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CALIBRATION OF AUTOMOTIVE HOT-FILM ANEMOMETERS FOR SCIENTIFIC APPLICATIONS

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Abstract. *The measurement of air mass flow in experimental pipe lines that are subject to vibrations, rapid variations in the speed of flow and temperature can be challenging. If sensors that are not specifically designed for operation under these conditions are used, the quality of the measurements obtained will be compromised, and the sensor life will be drastically reduced. Automotive sensors are ideal for this type of application, but a huge drawback is the fact that their calibration curves are hardly available from the manufacturer. This work aims at the calibration of hot-film anemometers commonly used in automotive applications to measure the air mass flow admitted by the engine in order to allow them to be used in other applications, in this specific case in a test bench of gas turbines. To achieve this goal, a calibration bench was built.*

Keywords: *automotive hot-film anemometer, airflow calibration bench.*

1. INTRODUCTION:

Taking measurements of gas mass flow rates can be very difficult depending on the conditions in which it should be performed. In this paper, a hot-film anemometer of automotive application will be retrofitted in a gas turbine test bench developed by the "Laboratório de Energia e Ambiente – LEA" of the "University of Brasília – UnB", which originally uses a turbine type sensor, as can be seen in the work of Ferreira, M. C. (2007). In Fig. 1 we have a photo of the mounted bench.

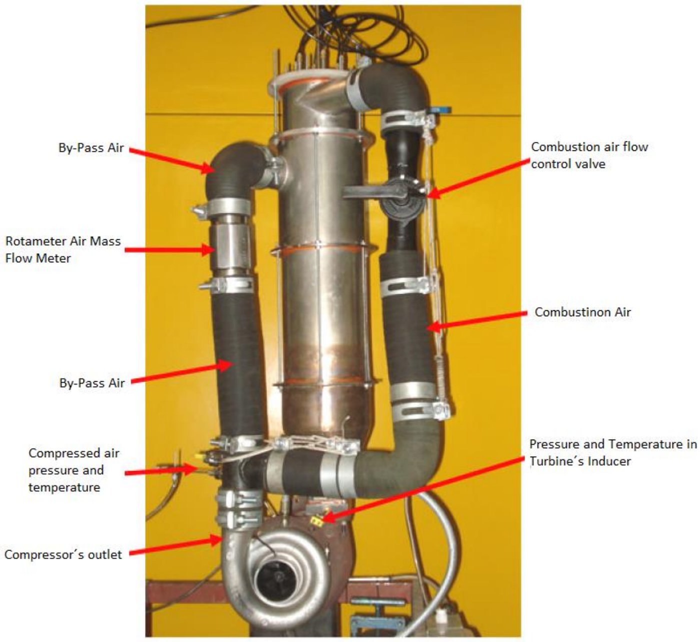

Figure 1. Gas Turbine test bench (Costa Ferreira, M., 2007)

Hot-film anemometers have several advantages over turbine type sensors for gas mass flow measurements. Among the advantages, we can mention the absence of moving parts, avoiding variations in the measurements due to mechanical wear of the sensor (McAllister, E.W., 2005).

The main disadvantage in using an automotive sensor in a different application is the need to obtain its calibration curve, since the manufacturer does not usually make this information available openly.

To obtain the calibration curve, the calibration bench was developed around the sensor chosen for the application. For the calibration of hot-film anemometers at speeds typically higher than 1.5 m/s, we can use traditional methods with excellent results (Emrah Özahi et al., 2010), in this way the developed bench is quite simple, as can be seen in the schematic drawing shown in Fig 2.

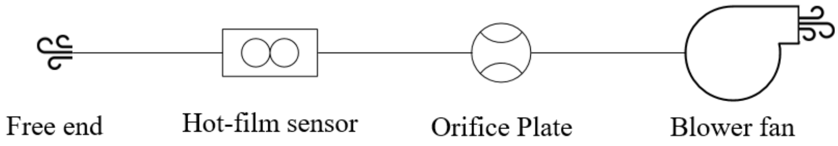

Figure 2. Schematic drawing of calibration bench

Taking in account the accuracy and the precision needed for the application, the sensor was calibrated against an orifice plate manufactured specifically for the calibration bench, making the bench a secondary calibration system (Guido Belforte et al., 1997).

2. SELECTED HOT-FILM ANEMOMETER:

The sensor selected for the application was the BOSCH 0280218065 HFM Sensor, used in several VW/Audi vehicles for measuring the engine intake mass air flow. This sensor was chosen because it has an internal diameter compatible with the existing pipe in the turbine test bench, facilitating its installation, for having a proper measurement range for the application and already having an internal signal conditioner. Figure 3 is a schematic drawing of a similar Bosch sensor.

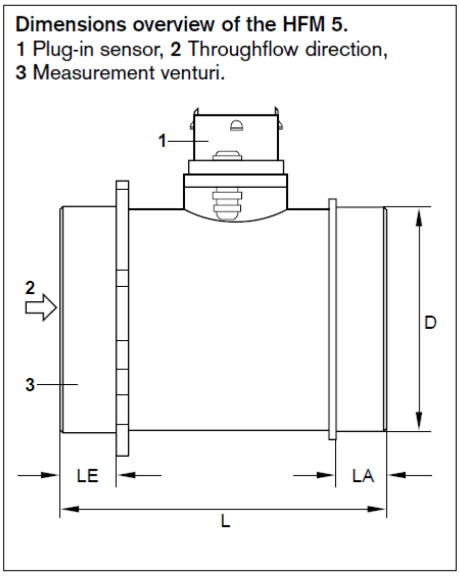

Figure 3. Schematic drawing of Bosch sensor (Bosch, 2018)

Because it already has an internal signal conditioner, its output is an analog signal ranging from 2.5 V to 5 V proportional to the flow measured by the sensor. The sensor housing has a diffuser in order to reduce turbulence in the flow and ensure a more accurate measurement.

3. THE CALIBRATION BENCH:

The bench was built for simplicity in both construction and operation.

The bench consists of a blower type fan with an AC electric motor with a power of 1471 W, which has its speed controlled by a frequency inverter. In the admission of the fan there is a section of steel tube with internal diameter of

0.0722 mm and a length of 0.6 m in which the orifice plate is installed. In the other end of the plate, there is another section of tube of the same diameter and with 1.5 m of length where the hot-film anemometer is installed. At the other end of the anemometer, there is another section of tube with its end free to the atmosphere. This section has 0.6 m of length. The fan exhaust is also free to the atmosphere.

Such design is very similar to that used by Santiago Pezzotti et al., 2011.

4. ORIFICE PLATE:

The sensor was calibrated using the mass flow measurements obtained by an orifice plate. Orifice plates are differential pressure type flow meters, ie the flow rate is calculated from the pressure difference upstream and downstream of the plate. The main disadvantage in the use of this method is great pressure drop caused by the plate (Myer Kutz, 2013), however, in this specific case is not worrisome.

One drawback with orifice plates is their rangeability, which is around 4:1 (S. Basu, 2015). From Ferreira, M. C. (2007) and Cruz, T. V. G. (2016), the mass flow going to the combustor of the turbine test bench should varies between approximately 0.040 kg/s up to 0.240 kg/s, meaning that two plates with different orifice diameters will be needed to cover the entire range.

Both plates were dimensioned following the guidelines of the NBR ISO 5167-2 standard, with a central orifice and type “D & D/2” pressure ports. The installation on the bench also followed the guidelines of the same standard. The mounting mechanism was designed in a way that only the plates could be easily swapped while keep everything else assembled. Table 1 shows the measuring range and physical dimensions of each orifice plate.

Table 1. Orifice plates physical characteristics

	Orifice Plate 1 (OF1)	Orifice Plate 2 (OF2)
Orifice diameter (d)	0.0336 m	0.053.6 m
Pipe diameter (D)	0.0722 m	0.0722 m
β	0.4654	0.7424
Thickness (E)	0.001 m	0.001 m
Measuring Range	0.020 – 0.080 kg/s	0.060 – 0.240 kg/s

Utilizing a simple MatLab routine, the relationship between the differential pressure across the orifice plate and the mass flow rate was determined using the methodology provides by the NBR ISO 5167-2 standard. Figure 4 and Fig 5 shows the results of both orifice plates.

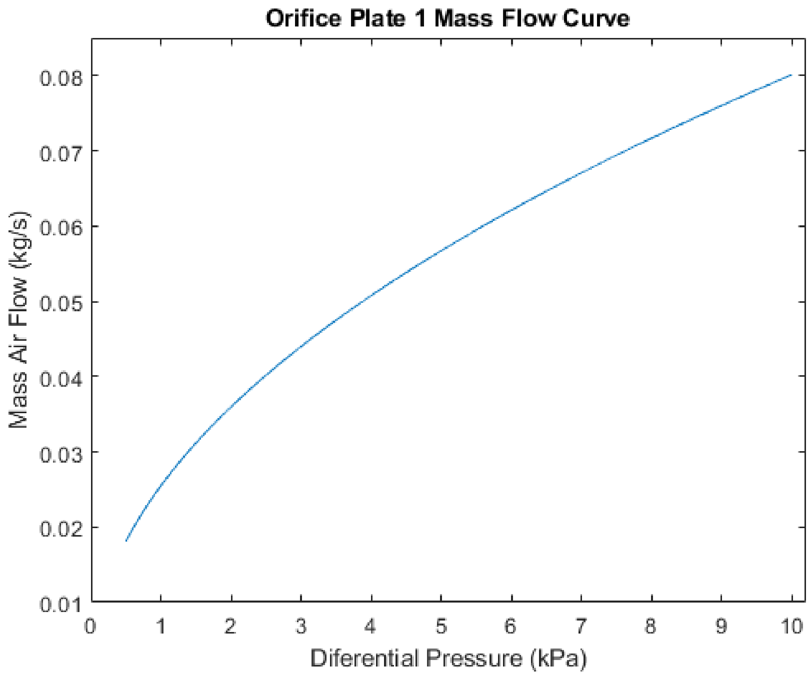

Figure 4. Orifice plate 1 mass flow characteristic curve

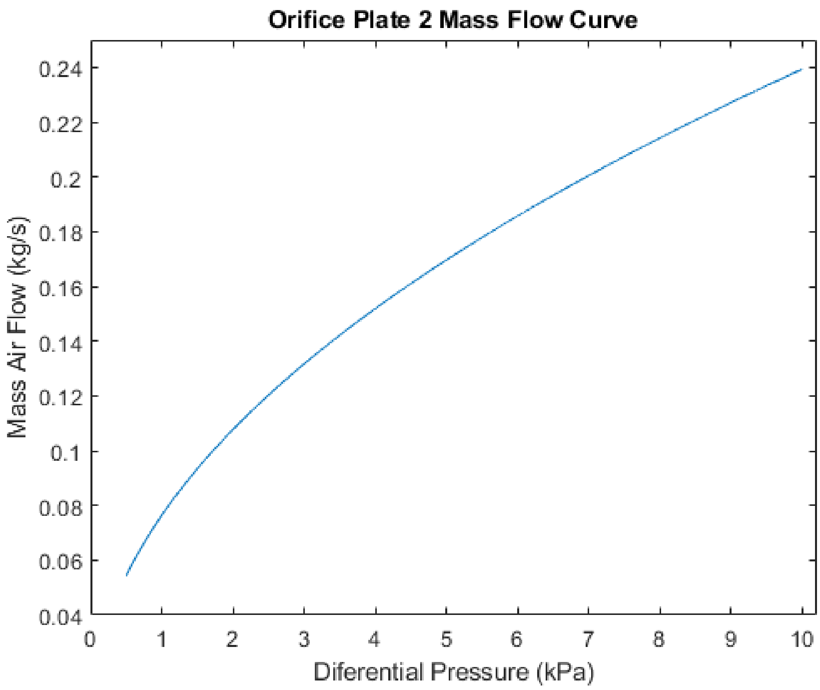

Figure 5. Orifice plate 2 mass flow characteristic curve

5. PRESSURE TRANSDUCER:

The pressure transducer used was the NXP MPX5010DP. This is a piezoresistive differential pressure transducer with a measurement range of 0 to 10 kPa, has internal temperature compensation. The typical output signal is shown in Fig 6:

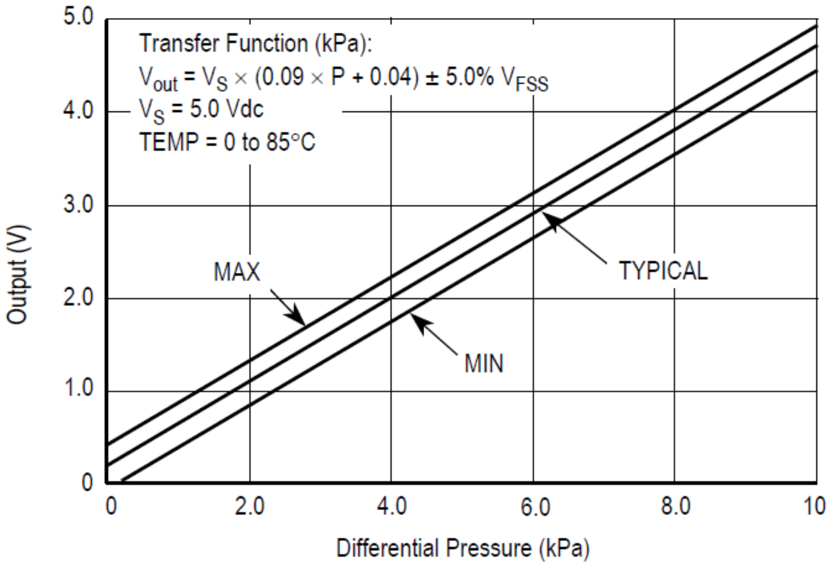

Figure 6. Typical output signal of MPX5010DP (NXP, 2018)

6. DATA ACQUISITION HARDWARE:

Since the hot-film anemometer used already has an internal signal conditioner, data acquisition can be done directly by an Analog to Digital Converter (ADC). For this, the ADC must have a resolution and a refresh rate to the content of the application. The ADC should also support the signal range of the sensor (H.H. Bruun, 1995).

The signal of the pressure transducer also allows it to be connected directly to an ADC by looking at the same parameters as the anemometer, since it also has a 0 to 5 V output and both sensors should be read at same sample rate.

In order to simplify the data acquisition system, a microcontroller with an integrated ADC was used, in this case the ATmel ATmega2560. Its ADC has 16 channels, each with a 10-bit resolution at a max sample rate of 15,000 samples per second, allowing the measurement of variations of up to 0.005 V in the signals.

For better stability and noise reduction in the signal, decoupling capacitors were used in both sensors.

The data is then sent in real time to a computer, via RS232, where it is saved to an ASCII file with comma-separated fields for post-processing.

7. HOT-FILM ANEMOMETER CALIBRATION:

For obtaining the characteristic curve of the HFM sensor, 13 data points were collected along all the desired measurement range. Ideally, they should be equally spaced from each other, however with the actual control system installed in the test bench, the fan speed control resolution does not permit this.

Each data point consist of output values of both sensors read within less than 0.001 s of each order. For every data point, data were acquired for 10 seconds at a sample rate of 10 Hz.

For the analysis and post-processing of the data points, a Matlab routine was developed. Both RAW ADC data were converted to voltage and then, for the orifice plate signal, to pressure and finally to air mass flow. The highest standard deviation was 0.0118 for the HFM voltage signal and 0.001 for the measured mass flow from the orifice plate.

The characteristic curve, described in Eq. 1, is obtained by using a polynomial approximation. It was determined that the 3rd degree polynomial already had an error inferior to most uncertainty existents in the experimental measurements in this experiment. The equation takes the voltage signal (V), in Volts, from the HFM Sensor as input and outputs the mass air flow ($\dot{m}$) in kg/s. Also, the equation is valid only in the range from the smallest to the largest data point.

$$\dot{m}(V) = 0.01274 \cdot V^3 - 0.1019 \cdot V^2 + 0.3174 \cdot V - 0.3289 \quad (1)$$

In Fig. 7 we have all the data points and the characteristic curve plotted.

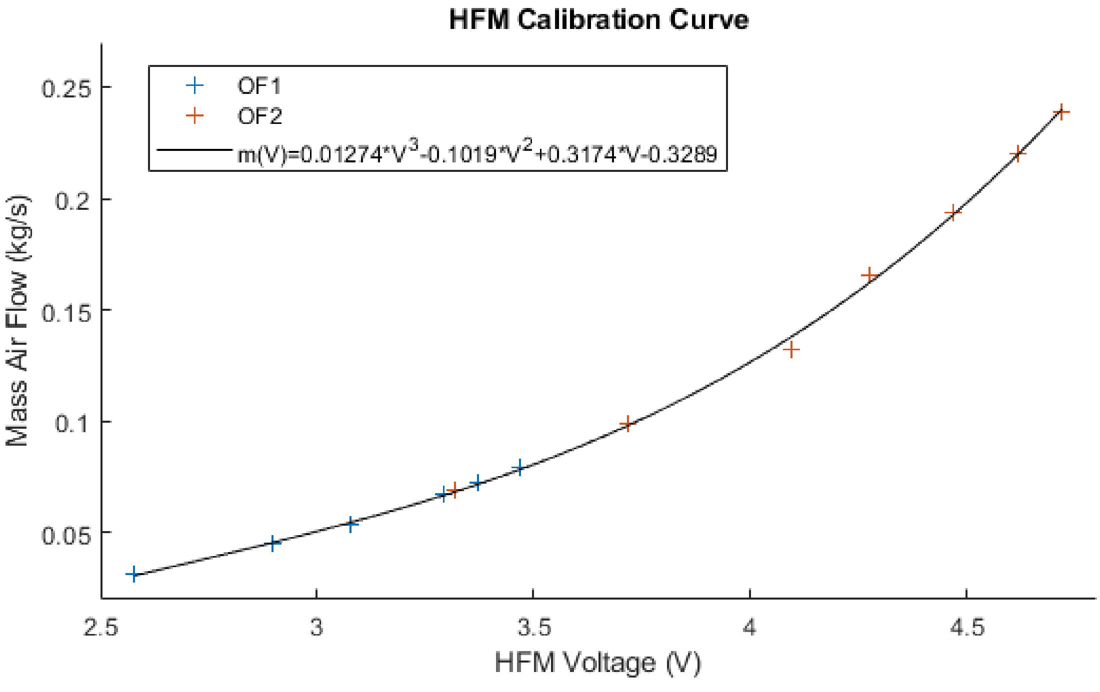

Figure 7. HFM characteristic curve

8. REFERENCES

Ferreira, M. C. (2007). "*Desenvolvimento e caracterização de uma câmara de combustão DLN – Dry Low NOx com tecnologia LPP – Lean Premixed Prevaporized*". Dissertação de Mestrado em Ciências Mecânicas, Publicação ENM.DM – 121 A/07, Departamento de Engenharia Mecânica, Universidade de Brasília, Brasília, DF.

McAllister, E.W., 2005. Pipeline Rules of Thumb Handbook, Gulf Professional Publishing, 6th edition

Emrah Özahi, Melda Özdinç, Mehmet Yaar, 2010. *"Simple methods for low speed calibration of hot-wire anemometers"*, Flow Measurement and Instrumentation Vol 21, pp. 166-170

Guido Belforte, Massimiliana Carello, Luigi Mazza, Stefano Pastorelli, 1997. *"Test bench for flow rate measurement: calibration of variable area meters"*, Measurement Vol. 20, No. 1, pp. 67-74

Bosch, 2018. "*Air-mass meters: Hot-film air-mass meter, Type HFM 5*", Robert Bosch GmbH, 10 Nov. 2018 < https://www.bosch.com/>

Santiago Pezzotti, Juan I. D'Iorio, Vicente Nadal-Mora, Alejandro Pesarini, 2011. *"A wind tunnel for anemometer calibration in the range of 0.2–1.25 m/s"*, Flow Measurement and Instrumentation Vol 22, pp. 338–342

S. Basu, A. K. Debnath, 2015. Power Plant Instrumentation and Control Handbook, Academic Press.

Cruz, T. V. G. (2016). *Identificação Experimental de um Modelo Dinâmico de uma Microturbina a Gás com Câmara de Combustão com Biaxa emissão de NO_x*. Dissertação de Mestrado em Ciências Mecânicas, Publicação ENM.DM – 98 A/06, Departamento de Engenharia Mecânica, Universidade de Brasília, Brasília, DF, 152 p.

Myer Kutz. 2013. Handbook of Measurement in Science and Engineering. Wiley, 1st edition

ABNT, 2011.*"NBR ISO 5167-2 Medição de vazão de fluidos por dispositivos de pressão diferencial inseridos em condutos forçados de seção transversal circular – Parte 2: Placas de orifício",* Associação Brasileira de Normas Técnicas.

NXP, 2018. "*MPX5010, 0 to 10 kPa, Differential, Gauge, and Absolute, Integrated, Pressure Sensors*", NXP Semiconductors, 10 Dec. 2018 < https://www.nxp.com/docs/en/data-sheet/MPX5010.pdf>

H.H. Bruun. 1995. Hot-Wire Anemometry: Principles and Signal Analysis. Oxford University Press, 1st edition

9. RESPONSIBILITY NOTICE

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