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MEASUREMENT OF AIR MASS FLOW IN COMPRESSION IGNITION ENGINES

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Abstract. *In many applications it is necessary to know the mass flow of air, being a quantity consisting of a determined mass of air flowing through a section in a time interval. In the automotive area this application becomes essential for the correct relation between air-fuel, looking for fuel economy, better engine performance and reduction of emissions. This study aims to develop an efficient methodology for the measurement of mass air flow in diesel cycle engines using two different meters (Measuring tools): the MAF (flow) sensor and Pitot tube (velocity). An experimental apparatus was assembled in the engines laboratory of the UFPA (Labmotor), where a diesel generator manufactured by YANMAR model 4TNV88-GGE naturally aspirated was used in the measurements, on him the original air intake system of the engine was preserved. The meters were installed simultaneously in a duct with known cross section, the objective is determining the disparities between the measurements and find a correlation between the meters. The measurements showed a superiority of the MAF sensor in relation to the Pitot tube, because the flow is highly turbulent due to the opening and closing of the engine valves, and the Pitot tube captures all this disturbance, however the MAF sensor is designed for this type of flow and presents filters, capable of decrease these disturbances.*

Keywords: *Diesel engines, Air mass flow, Sensors, MAF.*

1. INTRODUCTION

Currently there are major research efforts in the scientific and technological areas, stands out the manufacture and use of sensors for the wide range of applications, as well as the high performance. As a result, thermal flow sensors have evolved considerably, becoming indispensable in their areas of activity, such as petrochemical, textile, hospital, etc. The sensors that measure the mass flow of air through (hot wire) anemometers according to [4] show very sensitive and technological devices that are very versatile.

Internal combustion engines (MCI), although widely applicable in cars, aircraft, trains, ships and others, have a limited thermal efficiency, being part of their energy lost in the exhaust gases, friction, temperatures and high pressures causing a generation entropy among others [2]. To mitigate this reality, there are several researches to improve its efficiency, changing some parameters, such as volumetric efficiency. In diesel cycle engines in particular, one of the key performance factors is the airflow imposed at the inlet of the engine, how much more inside the cylinder, more complete can the combustion be. This is called volumetric efficiency, see equation (1). Where, represents the mass flow obtained experimentally and is the theoretical mass flow.

$$\eta_V = \frac{\dot{m}_{real}}{\dot{m}_{theo}} \tag{1}$$

The determination of the volumetric efficiency depends on the motor air consumption, which is the actual mass flow, see equation 1, and according to the instrument used can be found from the air velocity (pitot tube) or directly with the flow (MAF). In this work, we have tried to develop a methodology for comparing these two real mass flow meters to verify their reliability in diesel engine measurements.

2. MATERIALS

• Pitot Tube

The Pitot tube is a velocity measurement instrument, much used to measure the velocity of fluids, with it simultaneously we obtain the dynamic pressure p, and the stagnation pressure p0, in a flow, then we find the velocity of the flow, see equation 2.

$$V = \sqrt{\frac{2(\Delta p)}{\rho}} \tag{2}$$

To obtain velocity (V), we need to correct the specific mass of the fluid (ρ), according to the temperature of the flow.

• Differential Pressure Transducer

The use of the pitot tube, see Figure 1a, is the most usual way to obtain velocity in a flow, associated to a micro manometer, it is possible to find small velocity gradients. The micromanometers (differential pressure transmitters) used, see Figure 1b, have high resolution and have analog output of 4-20 mA allowing real-time acquisition of pressure differential.

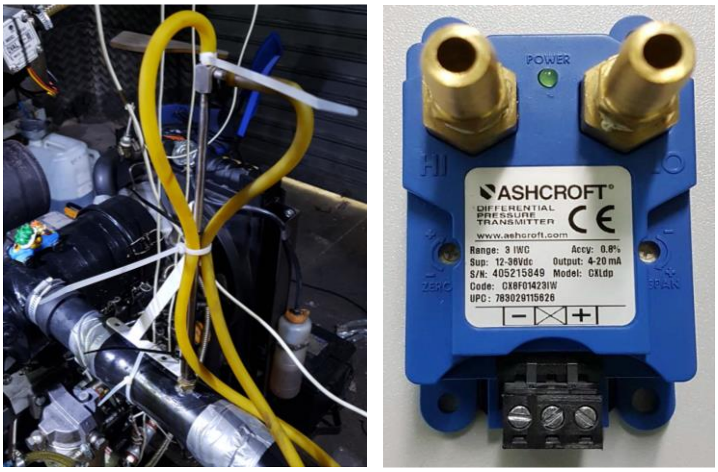

Figure 1: a) Pitot Dwyer 160i Tube. b) Micro manometer ASHCROFT measuring range 0 to 76 mmW.C.

The adjustment curve of the differential pressure transmitter is supplied according to the manufacturer's manual [ASCROFT] and represented by equation 3:

$$Y = 0.046704X - 0.186816 \tag{2}$$

Where we have the value of the pressure differential as a function of the current signal (4-20mA).

• Hot Wire Anemometer (MAF)

Hot wire anemometers are used for speed measurement in fluids. They are made of short strands of resistors, having a circular cross section, the reading is performed by heating the resistance with electric current, and can increase or decrease depending on the mass of air passing through the resistor.

The Air Mass Flow Sensor (MAF) is a hot wire anemometer used in automotive applications to measure the volume and density of air entering the engine at a given time. As shown in Figure 2a, shows the operating principle, where the fluid passes parallel to the sensors, one of which is the hot wire to connect the MAF (Figure 2b).

a) b)

Figure 2: Mass Flowmeter (MAF) sensor. (a) Principle of operation of the MAF; (b) MAF. Source [3].

Figure 3 shows a table provided by the manufacturer Bosch, which relates the mass flow of air to the voltage, with this table, we plot the mass flow rate as a function of the voltage signal, represented by figure 4, and the equation that correlates them.

Output voltage $U_A = f(Q_m)$ of the air-mass meter

Part number	0 280 217 123	0 280 218 019	0 280 217 531	0 280 218 008	0 280 002 421
Characteristic curve	1	2	3	4	5
Q_m/kg/h	U_A/V	U_A/V	U_A/V	U_A/V	U_A/V
8	1.4837	1.2390	–	–	–
10	1.5819	1.3644	1.2695	–	–
15	1.7898	1.5241	1.4060	1.3395	1.2315
30	2.2739	1.8748	1.7100	1.6251	1.4758
60	2.8868	2.3710	2.1563	2.0109	1.8310
120	3.6255	2.9998	2.7522	2.5564	2.3074
250	4.4727	3.7494	3.5070	3.2655	2.9212
370	4.9406	4.1695	3.9393	3.6717	3.2874
480	–	4.4578	4.2349	3.9490	3.5461
640	–	–	4.5669	4.2600	3.8432
850	–	–	–	4.5727	4.1499
1000	–	–	–	–	4.3312

Figure 3: Table that correlates the mass flow with the voltage signal.

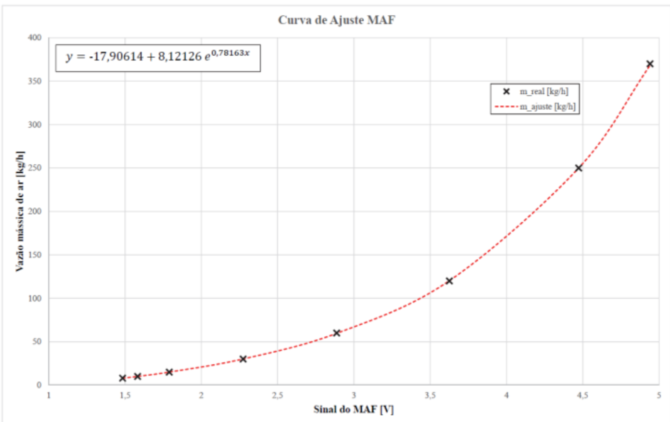

Figure 4: Adjustment curve of the MAF sensor.

- **Data Acquirer (CONTEMP A202)**

The A202 (Figure 5) is a highly versatile standard data collector that allows recording and monitoring of analog variables on a computer or on the instrument itself, usually done through DAQFactory-Pro v16.2 that accompanies the acquirer. The receiver has eight configurable analog inputs, galvanically isolated serial communication (RS-485 electrical standard), data logging for up to 2 MB of register, sixteen configurable alarms, two relay outputs and one digital input [5].

Figure 5: Data Acquisitor Contemp, Datalogger A202 8 configurable channels.

3. EXPERIMENTAL PROCEDURE

According to figure 6, we have a schematic representing the experimental apparatus, we have in point (1), the generator set, which in operation generates a depression with the opening and closing of the valves, which draws air from the point 6) through the air filter, then the MAF sensor, point (5), where the mass flow rate of the air is measured, is installed in the same air intake duct, a pitot tube (2) is installed, which is associated with a micromanometer (3), which measures the dynamic flow pressures and records the differential pressure value. The PTC 100 temperature sensor (4) is used to correct the specific mass of the air, which will be used to calculate the velocity from the pitot tube. The air flow meter (MAF) and pressure gauge are connected to Contemp (4), which acquires signals from the MAF and the pressure gauge. The signals acquired by the Contemp through the MAF are voltage signals that can vary from 0 to 5 volts according to the data of the manufacturer BOSCH [1], the larger the air mass flow the greater the voltage signal at the MAF output. The signals acquired by the Contemp through the pressure transducer are current signals ranging from 4-20 mA. The Contemp A202 Aquisitor conditions the signals and displays through the DAQFactory-Pro v16.2, installed in the microcomputer, the voltage values for the MAF, and current for the differential pressure meter as a function of time. For configuration of the datalogger are defined which are the inputs of the purchaser that are being connected and what type of signal will be acquired. In DAQFactory-Pro v16.2 the current voltage values are displayed in real time.

For the acquisition of mass flow rates and pressure variation, loads were applied in the generator set, using a range of 50, 70 and 100% of their rated power.

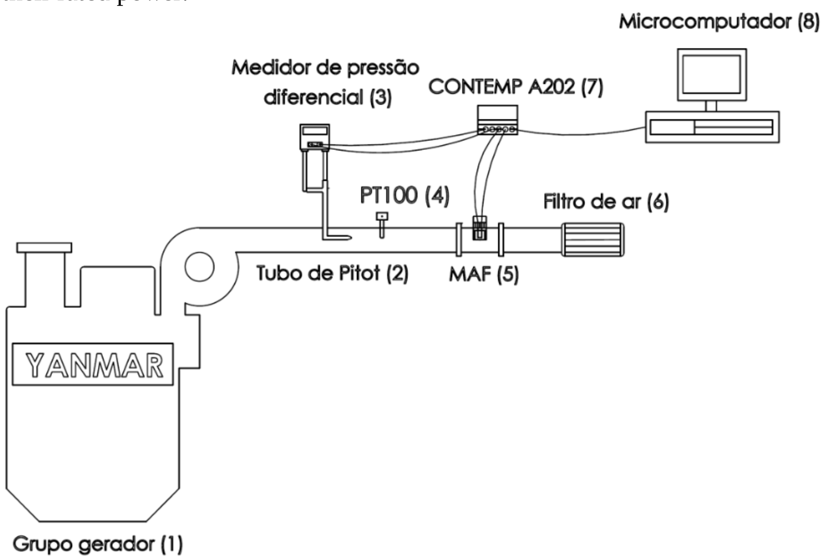

Figure 6: Scheme of the bench with sensors and data of the competitor.

4. RESULTS AND DISCUSSION

With the equation and adjustment curve of the MAF, we inserted in the DAQFactory-Pro v16.2 the equation of the mass flow as a function of the voltage so that we obtain the real time value of the mass flow as a function of time. With the generator set in the loads of 50%, 70% and 100% were applied and we obtained the graph represented by Figure 7. The peaks observed in the graph represent the changes of loads.

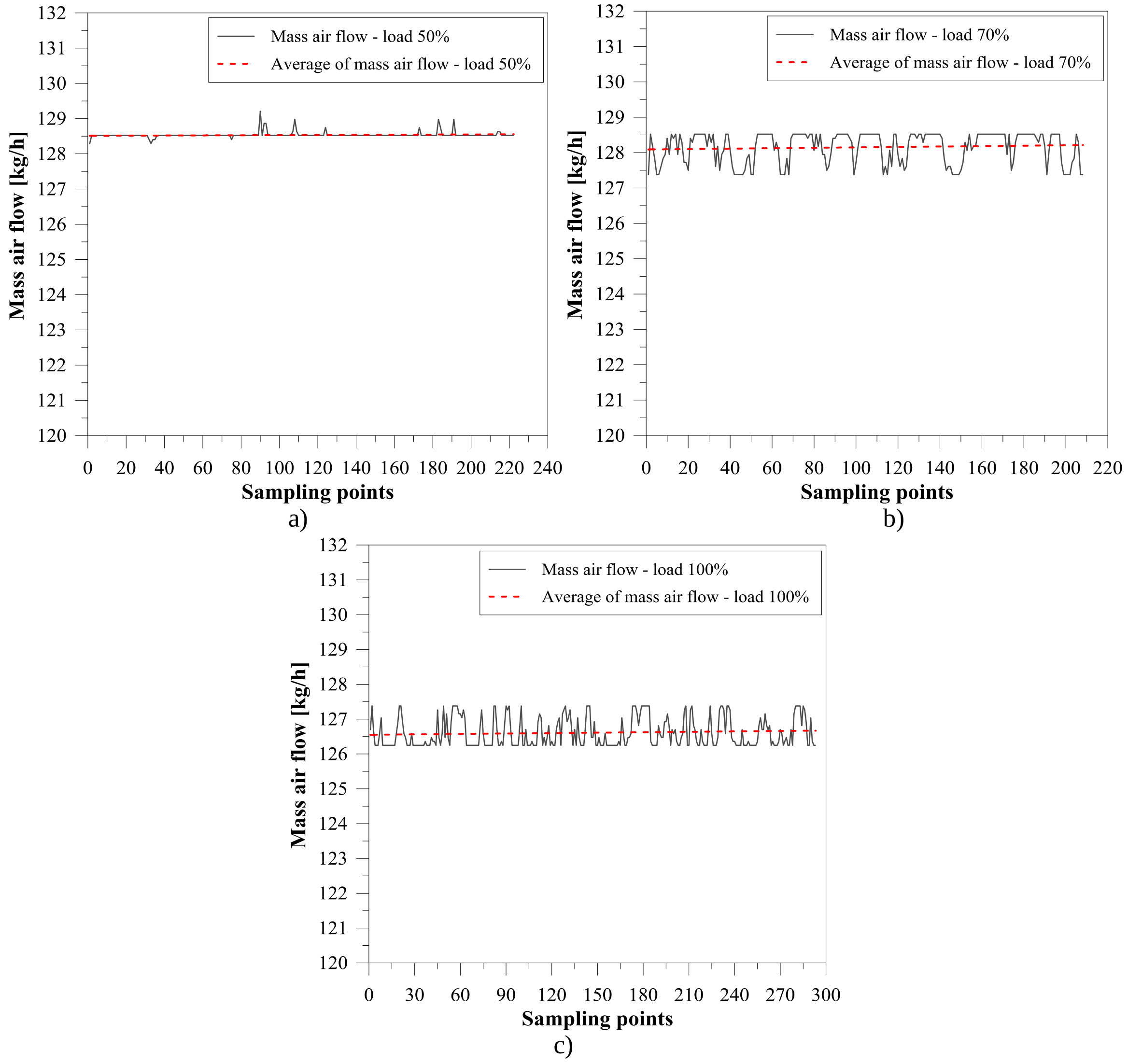

Figure 7: Mass air flow with: a) 50% b) 70% c) 100% of load..

The graphs above present values of the mass flow rates measured by the MAF sensor which has filters capable of attenuating the disturbances caused by the operation of the diesel engine, this reflects in the graph obtained, because in each load it is possible to notice a certain stability in the measurement of the flow.

With the differential equation and curve of the differential pressure transmitter, the differential pressure equation was plotted in DAQFactory-Pro v16.2 as a function of the mA signal. With this we obtained the pressure differential as a function of time. With the generator set in the loads of 50%, 70% and 100%, were applied and we obtained the graph represented by Figure 8. The peaks observed in the graph represent the changes in loads.

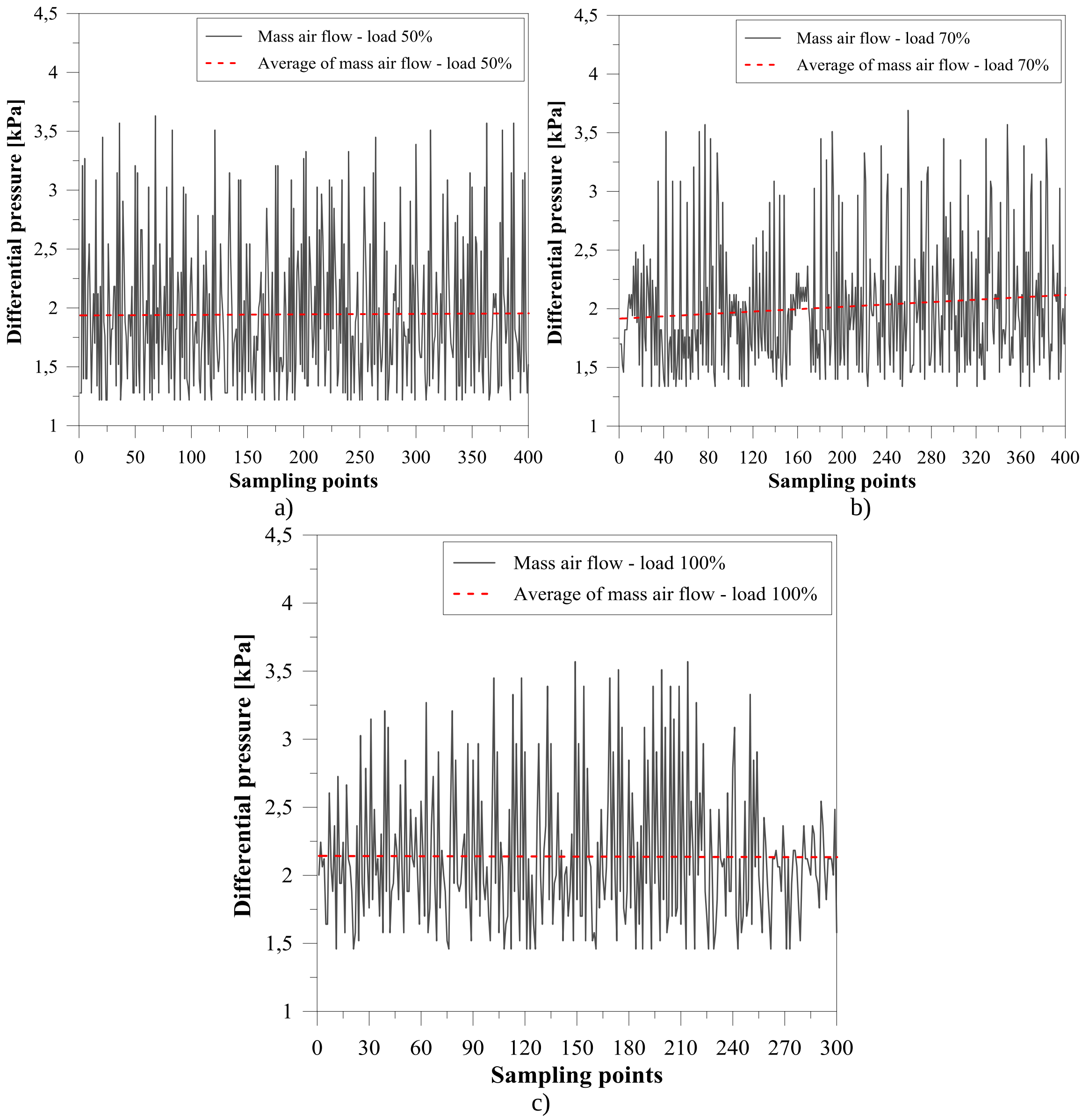

Figure 8: Pressure variation as a function of sample number for the loads of a) 50%, b) 70% e c) 100%.

In Figure 8a, 8b and 8c we obtained values of 50%, 70% and 100% of the load, respectively, a pattern is perceived as they were increased. It is noticed that there is an eminence of the pattern shown between loads of 50 and 70%, already in 100%, this proximity of pressures as a function of time tends to be smaller, the red lines are the average. An explanation for this fact would be the delays in ignition, where the start of combustion at low loads occurs more abruptly than the larger ones (Pasqualette, *et al*, 2014; Oliveira, 2016). There has been a high rate of disturbances due to the opening and closing of the valves generating a counter flow present in the pressure measurements, this mass flow of air is desirable mainly in motors by compression ignition so that there is a reduction of the possibility of incomplete burning. After the analysis of the perturbations by virtue of the dynamic pressure, the average cut-off pressure was removed so that we obtain an approximate frequency relation between the pressures and the pressure variation in each sensor load shown in the graphs. In addition, the relative error was calculated, being approximately 1.49%, 5.84% and 12.87% for the charges of 50, 70 and 100%, respectively, increasing their values according to the increase of the load.

The flow values are shown below using the MAF sensor and the differential pressure sensor together with the Pitot tube.

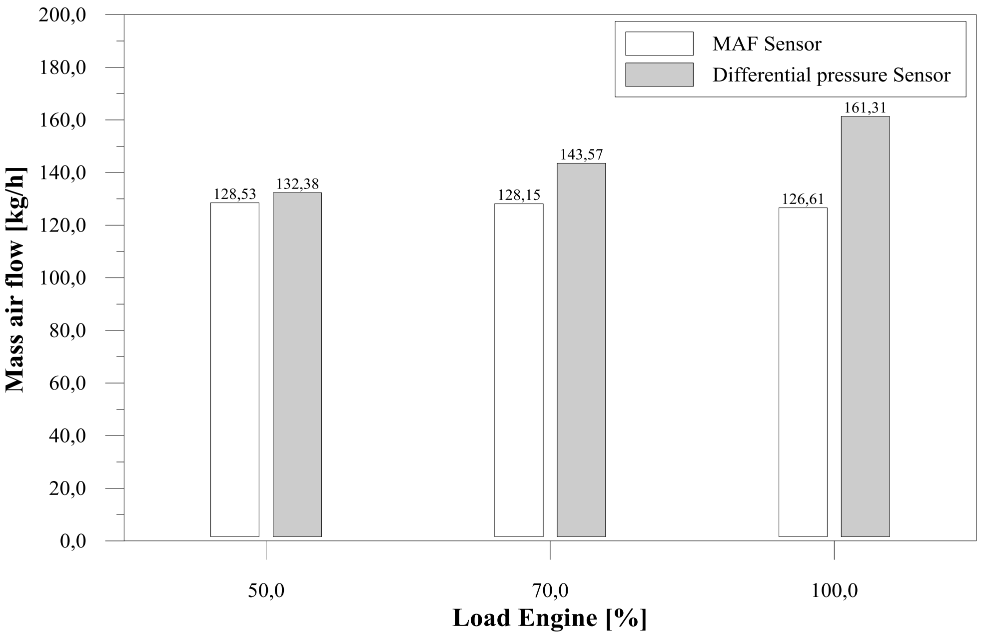

Figure 9: Mass air flow for MAF sensor and Differential pressure Sensor.

It can be seen in figure 9 that the calculated mass flow rates are higher using the differential pressure sensor.

It should be noted in figure 9 that the calculated mass flow rates are the largest used the differential pressure sensor, especially for the 100% load that is higher, this fact can occur because the sensor does not present filters able to attenuate the disturbances caused by the operation of the diesel engine, as it happens with the sensor MAF.

5. CONCLUSION

Current methods of air flow determination for the control of internal combustion engines are based on specific sensors such as hot wire anemometers (MAF), which is inserted in this study and that have a greater precision to calculate the air flow.

It can be seen that the values presented in this study demonstrate discrepancies in both the MAF and the differential pressure sensor shown in figure 9, to obtain the mass flow of air in diesel engines, containing smaller relative errors for the 50% load and then the same ones tending to grow, as already expected by virtue of this increase of turbulent air flow in the entire intake.

For this study, the Pitot tube coupled to the differential pressure sensor, can be used as an alternative to measure this airflow at the intake inlet, always carrying out an adequate calibration.

6. REFERENCES

BOSCH. *Sensores maf <maf2maf.com* > Acessado em: 01 dez. 2017.

CARVALHO, M. A. S. *Avaliação de um motor de combustão interna ciclo Otto utilizando diferentes tipos de combustíveis*. Salvador: Universidade Federal da Bahia – Escola Politécnica, 2011.

CONTEMP. *Datalogger A202 8 canais.<www.contemp.com.br/produto/data-logger/>*. Acessado em: 01 dez. 2017.

KHAMSHAH, N. et al. *Optimization of Hot Wire Mass Airflow Sensor by Using Fuzzy Logic Controller*. PROCEDIA ENGENEERING - ELSEVIER. International Coference on Modeling, Optimization and Computing. Disponível em: < www.sciencedirect.com>, 2012.

MTE, THOMSON. *Como funciona - Sensor de Fluxo de Ar (MAF).* Disponível em: <mte-thomson.com.br/site/dicas/como-funciona-sensor-de-fluxo-de-ar-maf/>. Acesso em: 01 dez. 2017.

PASQUALETTE, M. de A. et al. *Métodos para a determinação do atraso de ignição em um motor marítimo diesel operando com óleo diesel marítimo*. VIII congresso nacional de engenharia mecânica. Departamento de Engenharia mecânica, Universidade Federal do Rio de Janeiro. Rio de Janeiro, 2014.

RESENDE, T. A. C. *Estudo da dinâmica das válvulas e desempenho dos coletores de admissão e de escape de um motor de combustão interna de ignição por centelha.* Programa de Pós-Graduação em Engenharia da Energia, Universidade Federal de São João Delrei. São João del-Rei, Minas Gerais. 2017.

SANTOS, F. S. dos ; SILVA, L. G. da ; GODOIS, R. B. *Medição de vazão mássica de um motor dois tempos* . 2007. 12 p. Relatório de trabalho de conclusão (Disciplina de medições Térmicas)- Departamento de Engenharia Mecânica, Universidade Federal do Rio Grande do Sul, Porto Alegre, 2007.

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