SICK AG WHITE PAPER

FLOWSIC200

VERIFICATION OF THE MEASUREMENT FUNCTION AS PART OF FIRE TESTING IN TUNNEL SYSTEMS

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SUMMARY

For fire tests in tunnels, the FLOWSIC200 measuring system proves its excellent suitability as an automated measurement system for flow velocity.
The FLOWSIC200 is able to depict the flow conditions, which change significantly in the event of a fire, flawlessly and without limitations and therefore delivers a reliable basis for the effective control of the ventilation system.

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1. Introduction

Pollutants are emitted by vehicle traffic in the tunnel. If the tunnel is insufficiently ventilated or not ventilated at all, then these substances can become concentrated and pose a risk to health.

A controllable ventilation system ensures sufficient infeed of fresh air and removal of polluted tunnel air, which guarantees sufficient ventilation at any time. The proper and effective control of tunnel ventilation requires continuous and reliable measurement of the flow velocity and flow direction.

The ventilation system is of particular importance in the event of a fire. If there is a fire in the tunnel, the resulting combustion gas must be removed quickly and in a controlled manner so that the tunnel can be evacuated and people can be safely removed from the hazardous area. To do so, the fans in the ventilation system must be quickly and reliably controlled. The measurement of the flow velocity and flow direction play a central role here. The function of the ventilation system in the event of a fire is of ever-increasing value and is a fixed part of tunnel acceptance tests in many countries.

2. Measurement processes

With the FLOWSIC200, SICK has offered an ultrasound flow meter for tunnel systems for more than 20 years. The device was developed taking into account the specific application conditions in traffic and rail tunnels and has been continuously optimized since the time of its launch. The focus is to continue optimizing the metrological properties while expanding its field of application.
The current generation of the FLOWSIC200 takes advantage of the most recent SICK ultrasonic technology, which the sensor manufacturer – one of the world's leading vendors of gas flow measurement technology – has been using with great success. The FLOWSIC200 is characterized by its exceptional performance and durability even under demanding measurement conditions such as in the event of tunnel fires.

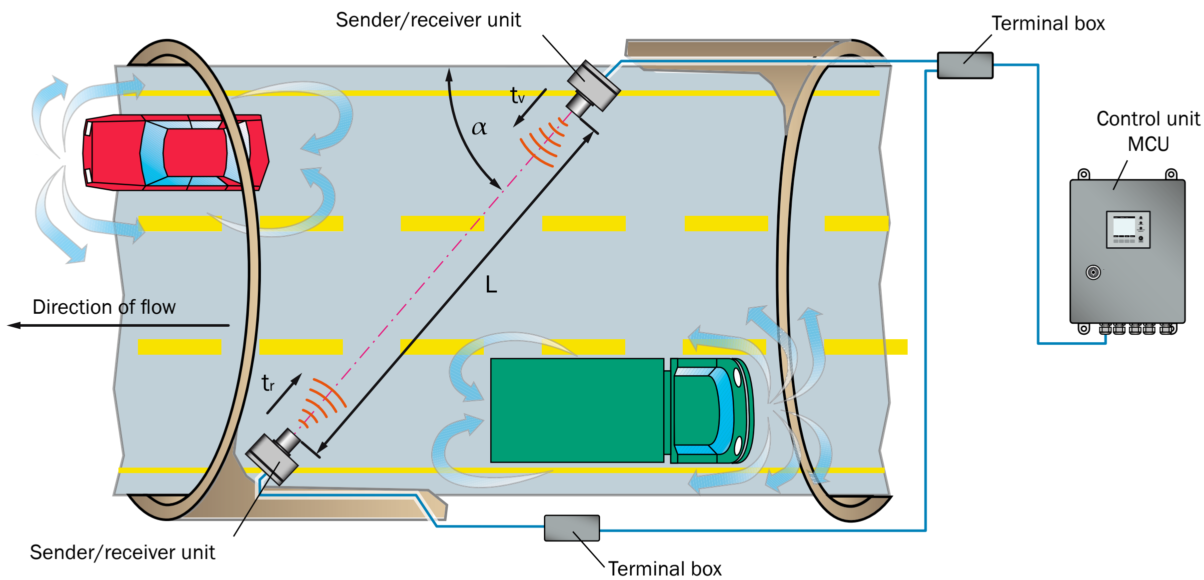

Image 1: The FLOWSIC200 principle of operation

$$v = \frac{L}{2 \cdot \cos\alpha} \cdot \left(\frac{1}{t_v} - \frac{1}{t_r} \right)$$

v = flow velocity (m/s)
L = measuring distance (m)
α = tilt angle (°)
t_v = time-of-flight of the sound in the flow direction
t_r = time-of-flight of the sound against the flow direction

Piezoelectric ultrasonic sensors are used for flow measurement at SICK, on the basis of the ultrasonic transit time difference method. In this, ultrasonic signals are transmitted alternately through the exhaust gas flow at an angle. Driving and braking effects due to the exhaust gas flow lead to different transit times of the signals through the flow of exhaust gas (Image 1). This difference in transit time is analyzed by the integrated electronics and converted into a flow velocity along the ultrasonic measuring path.

3. Special features of flow measurement in the event of fire

If a fire breaks out in a tunnel, significantly changed conditions result in the immediate area around the fire source and outflow area of the flue gas compared to the tunnel's normal operation.
Within a short time, there is a large increase in temperature and significant amounts of flue gas form. The combustion gas reaches the upper area of the tunnel very quickly and disperses there at high speed. As the fire continues and the amount of flue gas increases, the layering of the gas quickly reaches the lower areas of the tunnel cross-section.
This results in significantly changed thermodynamic conditions, particularly in the area around the fire source.
The changes in the tunnel caused by the fire pose fundamentally different and significantly more challenging requirements on the flow velocity measuring device than in the tunnel's normal operation with ambient air. The flue gas temperature, the flue gas composition and the dispersal of the gas play a significant role in the function of the measurement.

4. Function of the FLOWSIC200 in the event of fire

The high ultrasound energy and wide beam of the ultrasonic transducers and a sophisticated measurement algorithm guarantee reliable measurement, even if the application conditions are particularly challenging, such as in the event of tunnel fires, when conventional ultrasound technology often fails. The significantly changed gas composition of the tunnel air does not have any influence on the measurement accuracy and availability of the measurement.

In the FLOWSIC200 H and FLOWSIC200 H-M versions, the sensors are made entirely of stainless steel with ultrasound transducers made of titanium, therefore offering a robust and durable device solution in the event of fire.
Four fire tests were carried out by Forschungsgesellschaft für Verbrennungskraftmaschinen und Thermodynamik mbH (FVT mbH), in the Klaus (A9) tunnel chain in Austria in November 2018.

To verify the device function, the flow velocity measurement was closely examined during the fire tests. All of the examinations helped in the further optimization of the FLOWSIC200 and formed an important part of the continuous further development of the product.

4.1. Installation

The fire tests were carried out at an unfavorable location for tunnel ventilation. According to the calculations of a ventilation planner, the "worst-case" position was identified as approximately 1,960 m from the entrance (north portal) of the tunnel. The lowest flow velocities were expected at this fire location and with high portal pressure at the south portal.
In the fire tests, a defined amount of fuel (petrol-diesel mixture) was ignited in special fire trays. The fire trays were set up at around 1,960 m (around 20 m away from the next closest jet fan pair). This ensured that the fire was ignited in the correct fire zone.
Two FLOWSIC200 H measuring devices were properly installed with a measuring path angle of 45° and a height of approx. 4.20 m (above clearance). The resulting measuring distance was approximately 12.6 m each. Both measuring locations were arranged in the discharge direction downstream of the fire location.
Measuring location 1 (MS1) was approximately 25 m behind the fire location; measuring location 2 (MS2) was approximately 110 m behind the fire location.
For evaluation of the measurement results from the FLOWSIC200, a comparison was carried out with a reference measurement and with the permanently installed portal measurements in the tunnel system (see Image 2).

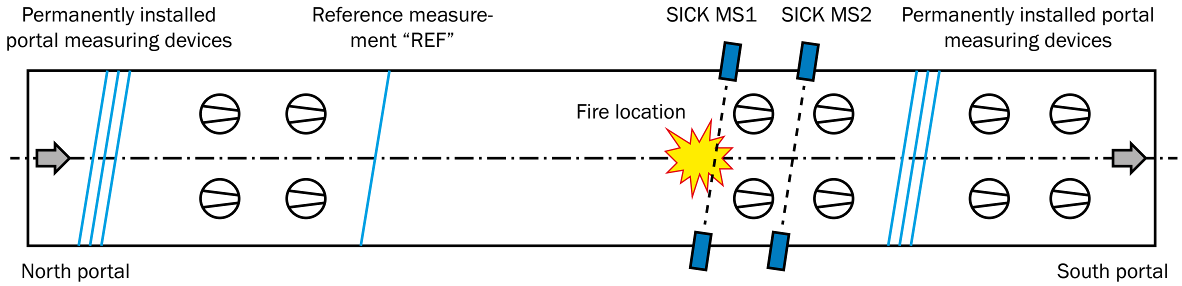

Image 2: Position of the FLOWSIC200 measuring devices (MS1 and MS2)

Image 3: Installation of the FLSE200-H sender/receiver unit in the area of the fire location.

Image 4: Fire test location

4.2 Results of the flow velocity measurement

The evaluation was carried out subsequently using two fire tests. Two fire trays with a mixture of 20 l diesel and 5 l petrol each were ignited per test. The fuel mixture was completely burned up over the duration of the test.
In test 1, the tunnel ventilation was carried out in the operating mode "one-way traffic"; in test 2, in the operating mode "two-way traffic". The difference between the two operating modes is the flow velocity with which ventilation is carried out. A higher fan speed is used for "one-way traffic" ventilation than for "two-way traffic". The main reason for this is that, in the case of a fire in "two-way traffic", vehicles are stopped in all directions, which create obstacles for air flow. Through the lower fan speed, additional air turbulence caused by these obstacles should be avoided and the flow can slowly be guided in one direction.
With the FLOWSIC200 measurement devices, there was continuous recording of measurement and diagnostic data over the entire duration of both tests.

Image 5: Fire and smoke development during a fire test

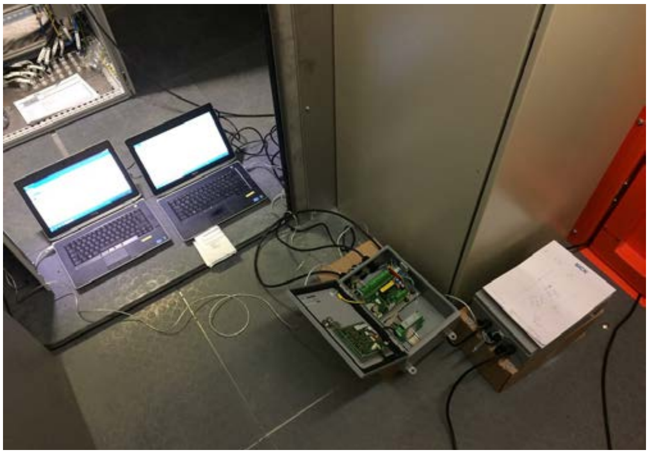

Image 6: Continuous data recording for both FLOWSIC200 measurement locations

Both measurement locations “MS1” and “MS2” displayed a comparable progression in the fire tests. The portal measurements “PM1” and “PM2” (each the average of 3 measurement paths installed near to one another) shown for comparison and the “REF” comparative measurement approximately 800 m upstream of the fire location also confirmed the chronological trend of the flow velocity before, during, and after the fire test. See diagrams 1 and 2.
An identified systematic deviation between the two measurements MS1 and MS2 was due to the fact that calibration of the measurement locations was not carried out for the tests. A value of +11.8% was determined for the measured value-weighted mean difference between MS1 and MS2. A subsequent adjustment was not carried out as this difference was insignificant for the further observations. A difference was also identified for the portal measurement devices, which was due to the temperature gradients along the course of the tunnel.

Very distinct pulsation is characteristic for the tunnel flow in the area of the fire source, which ceases immediately after ignition and is present over the entire duration of the fire.
The following aspects of the combustion process are to be taken into account for the flow situation:

- Energy in the form of heat and light is released from the combustion of fuel (exothermic reaction). Heat carried to the cold air flow causes the air volume to expand and therefore causes an increase in the flow velocity downstream of the fire source.
- Additional gas volumes (NOx, COx, H2O vaporous) are produced as a result of the combustion itself, which mix into the cold air flow as hot flue gas.
- The hot flue gas and the cold tunnel air mix together in an uncontrolled manner at the fire location.
- The free oxygen supply for the combustion itself is also uncontrolled. This means that the combustion process is subject to fluctuations, which in turn have an influence on the temperature and amount of the resulting flue gas.

From the effects described, one can draw the conclusion that a non-steady flow state occurs over the duration of a fire and this therefore causes increased flow dynamics close to the fire’s location in the tunnel.
No malfunctions of the FLOWSIC200 were identified in the measurements from the fire test. The pulsations in flow velocity identified correspond to the actual flow conditions at the device’s installation location. The type, intensity and duration of the pulsations identified allow for the assumption that they were caused by the thermodynamics during combustion.

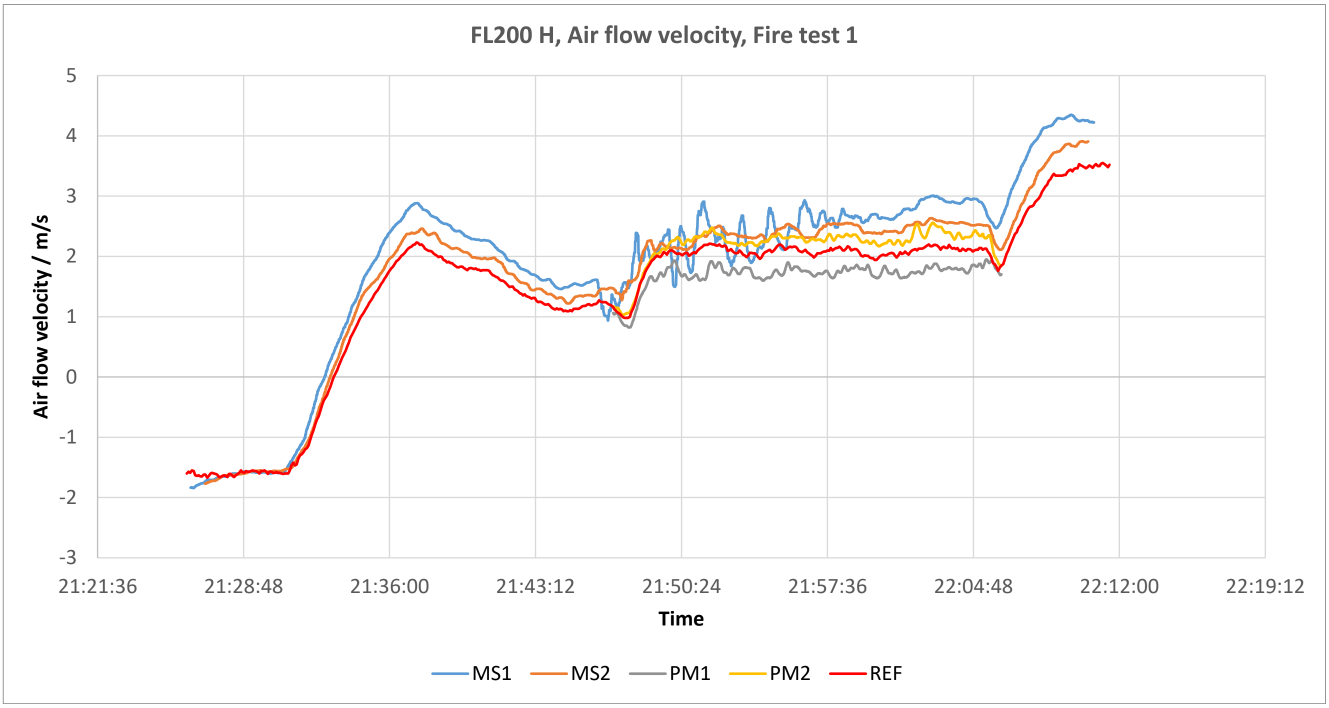

Diagram 1:
FL200 H, flow velocity, fire test 1, “one-way traffic” operating mode
MS1 approx. 25 m downstream behind the fire location
MS2 approx. 110 m downstream behind the fire location

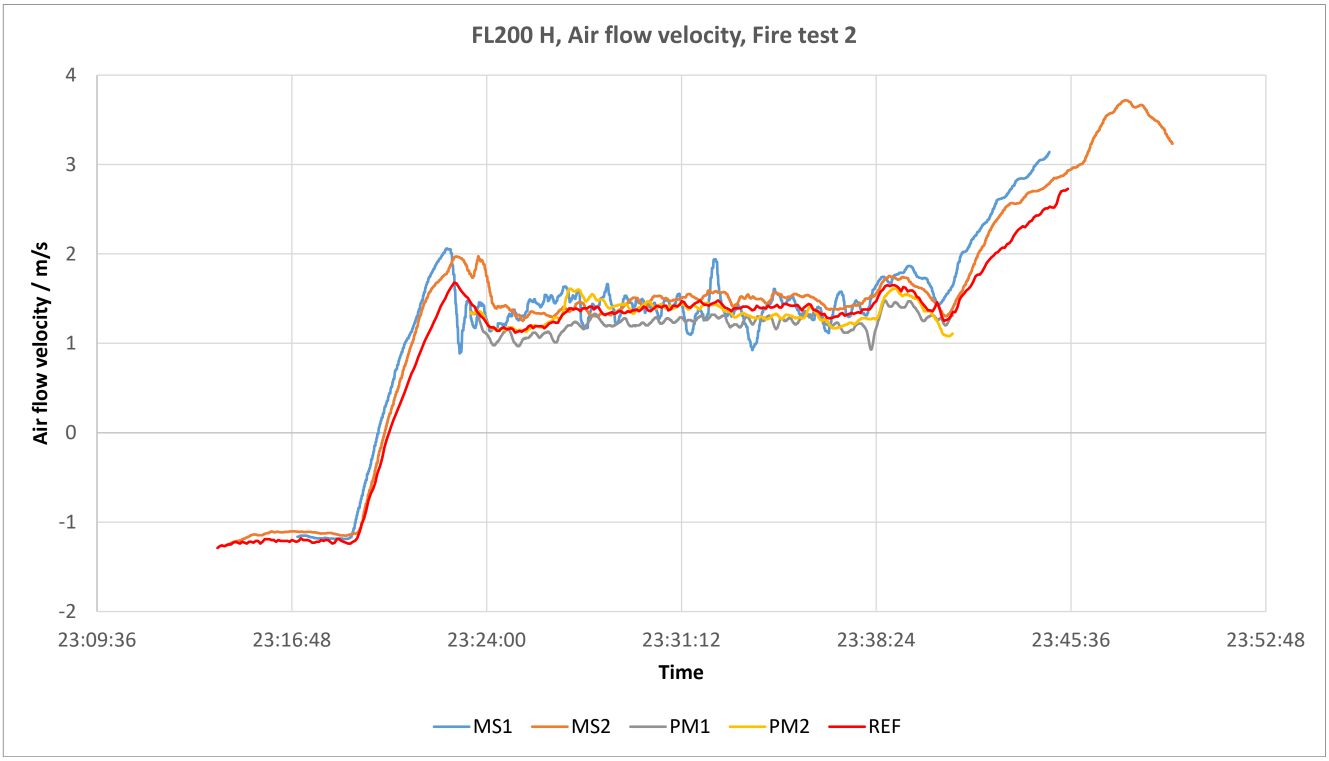

Diagram 2:
FL200 H, flow velocity, fire test 2 “two-way traffic” operating mode
MS1 approx. 25 m downstream behind the fire location
MS2 approx. 110 m downstream behind the fire location

4.3. Protection of the measuring function - device diagnosis

The FLOWSIC200 has a fully automatic check cycle for verifying the device function. The device also monitors specific diagnosis parameters. In the event of impermissible deviations that could affect the measurement result, warning messages are automatically output.

To protect the measurement results and to prevent device malfunctions, a detailed evaluation of the measured value quality based on specific diagnosis parameters is carried out. See diagrams 3 to 8.

4.3.1. Speed of sound

The speed of sound in gases is proportional to the gas temperature

$$\sqrt{\frac{273K+\vartheta_{gas}}{273K}}$$

Further, the specific speed of sound is also influenced by the gas composition. In the event of fire, one can assume that the greater CO_2 proportion (c_{CO2} = 266 m/s @ 20 °C) in flue gas has an influence on the resulting speed of sound compared to fresh air (c_{air} = 343 m/s @ 20 °C).
However, in the event of fire, the dominant, temperature-related increase in the speed of sound after igniting the fire trays and the abatement as the duration of the fire increases are to be observed.
In the measurements carried out in the fire test, the progressions of the speed of sound did not give any indication of device malfunction of the FLOWSIC200.

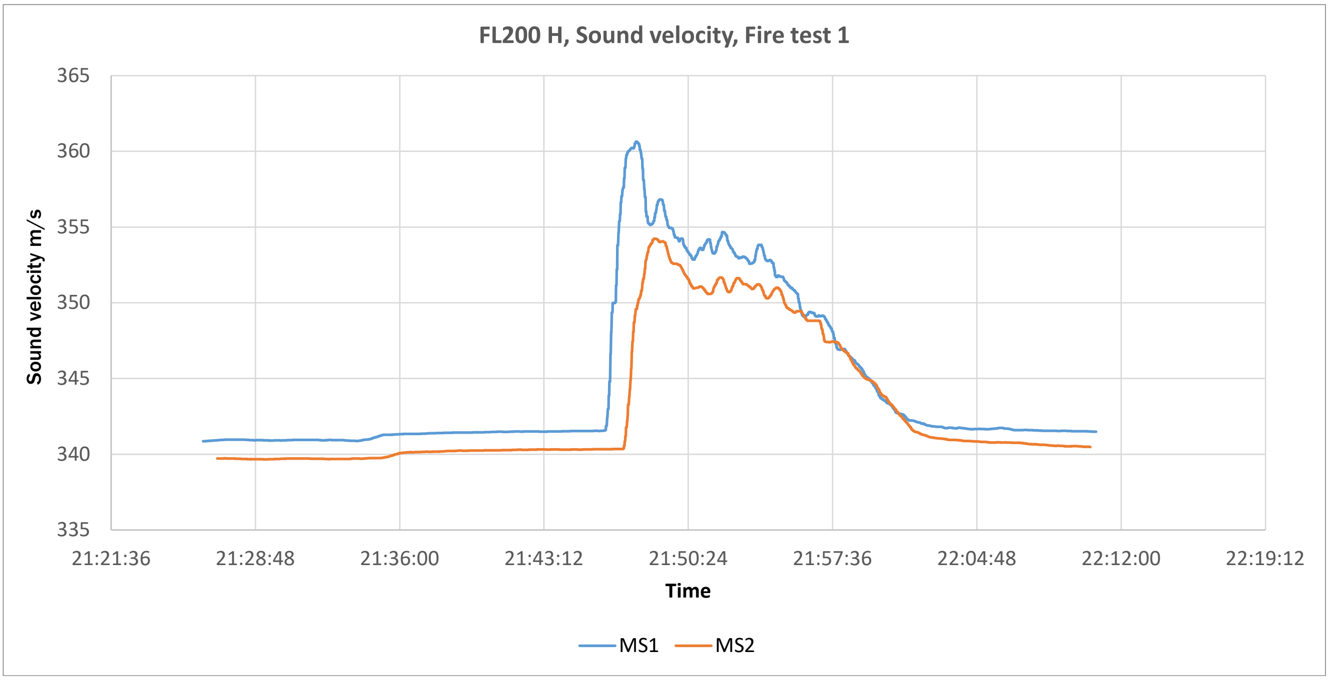

Diagram 3:
FL200 H, speed of sound, fire test 1, “one-way traffic” operating mode
MS1 approx. 25 m downstream behind the fire location
MS2 approx. 110 m downstream behind the fire location

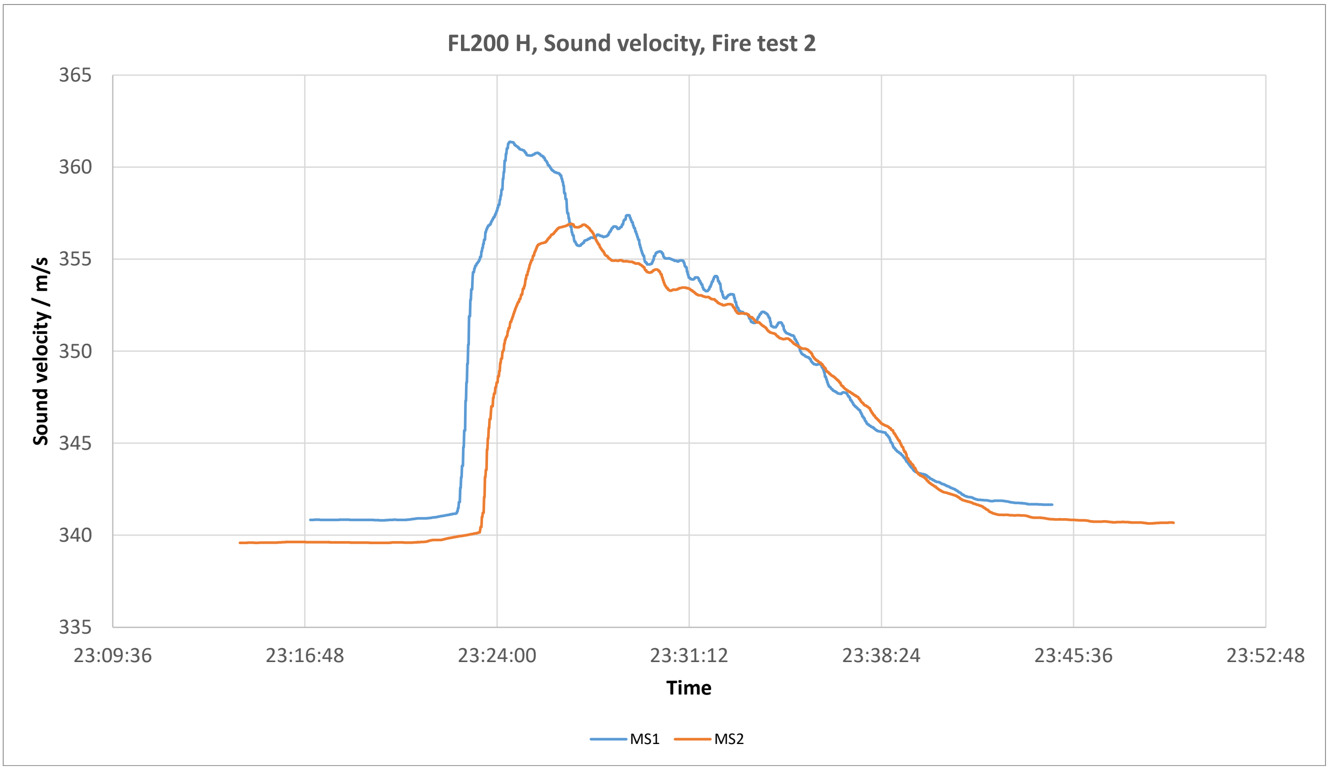

Diagram 4:
FL200 H, speed of sound, fire test 2, “two-way traffic” operating mode
MS1 approx. 25 m downstream behind the fire location
MS2 approx. 110 m downstream behind the fire location

4.3.2. Signal-to-noise ratio (SNR)

The signal-to-noise ratio (SNR) is an important parameter for monitoring and diagnosing the device functions. It can decrease due to difficult measurement conditions (e.g. gas mixtures with high proportions of sound-absorbing components such as carbon dioxide, high dust loads).
The FLOWSIC200 continuously monitors the signal-to-noise ratio. If a defined minimum threshold of 20 dB is undershot, the device automatically outputs a warning signal. In this case, the device and/or the application should be checked.
In the measurements carried out in the first test, consistently sufficiently high values with a safe distance to the minimum threshold of 20 dB with absolute SNR values in the range of 45 dB - 60 dB were proven. The value progression showed no major differences between the two measurement locations.
The following diagrams 5 and 6 represent the SNR values for probe A and probe B, respectively, for each measurement location (e.g. measurement location 1, probe A: MS1.SNR_A).

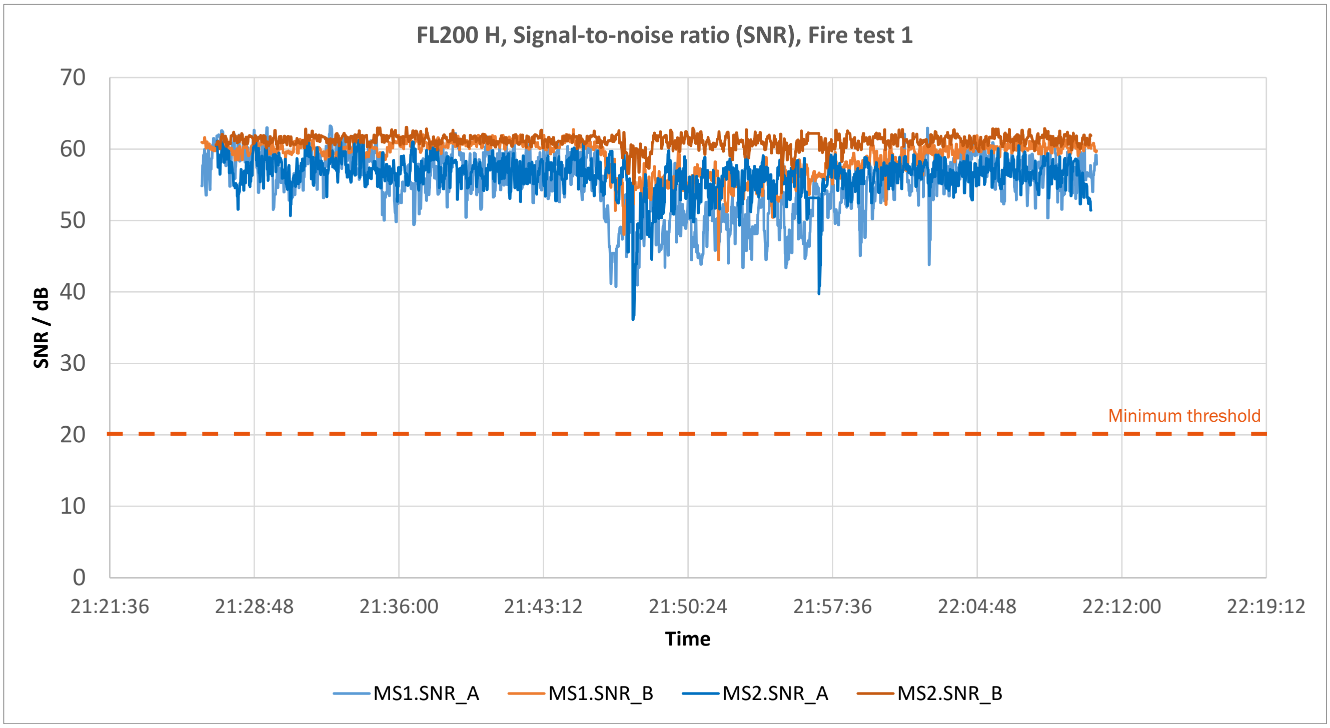

Diagram 5:
FL200 H, signal-to-noise ratio (SNR), fire test 1, “one-way traffic” operating mode
MS1 approx. 25 m downstream behind the fire location
MS2 approx. 110 m downstream behind the fire location

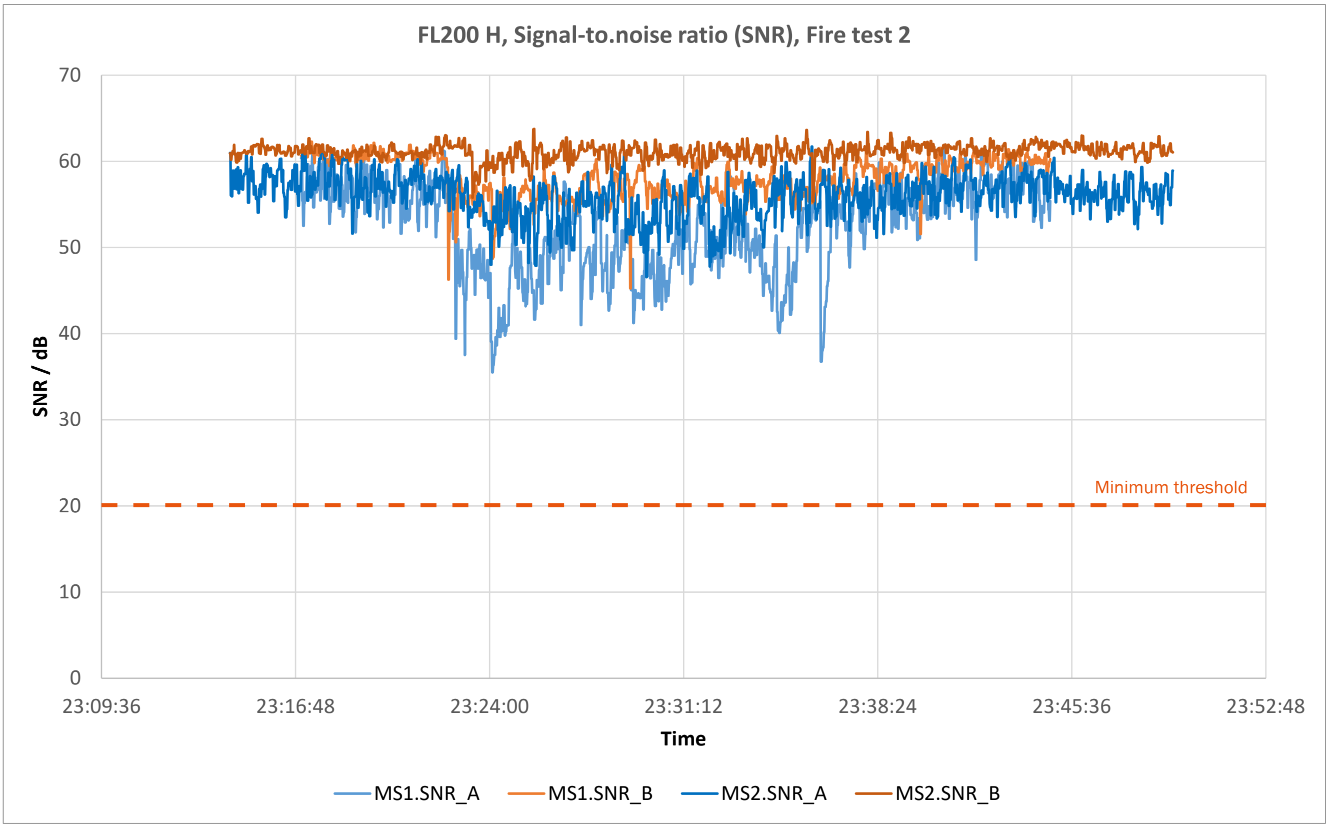

Diagram 6:
FL200 H, signal-to-noise ratio (SNR), fire test 2, “two-way traffic” operating mode
MS1 approx. 25 m downstream behind the fire location
MS2 approx. 110 m downstream behind the fire location

4.3.3. Automatic gain control (AGC)

The automatic gain control of the FLOWSIC200 automatically controls the receiver amplification of the ultrasonic signal if it is impeded due to changed gas conditions or contamination on the transducer, for example. A limit value (AGC limit) is parameterized in the device for the receiver amplification of the signal. If this value is exceeded, the device outputs a warning signal. In this case, the device and/or the application should be checked.

During the measurements in the fire test, the automatic readjustment of the reception sensitivity of the device displayed a difference of approx. 6 dB (factor 2) between the measurement locations MS1 and MS2. This is due to the higher temperature and certainly also the higher CO_2 concentration at the measurement location MS1. The carbon dioxide has greater specific acoustic damping compared to air.

The absolute values of the gain control also have sufficient distance to the maximum possible reception sensitivity of 70 dB.

The following diagrams 7 and 8 represent the automatic gain control (AGC) values for probe A and probe B, respectively, for each measurement location (e.g. measurement location 1, probe A: MS1.AGC_A).

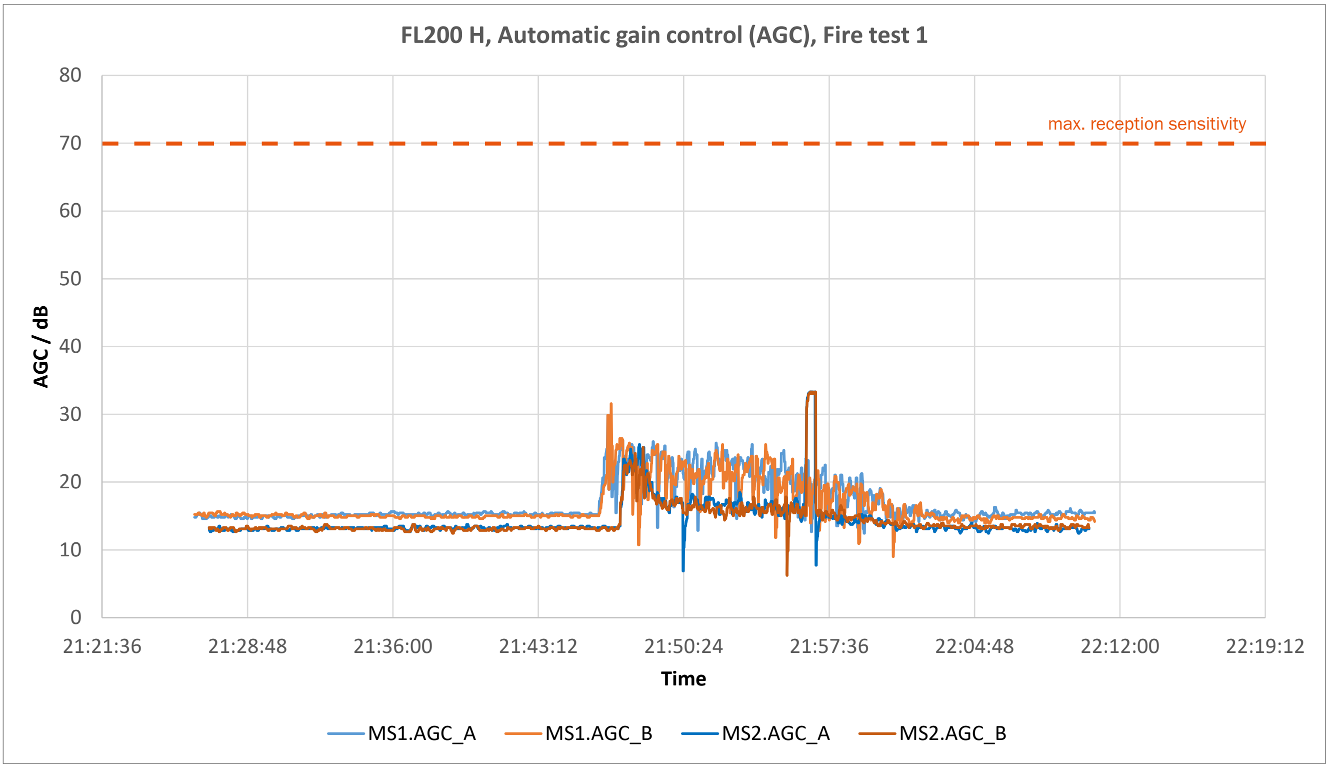

Diagram 7:

FL200 H, automatic gain control (AGC), fire test 1, “one-way traffic” operating mode
MS1 approx. 25 m downstream behind the fire location
MS2 approx. 110 m downstream behind the fire location

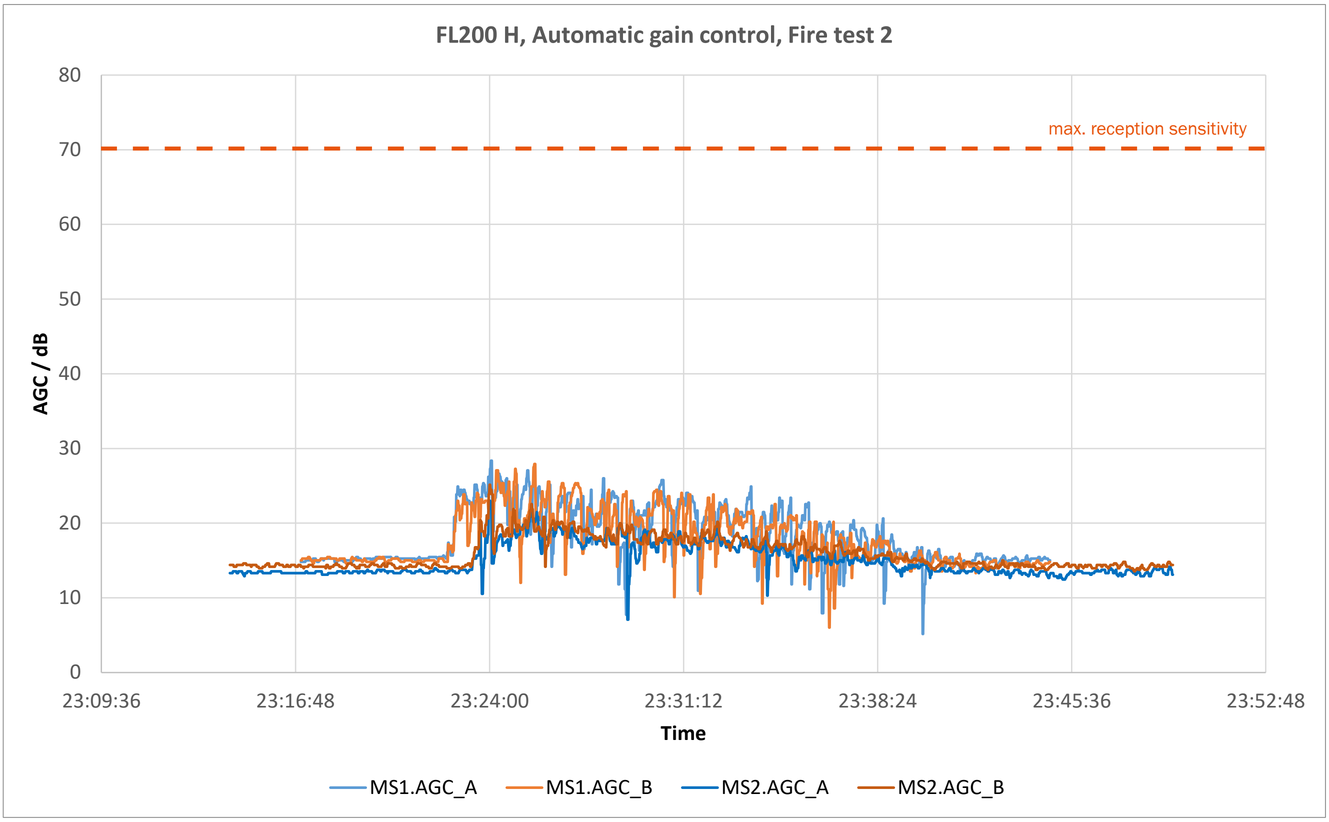

Diagram 8:
FL200 H, automatic gain control (AGC), fire test 2, “two-way traffic” operating mode
MS1 approx. 25 m downstream behind the fire location
MS2 approx. 110 m downstream behind the fire location

4.3.4. Signal error rate

The signal error rate corresponds to the percentage proportion of erroneous individual signals to the total number of signals. The signal error rate can increase in the case of significantly deteriorated measurement conditions (e.g. very contaminated gas, high background noise level) or if the device malfunctions.
Thanks to the most state-of-the-art signal evaluation algorithms, the FLOWSIC200 is still able to generate analyzable measured values even at an error rate of up to 90%.
A limit value is parameterized in the device for the signal error rate. If this value is exceeded, the device outputs a warning signal or a fault. In this case, the device and/or the application should be checked.
The signal error rate rose insignificantly in the measurements for the duration of the fire test. Measurement location MS1 also displayed slightly higher signal error rates (approx. 5%) when compared to measurement location MS2 in the test. The cause of this was the pre-existing constant mixing of hot and cold air near measuring location MS1 throughout the duration of the fire. The peaks lead to distortion in the acoustic signal received. These signals are filtered out in signal processing and are not used for the signal runtime determination.

5. Summary

In the event of a tunnel fire, the conditions in the area of the fire and in the immediate outflow area of the flue gas change significantly. The gas composition, gas temperature and flow dynamics play a substantial role here.
A fire source represents a local heat source in the tunnel, as a result of which, equalization processes between dominant flowing tunnel air and the heated air portion at the fire source occur. The resulting mixing processes create a changed thermodynamic situation.
The changes in the tunnel caused by the fire pose fundamentally different requirements on the flow velocity measuring device than in the tunnel's normal operation with ambient air.
As part of the fire tests, the influence on the performance of the FLOWSIC200's flow measurements was examined more closely. Any device-related causes for the special flow dynamics were ruled out. For all measurements in the fire tests, the device-specific diagnosis parameters were clearly far from the individual limit values and did not allow for a conclusion of faulty device behavior. The measurement functions reliably and without any appreciable performance losses. Measurement availability was 100 percent in all fire tests.
The function of the FLOWSIC200 was documented as impressive and without limitations during fire tests as part of the functional testing of tunnel ventilation systems. With a short response, the measurement results reflect a highly detailed representation of the flow conditions on the ultrasonic measuring path. The device is able to record the particular dynamics of the tunnel flow reliably and precisely and therefore delivers a reliable basis for the effective control of the ventilation system.

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