Low-pressure gap discharge ultrasonic gas flowmeter

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Abstract

Low-pressure gas measurements are of increasing interest in the process industry for both control purposes and emission measurements. Industrial measurement environments include some very challenging components, such as:

- Dust, particles, vapor, water droplets, etc.
- Temperatures up to 1200 ^oC
- Pipe diameters of 1 to 10 m

Ultrasound flow measurement techniques have many advantages for such industrial measurement problems. Currently, a major problem is the lack of transducer technology that is sufficiently robust to operate in the presence of the above given industrial components. For the purpose of producing more robust technology, a gap discharge sound transmitter has been developed [1, 2]. Theoretical and experimental studies of the gap discharge transmitter indicate that flow measurement performances in the range of 1-2% of the actual flow is achievable [3].

Based on this gap discharge transmitter, an experimental ultrasound gas flowmeter was designed. The design features a gap discharge transmitter and piezo-based receivers. The design was tested in a real industrial environment. The test environment included heavy dust and water vapor in an exhaust pipe at a pelletization plant at LKAB, Kiruna, Sweden. The pipe diameter is 3 m, the pressure is ambient, and the gas flow speed is in the range of 5-20 m/s. The flow conditions were highly turbulent, using a straight pipe length ten times the pipe diameter in front of the experimental flowmeter. This paper presents the experimental gap discharge ultrasonic flowmeter design, the experimental setup and some measurement data. These data indicate that the gap discharge transmitter is feasible for operation in an industrial environment. Further preliminary flow measurement data demonstrate the feasibility of using a gap discharge transmitter as the sound-emitting source in an ultrasonic gas flowmeter.

Keywords: *Gap discharge ultrasonic flow meter, harsh industrial environment, Low-pressure gas flow, large pipe diameters, high temperature*

1 Introduction

Low-pressure gas measurements are of increasing interest in the process industry for both control purposes and emission measurements. Industrial measurement environments involve some very challenging components, such as:

- Dust, particles, vapor, water droplets, etc.
- Temperatures up to 1200 ^oC
- Pipe diameters of 1 to 10 m

Currently, the most commonly used flow measurement approach for such conditions is the Venturi meter. Numerous short comings of the Venturi meter are well known, see for example [4].

Flow measurement technology that can operate in an industrial environment will require transducers that can withstand such conditions. One technique that has many advantages for such industrial measurement problems is ultrasound [5]. For a widespread usage of an ultrasound flowmeter in harsh conditions, we need to address the problem of robust transducer technology. For the purpose of producing technology that can fulfill industrial requirements, a gap discharge sound transmitter has been developed [1, 2]. Theoretical and experimental studies of the gap discharge transmitter have indicated that flow measurement performances in the range of 1-2% of the actual flow is achievable [3].

Based on this gap discharge transmitter, an experimental ultrasound gas flowmeter was designed. This paper presents the design and initial experiments in a harsh industrial environment. This paper also presents the experimental gap discharge ultrasonic flowmeter design, the experimental setup and some measurement data. Finally, a discussion of the reliability of the experimental design is given, based on a shorter test period in a real industrial environment.

2 Experimental setup

2.1 Gap discharge transducer design and setup

The designed gap discharge transducer is shown in Figure 1. For the endurance experiment, the discharge gap was duplicated, thus allowing for one discharge gap to be used in operation and one to be maintained as a reference. This type of gap discharge transducer was used both for the environment endurance experiment and for preliminary flow measurement tests.

For the reliability tests, two gap discharge transducers with associated excitation electronics were installed in a real industrial environment. The test environment included heavy dust and water vapor in an exhaust pipe stack at the KK3 pelletization plant at LKAB, Kiruna, Sweden. Two stacks, the DDD stack and the PH stack, were used, each with a pipe diameter of 3 m, at ambient pressure with a gas flow speed in the range of 5-20 m/s. The flow conditions were highly turbulent, using a straight pipe with a length ten times the pipe diameter in front of the location of

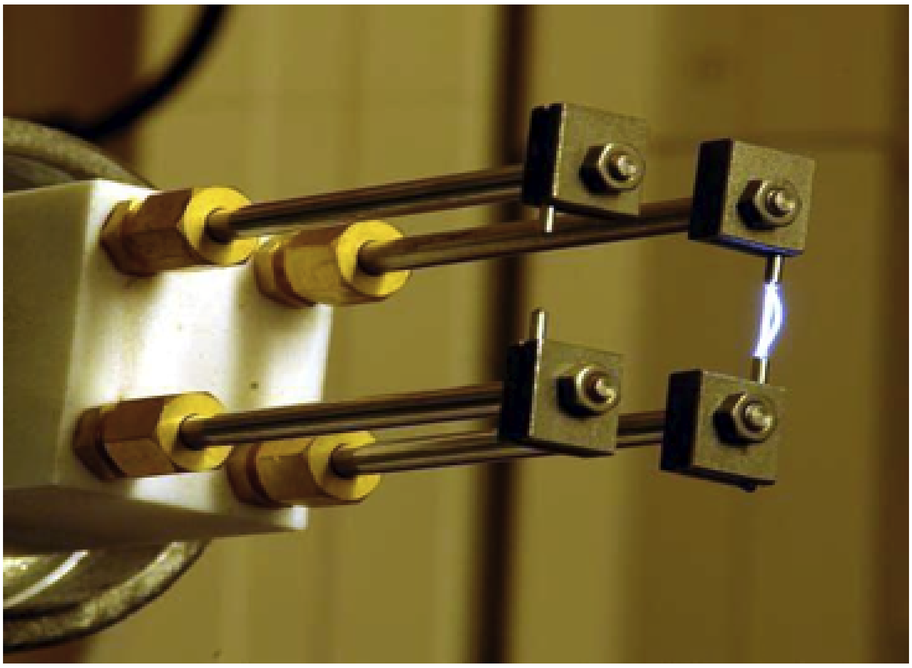

Figure 1: The experimental gap discharge transmitter. For evaluation purposes, two discharge gaps were built: one for use and one as a reference.

the experimental sound transmitters. The gas used was mainly air (O_2 and N_2) with the addition of carbon dioxide, sulphur dioxide, fluorides, chlorides and NO_x.

The dust in the PH stack has a density of approximately $1.2 - 1.3 mg/m^3$. The particle sizes are less than 10 μm. Here, the temperature is about 75^oC. For the DDD stack, we have a temperature of about 60^oC and a humidity of nearly 100% with a lower particle concentration.

For the reliability tests, we measured the actual number of generated discharges. These results were compared to the number of trigger pulses sent to the discharge electronics. The trigger frequency was set to 15 pulses/s. The trigger pulses were counted by a battery-operated counter, and the discharges were detected by an inductive pickup, located at the connector of the transmitter, and counted in the same way as the trigger pulses. A successful gas discharge, and thus sound transmission, was determined as one with an output from the inductive sensor larger than 5 volts.

For first flow measurement tests, one gap discharge transducer was installed in a lab flowmeter as described below.

2.2 Gas flowmeter design

The experimental ultrasound flowmeter is based on traditional transit time theory [5, 6]. The general equation is:

$$v = k(Re)\frac{L}{2}(\frac{1}{t_1} - \frac{1}{t_2})$$

where v is the fluid velocity, L is the transducer distance and $t_1 and t_2$ are the transit times in the downstream and upstream directions, respectively.

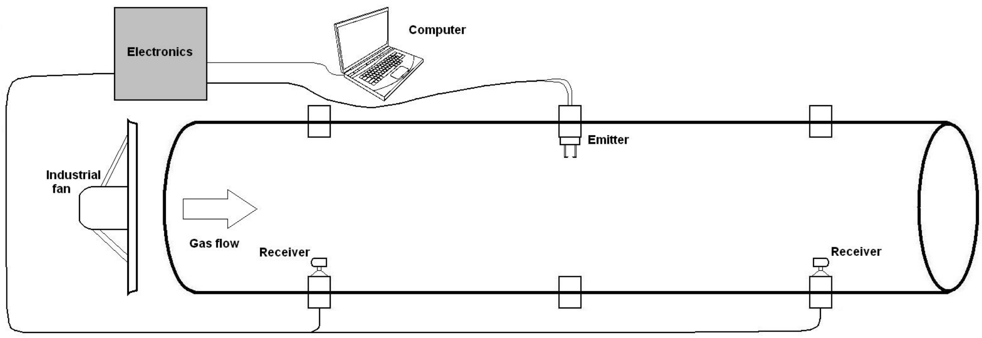

Figure 2: Experimental gas flowmeter design.

The experimental gas flowmeter has a pipe diameter of 0.63 m. As a sound transmitter, we used a gap discharge transmitter [2], see Figure 1. As sound recievers, we used piezo-based transducers with a center frequency of 200 kHz. The general setup is shown in Figure 2. The experimental setup for the gas flow measurements consists of a 3 m long and 63 cm in diameter sheet metal pipe, fitted with three holes (at 0.5, 1.5, and 2.5 m) on one side and three on the opposite side, where the gap discharge transducer can be placed. The flow was generated using an industrial fan controlled by a power converter.

The electronics used for the gap discharge excitation are shown in Figure 3 and 4.

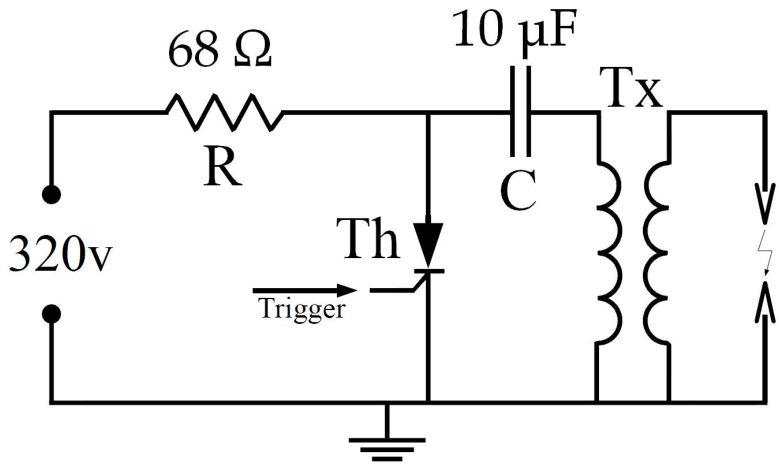

Figure 3: Schematics of the electronics used for the experimental flowmeter design, comprising both the gap discharge excitation electronics and the electronics necessary for the flow measurements.

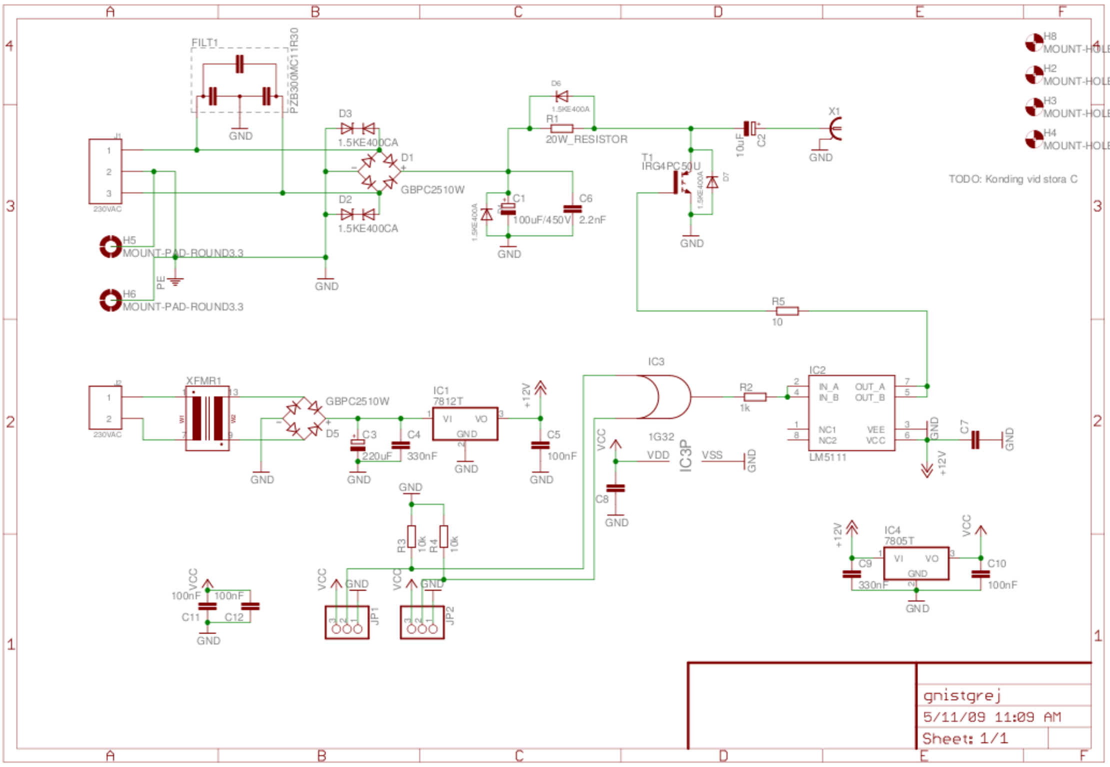

Figure 4: Schematics of the electronics used for the experimental flowmeter design, comprising both the gap discharge excitation electronics and the electronics necessary for the flow measurements.

3 Experiments

Two types of experiments were conducted. First, an endurance test of the gap discharge sound transmitter was carried out. Here, the number of successful gas discharges was measured for a period of several days.

Second, an initial flow measurement trial was conducted using the lab flowmeter described in Section 2.2. Thus far, the experiment is limited to verifying that the flowmeter is capable of tracking flow variations. Flow variations of roughly 1:20 were generated using the power converter control of the fan. This experiment was repeated six times. Due to the very stable gas temperature and pressure conditions employed, we expect that the test rig had a fairly good repeatability.

Stack	Excitations	Generated sound pulses	%	Note
DDD stack	7,316,270	6,663,198	91%	malfunction after 135 hours
PH stack	2,875,187	2,311,935	80%	malfunction after 53 hours

Table 1: Reliability test data showing the number of generated pulses and the number of actual sound pulses.

Figure 5: Appearance of one of the tested transmitters after one week of operation in the DDD stack.

4 Results and discussion

For the reliability test, the results are summarized in Table 1. The results clearly indicate that both transducers performed reasonably well. The cause of the unsuccessful excitations is currently unknown. Both experiments were terminated due to malfunction of the electronics. The major reason for this was insufficient encapsulation of the electronics.

For the experimental lab flowmeter, the flow tracking results are shown in Figure 6. Here, it is obvious that the flowmeter is capable of tracking flow variations over the tested flow range of about 1:20. For each flow setting, 100 velocity measurements were taken. In total, ten flow settings were used, with each of them repeated six times.

Repeatability for the flow meter is for these experiments indicated with 2σ bars, see figure 6. We have identified the following sources for these spread in the measurements:

- One source found for the rather high spread is that the generated spark was not always fired between the electrodes. Sometimes the spark was generated from the base of the metal bars, leading up to the electrodes, and the metal pipe itself, cf. figure 1. Thus giving the sound longer travel distances than designed. This phenomena can generate velocity errors of up to many meters per second. Thus indicating that additional development is needed on the transmitter design.

- Another source for errors is the time jitter associated with the sound generated by a spark. The time jitter is random and caused by the spark taking different paths between the electrodes. This jitter is in the ballpark of a few μs according to Martinsson [2]. By averaging this error should be reduced to practically zero.

- Supersonic behaviour of the sound burst can be another source. The sound generated by

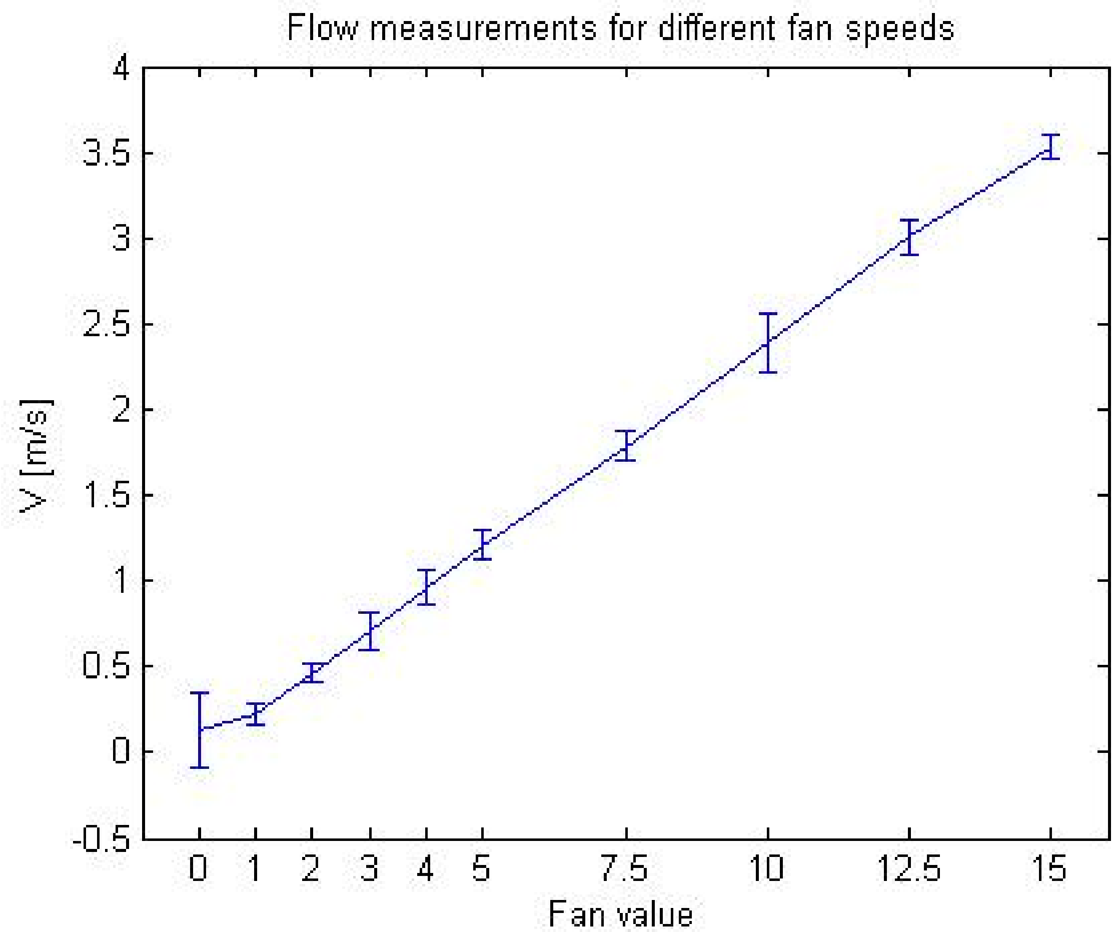

Figure 6: Gas flow velocity measured with the gap discharge flowmeter versus fan speed. No real reference data are available for the present setup.

a spark is supersonic as it leaves the gap discharge transducer. The sound speed is then reduced towards the small linear region normal speed of sound as it progresses. Yielding a non linear sound speed over the sound path. Variations over time in this phenomena can be canseled using more advanced velocity calculation algorithms [7]. The influencies of supersonic phenomena is yet to be investigated in more detail.

- Geometrical uncertanties. Resulting in e.g. zero flow errors. This type of error can be reduced to low levels enough by proper calibration.

- Sound arrival time detection. The current arrival time detection technique used is a zero crossing technique. Studies of our data indicates that this might be a major contributor to the current data spread. By proper tuning of zero crossing detection circuitry stable arrival time detection down to ps resolution is possible, see for example [8].

5 Conclusion

A gap discharge sound transmitter has been successfully used in an experimental ultrasonic gas flowmeter. Preliminary tests indicate its functionality as a flowmeter. However, no real calibration data are available at this time. The reliability test of the gap discharge transmitter indicates that the gap discharge design is feasible and that the electronics design needs further improvement to survive an industrial environment, yet this is not seen as a major problem.

Future work will include full flowmeter tests in a real industrial environment as well as calibration and comparison to Venturi meters in a real industrial environment.

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