

ENCIT-2018 DEVELOPMENT OF AN EXPERIMENTAL BENCH FOR THE REALIZATION OF TESTS IN DIESEL GENERATOR SETS

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Abstract. Diesel generating sets are machines capable of supplying electrical energy through the combustion of fuels, such as diesel, biodiesel, vegetable oil. The principle of operation is based on the transformation of thermal energy into electrical energy, used in several applications, mainly industrial and residential. The operational parameters of the generator sets have direct dependence between them and their variation can significantly affect the engine performance. Therefore, the careful analysis of these characteristic parameters of the generator set is of great importance, mainly for conducting research in the laboratory. This paper describes the minimum requirements to establish a laboratory bench to conduct research on generator sets, and thus analyze their performance when operating with different types of fuels. For this, an experimental bench was designed, considering the minimum requirements of all the subsystems, including fuel supply, intake air, exhaust gases and generated power.

Keywords: Instrumentation, Generation Groups, Experimental Bench, Sensors.

1. INTRODUCTION

In the English literature, there are synonymous words for bench test (Encarta, 2005), benchmark and testbed, whose meanings refer to: used as standard to measure or evaluate something; equipped to test machinery in circumstances as close to actual operating conditions as possible (Amorim, 2006).

The accuracy of any experimental measure is a parameter that can be interpreted as the quality of interpretation of the entire instrumentation system. Instrumentation is the science that analyzes, monitors and develops measuring instruments to analyze effects that happen in a system, this process can be done using sensors. According to Patskp (2006) a sensor is considered as any component or electronic circuit that allows the analysis of a certain category. In this way it will be possible to analyze the operation of generator sets through the parameters obtained with the measurements, in order to improve their performance.

Didactic benchmarks are solutions used to analyze parameters of any system. These benches are commonly used for the development of projects in general. Test benches have become an important basis for study and research activities, since engineering has always required testing small-scale concepts and applications in a wide range of fields (Goulart, 2008).

This paper deals with the development of a laboratory bench to perform tests in generator sets with the purpose of obtaining experimental parameters, such as gas temperature, mass air flow and electric power of the generator set and,

therefore, obtain in real time through computer programs the specific fuel consumption and the brake power of the generator that can operate with different fuels.

2. METHODOLOGY

2.1 Materials

2.1.1 Generator set

The generator set used was the BRANCO BD-6500 CF3E driven by a four-stroke single-cylinder engine which is connected to a 50 kW resistor bank used to change loads by 20%, 40%, 60% and 80% of rated power maximum. It is known that single-cylinder engines have low fuel consumption, this makes the performance of the tests more feasible and allows a greater number of tests compared to engines that have more than one cylinder. The generator set specifications are in Tab. 1, which were found in the Equipment Manual made by the manufacturer.

Table 1. Characteristics of diesel generator set.

Parameters	
Manufacturer	Branco
Model	BD-6500 CF3E
Engine	
Aspiration	Natural
Fuel injection	Direct
Angle of fuel injection	16° APMS
Cooling	Induced air
Number of cylinders	1
Diameter (mm) x Curso (mm)	86 x 70
Cylinder capacity (cm ³)	406
Compression ratio (-)	19:1
Rotation (rpm)	3600
Generator set	
Electrical frequency (Hz)	60
Voltage (V)	220
Number of phases	2
Efficiency (%)	85,0
Maximum rated power <i>prime</i> (kW)	4,0
Rated power <i>standbay</i> (kW)	4,5

2.1.2 Electrical quantities meter

In order to measure the electric quantities, the Landis + Gyr SAGA 4500 was used. The parameters measured with this equipment were Frequency and Electric Power (P_{el}), which will be related to the brake Power (P_g) of the generator set for each load. This equipment measures these quantities and then it is sent to a computer through its own software. By the software, it is possible to monitor them in real time and store them for later analysis. Next, Table 2 presents the specifications of SAGA 4500.

Table 2. Specifications of SAGA 4500.

Parameters	
Manufacturer	Landis+Gyr
Model	SAGA 4500
Maximum current supported (A)	1000

Isolation class (kV)	2
Accuracy	1%

Source: Equipment manual.

2.1.3 Flowmeter

The equipment designed to measure the mass flow of air passing through the intake system was Mass Air Flow (MAF). For the measurement of fluid velocity, this equipment reads from the heating of an internal resistance with electric current, which changes according to the variation of the mass of air passing through the resistance. The Table 3 shows the specifications of sensors that were obtained in the equipment manual.

Table 3. Specifications of MAF.

Manufacturer	BOSCH
Model	HFM 5
Nominal supply voltage (V)	14
Supply voltage range (V)	8 a 17
Output voltage (V)	5
Input current (A)	0,1
Accuracy	3%
Temperature range (°C)	-40 a 120

Source: Equipment manual.

2.1.4 Temperature sensors

The sensors used to measure temperature were the thermocouples. Thermocouples are temperature sensors that show their operation based on the Seebeck effect, in which two distinct metals connected to each other through a junction will produce a potential difference as a function of temperature. The thermocouples applied were those of type K. According to ASTM, these equipments comprise a range of use of 0 to 1260 ° C, other specifications of this equipment can be seen in Tab.4.

Table 4. Specifications of Type K thermocouples

Sheath material	Stainless steel
Thermocouple junction	Isolated
Operation range (°C)	0 a 1260
Reading mistakes	2,2%

Source: Equipment manual.

2.1.5 Gas analyzer

The characteristics of the combustion process and exhaust emissions of an internal combustion engine (ICE) are affected by various particularities such as fuel spray, atomization and fuel properties. In order to analyze combustion gases, GreenLine 8000, produced by the AOIP, is responsible for determining the composition and percentage of the gases that pass through the exhaust. This equipment is capable of measuring O₂, CO, CO₂, CO, NO, NO_x, HC, H₂S, through its electrochemical sensors and non-dispersive infrared (NDIR); it is also able to measure the relative humidity of the air. Table 5 covers the apparatus specifications for the chemical species which were analyzed in this paper.

Table 5. Specifications Green Line 8000.

Species	Sensor	Reading range	Resolution	Reading mistakes
CO	NDIR	0 a 2500 ppm	10 ppm	± 3%
CO ₂	NDIR	0 a 20%	0,01%	± 0,3%
NO	Electrochemical	0 a 4000 ppm	1 ppm	± 4%

NOx	Calculated	0 a 4000 ppm	1 ppm	Calculated based on NO and others species' of NOx
HC	NDIR	0 a 50000 ppm	1 ppm	± 3%

Source: Equipment manual.

2.1.6 Digital Scale

The equipment selected to measure the fuel consumption is the digital scale of the DIGIMED brand model DG15WT, this scale has digital input and the monitoring of its data is done in conjunction with the DaqFactory software. The balance features have been found in the manufacturer's manual and are listed in Tab. 6.

Table 6. Specifications of DIGIMED DG-15WT balance.

Parameters	
Manufacturer	DIGIMED
Model	DG-15WT
Capacity (kg)	15
Resolution	0,1g
Reproducibility	± 0,2g
Linearity	± 0,2 g
Output digital	RS232
Voltage (Vca)	90 a 240

2.1.7 Data acquisition

CONTEMP A202 is used for data acquisition that enables the recording and monitoring of analogue variables in a computer (Conceição, 2015). It is responsible for capturing the signal emitted by thermocouples and MAF. To carry the signal from the sensors to the computer is used a converter, which acts in conjunction with the COMTEMP A202, its point of action is to transform the analog signal obtained by the acquisition system into a digital signal that will be read from the program DAQfactory, manufactured by Azeotech. The main characteristics of the equipment are shown in Tab. 7.

Table 7. Specifications of CONTEMP A202 acquisition data.

Number of inputs	8
Input current (mA)	0 a 20
Reading accuracy	± 0,3% F.E.±1 digit at 25°C
Reading	170ms/8 channels
Communication	RS-485
Protocol	Modbus RTU

Source: Equipment manual.

2.2 Calculation of uncertainty

In any measurement process it is necessary that there be reliability in the results, since it is from this that the validation of this process occurs. The equipment used may suffer changes with the operating conditions as well as internal interferences that occur in your system, so it becomes substantial the calculation of the uncertainty thereof. In this paper, the methodology described in Rocha (2016) and Oliveira (2016) was used to calculate equipment uncertainty, this calculation should be done for each source separately. The uncertainties are classified as type A and type B. Table 8 shows the values obtained:

Table 8. Average uncertainties of the measured parameters.

Parameters	Uncertainty
Electrical power	$\pm 1,0\%$
Gas temperature ($^{\circ}\text{C}$)	± 2
CO (ppm)	± 10
CO ₂	$\pm 0,1\%$
HC (ppm)	± 4
NO _x (ppm)	± 5
Variation in mass of fuel (g)	± 0.2

2.3 Development of the experimental bench

The preparation of the bench took place in the Motors Laboratory at the Faculty of Mechanical Engineering of the Federal University of Pará.

In order to verify the operation of the generator set, the instrumentation plays an essential role in the realization of the project. The parameters to be measured were chosen as a function of the systems present in the generator set. They are: Resistance bench - connected to the generator, intake, fuel and engine exhaust systems.

Among the wires connecting the generator resistor bank is the SAGA 4500 electric meter. The temperature of the intake air as well as the fuel and exhaust gases will be evaluated by thermocouples. The mass flow sensor was installed after the airbox, used to expand the air before channeling it into the intake system. The gases from the combustion process will be collected and their composition verified by the gas analyzer.

In order to avoid propagating to the balance the vibration caused by the transmission lines and fuel return, lines were installed in the upper portion of the open tank. Figure 1 shows the layout of the workbench.

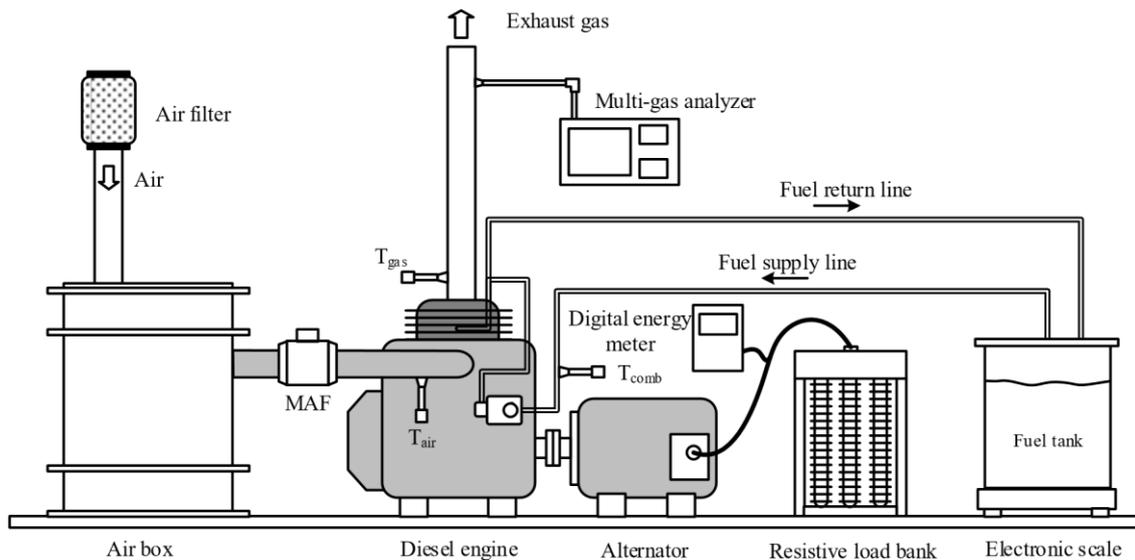


Figure 1. Schematization of experimental bench.

2.4 Software for data processing

DaqFactory is software that receives information from measuring equipment. Figure 2 shows the interface created from the software. On that, it is possible to monitor the data in real time and save it for later studies.

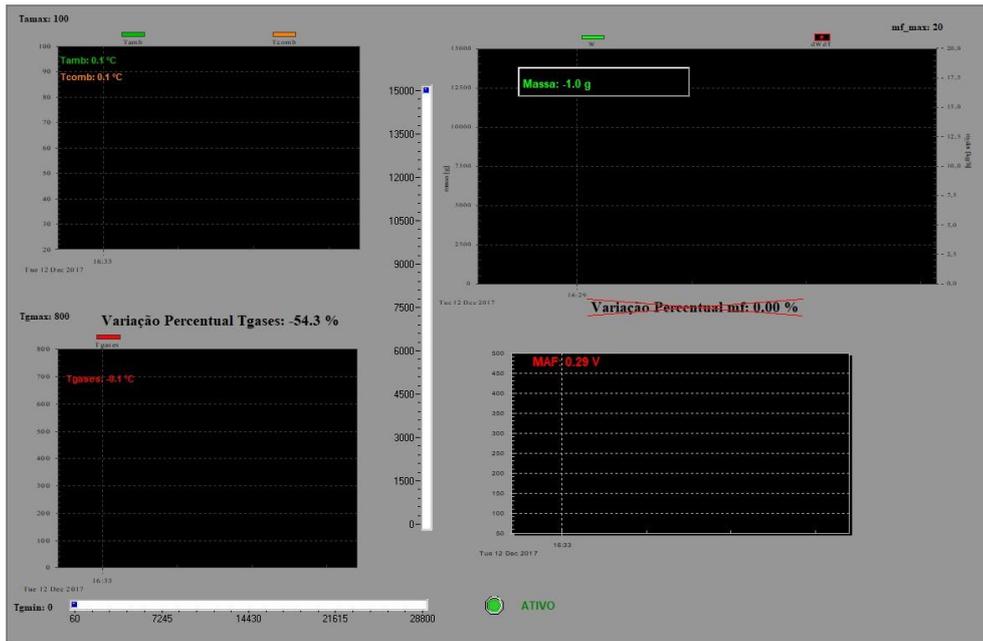


Figure 2. Interface created for data acquisition.

2.5 Obtaining the Brake Power, Specific Consumption, Relative Fuel-Air Fraction, Thermal Efficiency and Volumetric Efficiency.

One of the purposes of this work is the determination of indirect parameters from the parameters acquired with the equipment selected to develop the bench, which were: brake power (P_e), specific fuel consumption (C_{esp}), relative fuel-air fraction (F_R), thermal efficiency (η_T) and volumetric efficiency (η_V).

For Rocha (2016) the choice of these parameters is made because they are constantly monitored in diesel power plants.

Obtaining the brake power through the electric power (P_{el}) is made from Eq. (1).

$$P_e = \frac{P_{el}}{\eta_{ger}} \quad (1)$$

The efficiency of the generator (η_{ger}) for the rotation of 3600 rpm has been acquired in the manufacturer's manual. The specific consumption (C_{esp}) is based on the ratio of specific mass of fuel (\dot{m}_f) to brake power (P_e) as shown in Eq. (2).

$$C_{esp} = \frac{\dot{m}_f}{P_e} \quad (2)$$

In internal combustion engines (ICE), one of the ways to determine the engine operating condition is through the relative fuel-air fraction (F_R), such that it can be defined as the actual fuel-air ratio and the stoichiometric ratio. From there, the combustion process is defined as poor, if there is excess air, rich mixture, if there is excess of fuel or ideal, if the proportions are equal. Through Eq. (3) this relative fraction is defined.

$$F_R = \frac{\left(\frac{\dot{m}_{com}}{\dot{m}_{ar}}\right)_{real}}{\left(\frac{\dot{m}_{com}}{\dot{m}_{ar}}\right)_{est.}} \quad (3)$$

The thermal efficiency calculation (η_T) is made to quantify the performance of the thermal machine. For internal combustion engines, this calculation considers the brake power and mass of the fuel, in addition to the lower calorific value (ICP), which is related to the amount of energy contained in the fuel. During the tests the fuel used was B7, which was commercially sold at the stations and has a PCI of 40687 kJ / kg. This efficiency can be calculated as described in Eq.(4).

$$\eta_T = \frac{P_e}{\dot{m}_{com} PCI} \quad (4)$$

The volumetric efficiency (η_V) quantifies the efficiency of air pumping in the intake system of the internal combustion engine. As Heywood (1988) explains, several factors influence volumetric efficiency, including piston speed, inlet and exhaust pressures, engine compression ratio, heat transfer, intake geometry and exhaust, and other engine operating variables. The calculation of the volumetric efficiency is described in Eq. (5), V_d is the volume of the total displacement and N is the rotation of the engine.

$$\eta_V = \frac{2 \cdot \dot{m}_{ar}}{\rho_{ar} \cdot V_d \cdot N} \quad (5)$$

3. RESULTS

The loads chosen to perform the tests in the generator set were 20%, 40%, 60% and 80%, which were obtained from a circuit of electrical resistances. The results obtained can be observed in Fig. 3.

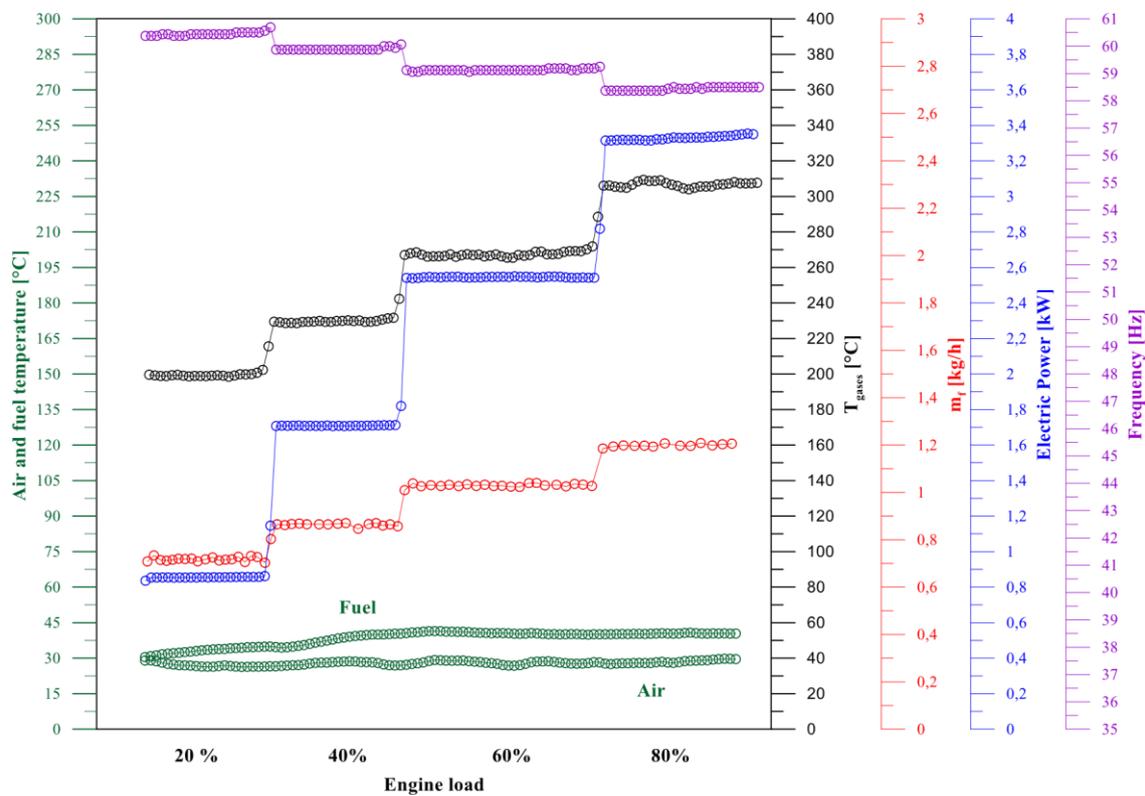


Figure 3. Graph with the instrumentation result.

Based on Figure 3, it is possible to obtain the means of the specific mass of fuel (\dot{m}_f) and brake power (P_e), and thus obtain a specific consumption for each load as observed in Tab. 9.

Table 9. Specific consumption (medium).

Loads	Specific consumption (kg/J)
20%	838,79
40%	507,79
60%	403,86
80%	360,40

An analysis of brake power and specific consumption can be made from the relationships shown in item 2.5 and the results presented in Fig. 3. The engine power variation can be made, at a constant rotation of 3600 rpm, by the control

of the amount of fuel injected into the engine for the same mass of air. Therefore, it can be said that increasing the load requires an increase in fuel mass as well as an increase in the electrical power measured by SAGA, as seen in Fig. 3. It is known that the electric and brake powers are directly proportional, so it is concluded that there is an increase in the brake power of the motor. However, both quantities are inversely proportional to the specific consumption, this fact is evidenced by the decrease in the values of specific consumption observed in Tab. 9. Thus, the most favorable results are those found for the 80% load, which have maximum electrical power and minimum specific consumption. As the load is decreased, the brake power values reduce, so the efficiency is lower, as the specific consumption increases, requiring higher fuel consumption for better results.

In the development of the project, the flow meter initially selected was the Hot Wire Anemometer, later, with the analysis of the tests it was noticed that the MAF is the most suitable for this function. For the correct measurement of the mass flow rate of air admitted by the motor, the anemometer requires that the flow be laminar or with less turbulence possible, requiring the use of filters to obtain such a condition. The use of several filtration systems adds load losses to the air intake pipe, these load losses reduce the amount of air admitted per cycle in the engine, reflecting the reduction in volumetric efficiency and negatively affecting the overall thermal efficiency of the engine. In contrast, the MAF has an internal filtration system to develop the laminar flow, not interfering drastically in the volumetric efficiency maintaining the normal conditions of operation of the engine. The thermal efficiency and volumetric efficiency for each load can be seen in Fig. 4.

Thermal efficiency helps in understanding the combustion efficiency that occurred in each test with different loads. Figure 4 shows that the relationship between the amount of work produced by the burning of fuel and the amount of heat capable of being generated in a complete burning increased as the load increased. This happens because the more fuel is injected into the combustion chamber, the higher are the pressure and the temperature values inside the piston, as well as the torque produced on the shaft and finally the brake power. In the first graph presented above, it is not possible to observe the efficiency drop that occurs if the amount of diesel oil was still increased, because the generator sets are designed to work at the maximum nominal power before there is a decrease. The volumetric efficiency is a parameter that seeks to be maximized for the complete burning of fuel. In the Figure 4-b, the results show a reduction of the air intake compared to the growth of the applied load, however, the values acquired are quite satisfactory, since they are comprised in a range close to 75% on average.

As mentioned previously in section 2.5, it is possible to define the combustion process from the fuel-air ratio. In the engine used, the calculated value was approximately 0.5992, which shows that in this engine what prevails is a poor mixture, with excess air, causing an incomplete combustion.

4. CONCLUSIONS

Currently, the way of production of electric energy are inserted in the world trade as sources of high investments and in constant development. In this way, it is important to study the quality of the electric energy production processes, in order to increase the generation of energy, without changing (or reducing) the consumption of fossil fuels. Therefore, the objective of this work is the development of an experimental bench using the BRANCO BD-6500 CF3E generator set and the analysis of the performance and operating conditions of the motor to describe the quality of the experimental bench.

After defining the parameters to be analyzed, the choice of the sensors was fundamental to obtain the most accurate and coherent data possible. After the tests were carried out, the means of specific mass of the fuel and brake power were obtained. Next, the results of specific consumption, thermal and volumetric efficiency and fuel-air ratio were shown. The behavior of growth of the brake power and thermal efficiency and decrease of the specific consumption and volumetric efficiency as a function of the load variation were detailed. The generator set had a acceptable behavior, characterized according to the specifications and according to the references used. At that time, the engine had an incomplete combustion of the fuel-air ratio of 0.5992 and could be improved. Nevertheless, there was a success in the development of the experimental bench.

In this paper, only the results presented by B7 diesel were used. However, the bench can be used for analysis and monitoring of the generator set operating with other types of fuels.

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