Effect of Contamination on the Sensitivity of Optical Scatter Smoke Sensors

Stephen Ellwood
AW Technology Ltd, Earl Shilton, Leicestershire, United Kingdom

Abstract

A review on the limits to the compensation applied to smoke detectors is being carried out to enable a revision of the clauses in EN54 standards relating to the response to slowly developing fires. The effects of sensor non-linearity and maximum output are understood, but data on the effects of contamination on the sensitivity and the sensor signal were not available. The effects on optical scatter smoke sensing chambers are considered here as they are the most commonly used type.

A simple general mathematical model is presented which can calculate the limit of compensation when the response value is increased by a factor of up to 1.6. Some practical tests were carried out on a typical optical scatter smoke sensor with dust applied to the inside surfaces of the chamber. These indicated that when only considering the optics of the sensor the limits may be large compared with the increase in signal to an alarm of a new detector.

Keywords, Optical smoke sensor, contamination, compensation, dust

Introduction

Smoke detectors include algorithms that compensate for changes in the sensor output with no smoke present. The changes could be due to short term variations in temperature, long term ageing of sensor components or contamination on surfaces. The response to slowly developing fires clauses in EN54 standards are intended to limit the rate of compensation so that any correction for short term changes does not significantly delay the response to a slowly developing fire. They also limit the range of compensation so that the response value of the detector will not get significantly greater than when it was newly manufactured. The effects of sensor non-linearity and maximum sensor output are already understood.

This work is intended to quantify some effective limits for compensation when considering the effect of contamination.

As a smoke sensor becomes contaminated the signal without smoke can either decrease or increase. The sensitivity to smoke can also change. A simple analysis shows that the worst case for compensation is when the signal increases, but the slope sensitivity of the sensor decreases. The compensation will increase the alarm threshold, which will then increase the overall detector response value rather than help to maintain it at a constant value. This situation could occur if an optical scatter smoke sensing chamber is contaminated with light coloured dust which increases scatter but partially blocks the optics. Aging of components could also decrease the sensitivity of the sensor, but this normally tends to decrease the signal.

The aim here is to model how the sensitivity of a detector will change as the sensor becomes contaminated. Some tests will also be carried out on a typical optical scatter smoke sensor chamber in order to establish a limit for compensation in this case.

General model of change of sensitivity with increasing sensor contamination

A general model of the change in sensitivity with increasing contamination is proposed that could apply to any type of smoke sensor, but point optical scatter detectors are used as an example. In the following the sensor output is expressed as a voltage (V) and the smoke concentration as m value (as defined in EN54-7 [1]). Compensation for an increase in the output without smoke (V_0) is assumed to result in an equivalent increase in the alarm voltage (Va), and as also shown in [2]:

$$(Va - Va_{new}) = (V_0 - V_{0new}) \quad \text{V} \qquad \text{(Eq. 1)}$$

Assuming a linear response the sensor slope gain (S) is defined as the increase in sensor output divided by the smoke concentration:

$$S = (V - V_0) / m \quad \text{V/dB/m} \qquad \text{(Eq. 2)}$$

V is the sensor output at smoke concentration m dB/m. S_{new} refers to the sensor slope gain of a new sensor.

$\Delta alarm$ is the increase in the alarm threshold scaled by the difference between the alarm threshold and sensor output with no smoke for a new detector ($Va_{new} - V_{0new}$). It is often refered to as the ‘number of alarm thresholds‘. If the increase in alarm threshold since the detector was new is ($Va - Va_{new}$), then:

$$\Delta alarm = (Va - Va_{new}) / (Va_{new} - V_{0new}) \qquad \text{(Eq.3)}$$

If the slope gain decreases by the same proportion for each $\Delta alarm$, then this will result in an exponential decay in slope gain:

$S = S_{new} * e^{-(\Delta alarm / C)}$ V/dB/m (Eq. 4)

C is a constant that controls the rate of decrease of slope gain with $\Delta alarm$.

The EN54 smoke detector standards require that compensation of V_a for changes in the sensor output without smoke is limited to maintain the response value close to the new condition. This is equivalent to a decrease in slope gain by a factor of up to 1.6. At this limit

$$S / S_{\text{new}} = 1/1.6 = e^{-(\Delta alarm/C)} \qquad \text{(Eq. 5)}$$

If the rate at which the slope gain decreases as the no smoke signal increases is known, then it is possible to calculate the maximum increase in V_a that will enable the detector to remain within the requirements of EN54 standards.

$$\Delta alarm = - C * \ln(1/1.6) \qquad \text{(Eq. 6)}$$

Some examples are given in table 1 below.

Table 1. Example calculation of Δ*alarm* to decrease the slope gain by a factor of 1.6.

Fractional loss in the slope gain for each *Δalarm*	Constant C	*Δalarm* to decrease the slope gain by a factor of 1.6
0.05	19.50	9.16
0.10	9.49	4.46
0.20	4.48	2.11
0.30	2.80	1.32
0.40	1.96	0.92
0.50	1.44	0.68

The above indicates that if the slope gain varies slowly with increases in Va then the compensation can increase the alarm threshold by a large *Δalarm*. But if for example slope gain decreases by a factor of 0.2 for each *Δalarm,* the compensation of Va has to be limited to 2.11 * *Δalarm* to keep the detector within the requirements of EN54 detector standards.

Some examples showing how the gain decreases, with different values of the constant C, are plotted in Fig. 2 which also shows the results of practical tests.

Practical tests

It is difficult to predict the degree to which the slope gain will change with increases in the sensor output without smoke as the nature of contamination, and the degree of aging, will vary with the environment in which the detector is sited.

Some test equipment has been proposed [3] which simulates the exposure of the complete detector to dust that can cause false alarms [4]. This paper is mainly concerned with the direct response of the optics to long term exposure to dust so it was directly applied over internal surfaces of the sensing chamber.

Some practical contamination tests were carried out by the author. These were intended to test the model and to establish some realistic values for the constant C. The tests were carried out on a typical single wavelength, single angle, optical scatter smoke sensing chamber as this is the most common type in use. The chamber was taken from a production example of a smoke detector complete with the LED emitter and photodiode receiver. This was connected to a test circuit with a simple voltage output so that any effects of algorithms within the detectors are not included in the response.

Contamination was applied by exposing sensor chambers to dust deposited evenly over the inside surfaces, including the surfaces of the emitter and receiver. This was applied using a soft brush. The dust was collected from the offices of AW technology, and the distribution of the dust was checked using a microscope. This technique is not intended to simulate a particular environment as the dust is applied directly, but has been shown to be a useful development tool for comparative measures of the effect of contamination on smoke sensor chambers. It is a method that could be used for determining realistic values of the constant C*,* and thereby the limit that can be placed on the alarm threshold compensation to remain within the requirements of the EN54 standards.

The sensitivity tests were carried out in an AW Technology 1800 smoke / heat detector test tunnel, which conforms to the test requirements of EN54-7. The output voltage of the test circuit was measured in clean air and then at increasing aerosol concentration in 0.1dB/m steps. The slope gain in a clean condition (S_{new}) and with dust applied (S) could then be calculated from these measurements using Eq. 2. The calculation of $\Delta alarm$ was made using a simple alarm threshold of 0.15dB/m when the chamber was clean.

The dust on the chamber surface is shown in Fig.1. It incudes a lot of fibrous material and small particles of mineral grit. It is a very high level of contamintation, greater than would be expected inside a smoke sensing chamber even after 10 years in a normal environment.

Fig. 2 shows the values of S / S_{new} plotted against $\Delta alarm$ for the optical scatter chamber tested, together with calculated values using different values of the constant C. Of the three values plotted the data is a best fit to C = 9.49, which corresponds to a decrease in gain of 10 % for each $\Delta alarm$.

A decrease to a S / S_{new} of 1/1.6 would then occur on average at a *Δalarm* of 4.46, which could be used as a limit of compensation when considering the effects of contamnination by dust.

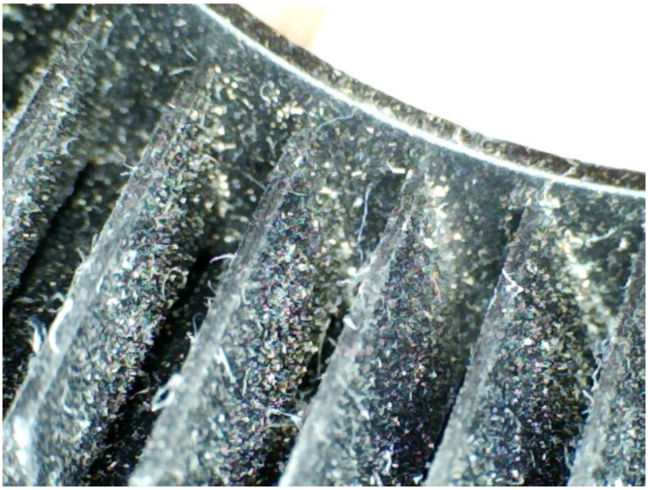

Fig. 1. Dust on surface of smoke sensing chamber at a *Δalarm* of 4.4.

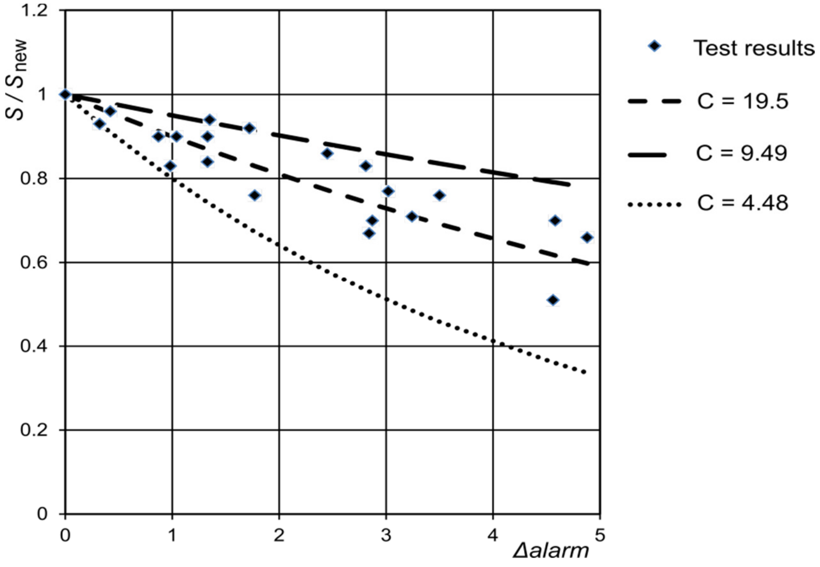

Fig. 2. Results of tunnel tests on smoke chamber after contamination with dust.

Comments

The model used was intended to provide a stimulus for discussion in the consideration of the limits to the compensation. It was not intended to accurately model to optics of the sensor, but to enable discussion about the limits to compensation in terms of the number of alarm thresholds (*Δalarm).* It helps to answer the question about the increase in response value by a factor of 1.6, if the reduction in slope gain is "XX% per alarm threshold". It is recognised that different types of smoke sensor will have different laws controlling the change in sensitivity with increasing contamination.

The main conclusion from this work is that a typical optical scatter smoke sensor can be highly contaminated by dust before the sensitivity change will cause an increase in the response value by more than a factor of 1.6. In practice it will be very hard to achieve this level of contamination inside a smoke sensive chamber without the entrance to the smoke sensor or insect screen becoming partially blocked, which would also increase in the response value when measured in a smoke tunnel. It is also possible that in very dusty environments false alarms could occur while dust particles are still air-borne within the chamber.

In the calculation of the limit of compensation of V_a for changes in V_0 several factors need to be considered together. The decrease in slope sensitivity due to increasing contamination is only one consideration and is discussed in this paper as it was thought to be the least understood.

This work is being used by a group that has been tasked by CEN TC72 to review and revise the 'Response to slowly developing fires' clauses within EN54 detector standards. The author is a member of this task group and the contribution from the chairman and other members is acknowledged. It is intended that the results presented here will be a contribution to the work of the task group as this data was not previously available.

References

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