First Sensor

LDE/LME/LMI Series – superior immunity to humidity

In this application note LDE differential pressure (Δp) sensors from First Sensor are experimentally compared to other sensors which use the same (thermal-anemometer-based, non-membrane) sensing principle, where differential pressure is inferred from a gas flow through the sensor. In high-humidity environments, all other sensors with flow impedances from 15 Pa/(ml/s) to 300 Pa/(ml/s) went out of calibration or failed entirely while the LDE sensors with a flow impedance of >10 kPa/(ml/s) kept their calibrated sensitivity. The LDE/LME/LMI Δp sensors require only very tiny flows through their body and therefore provide high immunity to humid environments.

1. Introduction

The LDE/LME/LMI series low-pressure sensors with ranges from 25 Pa (0.1 inH_2O) full scale sense differential air or gas pressure, inferring differential pressure from nanoliters per second gas flow through an integrated air flow channel having high flow impedance. The transducer is a MEMS-based thermoanemometer on a monolithic silicon chip, only 4 mm^2 (0.006 in^2) in size. Further, the LDE/LME/LMI sensors utilize a microcontroller for precision digital signal conditioning.

2. Flow-through leakage

Because of the sensing mechanism, there is nonzero air flow leakage through the sensor itself during operation. This is true of all differential pressure sensors using the thermal-anemometer sensing principle, (as opposed to dead-end sensors such as piezo-resistive membrane-based sensors, whose sensing element does not leak). Still, thermal-anemometer-based Δp sensors have considerable success in the marketplace, because they enable practical and cost-effective sensing of very low Δp, such as a few hundred Pa full-scale and below. In this context, the question arises, how much flow-through leakage is too much? The answer depends on details of the application, and on how the Δp sensor is connected and used.

Being able to measure differential gas pressures below a few hundred Pa, with resolution better than 0.1 Pa, these sensors may be affected by other components of the measurement system such as connecting pipes/tubes and filters, and by the quality of the gas which may contain dust, humidity or liquid droplets.

Some manufacturers of thermal-anemometer-based Δp sensors recommend the use of connection tubes having a particular length, in order to avoid distortion of the response of the manufacturer-calibrated sensors. Manufacturers also may recommend the use of dust filters, or may use dust-segregation elements/mechanisms as part of their sensors. Note that these types of precautions are not needed for membrane-type sensors where the gas flow through the connection tubing is zero (in static mode).

In general, designers of a flow-measurement system using a thermal-anemometer-based differential pressure sensor must consider factors caused by non-zero gas flow through the sensor, in order to provide reliable long-term operation. Unfortunately, there are no standard test/certification procedures and detailed technical information to address these issues. The tests described below were performed with thermal-anemometer-based sensors from different manufacturers, to demonstrate the principal importance of the flow-through leakage (pneumatic impedance, or flow impedance) of the sensors, for reliable operation in practical applications.

Note:
The pneumatic impedance R_{pn} of the sensor, measured in [kPa/(ml/s)], determines the gas flow through the sensor at a certain pressure drop, Δp_s across the sensor:

$$\text{Flow-through leakage} = \frac{\Delta p_s}{R_{pn}}$$

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3. Flow measurement using differential pressure sensors

Micro-flow-based differential pressure sensors are typically used to measure differential pressure generated by gas flow passing through an air-flow duct or “flow tube”. Examples are respiratory flow measurement in medical ventilators as well as air flow measurement or filter control in HVAC applications.

Consider, for example, the sensor being used in a shunt configuration, to sense differential pressure Δp = p1 – p2 across a flow-restrictive element in an air duct, thereby inferring measurement of air flow in the duct as shown in **Figure 1**. Such conversion elements, designed for different applications, include orifices, baffles, Pitot tubes, Venturi tubes, calibrated diaphragms, and special flow-to-pressure converters used in respiration equipment such as Fleisch or Lilly tubes.

LDE/LME/LMI differential pressure sensors feature very high flow-through impedance, greater than 10 kPa per (ml/s) for the most-sensitive models and up to hundreds of kPa/(ml/s) for higher full-scale ranges. In principle, these sensors with high flow impedance need less parasitic flow in order to make a measurement, and thus cause less disturbance to the main flow than other sensors with lower flow impedance. This makes the sensor virtually equivalent to membrane-type (dead-end type) differential pressure sensors regarding this important aspect of performance for many applications.

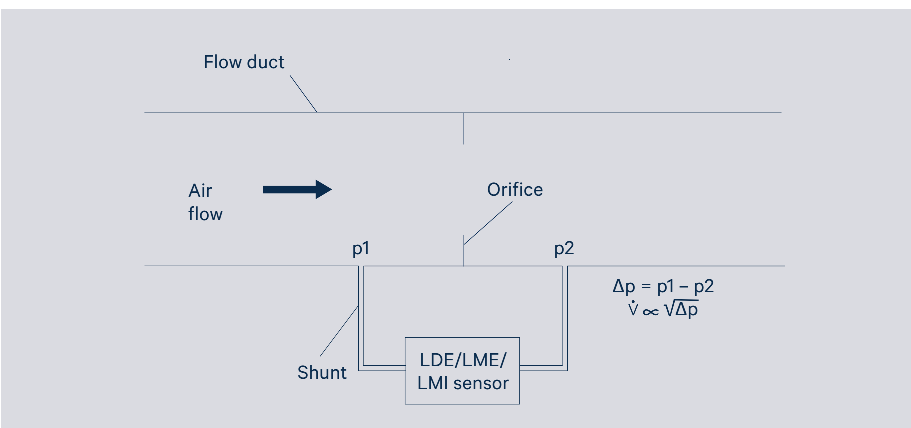

Figure 1 Typical volumetric flow measurement set-up with differential pressure sensor

4. Risk from high-humidity environments

In some applications the main gas flow contains substantial humidity, and is warmer than the ambient temperature. This is typical for applications such as medical respiration measurement, where the patient exhales humidified air which is typically at a temperature higher than the ambient room temperature or the temperature of the measuring equipment. In such cases, water may condense out of the gas flow on the inner walls of the gas flow ducts or connecting tubes, connectors, and other elements. While small condensed water droplets may be unaffected by gravity, the fine water droplets can join together to form larger water drops which then can form larger water accumulations. This may occur in the main gas flow path, in the tubes and connectors to the sensor, or in the sensor itself. Such water accumulations can change the pneumatic properties of the measurement system, or obstruct (or block entirely) a connector or connection tube, thus degrading or defeating the measurement system.

In general, the presence of high humidity presents a reliability/operational hazard, but the extent of the hazard is primarily determined by the flow-through impedance (pneumatic impedance) of the sensor.

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5. Experimental investigation of effects of high-humidity

In order to investigate the risk presented by high humidity, comparative experimental studies were conducted.

The experimental setup was designed and built to provide reproducible and controllable conditions for the tested sensors, and to allow fair comparative analysis of different sensors. With this target, sets of Δp sensors using the thermal-anemometer sensing principle were subjected to common applied differential pressures.

In each experiment, typically three or more sensor samples, often having different flow impedances, were connected in parallel such that a common differential pressure was present across all sensors.

5.1 Experimental setup

The setup shown in **Figure 2** was designed and built to provide reproducible near-100 % humidity in a test volume inside a plastic tube having an inner diameter of 2 cm. The test volume was fed from a typical household warm steam vaporizer. The other end of this main tube was connected to the air blower, through a flow-restrictive element. The flow restrictive element was another (narrower) plastic tube having an inner diameter of 1/16 inch and a length of ~5 cm. To avoid water blockage of the flow-restrictive element, a water collector was connected between the test volume and the flow-restrictive element. The water collector had a volume of 1.5 L, with a much larger inner diameter than the test volume. The test volume was connected to one port of each sensor.

The design was intended to maintain the pressure in the test volume very close to the ambient atmospheric pressure, while slowly pulling humidified air from the vaporizer into the test volume.

The temperature of the humidified air directly at the output of the vaporizer was approximately 90 °C, which was considered to be too high to imitate normal operation of the sensors. Therefore, the test volume was located approximately 25 cm from the output of the vaporizer. Temperatures T_1 (at the input to the test volume) and T_2 (at the other end of the test volume), were monitored inside the test volume by two NTC thermistors. The temperature distribution across the test volume depends on the air flow generated by the air blower. When the air blower was off, the temperature in the test volume was close to room temperature.

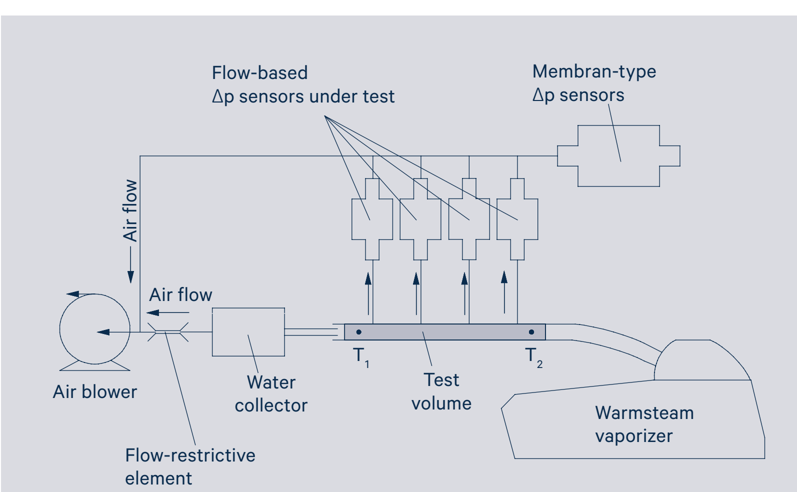

Figure 2 Schematic diagram of experimental setup

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5.2 Test procedure

The sensors under test were connected in parallel to each other as shown in **Figure 2**. One port of each sensor was linked to the test volume. The other port was connected to another tube that was directly linked to the air blower (not through a flow restrictive element). This arrangement caused a differential pressure to be established across the sensors under test, such that humidified air tended to flow through the sensors.

The differential pressure Δp across the tested sensors was monitored by a membrane-type pressure sensor. The other port of this differential pressure sensor was open to the ambient room pressure. The voltage output was used in an electronic feedback circuit to regulate the speed command voltage applied to the air blower, in order to maintain the differential pressure Δp at a constant level during a given experiment.

The sensors under test were arranged vertically, such that the humidity-bearing air had to flow upward from the main test volume tube toward the sensors. This served to prevent agglomerated water drops from flowing into the sensors.

5.3 Sensors under test

Sensor from **First Sensor**
LDES250UF6S

Measurement range	0...250 Pa (1 inH_2O)
Flow impedance	~80 kPa/(ml/s)
Output	0.5...4.5 V

Sensor from **First Sensor**
LDES050UF6S

Measurement range	0...50 Pa (0.2 inH_2O)
Flow impedance	~30 kPa/(ml/s)
Output	0.5...4.5 V

Sensor from **Manufacturer #1**
Sensor 1-1

Measurement range	-20...+500 Pa (2 inH_2O)
Flow impedance	~300 Pa/(ml/s)
Output	0.25...4.00 V

Sensor from **Manufacturer #2**
Sensor 2-1

Measurement range	0...±20 Pa (±0.08 inH_2O)
Flow impedance	~15 Pa/(ml/s)
Output	±70 mV

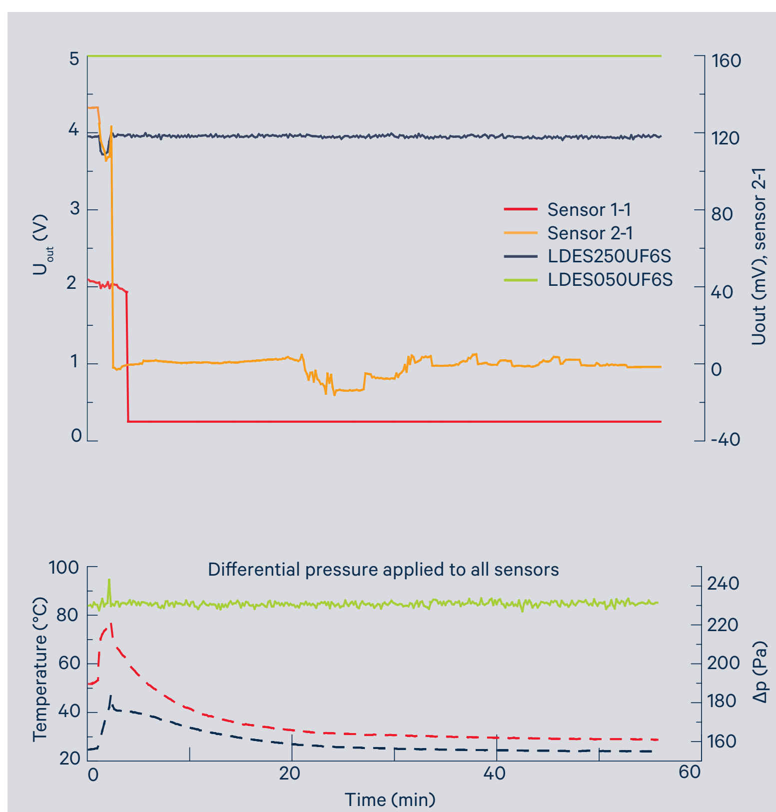

Figure 3 Sensor output signals during Test #1

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6. Test #1

In a first test, all four sensors identified above were connected to the test volume each using 10 cm of 1/8 inch ID plastic tubing. The sensor output signals measured during the test are shown in **Figure 3**. The pressure Δp applied to the sensors was maintained at a constant level of approximately 230 Pa during the whole test

The vaporizer and the air blower were turned on approximately 30 minutes before connection of the tested sensors. This time delay was needed to create a warm and humid environment in the test volume. Next, the sensors with their connection hoses (10 cm, as described above) were connected to the test volume. Immediately (within 30 seconds from the time of connection of the sensors), visible traces of water condensation (see **Figure 4**), could be observed inside the connection tube to Sensor 2-1, which has the lowest pneumatic impedance of the four. Sensor 2-1 lost proper function the earliest. After only ~1 minute, it showed a rapid decrease in its output signal (while the green line representing the membrane-type pressure sensor showed a relatively constant applied pressure). After approximately another minute of erratic output voltage behaviour, the output voltage of sensor 2-1 decreased dramatically from ~120 mV to ~0 mV, caused by visible blockage (obstruction) of its connection tube by accumulated water.

When Sensor 2-1 became blocked, this caused an abrupt decrease in air temperature in the test volume, as seen in **Figure 3**, (as well as a short spike in the measured air pressure, as the air blower's feedback circuit adjusted the air flow).

Sensor 1-1 also lost proper function quickly (after ~4 minutes). Its output voltage dropped to zero, again due to visible blockage of its lower tube connector by water accumulation (see left-most tube in **Figure 5**).

Figure 5 was photographed at the end of Test #1. The two rightmost tubes linked to the LDE sensors LDES250UF6S and LDES050UF6S showed no visible traces of water and no condensation was found inside the LDE tubes throughout the whole ~55-minute test.

No degradation of the output signal of sensor LDES250UF6S was seen in ~55 mins of test. The output of sensor LDES050UF6S was saturated since the applied pressure Δp exceeded its operating range of 50 Pa.

Figure 4 Connecting tube of sensor 2-1 ~30 s after start of Test #1

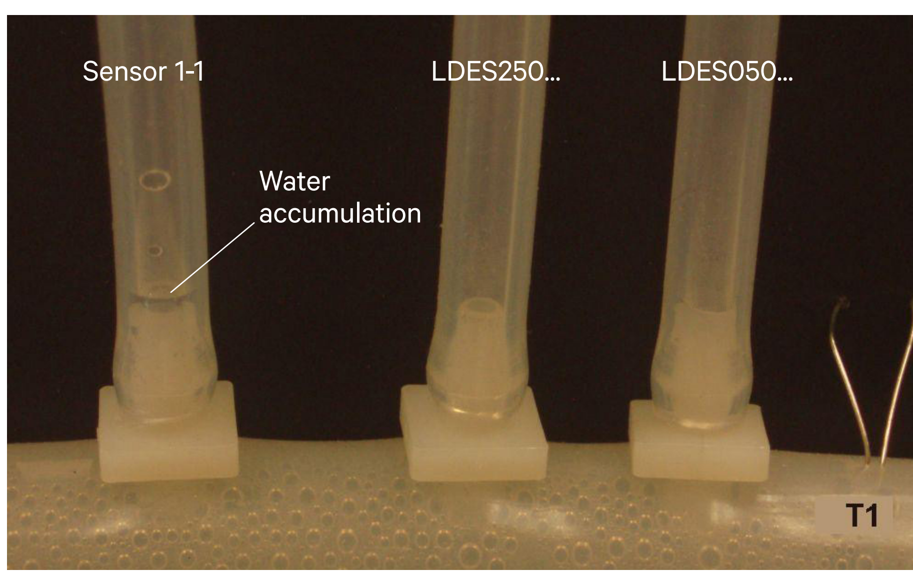

Figure 5 Connecting tubes ~10 min after start of Test #1

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7. Test #2

The second test, was set up in a way to give sensor 1-1 an advantage while handicapping the LDE sensors. Sensor 1-1 was connected to the test volume with wider 1/4" ID tubing (double the previous ID of 1/8"), while the LDE sensors were placed closer to the test volume at a distance of 3 cm instead of 10 cm, using the same 1/8" ID tubing as used previously. sensor 2-1 was not tested in Test #2.

The wider connection tubing for Sensor 1-1 was intended to be less susceptible to blockage by water accumulation, due to a wider cross-section near the connector which can accumulate a greater volume of condensed water without becoming obstructed.

The output signals of the sensors measured during Test #2 are presented in **Figure 6**. The photos in **Figure 7** demonstrate the process of clogging of 1/4" tubing.

As expected, Sensor 1-1 was able to operate for a longer time in Test #2 than in Test #1, before complete clogging of the connecting tube. The connection tube to sensor 1-1 became blocked approximately 60 minutes after the start of Test #2. There also occurred several temporary and partial reductions of the output signal of Sensor 1-1 (at constant applied differential pressure). These were observed at ~20 min and ~40 min (see **Figure 6**).

These partial reductions can be explained by partial clogging/restriction of the flow passage, either near the connection to the test volume, or inside the sensor's flow channel assembly. Since there is a continual air flow through the sensor, such restriction could be "cleaned out", which would explain temporary reduction and then restoration of the output signal to the original (unrestricted) level of about 2 V.

As in Test #1, both LDE sensors showed no sign of significant obstruction or degradation (see **Figure 6**) through >2 hours of operation with 3 cm-long 1/8" ID connection tubing.

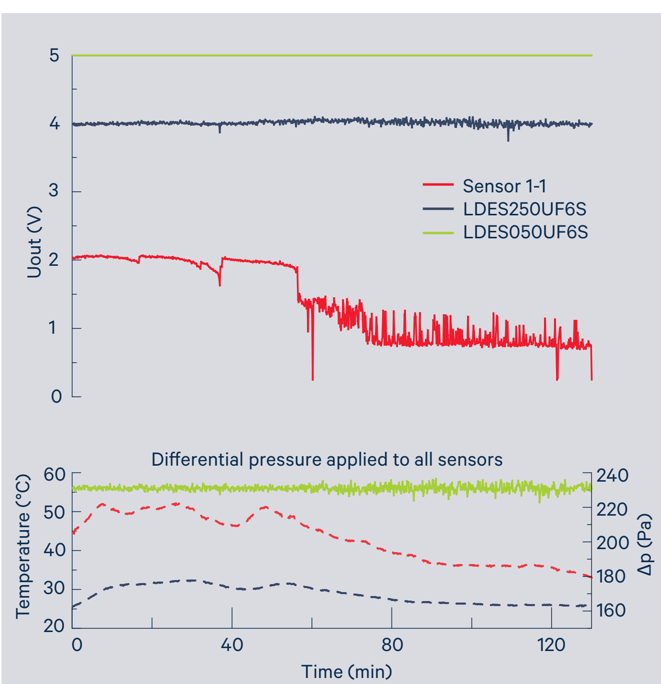

Figure 6 Sensor output signals during Test #2

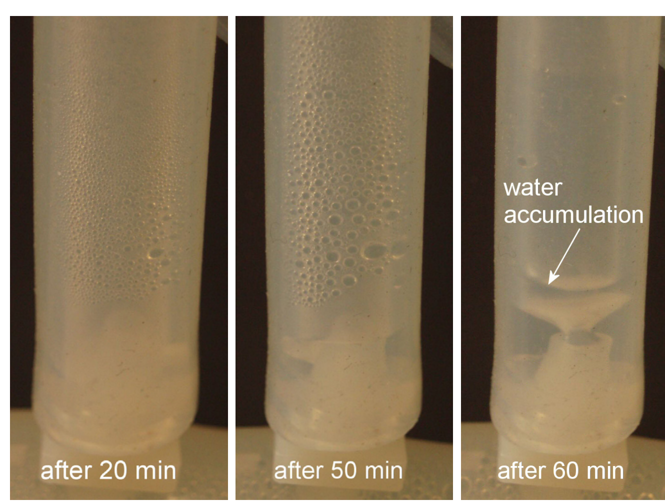

Figure 7 Process of clogging of 1/4" tubing of sensor 1-1 in Test #2

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8. Discussion

These tests confirm the importance of high pneumatic impedance of the micro-flow sensors, for reliable operation in systems where the flow rate of warm and humid air must be measured.

In both Test #1 and Test #2, the LDE sensors were intentionally connected to the hottest spots in the test volume, and were therefore exposed to air containing the greatest moisture concentration, with the greatest potential for significant condensation. Still, no visible traces of water condensation were found inside the connections to the LDE sensors in 1-2 hours of operation at constant differential pressure of 230 Pa applied across the sensors, and both sensors continually measured correctly.

Further, in Test #2, the LDE sensors were connected at a shorter distance of 3 cm from the test volume. While Sensor 1-1 became prevented from making its intended pressure measurements due to water accumulation in its connecting tube, both LDE sensors continued normal function.

The above described Test #1 and Test #2 show systematic differences in function and performance, related to differences in pneumatic impedance of the sensors. When the shunted sensor's pneumatic impedance is not high enough, the sensor's function requires substantial flow of air through the sensor. With substantial moisture-bearing air flowing to the sensor, the tubing and connections to that sensor are prone to significant water condensation. If the connections allow or encourage water buildup, then the system may be prone to potential blockage and loss of function.

Beyond those systematic differences, note that during the test, big drops of water condensed from the main gas-flow onto the walls of the test volume (see **Figure 5**). Such water drops may agglomerate and/or displace themselves due to gravity or surface tension, to accidentally clog any connector, thereby potentially disrupting the operation of any sensor connected to the main flow path. Even though this did not occur in the experiments described herein, this accidental effect may happen with any type of differential pressure sensor membrane-type, or thermal-anemometer-type, regardless of pneumatic impedance. Protection of the flow and measurement system against this type of accidental water clogging is the responsibility of the designer of the flow path and measurement system, for each particular application.

9. Conclusion

For differential pressure sensors based on the thermal-anemometer sensing principle, involving intentionally non-zero leakage through the sensor's airflow channel, the flow-impedance of that airflow channel is an extremely important factor in determining the sensor's immunity to condensation- induced blockages and functional failure.

With high humidity in the air flow, the LDE sensors from First Sensor having flow impedance >10 kPa/(ml/s) were compared directly with two other manufacturers' sensors using the same sensing principle, but having much lower flow impedance, 15 Pa/(ml/s) to 300 Pa/(ml/s). In all cases the sensors having lower flow impedance lost calibration and/or failed completely after ≤1 hour of normal operation. The LDE sensors did not show degradation or blockage.

The high flow impedance reduces the volume of humidity-bearing air which can approach the sensor's input, which thereby reduces the amount of moisture available to condense and potentially restrict or block pneumatic connections.

Essentially, the less air flow the sensor requires through its body to make a measurement, the more ideal is the behaviour of the sensor, and the better is the immunity to humidity-bearing air. The LDE/LME/LMI differential pressure sensors from First Sensor provide very high flow impedance and therefore substantial advantages.

Potential users of thermal-anemometer-based Δp sensors are invited to repeat same or similar humidity tests to verify suitability for use in the conditions of their own application(s).