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(57) Abstract:

ABSTRACT A fixture-level apparatus and method for detecting a micro-leak at a plumbing fixture are disclosed. A passive piezoelectric contact transducer, maintained at a defined contact preload, receives structure-borne acoustic emission from the fixture. A controller conditions the transducer signal into a first, lower-frequency path responsive to a valve-actuation transient and a second, higher-frequency path responsive to turbulent leak emission. From the first path alone, the controller determines a valve-closed state, derives a post-closure decay envelope characteristic of the installation, and indicates a micro-leak when residual energy in the second path persists above the decay envelope. The residual may be classified as a periodic drip based on inter-impulse interval or as a continuous seep based on band energy. A second transducer may provide differential cancellation of common-mode plumbing noise. Envelope detection may reduce duty cycle, while energy harvesting may extend battery life. Multiple apparatuses may report to a hub for fixture-level attribution.

FORM 2

THE PATENTS ACT, 1970

(39 of 1970)

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The Patents Rules, 2003

COMPLETE SPECIFICATION

(see section 10)

Clamp-On Apparatus and Method for Detecting Micro-Leaks by Acoustic Valve-State Determination and Residual Decay Analysis

The following specification particularly describes the invention and the manner in which it is to be performed.

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FIELD OF INVENTION

The present invention relates generally to the field of fluid leakage detection and, more particularly, the invention relates to a clamp-on, non-invasive acoustic leak-detection apparatus employing a passive piezoelectric contact transducer for sensing structure-borne acoustic emissions from a plumbing fixture.

BACKGROUND OF THE INVENTION

Water loss in buildings is attributable not only to catastrophic pipe failures but also to low-rate, long-duration leakage at individual plumbing fixtures. Such leakage may arise, for example, from a dripping tap, a weeping spindle, a seeping compression joint, or a passing float valve. A tap dripping at approximately one drop per second may discharge on the order of ten thousand litres of water per annum. Such losses may continue for extended periods without detection, until consequential damage occurs or an anomalous water bill draws attention to the condition.

Existing leak-detection systems are generally configured for a different class of fault. Flow- and pressure-based systems installed at a service entry are primarily suited to detecting comparatively substantial or sustained flow conditions associated with burst pipes or major leaks. A domestic flow meter may have a start-flow threshold typically of the order of one to ten litres per hour, below which flow may not be registered. A substantial proportion of fixture-level micro-leaks may therefore fall below the effective detection threshold of such systems. Moreover, even when a whole-building or whole-house system detects a low-rate loss, the system generally indicates only that a leak is present somewhere within the installation, leaving identification of the responsible fixture to a manual search.

Acoustic sensing at or adjacent to an individual fixture is attractive for this class of fault. Leakage involves flow through a relatively small aperture, and such flow may generate turbulent acoustic emission that is coupled into the structure of the fixture. A passive piezoelectric transducer clamped to an external surface of the fixture can receive such structure-borne acoustic emission without intrusion into the fluid path, without requiring a pressure tap, and without modification or interruption of the plumbing connection. Further, because the sensing location is associated with an individual fixture, detection at that location inherently provides fixture-level localisation.

A significant obstacle to the practical deployment of acoustic sensing in a low-cost fixture-level product is false detection during ordinary operation. A contact transducer mounted on a plumbing fixture may receive acoustic emission generated during intentional fixture operation, acoustic energy conducted from neighbouring fixtures through connected plumbing, noise generated by pumps or domestic appliances, and mechanical disturbances applied directly to the fixture. In particular, turbulent acoustic emission associated with a leak and turbulent acoustic emission associated with ordinary water flow may exhibit overlapping characteristics at the transducer. Accordingly, amplitude or spectral characteristics alone may be insufficient to reliably distinguish a persistent micro-leak from legitimate fixture operation or environmental disturbance.

A WO patent WO2019099269A1 titled “Passive leak detection for building water supply” describes a passive leak detection system for building water supply networks that identifies small leaks without relying solely on continuous flow measurements. The invention monitors temperature and/or pressure decay characteristics in plumbing when no intentional water usage is detected to identify leakage conditions. It compares measured decay with expected hydraulic behavior to determine the presence of leaks and generate alerts.

A US patent US20170159267A1 titled “Simplified leak detection in a plumbing system using pressure decay principle” describes a plumbing leak detection system that identifies leaks by monitoring pressure decay characteristics within a fluid distribution network after water usage has ceased. The system compares measured pressure decay with expected decay profiles to determine the presence and severity of leaks while minimizing false alarms.

Existing approaches may address this problem by employing a second sensing modality to establish the operating context. Such arrangements may include a mechanical valve-position sensor, an ultrasonic flow-measuring device, an occupancy detector, or another independent sensing means. However, the additional sensing means increases apparatus cost and complexity, may require an additional installation operation, and, in the case of flow-measuring arrangements, may require apparatus to be introduced into or coupled directly with the fluid path. These requirements are undesirable for a retrofit product intended to be attached externally to an existing plumbing fixture by an untrained or minimally trained user.

Therefore, there exists a need for a fixture-level leak-detection apparatus and method capable of distinguishing a persistent micro-leak from normal fixture operation and transient environmental acoustic events without requiring a separate valve-position sensor, a flow sensor installed in the fluid path, or a skilled plumbing installation.

OBJECTIVES OF THE INVENTION

The principal objective of the present invention is to provide an apparatus and method for detecting a fluid micro-leak at an individual plumbing fixture.

Another objective of the present invention is to determine an open or closed operating state of the plumbing fixture from a signal obtained from a passive acoustic transducer alone, without requiring a dedicated valve-position sensor or a flow sensor.

It is also an objective of the present invention to provide a leak-detection criterion referenced to a decay characteristic measured for the particular installation, whereby the apparatus adapts the detection criterion to the hydraulic and acoustic behaviour of the installation.

A related objective is to provide an apparatus configured to be externally clamped to the plumbing fixture, without intrusion into the fluid path and without requiring plumbing modification or a plumbing operation for installation, and which may be constructed using low-cost components.

Yet another objective is to detect leak rates below a start-flow threshold of a flow meter associated with the installation and, by positioning the apparatus at an individual plumbing fixture, to attribute the detected leakage to that fixture.

The present invention additionally seeks to reduce false leak indications caused by normal fixture operation, neighbouring plumbing activity, mechanical disturbance, pumps, appliances, and other transient acoustic events by evaluating residual acoustic activity following determination of a valve-closed state.

An additional object is to provide a retrofit leak-detection apparatus capable of operation without a skilled installer and without materially altering the existing plumbing fixture or its fluid connections.

SUMMARY OF THE INVENTION

The following summary is provided to facilitate a clear understanding of the new features in the disclosed embodiment and it is not intended to be a full, detailed description. A detailed description of all the aspects of the disclosed invention can be understood by reviewing the full specification, the drawing and the claims and the abstract, as a whole.

The present invention relates to an apparatus and method for detecting a micro-leak at an individual plumbing fixture by acoustic sensing. In one aspect, the invention provides a passive piezoelectric contact transducer externally coupled to the fixture at a defined contact preload, wherein a single transducer channel is utilised for determining both an operating state of the fixture and a leakage condition.

In an embodiment, an output of the passive piezoelectric contact transducer is conditioned into a first signal path responsive predominantly to a valve-actuation transient and a second signal path responsive predominantly to higher-frequency acoustic emission associated with turbulent leakage.

In an aspect, a controller analyses the first signal path to determine that the fixture has entered a valve-closed state and, following the detected closure, derives a post-closure acoustic decay envelope corresponding to the particular installation. Residual acoustic energy in the second signal path is subsequently evaluated against the derived decay envelope, whereby persistence of acoustic energy beyond the expected decay characteristic is indicative of a micro-leak.

In another aspect, the apparatus thereby obtains an acoustic operating-state indication and a leak indication from a single passive contact transducer, without requiring a dedicated valve-position sensor or a flow sensor. In contrast with a fixed threshold or fixed-duration detection criterion, the decay envelope may be repeatedly measured and updated for the particular fixture, thereby adapting the leak criterion to installation-specific hydraulic and acoustic characteristics.

In yet another aspect, the apparatus is configured as an externally clamped, non-wetted retrofit device requiring no modification of the fluid path, no pressure connection and no plumbing operation for installation. The apparatus may consequently be mounted to fixtures of different constructions while maintaining fixture-level localisation of a detected leak.

In a further embodiment, residual acoustic activity following closure is classified according to temporal and spectral characteristics. A periodic impulsive residual may be classified as a dripping leak, with an estimated leak rate determined from an inter-impulse interval, whereas substantially continuous residual acoustic energy may be classified as a seepage condition and characterised according to relative band energy.

In another embodiment, a second piezoelectric transducer is coupled to a supply-side conduit to provide a differential acoustic channel. Acoustic disturbances common to the fixture and supply-side channels may thereby be attenuated, permitting residual acoustic activity originating at the fixture to be distinguished from building-wide plumbing noise.

In additional embodiments, an envelope detector permits persistence monitoring at a reduced duty cycle to facilitate extended battery operation, and a piezoelectric energy-harvesting stage may recover energy from flow-induced vibration occurring during fixture operation. A plurality of the apparatuses may further communicate with a common hub, whereby detected leakage events are associated with respective individual plumbing fixtures.

The invention accordingly provides a self-adapting, non-wetted and fixture-localised micro-leak detection arrangement capable of detecting leakage that may remain below the effective start-flow threshold of a conventional flow meter.

BRIEF DESCRIPTION OF THE DRAWINGS

The manner in which the present invention is formulated is given a more particular description below, briefly summarized above, may be had by reference to the components, some of which is illustrated in the appended drawing It is to be noted; however, that the appended drawing illustrates only typical embodiments of this invention and are therefore should not be considered limiting of its scope, for the system may admit to other equally effective embodiments.

Throughout the drawings, the same drawing reference numerals will be understood to refer to the same elements and features.

The features and advantages of the present invention will become more apparent from the following detailed description a long with the accompanying figures, which forms a part of this application and in which:

Fig. 1 illustrates the Measurement-method flow. The band-limited acoustic envelope is monitored at low duty cycle; an actuation transient in the low frequency path establishes the valve-closed state; the post-closure decay envelope is measured and stored; and a micro-leak is declared where residual energy persists above that envelope;

Fig. 2 illustrates the Apparatus (schematic elevation, with a transverse section at the clamp);

Fig. 3 illustrates the Signal chain. One passive transducer feeds a lower-frequency actuation path and a higher-frequency turbulence path, yielding both the gate (valve-state inference, decay-envelope estimation) and the evidence (envelope detector, persistence test), and thence the micro-leak indication;

Fig. 4 illustrates the (a) One transducer, two signal paths: the gate and the evidence; (b) persistence tested against the installation's own measured post-closure decay law, a sound fixture following the envelope while a micro-leak persists above it; (c) differential rejection of building-wide plumbing noise;

Fig. 5 illustrates the Classification of the residual surviving the persistence test: a periodic impulsive drip, from whose inter-impulse interval a rate is estimated, versus a continuous turbulent seep, from whose stationary band energy a relative severity is estimated;

REFERENCE NUMERALS

1 - Clamp band

2 - Passive piezoelectric contact transducer

3 - Couplant layer

4 - Electronics module

5 - Optional supply-side reference transducer

6 - Drip

7 - Seep

8 - Handle

9 - Valve seat

DETAILED DESCRIPTION OF THE INVENTION

The present invention will now be described in detail with reference to the accompanying drawing. The following description is provided to illustrate the invention and should not be construed as limiting the scope of the invention.

The apparatus is clamped onto a body of a plumbing fixture, such as a tap, an angle valve, a spindle housing, or an exposed supply stub immediately upstream of the fixture, by means of a clamp band (1) carrying a passive piezoelectric contact transducer (2) and a couplant layer (3). The clamp band (1) maintains the passive piezoelectric contact transducer (2) against the fixture at a defined contact preload. An electronics module (4) is coupled to the passive piezoelectric contact transducer (2) and establishes an acoustic baseline over an initial learning period.

Thereafter, a band-limited acoustic envelope generated from the output of the passive piezoelectric contact transducer (2) is monitored, optionally at a reduced duty cycle. Upon detection of a rise in a low-frequency signal path, the electronics module (4) captures the corresponding acoustic transient and classifies the transient as a valve-opening actuation, a valve-closing actuation, or a mechanical disturbance of the fixture.

Upon determination of a valve-closing actuation, the electronics module (4) measures decay of an ensuing hydraulic acoustic transient and updates a stored installation-specific reference decay envelope. During the resulting valve-closed state, residual acoustic energy in a higher-frequency signal path is evaluated against the reference decay envelope. A micro-leak indication is generated when the residual acoustic energy persists above the reference decay envelope beyond a time predicted by the measured decay characteristic.

The surviving residual acoustic activity may be classified as a drip (6) or a seep (7), and a corresponding drip rate or relative seep severity may be estimated. A handle (8) and a valve seat (9) of the plumbing fixture may constitute respective sources or structural portions through which the acoustic transients are generated and transmitted.

In an embodiment provided with an optional supply-side reference transducer (5), acoustic signals from the passive piezoelectric contact transducer (2) and the optional supply-side reference

transducer (5) are processed differentially, whereby common-mode acoustic disturbances originating elsewhere in the building plumbing are attenuated and residual acoustic activity attributable to the fixture is confirmed.

Detailed Description

A sprung clamp band (1) or C-clip of stainless steel or fibre-reinforced polymer releasably engages an external surface of the fixture and applies a defined contact preload, whereby acoustic coupling is rendered repeatable between installations. The apparatus is wholly external and comprises no wetted part, no pressure-bearing part and no plumbing connection. Carried by the clamp band (1) is a passive piezoelectric contact transducer (2), comprising a piezoelectric ceramic disc or an element of polyvinylidene fluoride film, acoustically coupled to the external surface through a thin compliant couplant layer (3). The transducer (2) is passive, and the apparatus injects no energy into the plumbing.

Signal Conditioning and Controller

A charge or high-impedance instrumentation amplifier feeds two signal paths. A first, lower-frequency path is responsive to the valve-actuation transient, comprising mechanical emission from a handle (8) being turned and a valve seat (9) being seated, together with the hydraulic step consequent upon extinction of flow. A second, higher-frequency path is band-limited to the turbulence band and rejects building structural vibration and audio-band speech.

Preservation of the first signal path is essential to the invention, as apparatus of the art customarily high-pass filters the transducer output to isolate the leak band and thereby discards the transient from which the operating state is derived. An envelope or RMS detector in the second signal path permits persistence to be monitored over extended periods at a reduced duty cycle and at low power. A low-power microcontroller with analogue-to-digital conversion performs event segmentation, valve-state inference, decay-envelope estimation, the persistence test and drip/seep classification, and maintains the rolling per-installation reference in non-volatile storage.

Self-Gating and Envelope-Referenced Persistence

The valve state is determined from the same passive piezoelectric contact transducer (2) as the leak evidence, by exploiting the fact that actuation is low-frequency, impulsive and non-stationary

while leak emission is high-frequency, stationary and continuous. The apparatus determines that the fixture is closed from the acoustic signature of the closure.

The leak criterion is referenced to the post-closure hydraulic decay envelope measured upon that installation and updated on every closure, so that a leak is declared upon departure from the installation's own decay law rather than upon a fixed threshold sustained for a fixed duration.

Supporting features, claimed only as dependent, include drip-versus-seep classification of any surviving residual and a differential against a supply-side reference transducer (5).

Deployment

In a base case, a single unit watches a single fixture and raises a local indication and an optional wireless notification. In a multi-fixture installation, several units report to a hub, which, because each unit is mounted at a fixture, obtains localisation and attributes a detected loss to an individual fixture.

The institutional case includes hostels, schools and offices, where the losses may be large, unowned and unnoticed, and per-fixture attribution provides the value proposition.

Figures 1-5 accompany this disclosure: the measurement-method flow diagram; the apparatus in schematic elevation with a transverse section at the clamp; the signal-chain block diagram; the inventive core comprising the two signal paths, the envelope-referenced persistence test and the differential; and the drip-versus-seep classification.

EXPERIMENTAL RESULTS

Status: A low-cost prototype is in progress, having an indicative bill of materials of approximately Rs. 1,500-5,000 and comprising off-the-shelf piezoelectric discs or PVDF film, a charge/instrumentation amplifier, an ESP32-class microcontroller, a sprung clamp with a 3D-printed housing, and a bench rig comprising a tap, an angle valve and a metering needle valve producing a calibrated leak rate. No measured results are available as of the date of this disclosure. The figures accompanying the disclosure are schematic and illustrative and do not represent measured data.

Planned Experiments:

1. **Detection-threshold curve:** Detection probability will be determined against calibrated leak rate in litres per hour, with the lowest reliably detected rate being stated relative to the start-flow threshold of the local flow meter.

2. **Self-gating accuracy:** A confusion matrix will be generated for acoustic valve-state inference over several hundred labelled open, close and knock events, providing enablement evidence for the primary mechanism.

3. **False-alarm comparison:** A realistic multi-hour recording containing normal usage, neighbouring-fixture use and mechanical knocks will be used to compare a fixed-threshold detector, a fixed-duration persistence detector and the closure-referenced envelope detector. This comparison constitutes the principal inventive-step evidence and is intended to be performed first.

4. **Drip-versus-seep discrimination:** Drip and seep classifications will be evaluated against a counted ground truth.

5. **Installation independence:** Testing will be repeated on at least three physically different fixtures without manual retuning.

6. **Power budget:** Power consumption will be evaluated in the duty-cycled envelope-monitoring mode.

CLAIMS

We claim,

1. An apparatus for detecting a micro-leak at an individual plumbing fixture, the apparatus comprising:

a) a clamp band (1) configured to releasably engage an external surface of the plumbing fixture and apply a defined contact preload;

b) a passive piezoelectric contact transducer (2) acoustically coupled to the external surface through a couplant layer (3), the passive piezoelectric contact transducer (2) being configured to receive structure-borne acoustic emission from the plumbing fixture; and

c) an electronics module (4) coupled to the passive piezoelectric contact transducer (2), the electronics module (4) comprising a first signal path responsive to a valve-actuation acoustic transient and a second signal path responsive to higher-frequency acoustic emission associated with turbulent leakage,

d) wherein the electronics module (4) is configured to determine, from the first signal path of the passive piezoelectric contact transducer (2) and without a valve-position sensor and without a flow sensor, that the plumbing fixture has entered a valve-closed state, to determine following the valve-closed state a post-closure acoustic decay envelope associated with the plumbing fixture, and to generate a micro-leak indication when residual acoustic energy in the second signal path persists above the post-closure acoustic decay envelope beyond a time predicted by the post-closure acoustic decay envelope.

2. The apparatus as claimed in claim 1, wherein the clamp band (1) comprises a sprung clamp or C-clip formed from stainless steel or fibre-reinforced polymer.

3. The apparatus as claimed in claim 1, wherein the passive piezoelectric contact transducer (2) comprises a piezoelectric ceramic disc or a polyvinylidene fluoride film element.

4. The apparatus as claimed in claim 1, wherein the first signal path is configured to respond to mechanical emission associated with operation of a handle (8), seating of a valve seat (9), and a hydraulic transient consequent upon extinction of flow.

5. The apparatus as claimed in claim 1, wherein the second signal path is band-limited to a turbulence band and configured to reject building structural vibration and audio-band speech.

6. The apparatus as claimed in claim 1, wherein the electronics module (4) is configured to update the post-closure acoustic decay envelope upon respective detected valve-closure events, thereby maintaining a rolling installation-specific reference.

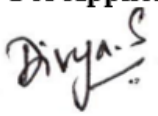
7. The apparatus as claimed in claim 1, wherein the electronics module (4) is further configured to classify residual acoustic activity persisting above the post-closure acoustic decay envelope as a periodic impulsive drip (6) or a substantially continuous seep (7), and to determine a corresponding drip rate or relative seep severity.

8. The apparatus as claimed in claim 1, further comprising an optional supply-side reference transducer (5), wherein the electronics module (4) is configured to differentially process an acoustic signal from the passive piezoelectric contact transducer (2) and an acoustic signal from the supply-side reference transducer (5) to attenuate common-mode acoustic activity.

9. The apparatus as claimed in claim 1, wherein the electronics module (4) comprises an envelope or RMS detector configured to monitor persistence of the residual acoustic energy at a reduced duty cycle.

10. The apparatus as claimed in claim 1, wherein a plurality of the apparatuses is respectively mounted at a plurality of plumbing fixtures and configured to report detected micro-leak indications to a common hub, whereby a detected micro-leak is attributed to an individual plumbing fixture.

Name and Signature of the Patent Agent
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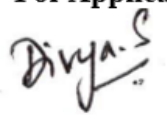
Clamp-On Apparatus and Method for Detecting Micro-Leaks by Acoustic Valve-State Determination and Residual Decay Analysis

ABSTRACT

A fixture-level apparatus and method for detecting a micro-leak at a plumbing fixture are disclosed. A passive piezoelectric contact transducer, maintained at a defined contact preload, receives structure-borne acoustic emission from the fixture. A controller conditions the transducer signal into a first, lower-frequency path responsive to a valve-actuation transient and a second, higher-frequency path responsive to turbulent leak emission. From the first path alone, the controller determines a valve-closed state, derives a post-closure decay envelope characteristic of the installation, and indicates a micro-leak when residual energy in the second path persists above the decay envelope. The residual may be classified as a periodic drip based on inter-impulse interval or as a continuous seep based on band energy. A second transducer may provide differential cancellation of common-mode plumbing noise. Envelope detection may reduce duty cycle, while energy harvesting may extend battery life. Multiple apparatuses may report to a hub for fixture-level attribution.

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