

# In-Use Compliance Emission Testing Analysis Applied in LabVIEW for Engineers

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## [ Abstract ]

Analyzing test data of a vehicle for evaluating its emission performance is an essential process in automotive development field, yet it is intricate and tedious task. In addition, clear understanding and care are required when the analysis process is carried out. Computer software solutions significantly reduce the time and the effort for such analysis. Developing a computer routine to analyze the emission data in a vehicle test demands a complete understanding of the emissions analysis and its related details. In this paper, the principals to develop a LabVIEW analysis routine (VI) are introduced helping automotive engineers comprehend the emission analysis process of a vehicle test data and instruct them to develop similar routines for such analysis.

**Key Words:** In-use compliance testing, Not-to-exceed method, Average window method, LabVIEW, Portable emission measurement system (PEMS)

## I. INTRODUCTION

In the process of development new vehicles models, their emission performance needs to be evaluated and tested during their use over their useful life. This kind of testing is referred to as in-use compliance emission testing set by the emission regulations in United States and Europe in order to ensure the conformity of a vehicle with emission standards accounting for the deterioration of the emission performance during the useful life of a vehicle with the considerations of real road conditions [1, 2].

As of the year 2007, in-use compliance testing has been conducted using portable emission analyzing instruments referred to as (PEMS). Using PEMS devices gives a big accessibility to test and evaluate a vehicle emissions performance in real world conditions providing more accurate emission

information than that of just testing in chassis dynamometers.

In an in-use compliance test, the vehicle is equipped with PEMS devices and prepared according to procedures recommended by the emission regulations. PEMS contains three main modules. First module is the controller area network (CAN) interface device for recording the vehicle and the engine data such as engine speed, engine torque, vehicle speed, etc. The second module is the exhaust flow meter mounted on the vehicle tail pipe to measure the exhaust flow, exhaust pressure, and temperature. The third module is the gas analyzer mounted on the vehicle board and connected to the tail pipe by a sample line to extract gas sample every second and measure the exhaust gas components such as CO<sub>2</sub>, NO<sub>x</sub>, CO, HC and particulate matter if needed. These modules are connected to a

<http://dx.doi.org/10.14702/JPEE.2014.127>



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**Received** 22 October 2014; **Revised** 12 November 2014

**Accepted** 20 November 2014

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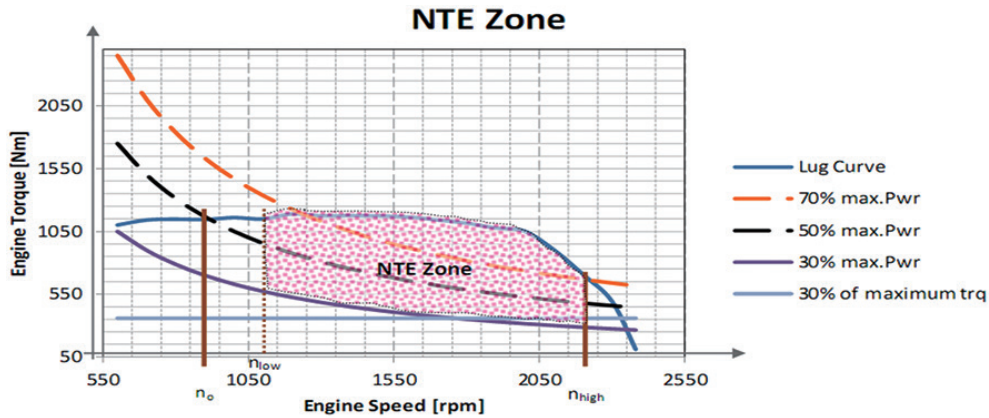


Fig. 1. NTE zone for a vehicle engine.

PC computer to log all the measured data in a second by second fashion. The PC computer of the PEMS device provides the test data in a text based files that need to be analyzed in order to evaluate a vehicle emission performance under an in-compliance test.

The test data of an in-use compliance test is analyzed by two methods that are not-to-exceed method (NTE) and average window method (AWM). NTE method is recommended by environment protection agency (EPA) in the United States of America whereas AWM analysis method is applied in Europe. The initial steps of both methods require the following; checking the consistency of the data regarding the recommended conditions and the time alignment of the recorded signals. However, the analysis calculations in each method use its own approach.

In this paper, the principals to develop a LabVIEW routine to perform the in-use compliance emission analysis using NTE and AWM Methods are demonstrated.

## II. IN-USE COMPLIANCE TEST EMISSION ANALYSIS METHODS

### A. Not-to-Exceed (NTE) Method

NTE method considers the emissions of a specific test data points that correspond to specific engine operating points defined on the vehicle engine speed-torque map within a designated area called NTE zone. NTE Zone is a set of operating points lie in a region limited by pre-described boundaries recommended by EPA [3] (Fig. 1).

In NTE analysis method, the test data points within the NTE zone need to be identified and extracted. Once the test data points corresponding to NTE zone are extracted, the test data points that are in sequence at least 30 seconds are grouped as NTE event. NTE method requires identifying these all the

events during the whole test duration of a vehicle. For the duration of each event, the emissions masses are calculated along with work done by the engine during that event in order to calculate the specific emission factors in g/kWh for each criteria pollutant such as Co, NOx and HC. Specific emissions of each criteria pollutant are compared in each event to the standard specific emission value set by the emission regulations called the threshold. NTE method requires that at least 90 percent of NTE events must be below the regulated specific emission value in order for the vehicle to pass the test.

The steps required to use NTE analysis method are summarized in a flow chart shown in Fig. 2 in order to help the development of a LabVIEW routine for NTE method.

### B. Average Window Method (AWM)

In AWM, the specific emissions are first calculated in what so-called a window. A window is a group of points that correspond to a sequence of the vehicle engine speed-torque operating points that accumulate a specific amount of work called the work reference or a specific amount of CO<sub>2</sub> mass called the CO<sub>2</sub> reference mass. These amounts are set by the regulation authorities according to a standard Engine test cycle. AWM requires the extraction all windows over the whole duration of the vehicle in the in-use compliance test. The first window is extracted from the first test data point until the point at which the reference work or reference CO<sub>2</sub> mass is reached then the start the process again by shift the beginning of the next window by 1 second from the beginning of the previous window and the process continues until all windows are extracted. The specific emissions in each window are then compared to the standard value set by the regulations. With AWM, the vehicle passes the in-use compliance test if at least 90 percent of the windows have their specific emissions below 1.5 of the standard emission value [4, 5].

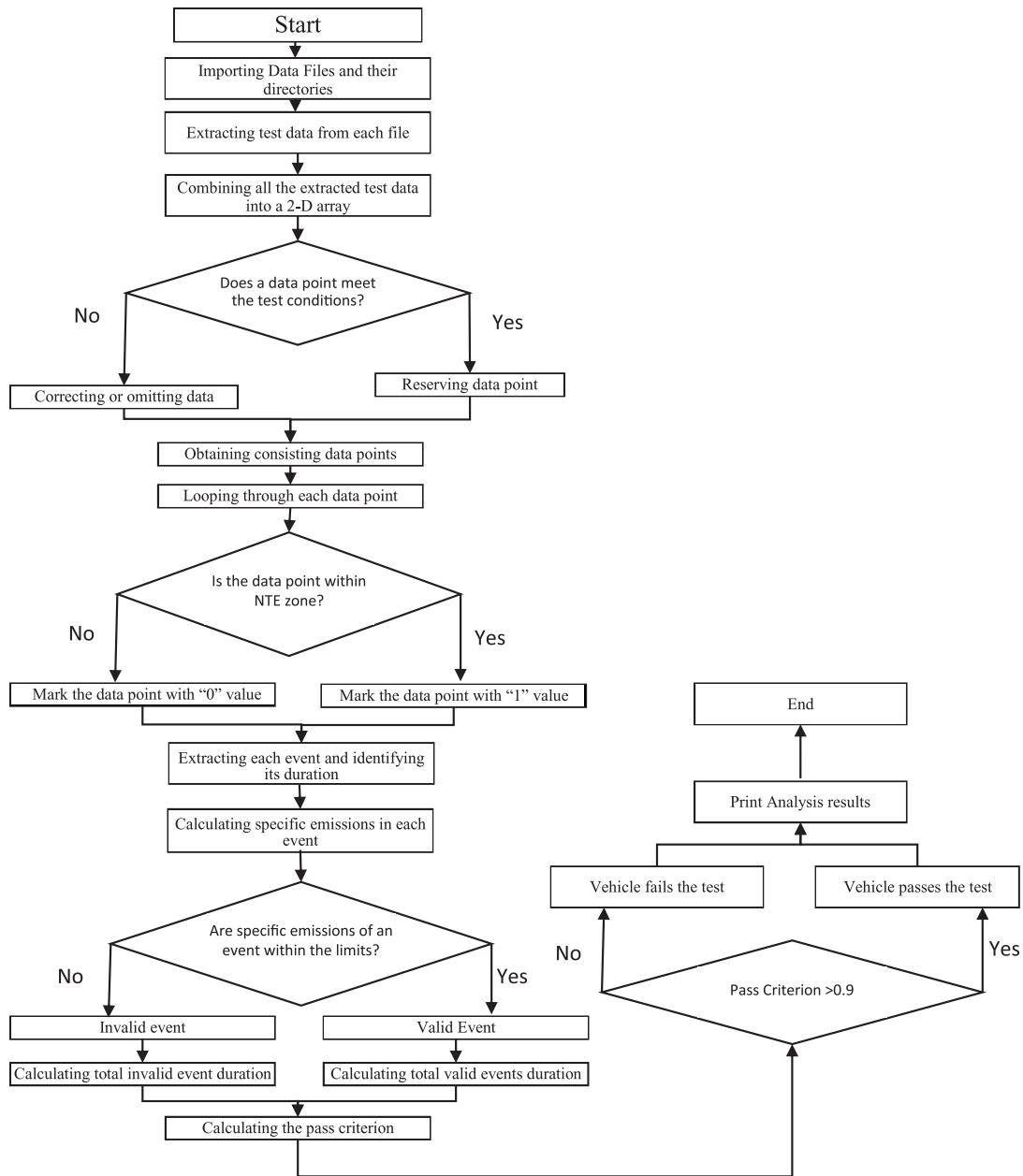


Fig. 2. Flow chart for NTE analysis method.

In Fig. 3, way of extracting a window based on a reference work is demonstrated. The duration  $t_{2,i} - t_{1,i}$  of the  $i_{th}$  averaging window is determined by

$$W(t_{2,i}) - W(t_{1,i}) \geq W_{reference} \quad (1)$$

where  $t_{1,i}$  and  $t_{2,i}$  are the beginning and end time moments of the  $i_{th}$  window, respectively;  $W(t_{1,i})$  and  $W(t_{2,i})$  are the accumulated work calculated at  $t_{1,i}$  and  $t_{2,i}$ ;  $W_{reference}$  is the work reference.

Also,  $t_{2,i}$  shall be selected such that

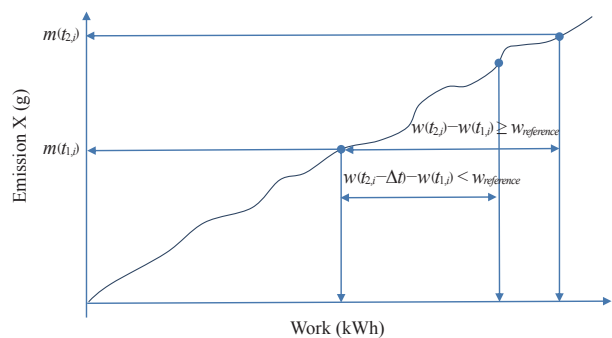


Fig. 3. Work window calculations.

$$W(t_{2,i}-\Delta t)-W(t_{1,i}) < w_{reference} \leq W(t_{2,i})-W(t_{1,i}) \quad (2)$$

where  $\Delta t$  is the data sampling period equal to 1 second.

The calculation of a specific emission gas per window is calculated by the following

$$e_{gas} = \frac{m}{W(t_{2,i})-W(t_{1,i})} \quad (3)$$

where  $m$  is mass of an emission constituent in g/window;  $W(t_{2,i})-W(t_{1,i})$  is the engine work during the  $i_{th}$  window in kWh.

The steps required to use AWM analysis method is summarized in Fig. 4 in order to help the development of a LabVIEW routine for AWM method.

### III. LABVIEW VI FOR ANALYZING THE EMISSION PERFORMANCE IN IN-USE TEST

Understanding the analysis of in-use compliance is essential to set the way to develop a VI in LabVIEW. Based on the procedure required by each method whether it is AWM or NTE, different techniques can be used to enable LabVIEW VI to perform an automated analysis effectively.

By comprehending both AWM and NTE methods for in-use compliance analysis, the initial steps for both methods are almost similar; such as importing the data into LabVIEW environment and checking the consistency and alignment of signals data. Thus importing data and consistency inspection are common for both methods.

The following sections will introduce the main features to develop VI performing in-use compliance analysis by the two methods [6].

#### A. Front Panel

The front panel is user-friendly design. The user first is to select the test data files then select the speed-torque curve (lug curve) in order to identify the boundaries of the vehicle engine. Then, the user has the choice to perform which analysis method; NTE or AWM. The data files directories are displayed in an array of strings.

Once the program runs, the results of the analysis are shown on a tab designated to the chosen method. In case of NTE method the test operating points along the test is shown in XY graph with the speed torque curve demonstrating the NTE zone. Also, the events of NTE zone are displayed with the related emission elements. At the end of the analysis, the pass/fail result is indicated in a string indicator (Fig. 5a).

In case of AWM method, the user ought to insert the reference work and the power threshold on the tab related to AWM analysis method. Emissions limits are also inserted according

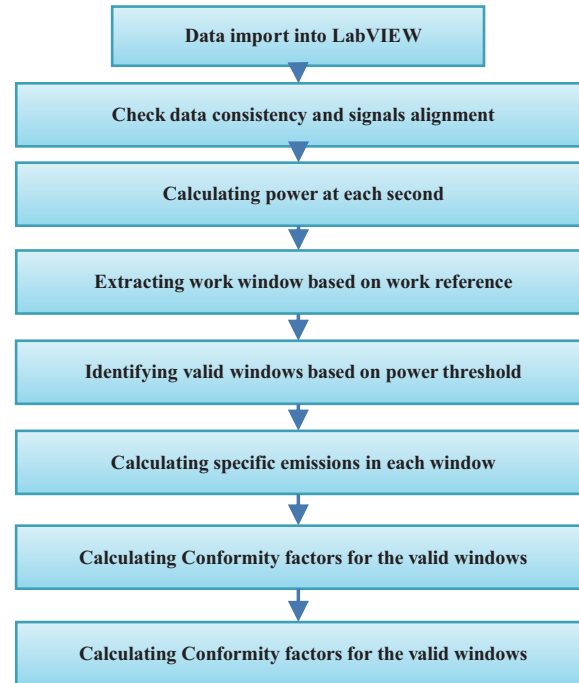


Fig. 4. Programming steps for developing LabVIEW routine.

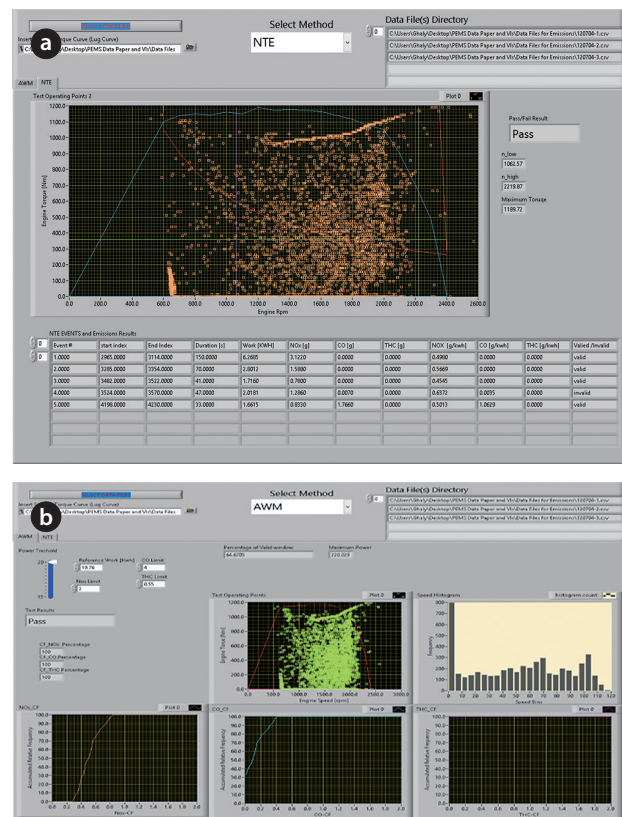


Fig. 5. (a) front panel for NTE analysis and (b) front panel for AWM analysis.

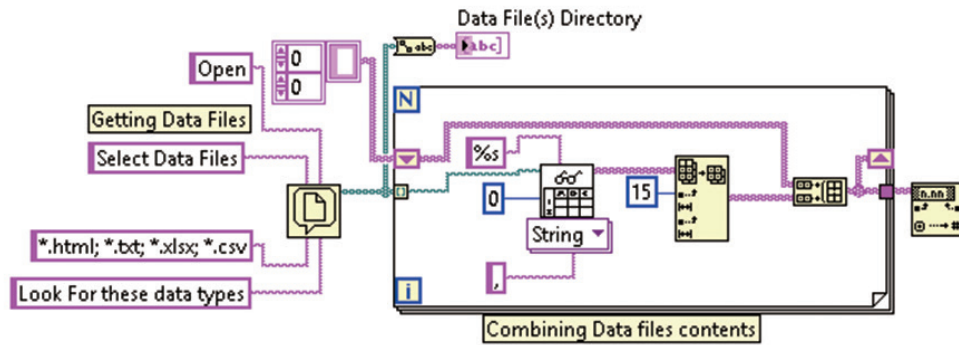


Fig. 6. Inserting multiple data files.

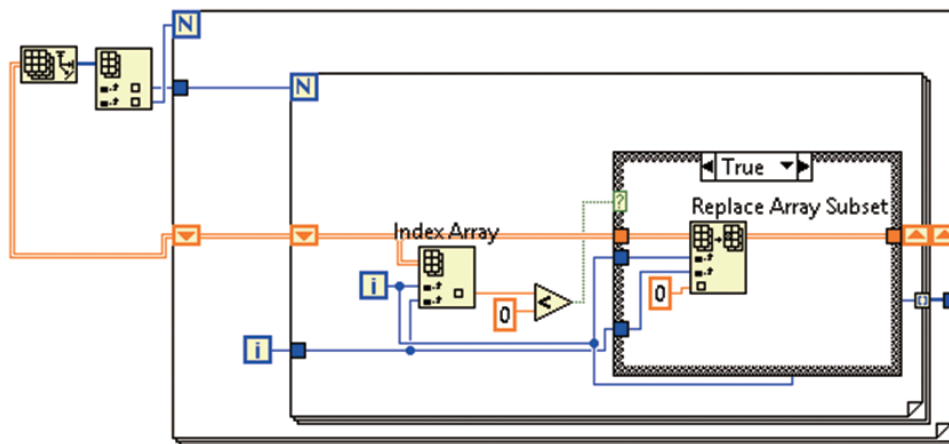


Fig. 7. Checking data consistency.

to the required emissions regulations for the vehicle model.

The program runs and the analysis result of AWM is displayed; cumulative frequency indicating the conformity factors for NO<sub>x</sub>, CO and THC gases, vehicle speed distribution during the test in a histogram, the results of percentages of Conformity factors that are less than the ratio 1.5 (Fig. 5b).

## B. Block Diagram

Preparing the test data in LabVIEW environment is almost common for both methods. Importing both test data files and speed torque curve are first done by using functions from File I/O palette. Fig. 6 shows how to import multiple files at once for the test data files.

### 1) Data importing and data consistency

The data points are first imported as arrays of strings and then are converted double array data for processing. The data then have to be checked for consistency and alignment. Data consistency indicated removing non-valid data points, such

as negative emission values coming from measuring instruments. Also, the test has to be performed in specified conditions of temperature, pressure, and humidity, according to the regulations procedures. Each test point has to be within these conditions. Those points that are outside these conditions have to be omitted from the analysis. For instance, negative values of emissions can be replaced with zero values. Fig. 7 shows the LabVIEW code to replace these negative values through looping through each column first then looping through each row (element) in this column.

Attention is needed when the invalid data rows are omitted. Omitting one data row means the order of the whole data indices is broken. A consistent order of the data indices is required in order for the LabVIEW routine works without problems. The technique used to overcome the problem of the lost indices within the data rows is to first create an additional array of the data rows indices where the indices to be removed are identified; marked with 0 value whereas the valid points are marked with 1 value. Then, using the additional array of data indices, a new data set is established by transferring only

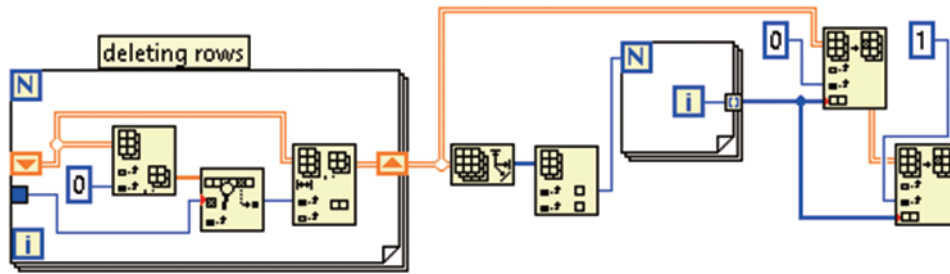


Fig. 8. Omitting invalid row data.

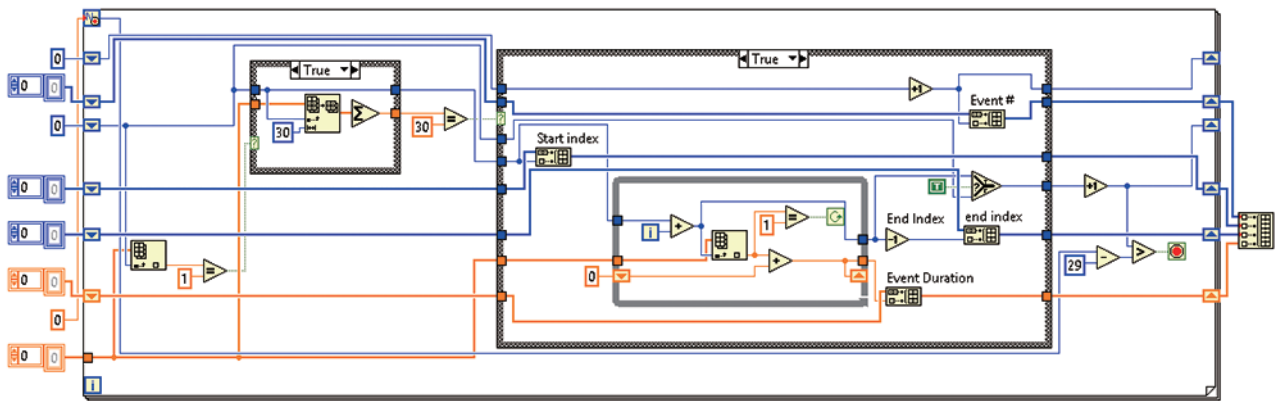


Fig. 9. LabVIEW routine to extract NTE events.

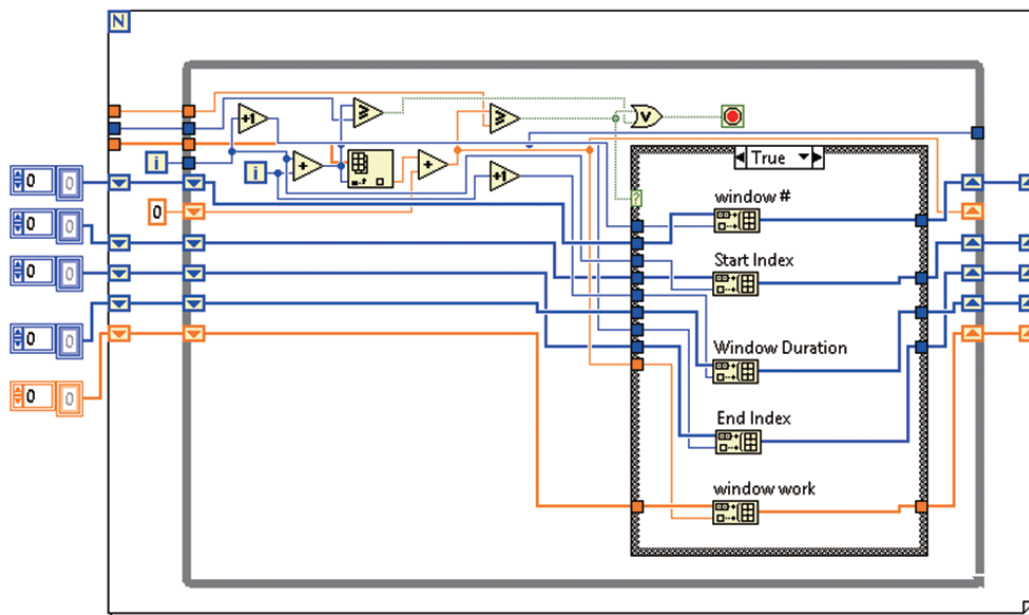


Fig. 10. LabVIEW routine to extract work windows for AWM method.



the valid data rows and skipping those that are invalid. Fig. 8 shows a LabVIEW code for omitting invalid data rows.

## 2) Extracting NTE Events

First, data points within NTE zone have to be identified. This can be done by looping through the speed and torque data within NTE zone and by marking those points with easy to handle value such as the numeric value “1” and those points that are outside the zone are marked with the numeric value “0”. Extracting NTE events is the next step in which care is needed when the NTE events are identified. The logic behind how these events are extracted is to first identify NTE zone points that are in sequence of a duration of thirty seconds (30 seconds) or more and then LabVIEW code identifies this sequence of points as an event. Next, for each identified event, its duration is calculated with a conditional looping that uses marking of the values; one and zero (1 & 0) values by adding only the points marked by the value 1 in a continuous sequence. Finally, each fully identified event is assigned with an index for other steps needed in the analysis of NTE method. The whole process of extracting NTE events in LabVIEW is shown in Fig. 9.

## 3) Extracting AWM Work Windows

The approach to extract work windows from the data is to use two nested loops. The outer loop is a For Loop structure to iterate through the rows of the data (engine speed and torque) as the data points number is known whereas the inner loop is a While-Loop as it operates conditionally until it accumulates the amount of work that is equal to or slightly bigger than the work reference. The next step is assigning an index to each identified window along with its time duration, start time, and end time. Extracting AWM windows with LabVIEW is shown in Fig. 10.

## IV. DISCUSSION AND COMMENTS

LabVIEW environment provides a convenient platform for users to work their ways towards their target with better flexibility and efficiency. Understanding the task before developing the code is of the essence. Once the user has comprehended the subject matter and how it works, LabVIEW environment helps the development of code to achieve the task faster than any other text-based computer languages do. For instance, the parallelism of the data flow in LabVIEW enables users to perform several other tasks, and hence the time to develop the routine is reduced. In addition, drawing the code is the key feature that contributes significantly to not only saving time but tracing the progress of code development as well. Such approach emphasizes that students acquire much more useful

knowledge by applying procedures to “real-world” problems.

Using a graphical language rather than a text-based one represents an easier way of interaction between the users and the computer language to achieve the task needed for any practical life problem. In fact, the use of a graphical language allows user to develop their application in a natural and logical way. On the other hand, using a text-based programming language has a difficulty to visualize the program follow compared to the graphical programming approach. The graphical programming language approach in LabVIEW is based on a simpler and more intuitive logic of interaction that remarkably simplifies the programming process.

## V. CONCLUSION

Concepts of in-use compliance testing have been demonstrated in order to help to set the necessary steps needed to develop a computer routine in a graphical programming language such as in LabVIEW. Two methods known for the emissions analysis of the in-compliance testing have been illustrated so as to make the computer routine development easier to comprehend. The important tasks needed to develop the LabVIEW code (LabVIEW VI) that perform the analysis of NTE and AWM methods have been shown along with the logic behind the code structure. The approach of graphical programming in LabVIEW environment and the visualization of the data flow offer a significant flexibility for engineers of different majors to develop computer applications performing any analysis task in effective and efficient ways.

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