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Compressed Air Ring Main Leak Localization System

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Abstract

This disclosure describes a method and system for localizing and quantifying compressed air system leaks within a ring main distribution network. The arrangement addresses the challenge of identifying which leaks are economically significant and verifying the effectiveness of subsequent repairs, a common deficiency in traditional leak survey approaches. By segmenting the main using isolating valves and monitoring pressure decay during periods of minimal air demand, individual segment leak rates are determined. This allows for targeted repair efforts based on calculated financial impact and provides a clear mechanism to confirm successful leak remediation.

1. Technical Field

[0001] The present disclosure relates to the management and maintenance of industrial utility systems, specifically focused on the identification and quantification of leaks within compressed air distribution networks, often referred to as ring mains. It addresses methods for localizing leak sources and verifying the effectiveness of subsequent repair actions.

2. Technical Context

[0002] Compressed air systems are a fundamental utility in many industrial operations. Leaks within these distribution networks can lead to significant energy waste, reduced system efficiency, and increased operational costs. Traditional leak detection methods often involve acoustic or ultrasonic surveys, which identify the presence and approximate location of leaks but typically do not quantify the leak rate or its financial impact. Furthermore, these surveys often do not provide a direct means to confirm whether a repair has been successful in eliminating the detected leak or reducing the overall system leakage to an acceptable level. The absence of quantitative data makes it difficult to prioritize repairs based on economic benefit and to verify the long-term effectiveness of maintenance efforts. This disclosure describes a system and method designed to overcome these limitations by providing quantitative leak rate data for specific sections of a compressed air ring main, facilitating targeted repair and post-repair verification.

3. System Overview

[0003] The system comprises a compressed air generation and distribution network, typically an industrial ring main, equipped with strategically placed segmentation valves (13) and pressure sensors (14). A data acquisition unit (15) records pressure data from the sensors, which is then processed by a central controller (16). The core principle involves isolating sections of the ring main during periods of low or no air demand, such as overnight or during planned shutdowns. During this isolation, the pressure decay within each segment (12) is monitored. By analyzing the rate of pressure decay, the leak rate for that specific segment can be calculated. This quantitative leak rate is then converted into an estimated financial cost, allowing for prioritization of repair efforts. Following a repair, the same measurement process is repeated to verify the effectiveness of the intervention. FIG. 1 illustrates the main components and their interconnections within the system.

4. Components

[0004] The primary components of the system include:

[0005]

- **Air Compressor (10):** Generates compressed air, typically operating between 6 bar and 10 bar gauge pressure. It supplies compressed air to an air receiver (11).
- **Air Receiver (11):** A pressure vessel that stores compressed air from the compressor (10) and provides a buffer for demand fluctuations. It typically operates at a pressure similar to the main system.
- **Ring Main Distribution Network (12):** The primary piping system that distributes compressed air throughout a facility. This network typically forms a closed loop or interconnected loops to ensure redundancy and consistent pressure. The network is divided into multiple, isolable segments.
- **Segmentation Valves (13):** Electrically or pneumatically actuated shut-off valves installed at strategic points within the ring main (12). These valves are capable of isolating individual segments of the ring main from the rest of the network and from the main air supply. They are typically full-bore ball or butterfly valves to minimize pressure drop during normal operation. A typical valve might have a response time of 2 to 10 seconds for full closure.
- **Pressure Sensors (14):** High-accuracy pressure transducers installed within each segment (12) of the ring main. These sensors measure the absolute or gauge pressure within their respective segments. They typically have a resolution of 0.01 bar or finer and a measurement range suitable for the system operating pressure, for example, 0 to 16 bar. One sensor may be installed per segment, or multiple sensors may be used for redundancy or finer spatial resolution.
- **Temperature Sensors (optional):** These sensors, not explicitly numbered, may be installed within segments (12) to measure air temperature. Air temperature influences pressure decay calculations, and accounting for it can improve accuracy, especially in systems with significant temperature fluctuations.
- **Data Acquisition Unit (15):** A device that collects and digitizes the pressure (and optional temperature) data from the sensors (14). This unit may include analog-to-digital converters, signal conditioning, and local data storage. It typically samples data at a rate of 1 Hz to 0.1 Hz during decay measurements.
- **Central Controller (16):** A programmable logic controller (PLC), industrial PC, or similar computing device that manages the operation of the segmentation valves (13), retrieves data from the data acquisition unit (15), performs calculations, and stores historical data. It is programmed with the system's operational logic and leak calculation algorithms.

5. Operation

[0006] The operation of the system involves a sequence of steps, primarily executed during periods of minimal or no compressed air demand, such as overnight or during scheduled plant downtime.

[0007]

- **Preparation Phase:** The central controller (16) initiates the leak localization routine. This involves ensuring that all production machinery and pneumatic tools fed by the ring main (12) are switched off or are in a state where they do not consume compressed air. The main air compressor (10) may be shut down or configured to maintain pressure only in the main air receiver (11), not actively supplying the ring main.
- **System Isolation:** All segmentation valves (13) within the ring main (12) are closed by the central controller (16) to divide the network into distinct, isolated segments. The main supply valve from the air receiver (11) to the ring main (12) is also closed. This isolates each segment (12) at its normal operating pressure, for example, 7 bar.
- **Pressure Decay Measurement:** For each isolated segment (12), the pressure sensor (14) continuously monitors the internal pressure. The data acquisition unit (15) records this pressure data over a defined measurement period, typically ranging from 30 minutes to 2 hours. During this period, any leaks within the segment will cause the pressure to decay. The rate of decay is recorded.
- **Leak Rate Calculation:** The central controller (16) retrieves the pressure decay data for each segment. Using the ideal gas law and the known volume of the segment, the volumetric leak rate (e.g., in liters per second or cubic meters per hour) is calculated. The volume of each segment (12) is determined from its pipe dimensions, including any attached equipment or local receivers. The calculation involves the initial pressure (P1), final pressure (P2), segment volume (V), and measurement time (Δt):
- Leak Rate = (P1 - P2) *V / (P1* Δt) [at standard conditions]
- Where P1 and P2 are absolute pressures. If temperature variations are considered, a more complex calculation using the combined gas law may be employed.
- **Cost Estimation:** The calculated volumetric leak rate for each segment is then converted into an estimated energy loss and financial cost. This conversion requires knowledge of the compressor's specific power consumption (e.g., 0.1 kW per L/s of compressed air at 7 bar) and the cost of electricity (e.g., 0.15 monetary units per kWh). This provides a quantifiable cost per segment per year due to leakage.
- **Data Analysis and Reporting:** The central controller (16) compiles the leak rates and associated costs for all segments. This data is then presented to maintenance personnel, often in a prioritized list, highlighting the segments with the highest financial impact.
- **Repair Verification:** After repairs have been carried out on a leaky segment, the entire measurement process (steps 1-6) is repeated for that specific segment, or for the entire system, during a subsequent low-demand period. The new calculated leak rate for the repaired segment is compared against the pre-repair leak rate. A significant reduction or elimination of the leak rate confirms the effectiveness of the repair.

6. Example Embodiments

[0008] **Embodiment 1:** A permanent installation in a large industrial facility with a complex, multi-loop ring main. The segmentation valves (13) are actuated by the central controller (16) on a pre-programmed schedule, typically nightly. Pressure sensors (14) are hardwired to a distributed data acquisition network (15) which feeds data to a central SCADA system acting as the controller (16). The system automatically generates daily or weekly leak reports, identifying the top three most costly leaky segments. Repair verification is performed by re-running the sequence for specific segments after maintenance.

[0009] **Embodiment 2:** A semi-portable system for smaller industrial plants or for ad-hoc surveys. Here, the segmentation valves (13) are manually operated ball valves, and the pressure sensors (14) are connected to a portable data logger (15). The central controller (16) is a laptop computer running specialized software. An operator manually closes the valves, initiates the pressure decay measurement, and then downloads the data for analysis. The system is moved between different sections of the ring main as needed. This approach reduces initial capital expenditure for segmentation valves by trading it for manual intervention.

[0010] **Embodiment 3:** A system integrated with an existing building management system (BMS). The BMS acts as the central controller (16), utilizing its existing communication infrastructure to command segmentation valves (13) that are already part of a fire suppression or process isolation system. New pressure sensors (14) are integrated into the BMS's data acquisition capabilities (15). This embodiment leverages existing infrastructure to minimize additional hardware installation, focusing on software integration and parameterization for leak detection specific algorithms.

7. Alternative Configurations

[0011] Instead of directly calculating leak rates from pressure decay, an alternative configuration could involve using flow meters to measure the volume of make-up air required to maintain pressure in an isolated segment. This method would involve bleeding air from a segment to a known lower pressure, then isolating it and using a flow meter to measure the volume of compressed air required to bring it back to the original pressure, effectively quantifying the leak. However, this requires additional valving and a controlled compressed air supply to each segment. Another configuration could involve integrating acoustic sensors (not numbered) directly into each segment (12). While these sensors identify leak presence, correlating their output to a quantitative leak rate for verification purposes would require a calibration step against a known pressure decay.

8. Parameter Variations

Parameter	Range	Effect of Moving Towards Lower End	Effect of Moving Towards Higher End
Measurement Duration	15 minutes to 4 hours	Reduced accuracy for slow leaks; faster repair cycle.	Increased accuracy for slow leaks; longer analysis time required.
Pressure Sensor Resolution	0.005 bar to 0.1 bar	Higher accuracy in leak rate calculation, especially for small leaks.	Lower accuracy, potentially missing small, but significant leaks.
Segmentation Valve Count	2 to 200+	Fewer isolable segments; broader leak localization area.	Finer leak localization; increased installation complexity/cost.
System Operating Pressure	5 bar to 12 bar (gauge)	Lower energy waste per leak; compressor less stressed.	Higher energy waste per leak; higher potential for rapid decay.
Segment Volume			

Parameter	Range	Effect of Moving Towards Lower End	Effect of Moving Towards Higher End
	1 m^3 to 500 m^3	Faster pressure decay for a given leak size; easier detection.	Slower pressure decay for a given leak size; harder to detect.
Data Sampling Rate	0.01 Hz to 1 Hz	Smoother pressure decay curve; potentially less sensitive to spikes.	More granular data; higher data storage requirements.

9. Additional Implementations

[0013] The described system can be extended to include predictive maintenance capabilities. By continuously monitoring the leak rates of individual segments over time, trends can be identified, allowing maintenance teams to anticipate and address potential increases in leakage before they become critical. For instance, a segment showing a consistent, gradual increase in leak rate might indicate a degrading component that requires proactive replacement. Furthermore, the system can be integrated with enterprise asset management (EAM) or computerised maintenance management systems (CMMS) to automatically generate work orders for identified leaks, streamlining the repair process. This integration would include the estimated cost of the leak, allowing for automated prioritization within the EAM/CMMS. The methodology of segmenting a utility network and measuring decay can also be applied to other gaseous distribution systems, such as natural gas or industrial process gases, where leakage leads to waste or safety concerns. The core principles of isolation, pressure monitoring (FIG. 2), and calculation remain applicable, requiring only adjustments to material compatibility and safety protocols for the specific gas.

10. Figures

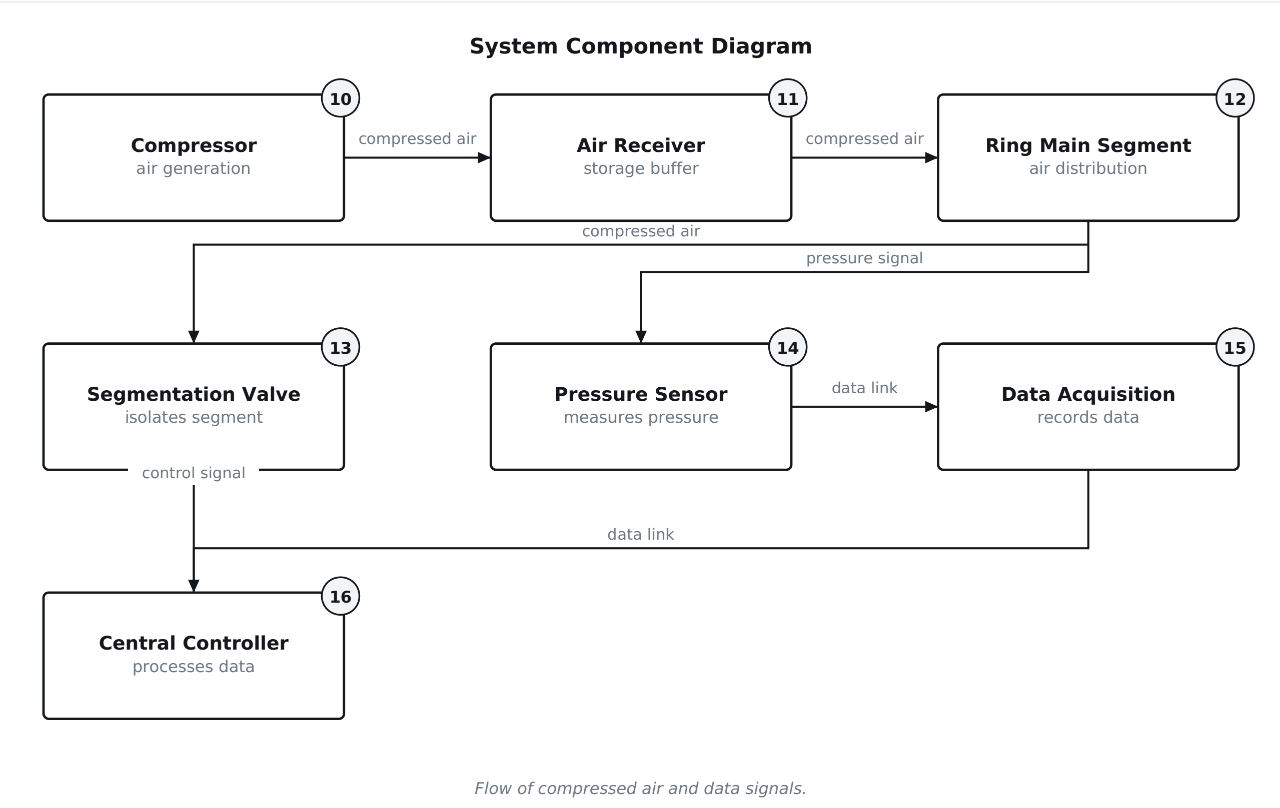

FIG. 1 A block diagram illustrating the functional components of the compressed air leak localization system.
PNG

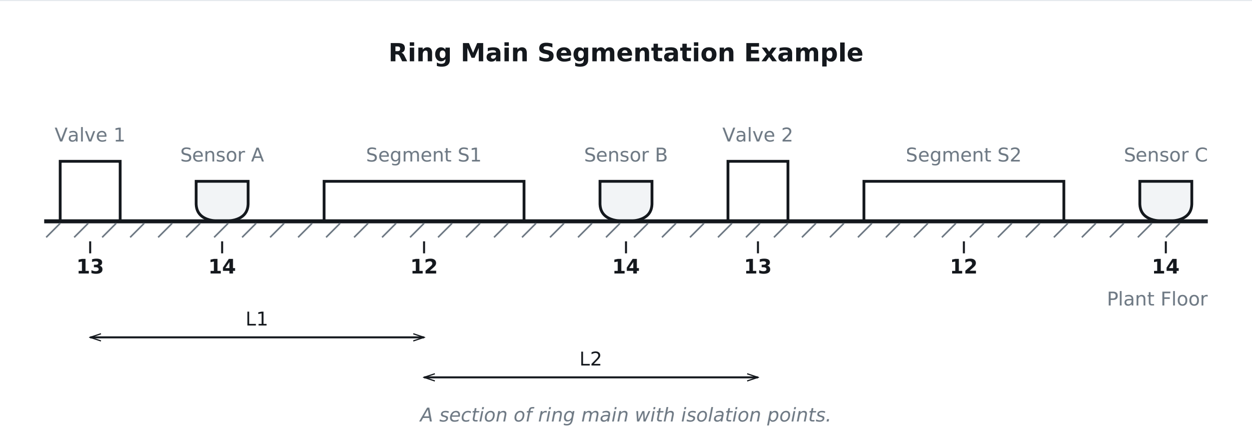

FIG. 2 An example layout of a segmented compressed air ring main. PNG

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