A LOW-COST TECHNIQUE TO MONITOR VENTILATION FAN OPERATION AT ANIMAL BUILDINGS

Ji-Qin Ni, Albert J. Heber, Teng T. Lim, Claude A. Diehl

ABSTRACT

When measuring emissions of gases, particulate, and odor from animal buildings, the ventilation data are equally important as the concentration data, because emission rate of a pollutant is the product of its concentration and the ventilation rate. However, effectively measuring and monitoring building ventilation remains a technical challenge, especially in barns with numerous fans. Although several measurement and monitoring techniques have been used in livestock barn studies, they are either relatively expensive or unreliable.

A new technique was introduced for continuously monitoring exhaust fan operation in real-time by detecting the vibration of its housing or frame member. A low-cost vibration sensor, a 2-conductor cable, a signal filter, and a digital input channel are used for each fan. A laboratory test was conducted to evaluate the technical viability of using the sensor in continuous vibration conditions. A 4-month field test in layer barns was conducted to test the accuracy and life of three vibration sensors, which were installed on the fan housings and cones. The fan operation data was logged by a computer every minute. Coupled with simultaneous building static pressure measurement, the continuous ventilation rate can be calculated by using the fan airflow vs. pressure performance curve.

The advantages of this technique include low cost (only about 1% to 10% of the cost of other tested techniques), simplicity, no interference by wind and dust, and the capability of directly monitoring individual fans to avoid false signals caused by fan failure, fan management changes or other problems. This paper describes the technique and presents the test results.

KEYWORDS. Air quality, air pollution, emission, vibration, sensor

INTRODUCTION

Due to the increasing awareness of the importance of agricultural air quality, more and more research has been conducted to determine pollutant (PM, gases, odor, etc.) emission baselines or abatement efficiencies at confined animal buildings in the United States and other countries. Pollutant emission rate is a primary interest in the research and is the product of the pollutant concentration and the ventilation exhaust air flow rate. Therefore, obtaining reliable and accurate data is equally important for both concentration and airflow rate.

Measurement of ventilation airflow rate at mechanically ventilated (MV) animal buildings is relatively easier than at naturally ventilated buildings, because MV buildings have fixed air exhausts with limited outlet surface areas. However, airflow rate measurement at MV buildings still faces technical challenges, especially for buildings with numerous fans.

Different techniques have been tested and used to measure ventilation rates (direct method) or to monitor the fan operation and obtain ventilation rates by calculation (indirect method). Direct methods involve devices that measure air flow rate directly without depending on correlation from other measurements. The full-size ventilation rate sensor, composed of a freely rotating propeller, is a direct method for fans with diameters of up to 45 cm, a method exercised in Europe (Ni et al., 1999) and USA (Heber et al., 2001). Indirect methods, on the other hand, involve measuring one or more relevant physical variables and then calculating the airflow rate by using some models and/or constants. One indirect method is to continuously monitor the fan...
on/off status and calculate the fan airflow rate using the fan curve (air flow rate vs. static pressure) and the simultaneously measured static pressure across the fan inlet and exhaust (Heber et al., 2003; Lim et al., 2003). Hoff et al. (2004) described three groups of indirect methods: 1. fan indication methods, including sail switches and fan relay monitoring; 2. fan rotation methods, using magnetic sensors; and 3. airspeed measurement method, using propeller anemometers. Each of the tested techniques has its pros and cons as compared with other methods. Although motor vibration sensors are available commercially, monitoring of individual fan operation at animal buildings by detecting its housing or cone vibration is apparently a novel technique because the concept is not described in the literature nor are the authors aware of its use for monitoring barn airflows.

The objectives of the study were to: 1. study the feasibility of using vibration sensors for continuous real-time monitoring of fan operations; 2. evaluate the accuracy of vibration sensor signals compared with another monitoring method used in animal buildings; 3. measure the switching frequency of the vibration sensor when attached to fan housing, and 4. test the sensor life under outdoor field conditions.

**MATERIALS AND METHODS**

Vibration sensor

The vibration sensor (VS) tested in this study was the Mini Shock/Vibration Detector (Catalog No. 49-521, RadioShack®, Fort Worth, Texas). The list price was $3.99 and it was obtained at a volume discount price of $3.19. The Vibration Detector was originally designed for use in closed-circuit alarm systems, especially for window glass, walls and ceilings made of plastic board, to detect a vibration or shock on a protected surface and activate an alarm (Figure 1 and Table 1).

![Figure 1. Open-cover view of the Mini Shock/Vibration Detector from RadioShack®.](image)

<table>
<thead>
<tr>
<th>Category</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circuits</td>
<td>Normally-closed contact, momentarily open when activated</td>
</tr>
<tr>
<td>Contact pressure</td>
<td>Adjustment from 1 to 50 g, recommended setting between 5 and 25 g only</td>
</tr>
<tr>
<td>Contact rating</td>
<td>0.5A at 25VDC Max or 0.05A at 130 VDC Max *</td>
</tr>
<tr>
<td>Life</td>
<td>Over 100,000 contacts at 0.1A, 25 VDC applied</td>
</tr>
<tr>
<td>Contact</td>
<td>Pure silver</td>
</tr>
<tr>
<td>Case</td>
<td>ABS Reslin</td>
</tr>
<tr>
<td>Size</td>
<td>17mm(H) x 23mm(W) x 62mm(L)</td>
</tr>
<tr>
<td>Weight</td>
<td>24 g</td>
</tr>
</tbody>
</table>

* Source: In RadioShack® web page (http://support.radioshack.com/support_security/doc40/40572.htm) and in product literature, respectively.

There is a weight spring contact that either touches (closed) or un-touches (open) a pure-silver contact inside the detector. When the unit is vibrated, the spring-contact moves and momentarily switches the circuit from closed to open and/or vice-versa that triggers the alarm. The detector has a built-in tamper switch and is a normally-closed device that shows an open if tampered with, if the cover is open, or if the circuit has been tripped.
There are four screws on this unit. Three screws are for connection to the alarm system and the fourth screw is for sensitivity adjustment. In its initial setting, it corresponds to a contact pressure of approximately 1 g in the normally-closed position. If the adjustment screw is turned clockwise, the contact pressure increases about 5 g for every 45° turn and vice-versa.

To use it as VS for fan status monitoring in this study, the detector was converted to a normally-open device and its contact pressure was decreased so that the contacts were open when the sensor was on its side (horizontal), and closed when it was set up right (vertical) due to gravity (Figure 2).

![Figure 2. Schematics of cut-off view of the sensor and its adjusted contact pressure. Left: open at horizontal position; right: closed at vertical position.](image)

**Laboratory test**

The laboratory test was conducted to determine whether the sensor was capable of picking up vibration signals continuously so that it can be used with barn exhaust fans.

A sampling pump (Model number 79200-00, Cole-Parmer, Vernon Hills, Illinois) was used as a vibration source; the VS was attached to the pump in its horizontal (normally-open) position. One wiring terminal for the fixed contact (Figure 2) was connected to a 5 µF capacitor and a PCI 6601 DIO card (National Instruments Co. Austin, Texas), and another wiring terminal for the tamper switch (Figure 1) was connected to +5VDC. The DIO card was plugged into a computer that was used to record data (Figure 3). The PCI 6601 device had four 32-bit counter channels and 32 lines of TTL/CMOS-compatible digital I/O. The DIO channel had a 68.9-µA leakage current at 5 VDC, equivalent to a 72.6-kΩ resistor.

![Figure 3. Schematic of vibration sensor test.](image)

**Field test**

The field test began on February 26, 2004 (day 0) and finished on June 29, 2004 (day 124) at a layer facility, where an air quality monitoring project involving two 250,000-hen barns was under way. Each barn had 75 identical 122-cm fans that were grouped into seven fan control stages. The stage control signals were monitored and recorded in the data acquisition and control (DAC) computer in a mobile lab, parked between the two barns. The VS’s were connected to the data acquisition system using the same methods as in the laboratory test. Data were sampled each second and averaged every 15 and 60 s before being saved in two separated data files in the DAC computer.

When a fan operated, the vibration of the main fan housing and the fan cone was visible and easily felt. The magnitude of vibration at different locations of the housing and cone varied...
notably. Three VSs (VS 1 to VS 3), wrapped in electrical tape to protect them from precipitation, were attached to the fans with 2.2-cm cable clamps. VS 1 was attached on day 0 to the fan cone of Fan 63 in stage 3, which operated intermittently, to compare its signal with stage 3’s fan control signal (Figure 4). This sensor was moved to the housing of Fan 57 of stage 7, which also operated intermittently, on day 32. The test of VS 1 ceased on day 64 due to failure of the sensor caused by rain, which rusted the sensor contacts. To test the sensor life, VS 2 and VS 3 were mounted from days 8 to 124 onto the fan housing and fan cone, respectively, of fan 59 of stage 1, which operated continuously. The measurement of sensor switching frequency was conducted by connecting VS 2 to a counter in the PCI 6601 DIO card, without the RC filter, for 40 minutes on day 14.

![Figure 4. Mounting locations of vibration sensors on a ventilation fan of the layer barn.](image)

**RESULTS AND DISCUSSION**

**Feasibility of measurement and signal accuracy**

Laboratory tests demonstrated that the VS can be used to detect the vibration from sources other than windows, walls and ceilings. The vibration detector was originally designed for security systems to detect the sudden occurrence of a short-duration vibration. However, combined with an RC filter and an appropriate DIO device, it can be used to sense the continuous vibration/non-vibration status of an object and provide corresponding on/off digital signals.

Field test data show that the VS responded immediately when the fan was turned on by the fan controller. The VS’ “on” signal died out about 2 - 10 s later than the fan control signal. This was due to the fact that the fan impeller was still rotating for a few more seconds after the power was turned off. Thus, combined with the simultaneously measured barn static pressure and the fan airflow-pressure curve, the fan ventilation rate can be calculated with greater accuracy than when only the fan control signal was used.

Data comparison in the 64-day test showed that signals received from the fan controller (total 26,504 min) agreed very well with those from VS 1 (total 26,589 min) if the two days of incomplete data from the fan controller signal are excluded. A perfect curve fitting ($y = x$, $R^2 = 1$) was obtained in Figure 5, which compared the daily signals.

Figure 6 presents data from day 23 when a signal cable problem of the fan controller occurred in early morning and was not corrected until in the evening. The VS 1 recorded the operation of fan 63 the entire day and avoided a loss of ventilation data.

In long-term field air quality measurements at large animal buildings, lasting from several months to more than one year, fan problems occur frequently. When fans are monitored in groups, failure of individual fans cannot be recorded accurately.
Direct monitoring of individual fans using other techniques, for example, vane anemometers, RPM meters, etc., cost several hundred dollars per fan. Other less expensive techniques that are still more than 10 times the cost of the VS, for example, sail switches (Hoff et al., 2004) are subject to wind interference and dust accumulation. Another commercially available vibration sensor (Part # HOBO H06-003-02, Onset Computer, Bourne, MA) is designed to detect and record motor on/off status, at a cost of $69 ($59 with quantity discount) each. It includes an internal battery operated data logger so that it can be used as a stand-alone device; the data cannot be observed until they are downloaded thus preventing real-time feedback of data quality and operational problems with the fans or the sensor. It is not known whether the Onset vibration sensor has been used for monitoring barn ventilation fans nor whether it is reliable in this application. The Onset sensor is designed to be mounted on the fan motor and has not been tested on the fan housing or cone. It will be difficult to remove the Onset sensor from the fan motor for
downloading data, which also requires more labor. The VS technique developed in this study provides a low-cost and relatively reliable way of directly monitoring individual fans with immediate feedback and observation of fan status, which is extremely important for successful emission studies. Moreover, the VS sensor can be maintained without interrupting fan operation.

**Sensor switching frequency**

Figure 7 presents the measured switching frequency of VS 2 installed on fan 59. Although the fan operation was under stable conditions, the contact switching frequencies varied between 13.2 and 48.2 Hz, and averaged 26.0 Hz. This graph demonstrates that the sensor contact frequency was not controlled by the vibration source frequency. It also depicts the necessity of a good RC filter in order to use a DIO device for data acquisition. The RC filter with a 5-µF capacitor and an equivalent 72.6-kΩ resistor appeared to work well with the PCI 6601 DIO device. A different RC filter is needed if a DIO device with different leakage current is used.

![Figure 7. Mean switching frequency of vibration sensor 2 mounted on fan 59.](image)

**Sensor life and protection**

Vibration sensor 2 was tested for a total of 116 d under continuous vibration and was still in good condition at the conclusion of the test. If the mean vibration frequency was 26 Hz, the total contact switching was 2.24 million times a day, or about 260 million times during the entire test. There was a concern about the VS life because the sensor specification indicates a rated life of only about 100,000 contacts with a current of 0.1 A and a voltage of 25 VDC. This corresponds to only about 64 min of vibration at 26 Hz; the low current (expected at µA level) and low voltage (5 VDC) in this study could be the reason for the long sensor life.

However, VS 3, installed on the same day as VS 2, began to develop a problem on day 31 (23 d after installation) when its contacting frequency decreased. Its signal began to show less than 60 seconds of signal in 1-min duration, and the normal signals were restored after the sensor’s contact pressure was re-adjusted. Unfortunately, the problem resurfaced 24 d later (on day 55) and worsened. This was believed to be due to bad contacts or dirty contact surfaces. Careful selection of good sensors and the timely replacement of failed sensors become significant in VS applications. The damage of VS 1 by rain on day 64 also demonstrated that better protection of the sensors is needed when they are used outdoors.

**CONCLUSIONS**

1. The vibration detector by RadioShack® can be used as a vibration sensor after modification for continuously monitoring individual fan operation in animal barns.

2. The advantages of using the VS in animal barns include low cost (only 1–10 % of other tested techniques), easy installation, small size, real-time monitoring, lack of interference of normal farm activity, and freedom from dust and wind interferences.
3. Vibration sensor 1 provided very reliable fan operation signals that matched perfectly the corrected fan stage signals, and also avoided errors of the fan stage control signal. If all the barn fans are individually monitored with VS as a backup to fan stage control signals, measurement quality for barn emission can be improved substantially.

4. After 116 d of continuous vibration, VS 2 was still in good working condition; this demonstrated a much longer sensor life than was expected based on manufacturer’s specifications.

5. Careful selection of sensor contact quality and good protection of sensors when used outdoors is necessary.

REFERENCES


