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Development and Testing of a Fan Monitoring System Using Induction Operated Current Switches

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Abstract

Emissions of gaseous compounds and particulate matter are the product of the pollutant concentrations and air exhausted from the fans of mechanically ventilated animal confinement buildings. Direct methods of monitoring exhaust fan operation (i.e., mercury tilt, limit or whisker, and vibration switches) have been reported to have limitations due to mechanical failure and/or the effect of the environment (dust, wind, moisture). Another method involves monitoring the control relay status at the fan system control box. A problem could occur at the fan but not in the signal at the control box, thereby giving a false operational signal. The objective of this project was to find a more reliable method of monitoring fan operation status. This paper describes the development, lab testing, and use of a fan monitoring system based on induction operated current switches (ICS). ICSs are unaffected by the environment and can provide direct measurement of real-time fan operational status by sensing AC current. A laboratory test of the ICS was performed to simulate a fan off/on duty cycle in a two-year emissions study; no ICS failure was recorded. The Southeastern Broiler Gaseous and Particulate Matter Emission study led by Iowa State University has been using 28 ICSs for over 190 days without a failure. At a unit cost as low as $19.50 this method offers a reliable, accurate, and economical way of measuring the real-time operational status of ventilation fans – a critical component of any air emissions monitoring in a mechanically ventilated confinement system.

Keywords

Fan monitoring, emissions, air quality, air pollution, induction, current switch

Disciplines

Bioresource and Agricultural Engineering

Comments

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Abstract. *Emissions of gaseous compounds and particulate matter are the product of the pollutant concentrations and air exhausted from the fans of mechanically ventilated animal confinement buildings. Direct methods of monitoring exhaust fan operation (i.e., mercury tilt, limit or whisker, and vibration switches) have been reported to have limitations due to mechanical failure and/or the effect of the environment (dust, wind, moisture). Another method involves monitoring the control relay status at the fan system control box. A problem could occur at the fan but not in the signal at the control box, thereby giving a false operational signal. The objective of this project was to find a more reliable method of monitoring fan operation status. This paper describes the development, lab testing, and use of a fan monitoring system based on induction operated current switches (ICS). ICSs are unaffected by the environment and can provide direct measurement of real-time fan* *operational status by sensing AC current. A laboratory test of the ICS was performed to simulate a fan off/on duty cycle in a two-year emissions study; no ICS failure was recorded. The Southeastern Broiler Gaseous and Particulate Matter Emission study led by Iowa State University has been using 28 ICSs for over 190 days without a failure. At a unit cost as low as $19.50 this method offers a reliable, accurate, and economical way of measuring the real-time operational status of ventilation fans – a critical component of any air emissions monitoring in a mechanically ventilated confinement system.*

Keywords. Fan monitoring, emissions, air quality, air pollution, induction, current switch

Introduction

The establishment and update of the national air emission inventory for agricultural operations relies on the collection of reliable emission data. The Southeastern Broiler Gaseous and Particulate Matter Emission study being conducted with Tyson Foods broiler houses led by Iowa State University, continuously measures emissions of gases (NH_3, H_2S, CO_2, and non-methane hydro-carbon compounds) and particulate matter (TSP, PM_{10}, $PM_{2.5}$). This study is an example of collecting the needed baseline emission data for animal feeding operations. **Figure 1** shows the mobile air emissions monitoring lab used in the study. This lab houses all the necessary monitoring equipment as well as the data acquisition system used to record the measured variables, including the fan operational status data provided by the induction operated current switch (ICS). **Figure 2** shows the fan monitoring resistor circuit boards and DC power supply used in the ICS system inside the mobile lab.

Figure 1: Mobile air emissions monitoring unit on site at a Tyson Foods broiler house. The mobile lab houses the data acquisition system used for the Tyson study.

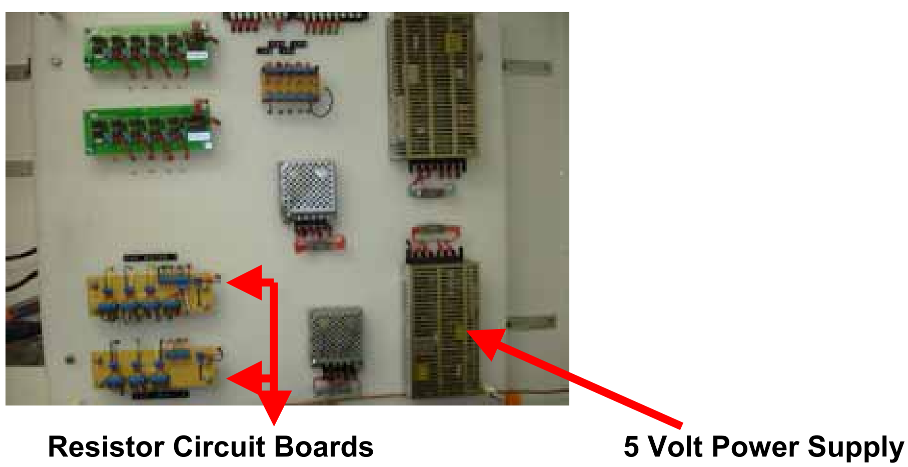

Figure 2: Fan monitoring resistor circuit boards and DC power source in mobile air emissions monitoring unit shown in figure 1.

Vibration switches (Ni et al., 2005), mercury tilt switches (Burns, 2006) and limit or “whisker” switches (Zelle, 2006) have been used in recent emission studies from animal feeding operations as part of a system that monitors fan operational status. The literature reports vibration switch failure due to moisture after 64 days of monitoring a fan with an intermittent duty cycle. The same paper reported mechanical failure after 55 days of monitoring a continuously running fan (Ni et al., 2005). The mercury tilt switch is reported to be durable, although somewhat troublesome due to the effects of the environment giving false positives (Burns, 2006). The whisker switch has reported performance similar to the mercury tilt. Inaccuracies with the whisker switch are due to wind moving it and giving false positives (Zelle, 2006). The ICS is unaffected by the environment and was chosen to be developed and tested for the Tyson study led by Iowa State. Xin et al. (2003) used current induction motor loggers to record operational status of exhaust fans in layer houses, although the monitoring period was relatively short (2 days at a time, followed by data retrieval from the loggers).

Emissions Monitoring

Accurate reporting of pollutant emissions from animal feeding operations is needed to develop improved emissions inventories and emission factors for such operations, as well as to determine if certain regulatory standards of emissions are required (Moody et al., 2006). To accurately monitor aerial emissions, the concentration of the pollutant of concern and the rate of exhaust air leaving the animal confinement, must be known. The following equation is taken from Moody, et al. (2006), and demonstrates the need for fan flow to be known in order to calculate emissions.

Equation 1

$$ER_{[g]} = ([G]_e \times Q_e \times \frac{T_{std}}{T_e} - [G]_i \times Q_i \times \frac{T_{std}}{T_i}) \times 10^{-6} \times \frac{P_a}{P_{std}} \times \frac{w_m}{V_m}$$

where $ER_{[g]}$ = Gas emission rate for the house, g hr^{-1} $house^{-1}$

Q_i,, Q_e = Incoming and exhaust ventilation rate of the house at field temperature and barometric pressure, respectively, m^3 hr^{-1} $house^{-1}$

$[G]_i$, $[G]_e$ = Gas concentration of incoming and exhaust house ventilation air, respectively, parts per million by volume (ppm_v)

w_m = molar weight of the gas, g $mole^{-1}$ (e.g., 17.031 for NH_3)

V_m = molar volume of gas at standard temperature (0°C) and pressure (101.325 kPa) or STP, 0.022414 m^3 $mole^{-1}$

T_{std} = standard temperature, 273.15 °K

$T_{i,}$ T_e = absolute temperature of incoming and exhaust air, respectively, °K

P_{std} = standard barometric pressure, 101.325 kPa

P_a = atmospheric barometric pressure at the monitoring site, kPa

Unique to a broiler production system is the use of intermittent ventilation. This characteristic of ventilation makes it necessary to relate the in-house gas concentrations to the periods of fan operation in order to calculate emissions that are representative of those exhausted from the broiler house (Li et al., 2006). In the Tyson study, a fan assessment numeration system (see **Figure 3**) was used to obtain the actual ventilation curves (airflow rate vs. static pressure) of the exhaust fans (Gates et al., 2004; Moody et al., 2006). Once the ventilation curve is developed, real-time static pressure measurements in conjunction with the real-time duty cycle of the exhaust fans is needed to accurately determine emissions data. **Figure 4** shows the variability in ventilation curves of exhaust fans. This variability makes it necessary to monitor each fan individually. A system using the ICS was developed to perform this task.

Figure 3: Fan assessment numeration system (FANS) unit being used in the Tyson Study to find the ventilation curve of individual exhaust fans.

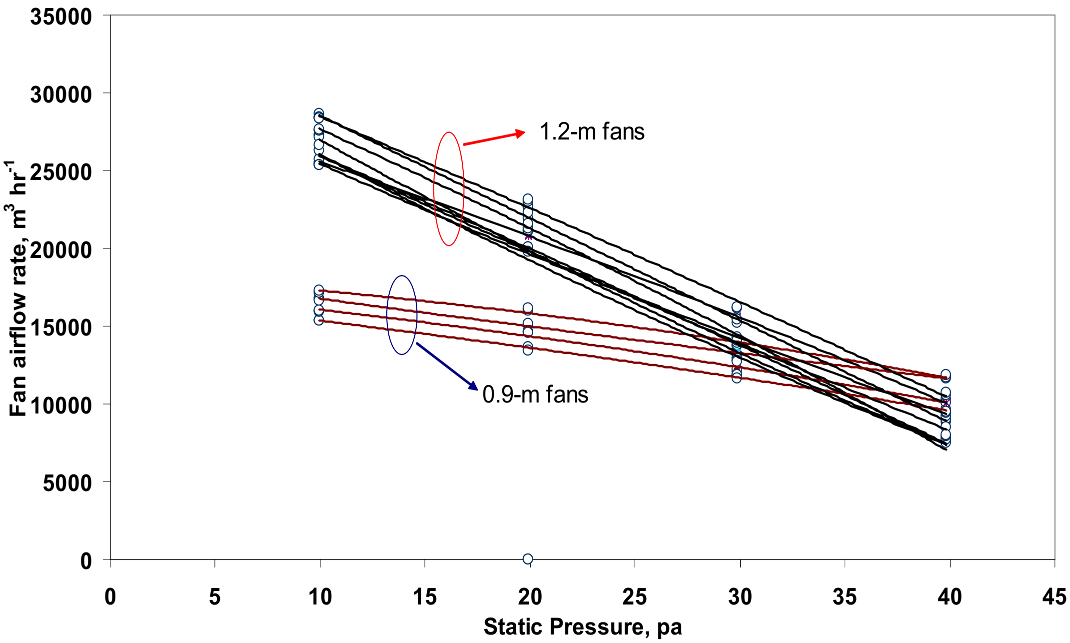

Figure 4: Variability in ventilation curves of exhaust fans in a broiler house. (1 m^3 h^{-1} = .589 ft^3 $minute^{-1}$, 1 Pa = .004 inches of water column)

Duty Cycle

In the Tyson study each broiler house has 14 fans. Four are sidewall minimum ventilation fans and 10 are larger tunnel fans (**see Figure 5**). The fan with the highest frequency of on/off (duty) cycle is Side Wall 1, (SW1) because it is the minimum ventilation fan. At its highest frequency of duty cycle SW1 had 12 on/off cycles in one hour (see **Figure 6)**. As the outside temperature increases, the frequency of SW1's duty cycle decreases because more air exchange is needed, thereby requiring the fan to run longer. A further increase in ambient temperature will activate the tunnel fans and deactivate the sidewall fans. This maximum SW1 duty cycle will be used for all theoretical analysis of the ICS and other methods discussed.

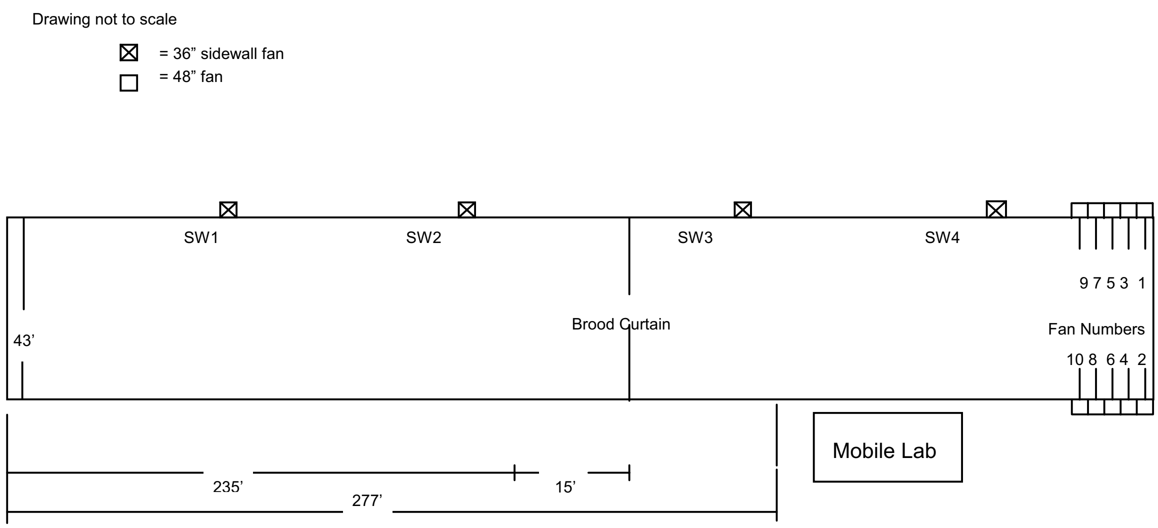

Figure 5: Schematic layout of the monitored Tyson Foods broiler house.

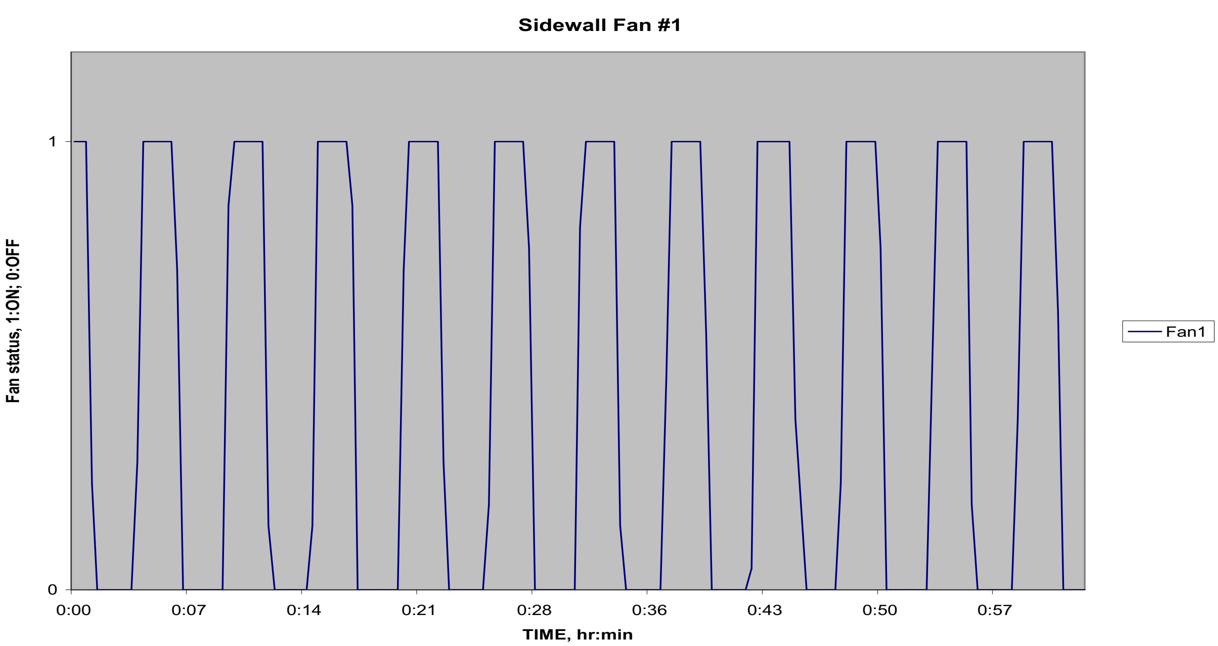

Figure 6: Example of duty cycle of sidewall fan 1 (SW1).

Materials and Methods

Induction Operated Current Switch (ICS)

The ICS used in the Iowa State system is the model CR9321 –PNP from CR Magnetics. As of this writing, April 2006, the price from CR Magnetics is $19.50 per unit. The ICS is widely used in manufacturing applications that only require an on-off indication of whether a current is present. The ICS is encased in a very durable plastic that is completely sealed for environmental protection. When AC current is present through the induction loop of the ICS, a current is induced in a transformer. The current from the transformer goes to an electrical sensor called a comparator. If the AC current is at least 350 mA the comparator sends the current to a transducer that fully closes the ICS allowing the DC current to return to its power source. **Table 1** gives the manufacturer's specifications for the ICS. **Figures 7** and **Figure 8** give the wiring schematic and physical dimensions for the ICS.

Rated full-on:	350 mAac RMS
Turn-on time:	100 ms. @ rated full-on
Turn-off time:	250 ms max to 80% of Vce
Maximum sense current:	Continuous: 100 Aac 1 second: 500 Aac
Frequency	50 - 400 Hz
Operating temperature:	-30 °C to +60 °C
Storage Temperature	-55 °C to +85 °C

Table 1: CR 9321 specifications (CR Magnetics, 2006).

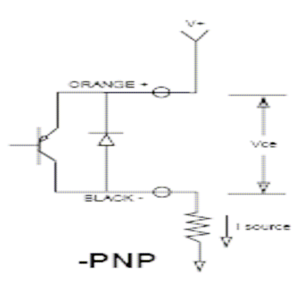

Figure 7: CR9321 schematic (CR Magnetics, 2006).

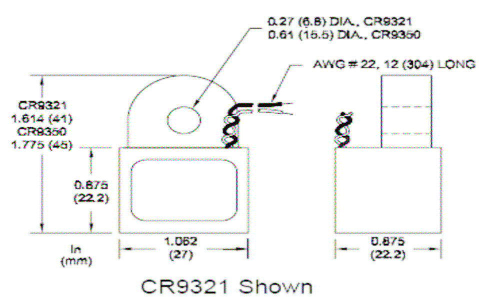

Figure 8: CR9321 dimensions (CR Magnetics, 2006).

ICS AC Power Cord (Pigtail)

In cases where the owner of the animal confinement allows for splicing of the fan's power cord, the ICS can be installed directly on the existing fan wiring. One wire of the fan's power cord can be stripped away and strung through the induction loop of the ICS. If it is not allowable to install the ICS directly, then a short lead, or pigtail, with plugs on each end can be constructed. A pigtail acts as a short extension cord. **Figure 9** shows the schematic and placement of a pigtail. If 15A, 120Vac, plugs are used a pigtail can be fabricated for approximately $6.00. For the Tyson study 20A, 220Vac plugs were used, increasing the cost to approximately $20.00/pigtail.

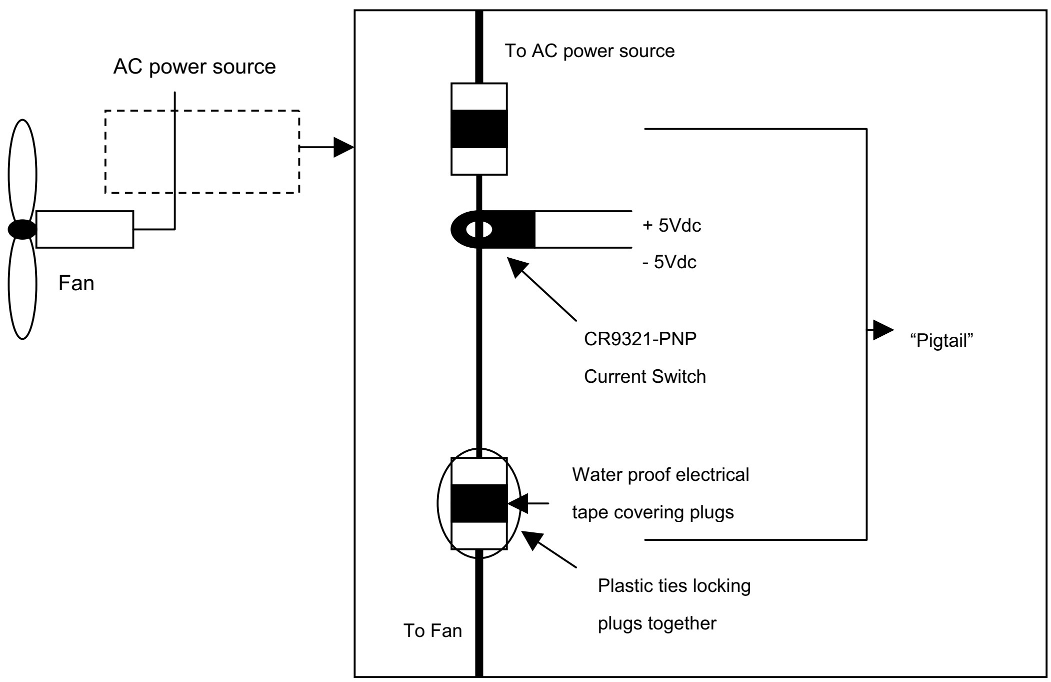

Figure 9: Position of pigtail relative to fan.

Laboratory Test

In the first laboratory test the ICS was activated the approximate number of times required for monitoring the maximum duty cycle of SW1 in the two-year Tyson study. In the second laboratory test the ICS was activated for an extended period of time to simulate a fan that was always on in a mechanically ventilated confinement.

A Campbell Scientific CR10 data logger was used as the data acquisition system and to actuate the AC relay. A humidifier was used as the 120Vac current draw (**see Figure 10**). Two ICSs were tested simultaneously (**see Figure 11)**. One wire of the 120Vac power source passes through the induction loop of both ICSs. **Figure 12** shows the schematic for the laboratory test. The AC relay was opened by the CR10 for 1 second, and then closed for 1 second continuously. This means the humidifier completed an on/off cycle every 2 seconds. Power from the 5Vdc power supply was connected to the positive wire of the ICS. When the ICS sensed AC current through induction and was closed, or "on," the 5Vdc returned to the power source through a 100 Ω resistor. Meanwhile, the CR10 recorded the voltage drop across the resistor.

When the humidifier was on (AC relay closed), the ICS was closed and the voltage drop at the resistor was approximately 3.7Vdc. When the humidifier was turned off (AC relay open), the ICS was open and the voltage drop at the resistor was 0Vdc. Data were collected every second by the CR10 and written to an output file every minute. For test 1**,** if a voltage drop greater than 3Vdc did not occur 30 separate times during the previous minute the CR10 recorded a failure. For test 2, a voltage drop greater than 3Vdc needed to always be present or a failure was recorded.

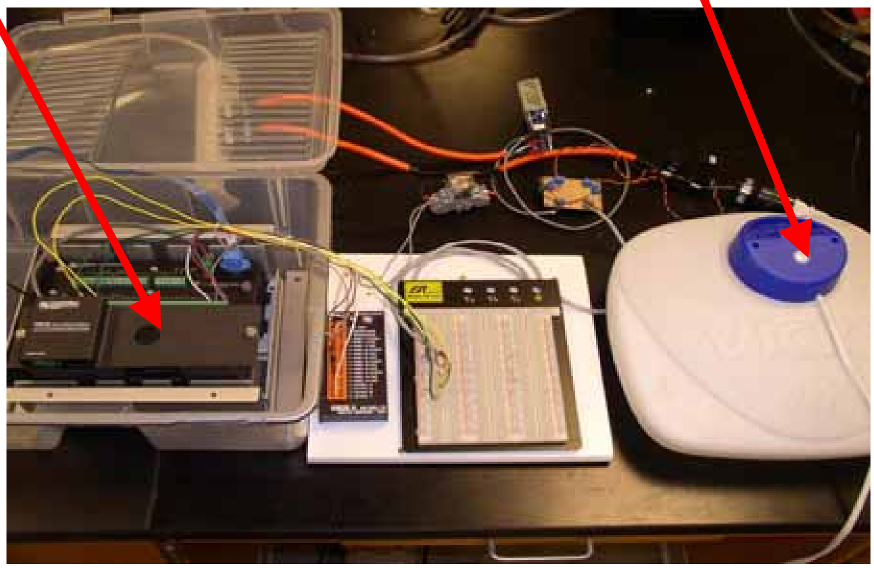

Figure 10: Lab test.

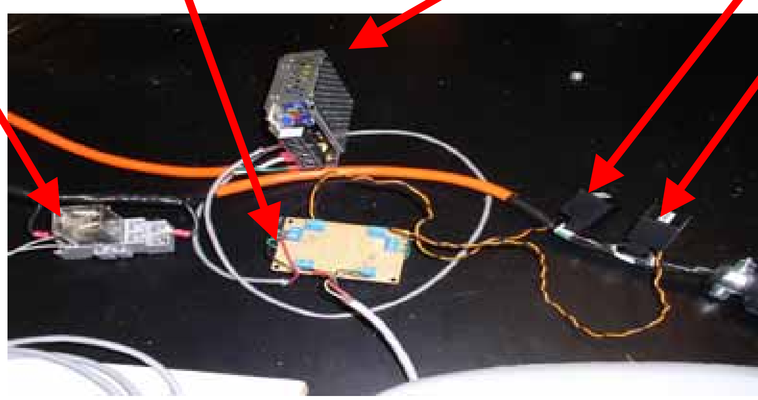

Figure 11: AC relay in pigtail, 5Vdc power supply, resistor circuit board, 2 current switches installed on pigtail.

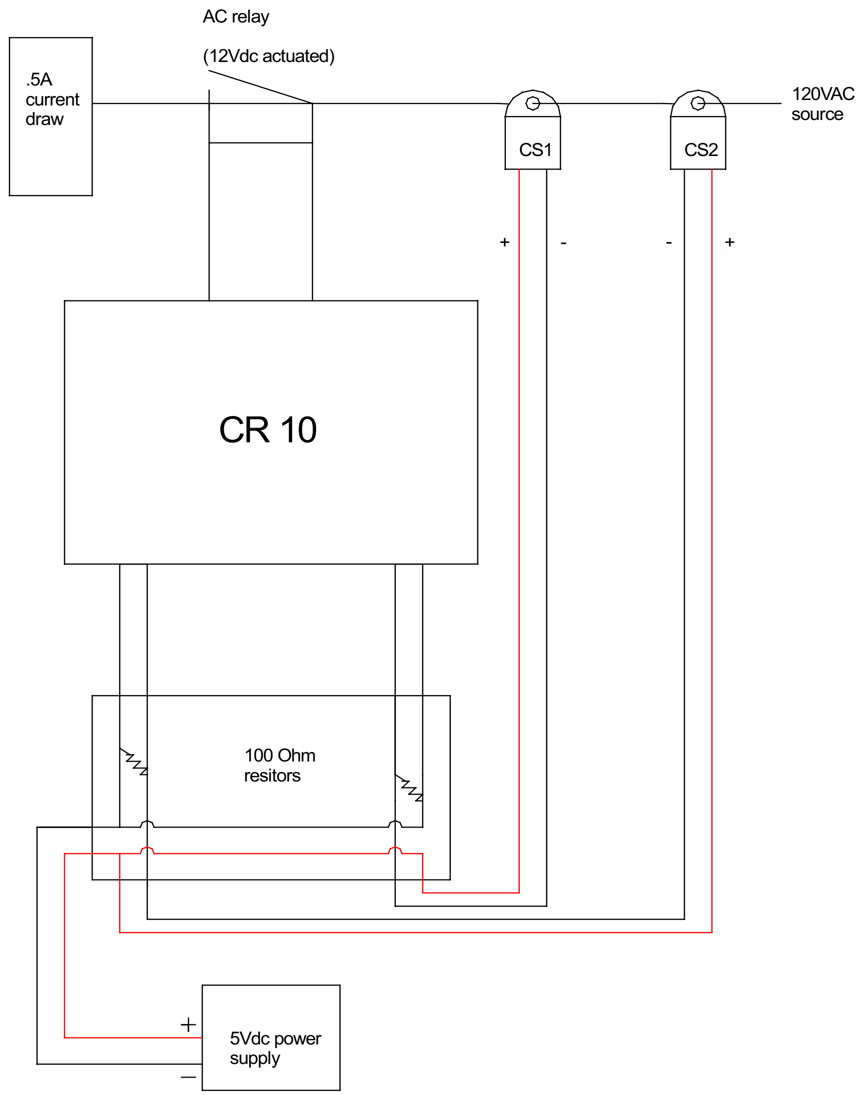

Figure 12: Lab test schematic.

Field Test

Since October 1, 2005, 28 ICSs have been used by the Tyson study in two commercial broiler houses to provide real-time fan duty cycle data. Each exhaust fan in the houses is being monitored using an ICS along with a 220Vac, 20A pigtail (**see Figure 13**). The pigtail connections are covered in electrical tape to prevent moisture from reaching the connections. The connection to the fan power cord is also “locked” together with plastic ties to keep anyone from un-plugging the pigtail.

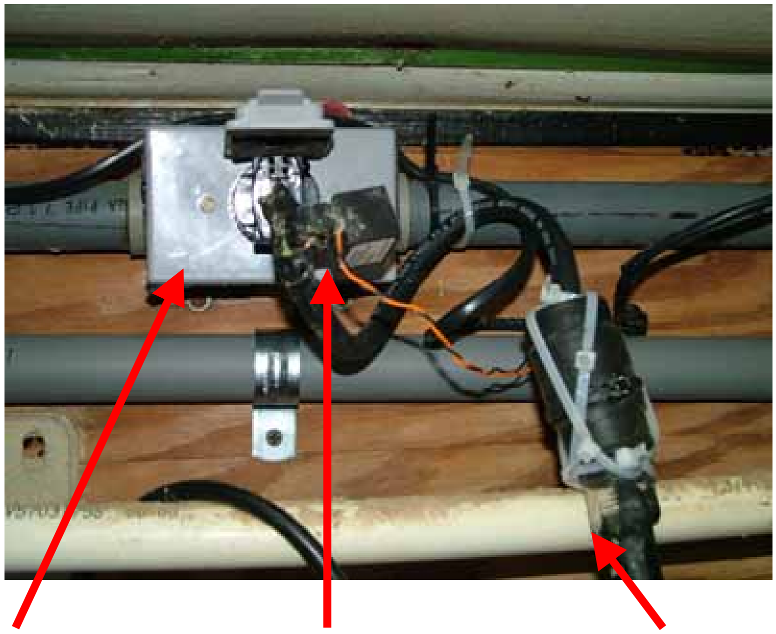

Figure 13: ICS and pigtail in Tyson Foods broiler house.

Results and Discussion

Laboratory Test Results

Tables 2 & 3 show the test results. In test 1, the ICSs were cycled on and off a total of 216,000 times with no recorded failures. In test 2, the ICSs were activated for 72 hours with no recorded failures.

Start time:	5:00 pm Feb 22, 2006
Stop time:	5:00 pm Feb 27, 2006
Total on/off cycles:	216,000
Total failures	**0**

Table 2: Test 1 - on/off cycle

Start time:	5:00 pm Feb 27, 2006
Stop time:	5:00 pm Mar 3, 2006
Total activated time (hours):	72
Total failures:	**0**

Table 3: Test 2 - continuous on

The maximum duty cycle of SW1 has a frequency of 12 on/off cycles per hour (see **Figure 6**). Assuming that SW1 runs at the maximum duty cycle, 105,120 cycles per year or 210,240 cycles for a two-year study, are performed, which is less than the 216,000 cycles in the lab test. Moreover, the actual operation cycle of each ICS will be much less during the seasonal weather, thus a different operation time of each exhaust fan. Hence, the lab test showed that the ICS could easily operate through a two-year study that required the monitoring of duty cycle equivalent to the maximum of SW1 without failure. The test also showed that being activated for days at a time had no apparent effect on the ICS. This is important for monitoring a fan that is always on.

Field Test Results

As of this writing the ICSs have been used to monitor 28 fans for 190 days without a single incidence of failure. All 28 ICSs have been constantly exposed to dusty conditions, fairly high ammonia concentrations, and routinely subjected to pressurized water while the fans are washed between grow-out cycles. The ICSs are checked for accuracy between each grow-out cycle by visually confirming each fan's duty cycle corresponds with the cycle reported by the ICS.

Comparison

Data from three studies using different fan monitoring methods were chosen for comparison: the vibration switch, mercury tilt switch, and limit or whisker switch. The vibration switch is activated when vibration from the fan motor or shroud is detected. It has contact points that vibrate at a mean of 26 Hz and have a manufacturer claimed life of 100,000 contacts, or approximately 64 minutes of activation time. However, a recent study has shown the experimental vibration switch life can be substantially longer (116 days) than the manufacturer's claim (Ni et al., 2005). This has been attributed to extremely low voltage/current application. The same study reported a vibration switch inaccuracy after 31 days, then a failure due to moisture after 64 days of monitoring an intermittently operated fan. A mechanical failure due to bad contacts was recorded after 55 days of monitoring a continuously operated fan. The mercury tilt switch is attached to the louvers on the fan housing. When the fan is on, the louvers are open, thus opening the tilt switch creating a break in an electrical circuit. Durable tilt switches have been reported to give false positives if the wind opened or even fluttered the louvers (Burns, 2006). The whisker switch is placed in the exhaust path of a fan. It is closed to complete a circuit when air flow is present. It has been reported to be susceptible to the effects of wind and moisture that could give false readings. It was also found difficult to match the sensitivity of the whisker switch to the monitoring needs of the study. For example, if a whisker switch is too sensitive it will give false positives when the wind blows. If it was not sensitive enough, it could potentially not detect periods of low flow rate (Zelle, 2006).

Comparative Cost Analysis

Table 4 shows an estimated comparative cost analysis of the ICS, vibration switch, mercury tilt switch, and whisker switch in a theoretical two-year emissions study in a broiler house.

	ICS with 220Vac pigtail	ICS with no pigtail	Vibration Switch	Mercury Tilt Switch	Whisker Switch
Approx. Unit Cost	$39.50	$19.50	$3.99	$6.00	$20.00
Number Installed *	1	1	12	1	1
Cost to Install **	$7.50	$5.00	$5.00	$5.00	$5.00
Total	$47.00	$24.50	$107.88	$11.00	$25.00

* Based on experimental and field data for the ICS and reported data for the Vibration Switch, Mercury Tilt Switch, and Whisker Switch. The Vibration Switch had a reported failure at 64 days while monitoring a fan that operated intermittently, and a failure at 55 days while monitoring a continuously running fan (Ni et al.). Sixty days between replacement is assumed for the Vibration Switches.

** Estimate with assumed labor rate of $10.00/hour.

Table 4: Comparative cost analysis of monitoring the maximum duty cycle of a ventilation fan in a two year emissions study.

Accurate data is paramount to any study but no monetary sum was assigned for lost or inaccurate data in this comparison. The ICS is slightly more costly than other compared methods, but it is the only method compared here without any reported failures or inaccuracies.

Conclusion

In long-term air emissions studies monitoring fan operational status is crucial and can be problematic. If the controllers or fan stages are monitored, a fan malfunction would not be recorded. That is the reason direct monitoring at the site of each fan is required to ensure recorded fan duty cycle accuracy. While the initial cost of the ICS is higher than some other options on a per unit basis, it is the only method compared that has had no reported failures or inaccuracies, making it very valuable to air emissions studies.

Once performance data for each fan and all the variables in **Equation 1** are obtained, direct real-time monitoring using the ICS (backed by periodic visual confirmation of accuracy) allows an emissions study to reliably, accurately, and cost effectively report fan flow for use in emissions calculations as the product of pollutant concentration and exhausting airflow.

Acknowledgements

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