Development of a virtual instrument for the calculation of thermal efficiency under the assumptions of standard cold air in a 3500cc diesel engine

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Abstract. This work presents the development of a virtual instrument for the acquisition of temperature data of a 3500 cc diesel engine and the calculation of its thermal efficiency at three different speeds, the analysis was made according to the standard cold air parameters for a diesel engine. To measure the temperature, type K thermocouples distributed around the combustion chamber and the engine exhaust was used; the data acquisition was carried out through a cDAQ-9178 and a NI-9213 thermocouple module from National Instruments.

1. Introduction
The energy lost inside diesel engines due to heat dissipation is critical to the energy efficiency of the engine, since it cannot be fully utilized, obtaining efficiency values between 35% and 40% approximately [1]. The most important aspect that can affect the thermal efficiency of these engines is the combustion process, its analysis can improve this parameter, and can also improve fuel consumption and pollutant emissions [2].

When analyzing a diesel cycle, phenomena such as friction and the speed of expansion and comprehension processes prevent the establishment of conditions of thermodynamic equilibrium [3], which is why it becomes simpler to keep these complexities at a manageable level and to use an ideal cycle made up of internally reversible processes [4]. An idealized model that preserves certain general characteristics of the real ones, allows studying the main effects that govern the cycle, such as temperature and heat transfer [5].

The monitoring of these last two parameters in this process allows to determine the efficiency which the internal combustion engines operate. By means of temperature sensors (thermocouples), data acquisition devices and a virtual instrument that interprets the electrical or physical signals obtained, it is possible to have a control and automation of the cycle that allows to expose the conditions in which it operates and the magnitudes of its main variables [6,7].

2. Methodology
This paper describes the characteristics of the devices used in the calculation of thermal efficiency. This virtual instrument shows the temperatures taken at different points of the engine, at four different speeds.
2.1. Electronic system design

A logical system was designed to obtain the different variables to be sensed, for thermal efficiency, the variable to be measured is temperature. A logical system was designed to obtain the different variables to be sensed, for thermal efficiency, the variable to be measured is temperature [8]. For the measurement of this one 4 thermocouples type K were used, because the motor temperatures are within the working range of these.

The information collected by the sensors in the different points of the engine is sent to the computer through a system of data acquisition cDAQ-9178 of National Instruments, to a module of thermocouples NI-9213, designed for this type of processes of taking of data of temperature. The scheme of the system is shown in Figure 1 [9,10].

![Figure 1. Block diagram of the data taking system.](image)

2.2. Equations for analysis

To find the thermal efficiency of the engine, two theorems were used:

- The assumption of standard cold air for diesel engines, which is used to make an ideal calculation approximating actual efficiency, taking into account experimental temperatures Equation (1). The four temperature points are not taken, since it does not refer to positions, but to execution times: compression, combustion, expansion and exhaust.

\[
N_{therm} = 1 - \frac{T_4 - T_1}{T_3 - T_2}
\]  

(1)

According to the previous thing the Equation 1 is modified taking two times as a position, according to the Figure (2) the points 2-3 represents the entrance of heat (energy), there is the combustion chamber where 2 thermocouples are located, the points 4-1 represent the exit of the heat (The escape) where 2 thermocouples are located. As result of this modification Equation (2).

![Figure 2. T-s diagram for ideal diesel cycle [11].](image)
Ntherm = 1 - \frac{\text{Mean Temp. Combustion chamber}}{\text{Mean Temp. Exhaust}} \tag{2}

- Taking the engine as the control volume, the input heat is the energy provided by the fuel to enter the combustion chamber and by calculating the heat transferred from the combustion chamber to the walls of the engine casing, to the coolant used, and the exhaust gases as output heat [12].

Equations (4) to Equation (6) relate the specific heats of the system, with these are determined the input heat shown in Equation (3) and the output heat shown in Equation (7). The calculation of the network is evidenced in Equation (8), where the difference between the input and output heat is appreciated, for the purpose of determining the efficiency of the system, Equation (9). All the elements are defined in Table 1.

\begin{align*}
\text{Qin} &= \varphi_c \ast \rho_c \ast P \ast C_c \\
\text{Qwall} &= \frac{k \ast A \ast (T_{s1} - T_{s2})}{L} \tag{4} \\
\text{Qcoolant} &= M_3 \ast C_p \ast (T_{s1} - T_{s2}) \tag{5} \\
\text{Qgas} &= M_4 \ast C_p \ast (T_{s1} - T_{s2}) \tag{6} \\
\text{Qoutput} &= \text{Qwall} + \text{Qcoolant} + \text{Qgas} \tag{7} \\
\text{Wnet} &= \text{Qin} - \text{Qoutput} \tag{8} \\
\text{Nthermal} &= \frac{\text{Wnet}}{\text{Qin}} \tag{9}
\end{align*}

\begin{table}[h]
\centering
\begin{tabular}{|l|l|}
\hline
Type & Description \\
\hline
M_c & Fuel mass flow \\
P_c & Fuel calorific power \\
\varphi_c & Fuel density \\
\rho_c & Fuel volumen \\
k & Thermal conductivity of the material \\
A & Surface area \\
L & Wall thickness \\
M_3 & Water mass flow \\
C_p & Specific heat \\
M_4 & Exhaust gas mass flow (ideally air) \\
\hline
\end{tabular}
\caption{Elements for the analysis.}
\end{table}

2.3. Virtual instrument design

The virtual instrument consists of multiple windows where the user can select between different options such as calculating the efficiency for each of the three speeds: 1000 rpm, 1500 rpm, 2500 rpm. "Multiple windows" is a type of modular programming that allows the correlation of different windows (different VTs), each with independent operations that can be carried out with each other (Figure 3). Figure 4 shows the final project, which is composed of:
• A VI, which is the main window called "motor efficiency" in which the efficiency window to be measured for three different speeds is shown.
• "Window skip", this VI allows the interaction of the efficiency calculation window with the main panel.
• "Engine temperature", this VI contains the window where the measured temperatures, the input and output heat, the plot of the temperature behavior and the thermal efficiency of the engine are displayed.

3. Results
The fuel mass flow in diesel engines is 14.5 times the mass flow of air entering the combustion chamber approximately. This engine is 3500 cc and works with four cylinders, two of its pistons go up and two go down to start a cycle in each revolution, so the work volume per cycle is half of the total volume. Table 2 shown the summary of the results.

Table 2. Summary of the analysis.

| V (rpm) | Q_{in} (kw) | Q_{ter} (kw) | Q_{res} (kw) | Q_{out} (kw) | Q_{es} (kw) | W_{net} (kw) | η_{net} (%) |
|---------|-------------|--------------|--------------|--------------|-------------|--------------|-------------|
| 1000    | 1324.840    | -191.00      | 247.00       | 1380.0       | 2603.24     | 1223.240     | 47          |
| 1500    | 1300.212    | -266.78      | 349.86       | 1383.3       | 3835.90     | 2452.608     | 64          |
| 2500    | 1296.140    | -296.00      | 509.83       | 1509.97      | 6387.42     | 4877.450     | 77          |

As an ideal theorem is being used, thermal efficiency is greater than the typical efficiency of these engines. Table 3 to Table 5 shown the temperatures measured in real time for approximately 20 seconds at speeds of 1000 rpm, 1500 rpm and 2500 rpm.
Table 3. Temperatures (°C) 1000 rpm.

|     | T1      | T2      | T3      | T4      |
|-----|---------|---------|---------|---------|
| 2000| 20.4764 | 34.58   | 63.37   | 96.60   |
| 2001| 20.4488 | 36.71   | 63.43   | 96.84   |
| 2002| 20.2800 | 38.93   | 63.65   | 96.93   |
| 2003| 20.0500 | 40.43   | 63.79   | 97.02   |
| 1900| 19.9400 | 40.68   | 63.92   | 97.24   |
| 1901| 20.0100 | 45.08   | 63.97   | 97.49   |
| 1902| 19.8900 | 50.95   | 64.16   | 97.53   |
| 1903| 19.7900 | 56.38   | 64.28   | 97.68   |
| 2000| 20.3200 | 59.70   | 64.47   | 97.80   |
| 1900| 19.7000 | 62.36   | 64.55   | 97.93   |

Table 4. Temperatures (°C) 1500 rpm.

|     | T1      | T2      | T3      | T4      |
|-----|---------|---------|---------|---------|
| 1500| 79.05   | 54.21   | 91.77   | 106.730 |
| 1501| 79.12   | 54.18   | 91.81   | 106.710 |
| 1502| 79.25   | 54.26   | 91.92   | 106.620 |
| 1503| 79.29   | 54.27   | 92.02   | 106.730 |
| 1504| 79.33   | 54.05   | 92.12   | 106.930 |
| 1505| 79.44   | 53.68   | 92.22   | 107.170 |
| 1506| 79.56   | 53.15   | 92.37   | 107.440 |
| 1507| 79.60   | 52.79   | 92.39   | 107.680 |
| 1508| 79.59   | 52.44   | 92.42   | 108.037 |
| 1509| 79.64   | 52.11   | 92.50   | 108.290 |

Table 5. Temperatures (°C) 2500 rpm.

|     | T1      | T2      | T3      | T4      |
|-----|---------|---------|---------|---------|
| 2500| 85.16   | 58.72   | 99.450  | 120.74  |
| 2501| 85.17   | 58.76   | 99.450  | 120.65  |
| 2502| 85.27   | 58.82   | 99.480  | 120.57  |
| 2503| 85.17   | 58.82   | 99.500  | 120.51  |
| 2504| 85.35   | 58.87   | 99.620  | 120.41  |
| 2505| 85.29   | 59.07   | 99.680  | 120.37  |
| 2506| 85.30   | 59.19   | 99.780  | 120.20  |
| 2507| 85.41   | 59.20   | 99.820  | 120.19  |
| 2508| 85.35   | 59.12   | 99.870  | 120.15  |
| 2509| 86.53   | 54.95   | 100.69  | 125.09  |

Figure 5 shows the behavior of the thermal efficiency with respect to time, this analysis was made at 1000 rpm. Figure 6 shows the thermal efficiency with respect to the three measured speeds. Figure 7 shows the implementation of the VI applied to the 3500 cc diesel engine. The physical connection of the thermocouples and the data acquisition system is observed.
4. Conclusions

The virtual instrument designed for the evaluation of the efficiency of a 3500cc diesel engine worked correctly, having a good interaction with the hardware used for data acquisition. LabView is presented as a suitable tool for the development of this type of applications, for the easy connection between hardware and software. The implementation of this VI, allows to calculate the ideal thermal efficiency with real temperature data. Proving that this diesel engine works better around 1000 rpm.

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