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The sound velocity in pur C_4F_{10} at $25.00 \pm 0.25^\circ\text{C}$ has been measured to be $101.1 \pm 0.1 \text{ ms}^{-1}$.

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Ultrasonic Gas Mixture Analysis System in the Forward RICH of DELPHI

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An ultrasonic velocity measurement is used to on-line monitor the percentage of C_4F_{10} in the Forward RICH of DELPHI with a precision better than 1%. The value is displayed in real time by a micro-computer.

The sound velocity in pure C_4F_{10} at 25.00 ± 0.25 °C has been measured to be : 101.1 ± 0.1 ms⁻¹.

1. Introduction

Sonar based devices have been used for many years in the analysis of binary gases. They have been developed for the CRID of SLD at SLAC [1, 2] and for the Barrel RICH in DELPHI [3, 4]. In these cases the sonars provide online monitoring of the $C_5F_{12} - N_2$ gas mixture.

For the DELPHI Forward RICH gas radiator [5], filled with C_4F_{10} , we have built a system based on the same technique. The main improvement consists in the use of a tiny PC for data acquisition and treatment. It allows the display of the proportion of the C_4F_{10} in real time.

The theory of speed of sound in ideal gases and for small amplitudes leads to the well known formula independant of the pressure [6]:

$c = \left(\frac{\gamma RT}{M}\right)^{\frac{1}{2}}$, where $\gamma = \frac{C_p}{C_v}$ and M is the molecular weight. Studies in molecular acoustics have shown a variation of the velocity at frequencies above 1 MHz. These effects will be ignored in the present work since the system is operated at 49 kHz.

2. The ultrasonic gas analysis system

The system layout is shown in Figure 1.

2.1. The transducer and its drive circuit

At the heart of the system is the Polaroid 6500 transducer [7] originally developed for application in the range finder of an autofocus camera. In the present set-up it has two functions:

—electrostatic loudspeaker: on a START signal, the driving circuit generates a train of 16

Figure 1. General layout of the ultrasonic system.

pulses at a frequency of 49 kHz and an amplitude of 400 V.

—microphone: after a 2.3 ms dead time, the transducer is set to the receiving mode. The typical operation is at a bias voltage of 200 V. During this period, the programmable gain of the amplifier is increased in 12 steps to compensate for the attenuation of the signal in the gas mixture. The received signal is converted by a comparator and

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a current generator into a multistep signal generating a STOP when it reaches a certain threshold. The driving functions are performed by two *Tezas Instruments* [8] integrated circuits.

2.2. PC-XT - Transducer interface card

This card is built around a 16 bit counter that counts the number of pulses of the internal clock (4.77 MHz or 210 ns) between the START and the STOP (Figure 2). On the card one finds:

Figure 2. The Interface card.

- two 8 bit DACs. One is used to display the percentage and the other one for data transfer to the programmable automat that drives and supervises the gas radiator system [9].
- two ADCs for the PT100 probes.

2.3. The mini PC-XT

All the standard functions of a compatible PC-XT or AT are grouped on one 3.6" × 3.8" card, which is very useful for embedded applications. Such a tiny PC-XT (COREMODULE/XT[10]) has been used in the present application. It runs

standard IBM PC software, including the disk operating system (DOS). Application programs are stored in solid state devices (EPROM).

2.4. Mechanics

The gas ready for analysis is passed through a 102 mm external diameter stainless steel tube equipped with the ultrasonic transducer at one end and the reflector at the other. The gas exits in the reflector end and enters by the transducer end where there are also cavities for the temperature probes. The distance between the reflector and the transducer is $L = 0.5830 \pm 0.0005$ m.

The temperature of the tube is maintained constant by means of a wind-up heating belt controlled by a programmable temperature module and a PT100 probe.

3. Calibration

3.1. Flowmeter calibration

All the flowmeters have been calibrated using a very simple method. The gas is used to drain a test-tube of its volume V of water and the time T to do this is recorded. The conversion factor is defined as $F_c = \frac{Dr}{Dl}$ where Dl is the flow displayed on the flowmeter and Dr is the real flow given by: $Dr = \frac{V \times 3600}{T} \text{ lh}^{-1}$.

The relative error on the conversion factor F_c ranges between 1.7% and 3.8%. For each conversion factor, a polynomial fit has been made with respect to the flow.

3.2. Time offset

The pulses are emitted with a delay T_{offset} after the START. This delay has been determined with pure gases for which the velocities V_s are known. T_{offset} is the mean value of the individual values of $T_m - \frac{2 \times L}{V_s}$, where T_m is the measured time between START and STOP.

Here: $T_{offset} = 0.226 \pm 0.009$ ms

4. Measurements

The velocity in any gas is calculated by the formula: $V_m = \frac{2 \times L}{T_m - T_{offset}}$.

4.1. Velocity in C_4F_{10}

In pure C_4F_{10} at 25.00 ± 0.25 °C the velocity is measured as: $V_{C_4F_{10}} = 101.145 \pm 0.087$ ms⁻¹.

4.2. Fit of the velocity as function of the C_4F_{10} percentage

Sound velocity has been measured in twelve calibration mixtures. The set-up is shown in Figure 3. For each sample, the C_4F_{10} proportion

Figure 3. Set-up for calibration with gas mixtures.

PC4 is computed through the formula:

$$PC4 = \frac{Dl_{C_4F_{10}} \times Fc_{C_4F_{10}}}{Dl_{C_4F_{10}} \times Fc_{C_4F_{10}} + Dl_{N_2} \times Fc_{N_2}}$$

Results are shown in Figure 4 and in Table 1.

For ideal gases, a good approximation for the sound velocity in gas mixtures [1] is obtained by assuming that it is proportionnal to the concentration by weight of the components:

$$V_m = \frac{\sum_i X_i \rho_i V_i}{\sum_i X_i \rho_i}$$

where X_i is the volume concentration of the i^{th} component, ρ_i its density at the measurement temperature and V_i the measured velocity in the pure i^{th} component gas.

Figure 4. Calibration curve giving the measured sound velocity versus C_4F_{10} proportion in a $C_4F_{10} - N_2$ gas mixture.

For gas mixtures containing C_nF_{2n+2} , this formula gives an error ranging from 1 to 10%. An empirical formula based on it has been used, but leaving ρ_i as free parameters. As we have to deal with a two component mixture, only the ratio $\rho = \frac{\rho_{C_4F_{10}}}{\rho_{N_2}}$ has been adjusted using the calibration data:

$$V_m = \frac{(100 - PC4) \times V_{N_2} + PC4 \times \rho \times V_{C_4F_{10}}}{(100 - PC4) + PC4 \times \rho}$$

with $V_{N_2} = 352.905$ ms⁻¹ [11]

and $V_{C_4F_{10}} = 101.145$ ms⁻¹.

The fitted value is $\rho = 5.878 \pm 0.084$.

5. Determination of the percentage of C_4F_{10} in a mixture

The above formula is coded in the system and allows the determination of the C_4F_{10} percentage in a mixture in real time. The computed fraction is directly shown on a digital display and can be

V_m ms^{-1}	ΔV_m ms^{-1}	PC4 (%)	$\Delta PC4$ (%)
101.145	0.087	100.00	0.00
103.930	0.090	92.23	0.36
106.415	0.087	86.25	0.45
111.640	0.087	74.45	0.64
124.016	0.087	60.87	0.82
130.746	0.087	53.65	0.91
140.923	0.087	46.30	1.24
145.860	0.087	44.80	1.16
154.030	0.087	40.14	1.11
158.530	0.087	39.20	1.82
180.880	0.088	27.70	0.83
199.860	0.088	21.86	1.06
230.570	0.089	13.60	1.02
352.905	0.093	0.00	0.00

Table 1
Values of V_m , ΔV_m , PC4 and $\Delta PC4$ for the various mixtures used for calibration.

transferred by the programmable automat monitoring system.

Table 2 shows the errors obtained on the C_4F_{10} percentages. All are below 0.2 %.

6. Conclusion

Sound velocity measurement allows the determination in real time of the percentage of C_4F_{10} in a mixture C_4F_{10}/N_2 . The system is cheap, reliable, easy to install and to maintain. Three such systems have been built at the ISN in Grenoble. Two are operational in the Forward RICH since 1994 (side C) and 1995 (side A).

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PC4 %	100.00	90.00	80.00	70.00	60.00	50.00
$\Delta PC4$ (%)	0.19	0.17	0.15	0.13	0.11	0.08
PC4 %	40.00	30.00	20.00	10.00	0.00	
$\Delta PC4$ (%)	0.08	0.06	0.05	0.04	0.03	

Table 2
Expected precision $\Delta PC4$ on PC4, the percentage of C_4F_{10} in a given mixture.

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