band background noise.

This research has developed a technique based on independent component analysis, which can deal with coherent noise. This technique uses knowledge of the dispersion characteristics of the wave mode, such as non-Gaussianity, and deconvolves signals in the time domain. It does not rely on frequency characteristics, but rather on statistical properties of signal and noise. Preliminary results show that independent component analysis algorithms are able to separate the defect signals from coherent noise in the context of temperature changes and constant frequency content of the defect signal. In all these scenarios, the independent component analysis algorithms are able to extract the defect signal, rejecting coherent noise [4]. This opens the possibility of extending the range of existing ultrasonic guided wave systems and to improve their sensitivity to minor degradation and in heavily degraded environments.

References

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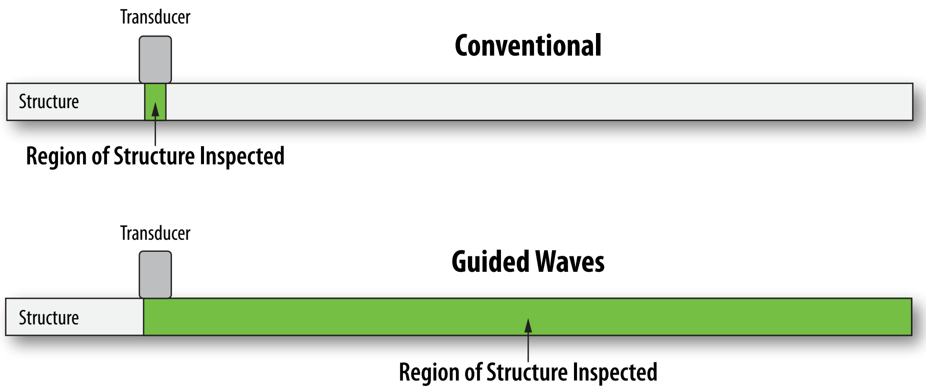

Figure 12. Inspection of UGWs versus conventional UT inspection [3].