

General Electric Advanced Technology Manual

Chapter 4.6

Air System Problems

Table of Contents

4.6 AIR SYSTEM PROBLEMS	1
4.6.1 Introduction	1
4.6.2 Generic Instrument Air System	2
4.6.3 Instrument Air System Problem Areas	3
4.6.3.1 Water Contamination	3
4.6.3.2 Particulates	3
4.6.3.3 Hydrocarbons	4
4.6.3.4 Manufacturing / Design / Fabrication Defects	4
4.6.3.5 Material Degradation.....	4
4.6.4 Component Failures.....	4
4.6.4.1 Compressors	4
4.6.4.2 Distribution System.....	5
4.6.4.3 Dryers and Filters	5
4.6.5 Regulatory Issues	5
4.6.5.1 Safety Issue Definition	5
4.6.5.2 Regulation and Guidance	5
4.6.5.3 NRC and Industry Programs.....	6
4.6.5.4 Operating Experience	6
4.6.5.5 Regulatory Rules and Observations	6
4.6.5.6 Plant Events.....	7
4.6.6 Summary.....	9

Tables

4.6-1 References.....	11
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Figures

4.6-1 Typical Air System

4.6 Air System Problems

Learning Objectives:

1. Recognize the potential consequences of a loss of instrument air event.
2. Recognize how instrument air can be used in safety related applications.
3. Identify potential causes of the instrument air system failures or degradation.
4. Identify the primary strategies used by licensees to ensure adequate air quality, system reliability and piping integrity.

4.6.1 Introduction

Many U.S. Boiling Water Reactor (BWR) plants rely upon air systems to actuate or control safety related equipment during normal operation. At most BWRs the air systems are not classified as safety systems. Plant safety analyses may assume that nonsafety related air systems become inoperable during abnormal transients and accidents. It is assumed that air operated equipment will fail in known, predictable modes. Air operated equipment which must function during transients or accidents are provided with a backup air (or nitrogen) supply in the form of safety grade accumulators or pressurized cylinders to aid in continued system operation.

A major safety concern with air operated valves is the simultaneous common cause failure of the valves which disable redundant trains of a system important to safety. The scenario of most concern is that during an accident or transient, air operated valves in redundant trains of a safety system fail when subjected to pressure, temperature, and flow conditions different from those seen during normal operation or testing.

The instrument air system has significant effects on the control rod drive system. If instrument air is lost the control rods drift into the core as a result of scram valves failing open. Control rod drift can cause peaking problems and possible fuel failure even though the rods are moving in the safe direction. Oil contamination of the air system has prevented control rods from scrambling by preventing the scram solenoid valves from functioning correctly.

Air operated valve failures can jeopardize key safety features such as main steam isolation valve and safety relief valve operation. Air operated valve failures can significantly impair emergency core cooling system (ECCS) actuation. Although many other systems such as reactor water cleanup and secondary containment ventilation have evidenced air operated valve failures, it is imperative to note that air operated valve failures can complicate if not impair:

- Reactivity control, reactor shutdown
- Emergency depressurization
- Pressure control if the reactor pressure vessel is isolated.
- ECCS operation

Improvements across the industry in filtering and drying instrument air have substantially reduced air operated equipment failure. Other improvements have been

made in instrument air systems since the NRC identified generalized problems. Nonetheless, instrument air related failures of important equipment continue to date and the importance of air operated equipment merits continued vigilance.

4.6.2 Generic Instrument Air System

There are variations between plant instrument air systems. As follows is a generic description of a BWR instrument air system (Figure 4.6-1). The instrument air system is typically isolated from the service air system, inasmuch as the quality standards for service air are not as stringent as those for instrument air.

There are two or more 100% capacity air compressors which are powered from nonvital 480 VAC electrical busses. The compressors are controlled by pressure switches located on the instrument air receivers. Typically instrument air header pressure is maintained at about 105 psig; however, values vary between plants. During normal operation, one of the air compressors is in service with a redundant compressor in standby. The running compressor loads (compresses air) when the air receiver pressure drops below a predetermined value and unloads when the air receiver pressure reaches its normal operating pressure. If instrument air pressure decreases below the designated operational pressure band, the standby compressor(s) is / are started.

Air receivers are volumes that store pressurized air. The air receivers supply the air to instrument and service air headers. Instrument air passes through air dryers and filters prior to supplying various plant components. Dryers remove moisture from the air supply and filters remove foreign particles. The dryers and filters are necessary components because of the materials and small clearances of the internal moving parts of pneumatic equipment. Clean, dry and oil free air is required for reliable, trouble free operation. The treated air is distributed throughout the instrument air system.

The number and types of instrument air loads varies between the plants. As follows is a generic description of instrument air loads.

The instrument air system may be subdivided by building location:

- reactor building
- turbine building
- auxiliary building
- fuel building
- containment building.

The reactor building instrument air loads include the outboard main steam isolation valves, control rod drive hydraulic system and various other components. The instrument air supply to the drywell is actually nitrogen and acts independently of the instrument air headers outside of primary containment. The drywell nitrogen supply is used for the inboard main steam isolation valves, safety relief valves and may supply equipment / floor drain isolation valves.

The turbine building instrument air supplies components such as the hotwell level control valves, turbine extraction steam and heater drain system, various valve actuators that control cooling water flow to generator hydrogen and oil systems,

condensate system demineralizer valves, building heating and air conditioning and the steam sealing system for the turbines.

The service air system is used to supply air to components such as the demineralizer backwash and precoat system and hose stations for pneumatic tools. Many boiling water reactor plants utilize separate service air systems to meet this need.

4.6.3 Instrument Air System Problem Areas

Instrument air failures are manifested from a diversity of mechanisms. Some of the prominent failures are due to:

- Water Contamination
- Particulates
- Hydrocarbons
- Manufacturing / Design / Fabrication Defects
- Material Degradation

A significant portion of air operated valve failures also result from electrical problems and solenoid failures. However, these problems are independent of air quality.

The solutions to instrument air problems have included improved:

- Air drying
- Air Filtration
- Material Selections
- Corrosion Control
- Fabrication
- Surveillance
- System Cleanliness

4.6.3.1 Water Contamination

Although the instrument air dryers are designed to remove water from the air system, moisture is one of the most frequently observed contaminants in the air system. Water droplets entrained in the air can initiate the formation of rust or other corrosion products which block internal passageways of electric to pneumatic converters resulting in sticking and/or binding of moving parts. Water droplets can obstruct the discharge ports on solenoid air pilot valves thus reducing their ability to function properly. Moisture can cause corrosion of air system internal surfaces as well as the internal surfaces of equipment connected to the air system. Rust and other oxides have caused the exit orifices of pilot valves and other equipment to be totally blocked, resulting in degraded equipment operation or its complete loss. Additionally, rust particles on the inside of the piping/equipment have the potential to be dislodged during severe vibrations which could lead to simultaneous common mode failures of many downstream components.

4.6.3.2 Particulates

Particulate matter has prevented air from venting through discharge orifices of solenoid air pilot valves and valve operators. A clogged orifice changes the bleed down rate, which affects the valve opening or closing times and could result in complete failure.

Additionally, small particles have prevented electrical to pneumatic converters from functioning properly. Air dryer desiccant has been found in air pilot valve seals, preventing the valve from operating correctly.

4.6.3.3 Hydrocarbons

Hydrocarbon contamination of air systems can cause sluggish valve operations as well as complete loss of valve motion. Compressor oil has deposited glue like residue on valve internal components. This causes the valves to operate sluggishly, erratically or completely fail to operate. Hydrocarbons have also caused valve seals to become brittle and stick to mating surfaces, thereby preventing valve motion. In some cases, parts of deteriorated seals were found in air discharge orifices of valves thus preventing the valve from operating correctly.

4.6.3.4 Manufacturing / Design / Fabrication Defects

There are several instances when the manufactured equipment for instrument air could not support their design function. Back fits were common to ensure the instrument air capacity met the design demand. There have been frequent fabrication errors, many of which involve line connections. Excess stress has lead to failure.

4.6.3.5 Material Degradation

Some materials used fail at higher than expected rates, causing leaks and obstruction. Some materials are prone to unacceptable corrosion, including stress corrosion cracking. Some gaskets and seals have exhibited service lives well short of their design. Lubricants and escaped desiccants have contaminated surfaces as a glue like layer that inhibits or prevents the operating mechanisms to change position. Improved material selection has helped to reduce air operated equipment failure.

4.6.4 Component Failures

Numerous components make up the plant service and instrument air system. The following paragraphs describe a few common failures and possible ramifications.

4.6.4.1 Compressors

In most plants, instrument air systems include redundant air compressors, but generally they are not designed as safety grade or safety related systems. As a result, a single failure in the electrical power system or the compressor cooling water supply can result in a complete loss of the air compressors. Because plants have redundant air compressors and automatic switching features, single random compressor failures usually do not result in a total loss of air. Most air system compressors are of the oil free type. However, some plants do use compressors that require oil as a lubricant, and have experienced oil contamination of their air systems. Similarly, the temporary use of oil lubricated backup or emergency compressors without provisions for adequate filtration and drying can result in significant air system degradation.

4.6.4.2 Distribution System

Since most instrument air systems are not designated safety grade, or safety related, they are vulnerable to a single distribution system failure. For example, a single branch line or distribution header break could cause partial or complete depressurization of the air system.

4.6.4.3 Dryers and Filters

Single failures in the instrument air filtration or drying equipment can cause widespread air system contamination, resulting in common failures of safety related equipment. For example, a plugged or broken air filter, a malfunctioning desiccant tower heater timer or plugged refrigerant dryer drain can cause desiccant, dirt or water to enter the air lines. As discussed in section 4.6.3.1, such contaminants could result in significant degradation, or even failure, of important air system components.

4.6.5 Regulatory Issues

4.6.5.1 Safety Issue Definition

Compressed air degradation has the potential to affect multiple trains of safety related equipment. Air system degradation includes air under pressurization or over pressurization outside the design operating pressure range of the associated equipment dependent on the air system.

4.6.5.2 Regulation and Guidance

Several general design criteria provide requirements for safety related structures, systems, and components. General design criterion (GDC) 1 states that structures, systems, and components important to safety must be designed, fabricated, and tested to quality standards commensurate with the importance of safety functions to be performed. GDC 5 requires that shared systems and components important to safety be capable of performing required safety functions.

Guidance provided in NUREG-800 standard review plan (SRP) section 9.3.1 "Compressed Air Systems," states that all safety related air operated devices that require a source of air to perform safety related functions be identified and reviewed. This requirement ensures that failure of an air system component or loss of the air source does not negate functioning of a safety related system.

Guidance for testing of air systems is provided in Regulatory Guide 1.68.3. The guide requires tests to determine the response of air operated or air powered equipment to sudden and gradual pressure loss, through and including a complete loss of pressure. In addition, response of equipment to partial reductions in system pressure must be tested. Functional testing of instrument/control air systems important to safety should be performed to ensure that credible failures resulting in an increase in the supply pressure will not cause loss of operability. If licensees of operating plants make modifications or repairs to their air systems, their proposed restart testing program will be evaluated according to RG 1.68.3. Generic Letter 89-04 provides guidance on what constitutes an

acceptable inservice testing program for valves and pumps, including air operated valves.

Generic Letter 88-14, requested that licensees perform a design and operations verification of their instrument air systems. The verification includes the following:

- Testing actual instrument air quality to ensure it is consistent with the manufacturer's recommendations for individual components served.
- Maintenance practices, emergency procedures, and training are adequate to ensure that safety related equipment will function as intended on loss of instrument air.
- The design of the entire instrument air system including accumulators is in accordance with its intended function.
- Testing of air operated safety related components to verify that those components will perform as expected in accordance with all design basis events.

4.6.5.3 NRC and Industry Programs

The NRC has issued several generic letters, bulletins and information notices that address compressed air system related failures at nuclear plants (Appendix A – References). The NRC noted the potential for air operated systems to fail because of oil, water, desiccant, and rust contamination. The NRC reported the failure of valves to move to a specified position on loss of air pressure. The actuators were depressurized gradually, rather than suddenly, resulting in the failure of the valves to move to their fail safe position. The NRC created Generic Issue 43, "Reliability of Air Systems," and assigned it a high priority for evaluation.

4.6.5.4 Operating Experience

Air operated valve failures have affected reactivity control by jeopardizing the proper operation of valves associated with the control rod drive hydraulic system interface with the reactor protection system. Air operated valve failures have reduced the reliability of key safety features such as main steam isolation valve and safety relief valve operation. Due to NRC requirements problems associated with air quality have in large measure been fully addressed. However, especially due to equipment aging, most recent failures result from fabrication and design inefficiencies.

4.6.5.5 Regulatory Rules and Observations

In 1987, the Office for Analysis and Evaluation of Operational Data (AEOD) completed a comprehensive review and evaluation of the potential safety implications associated with air system problems. The report indicated that the performance of air operated safety related components may not be in accordance with their intended safety function due to inadequacies in the design, installation and maintenance of the instrument air system. This report identified the following specific deficiencies:

- The air quality capability of the instrument air filters and dryers does not always

match the design requirements of the equipment using the air.

- Maintenance of instrument air systems is not always performed in accordance with manufacturer's recommendations.
- The air quality is usually not periodically monitored.
- Plant personnel frequently do not understand the potential consequences of degraded air systems.
- Operators are not well trained to respond to losses of instrument air, and the procedures for such events are frequently inadequate.
- At many plants the response of key equipment to a loss of instrument air has not been verified to be consistent with the FSAR.
- Safety related backup accumulators do not necessarily undergo surveillance testing or monitoring to confirm their readiness.
- The size and the seismic capability of safety related backup accumulators at several plants have been found to be inadequate.

In 1991, Generic Letter 91-15 noted that deficiencies in design and application, manufacture, maintenance, surveillance testing and feedback of failure data, and concluded that problems with SOVs need additional attention by the industry.

4.6.5.6 Plant Events

In July 1981, both of Palisades' residual heat removal systems became inoperable when a single air operated control valve failed. The failure was attributed to the accumulation of water at the lowest point of the air system lines which coincided with the valve location

On October 6th, 1984 at Susquehanna Unit 1 four rods could not be scrammed due to oil in the instrument air.

On September 27th, 1985 at Brunswick Unit 2, several main steam isolation valves failed to close due to contaminants in the instrument air.

On December 3rd, 1986, 140,000 gallons of radioactive water drained from the spent fuel pool at Hatch Units 1 and 2 due to deflated pneumatic seals resulting from a mispositioned air line valve.

On December 24th, 1986, Carolina Power and Light Company engineers discovered a potential for a common mode failure of all of the emergency diesel generators at Brunswick Units 1 and 2. They found that HVAC supply dampers for the diesel generator building would fail closed, due to the loss of air, during a loss of offsite power event. The dampers failing closed, would reduce the air flow and cause the diesel generator control system to heat up. It was calculated that within one hour the air temperature in the diesel rooms would exceed the environmental qualification temperature of the control system.

In 1988 and 1989, Pilgrim, Vermont Yankee and Fermi all experienced problems when using unqualified air to provide seals or valve integrity with regards to maintaining secondary containment integrity.

On November 25th, 1989, Cooper Nuclear Station experienced a closure of the outboard main steam isolation valves as a result of a total loss of instrument air pressure. An instrument air dryer prefilter pipe ruptured causing low instrument air pressure, which in turn caused the outboard main steam isolation valves to drift closed and some of the control rods to drift into the core.

On April 14th, 2003 Grand Gulf had a reactor scram following a main generator load rejection. High winds created a partial loss of offsite power. The winds forced an errant disconnect closed, creating a line to ground fault in the switchyard. Subsequently there were transmission fault relaying failures that left Grand Gulf with only one off-site power source, causing the main generator to load reject. Following the generator / turbine trip scram, there was a loss of power to the instrument air compressors. Instrument air pressure lowered at a rate of about 5 psig per minute. The low air pressure allowed the main steam isolation valves to shut. The air header depressurized in about 20 minutes following the trip of instrument air compressors. The instrument air system restart was delayed by complications associated with inadequate procedures. The reactor was isolated from the main turbine generator, requiring heat deposition in the suppression chamber. Safety relief valves were manually operated to cooldown the reactor until shutdown cooling was available 19 hours later.

On June 25th, 2006 Comanche Peak Unit 2 had instrument air pressure perturbations. An operator identified oscillations in the air pressure supplied to the actuator of one of the atmospheric relief valves. The manual instrument air supply valve was found stuck closed because of a manufacturing defect. The defect was of a nature where valve position indicated that the valve was open when it was actually closed.

On December 13th, 2006 Perry experienced a loss of instrument air which resulted in a feedwater transient and subsequent manual reactor trip. The loss of instrument air was due to separation of a soldered header tubing elbow joint. The joint failure was attributed to poor workmanship. Specifically, the tube was not adequately inserted into the socket during initial construction.

On January 23rd, 2007 Sequoyah Unit 2 automatically scrammed due to a failed control air line.

On March 31st, 2007 Robinson had a low pressure transient in the instrument air system. Maintenance personnel failed to properly seal the desiccant retention strainer on an instrument air dryer. Desiccant was released from the dryer tower and become clogged in an outlet valve. This resulted in a lowering instrument air pressure, start of the standby compressor and an automatic cross-connect of the station air header. There was no significant plant transient as a result of the error.

On May 25th, 2007 Oyster Creek found that they had not correctly translated the design of the containment hardened vent valve accumulators into a test procedure. The acceptance criteria established in the periodic test procedure did not adequately test the accumulator's ability to function following a loss of instrument air.

On June 20th, 2007, San Onofre Nuclear Generating Station Unit 2 (SONGS-2) was operating at about 96 percent power when a line in the instrument air system separated at a weak soldered connection. The solder connection was weak because the gap

between the tube and the coupling was too large. The connection eventually failed due to corrosion. The loss of instrument air greatly compromised reactor, feedwater and steam system control. The reactor had to be scrammed.

On March 26th, 2008, Nine Mile Point Unit 2 experienced an axial split in a two inch instrument air system supply header. The split was ¼ inch wide and 41 inches long and caused instrument air header pressure to drop from 110 psig to 80 psig. The unit was shut down for a refueling outage at the time, and the event had no significant operational effect. However, if the unit been at power, this event would have resulted in a scram with complications. The cause of the failure was determined to be stress corrosion cracking of the unannealed red brass pipe. Red brass is a susceptible material and in the unannealed state there are internal stresses left over from the manufacturing process. Sampling in the system showed the presence of moisture, along with small amounts of ammonia (believed to be from the decay of insects). The water and ammonia in the system created an environment conducive to cracking.

4.6.6 Summary

Complete and partial losses of instrument air have occurred in the industry. Equipment failures due to air system degradation generally have not been included in the plant safety analyses. Plants with significant instrument air system degradation have operated with a much higher risk than previously analyzed. Air operated equipment are finely tuned systems which are susceptible to failure from contaminants such as moisture, dirt particles, and oil which may be introduced through the pneumatic supply system. Water in contact with carbon steels can lead to the formation of rust particles. Poor manufacturing, fabrication and material selection have lead to significant system failures. Inadequacies in maintenance and testing methods have allowed some instrument air systems to remain inadequate in meeting their design bases. Despite great regulatory attention, instrument air failures occur that jeopardize reactivity control, safety systems and engineered safeguards features. Because of the widespread effects of instrument air failure, this remains a system that merits close inspection.

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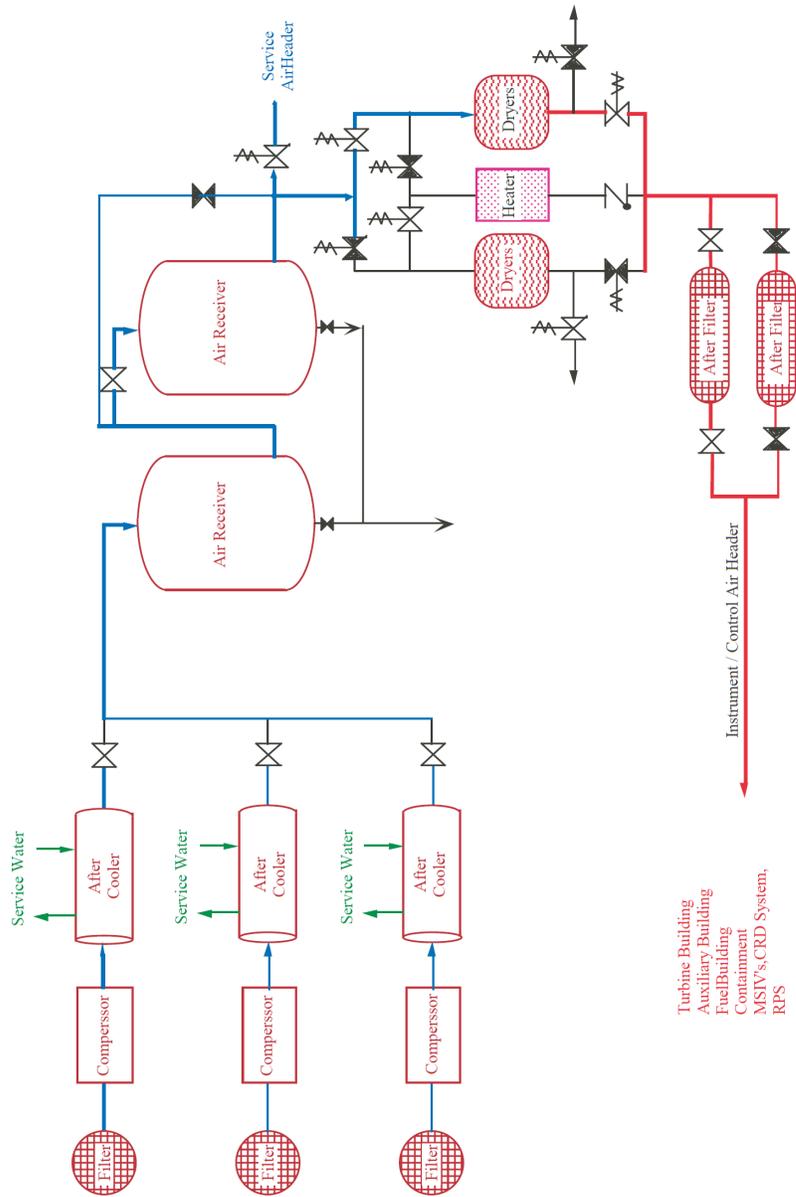


Figure 4.6-1 Typical Air System

Figure 4.6-1 Typical Air System