

The speed profile evaluation method in the vehicle operation

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Abstract. In this paper the authors present new approach to testing procedure for light vehicles which involves a better characteristics describing parameters. This method will allow one to obtain better correlation between the real output measurements and theoretical inputs used in the modelling. The new vehicle testing procedure, the Worldwide harmonized Light vehicle Test Procedure (WLTP) was introduced in 2017, whose purpose was to better emulate the vehicle natural operation, than the previously used test - the New European Driving Cycle (NEDC). It is our belief, that in the NEDC, the speed profile test might have been created for convenience of a study rather than a model for describing the real operations parameters. The differences in the outputs between the laboratory testing and real outputs convinced the experts to review the procedures and to implement some changes in the WLTP test procedures. These changes resulted in improved randomized speed profiles of various vehicles, which also attempt including driving habits of the drivers. However, there cannot be created universal profile for every case, therefore the differences between theoretical and the real one should be noticed. As a result, we were able to create a model and an instrument which can indicate the differences between the real conditions and theoretical ones. It is our goal that the correcting factors should take care of differences in the evaluation methods of different studies.

1. Introduction

The New European Driving Cycle (NEDC) [2] laboratory test was developed in the 80s and last updated in 1997. It was designed to measure the emission levels and fuel economy. It supposed to represent the typical car operation in Europe (excluding light trucks and commercial vehicles). The test was defined for CO₂ measurement, fuel consumption, electric consumption (hybrid and electric cars) [3] and for pollutants emission measurement [4]. It is maintained by UNECE World Forum for Harmonization of Vehicle Regulations [5].

Over the time, however, the NEDC test became outdated and obsolete when cars got to be more powerful and lighter. The real-life driving obviously showed that speed pattern in the test with low accelerations, constant and idling periods couldn't represent valid results of measurements.

Inability to emulate proper conditions of testing resulted in designing of a new test called: The Worldwide harmonized Light vehicles Test Procedure (WLTP) [6]. Presented in September 2017 finally replaced the NEDC test. The WLTP test introduced much more realistic testing conditions [1]:



- More realistic driving behaviour
- A greater range of driving situations (urban, suburban, main road, motorway);
- Longer test distances
- More realistic ambient temperatures, closer to the European average;
- Higher average and maximum speeds
- Higher average and maximum drive power
- More dynamic and representative accelerations and decelerations
- Shorter stops
- Optional equipment: CO₂ values and fuel consumption are provided for individual vehicles as built
- Stricter car set-up and measurement conditions
- Enables best and worst-case values on consumer information, reflecting the options available for similar car models.

The differences between NEDC and WLTP test are listed in table (Table.1).

Table.1 NEDC and WLTP test procedures comparison.

	NEDC	WLTP
Test cycle	Single	Dynamic (simulation of real driving)
Cycle time	20 minutes	30 minutes
Cycle distance	11 kilometres	23.25 kilometres
Driving phases	Two phases: 66% urban, 34% non-urban	Four phases: 54% urban, 48% non-urban
Average speed	34 km/h	46.5 km/h
Maximum speed	120 km/h	131 km/h
Influence of optional equipment	CO ₂ and fuel performance not considered	Additional features considered (depends on each)
Gear shifts	Fixed gear shift points	Different gear shift points
Test temperature	20-30 °C	23°C (CO ₂ values corrected to 14°C)

2. The Fast Fourier Transform

The Fast Fourier Transform (FFT) is an algorithm which allows to compute the Fourier Transform in much faster and efficiently way. The Fourier Transform decomposes a function of time into a function of frequency, so we can see basic harmonic components of the signal. It is described by equation [6], [7], [9], [12]:

$$\bar{f}(\omega) = \int_{-\infty}^{\infty} f(t)e^{-i\omega t} dt \quad (1)$$

$$f(t) - \text{function in time domain}$$

$$\bar{f}(\omega) - \text{transform in angular velocity domain}$$

$$\omega = \frac{2\pi}{T} - \text{angular velocity}$$

The working principle is that Fourier Transform changes domain from time (Fig. 1) to frequency (Fig. 2) so the representation of the same signal is different and it gives us different information.

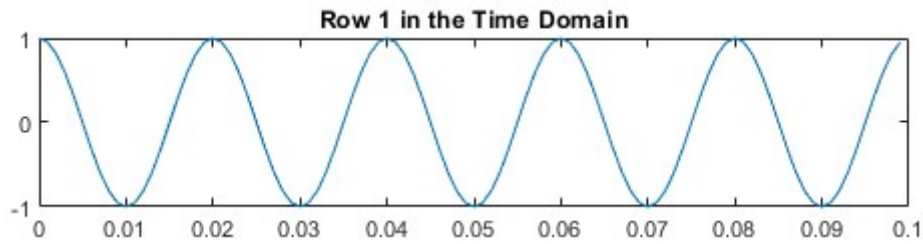


Figure. 1 The sinusoidal signal in the time domain [7].

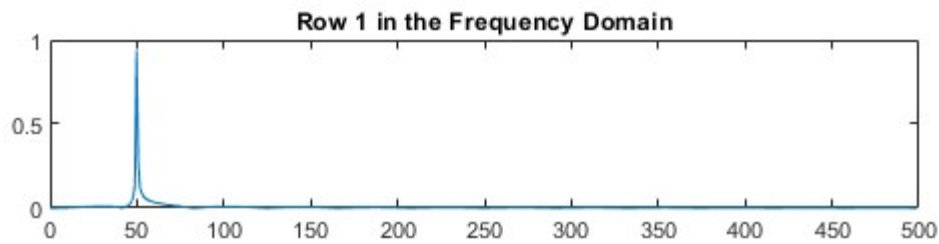


Figure. 2 The sinusoidal signal in the frequency domain [7].

The idea of this study was to examine whether the WLTP graph, which is the speed of time function, can be treated like every other signal commonly seen in the area of e.g. electronics. For the purpose of this research we assume the signal inputs according to the WLTP test description. The sampling period was 10 seconds.

3. The Pearson correlation coefficient

It is used for measuring the linear correlation between two variables. The coefficient takes the value in the range of -1 to 1. The 1 means the correlation is total positive, -1 means it is total negative and 0 is no linear correlation at all. If the x and y are random variables and [8], [10], [11], [13]:

$$\bar{x} = \frac{1}{n} \sum_{i=1}^n x_i, \bar{y} = \frac{1}{n} \sum_{i=1}^n y_i \quad (2), (3)$$

then:

$$r_{xy} = \frac{\sum_{i=1}^n (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^n (x_i - \bar{x})^2} \sqrt{\sum_{i=1}^n (y_i - \bar{y})^2}} \quad (4)$$

$$r_{xy} \in [-1, 1].$$

4. Results

In this study we wanted to compare how much the original WLTP graph (Fig. 3) is accurate regarding real-life car operation. For this purpose, we recorded three car rides and collect necessary data. All three last for the same period of time as the WLTP.

First, we took the original WLTP graph which begins with slow-speed phase 1 and ends with high-speed phase 4 and reversed the phases, starting with high-speed phase 4 (Fig. 4). Then we calculated the correlation between these two graphs and it was equal to:

$$r_{xy} = -0.49$$

It indicates the correlation is medium negative, so we could assume these two graphs are not very similar, however they are, only in their specific periods of time. This implicates that order of test performance is vital for correct comparisons and results. That is why we should not compare two graphs from their original form.

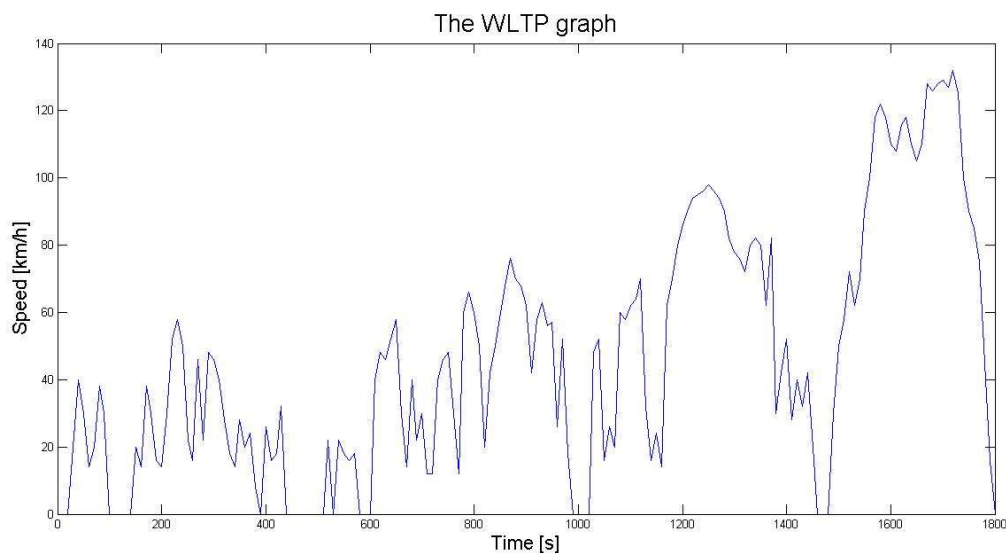


Figure 3. The WLTP graph

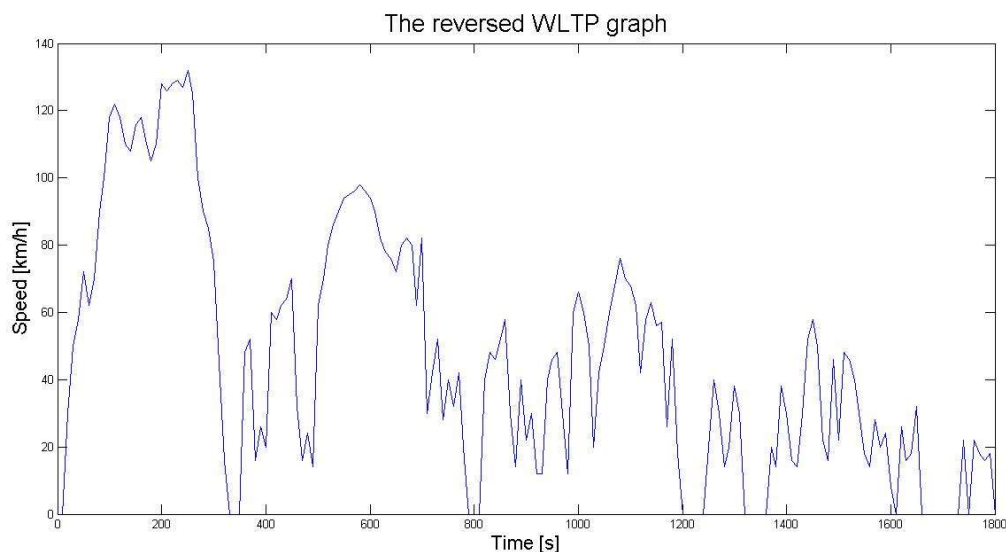


Figure 4. The reversed WLTP graph

Much more accurate results can be derived from Fast Fourier Transforms. Computing FFT of the WLTP graph (Fig. 5) and reversed WLTP graph (Fig. 6), the correlation between these graphs was equal to:

$$r_{xy} = 0.92$$

It shows that this method is much more accurate, however it is also not 100% exact and some deviations need to be taken into account, such as: approximations, compiling accuracy, software limitations.

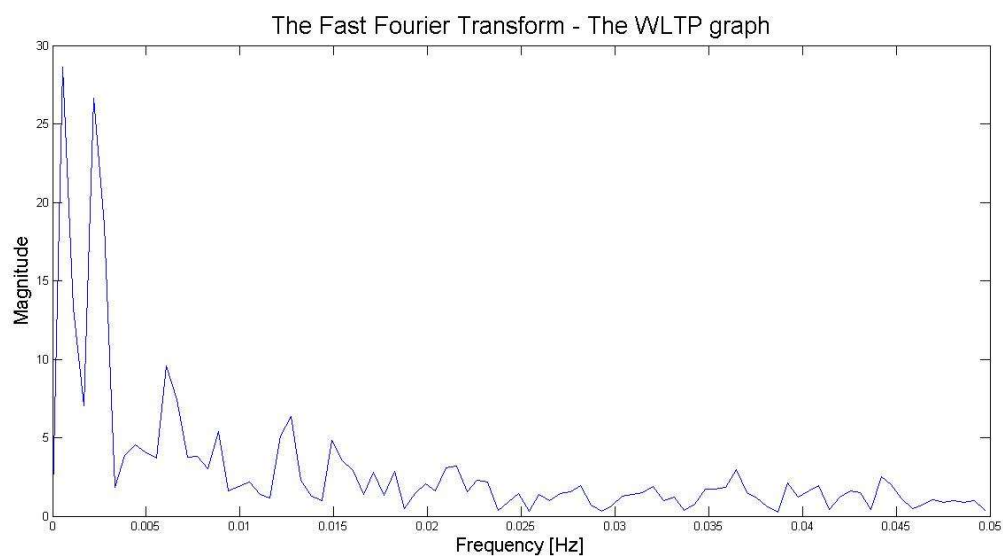


Figure 5. The Fast Fourier Transform - The WLTP

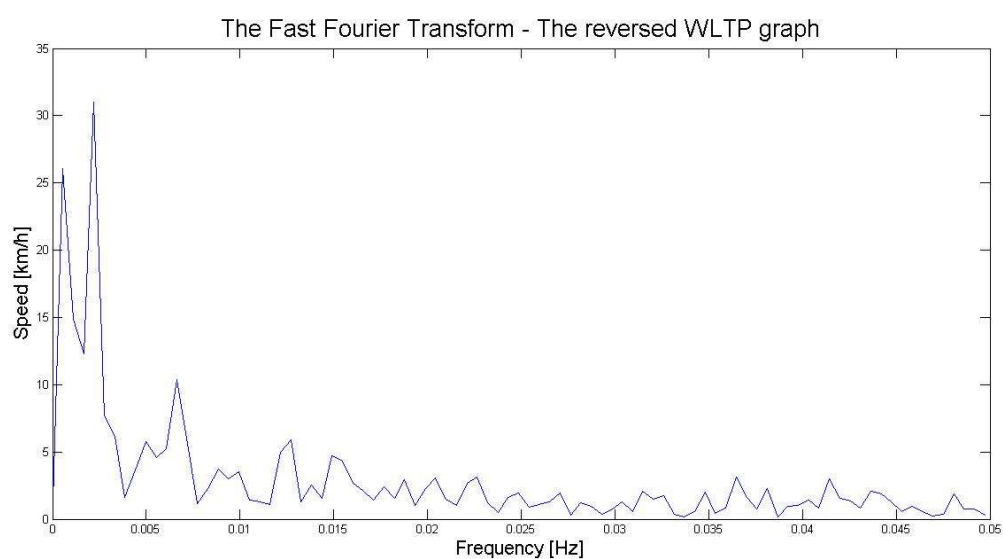
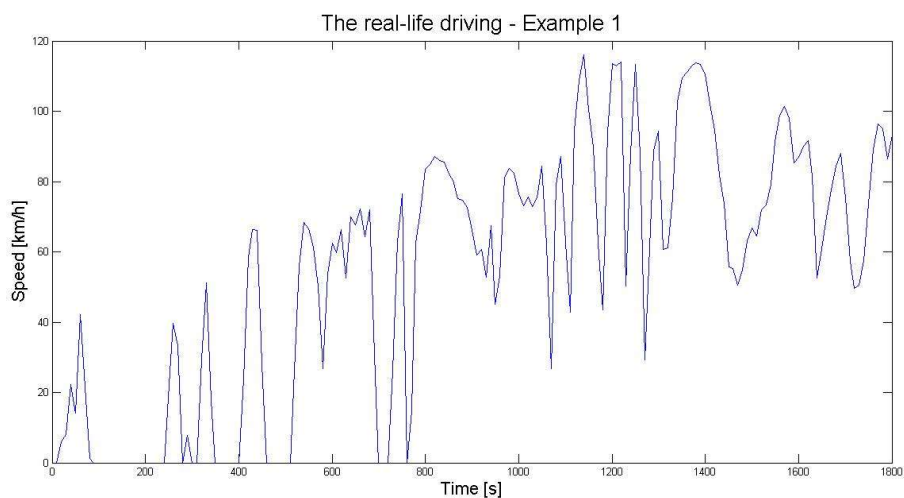
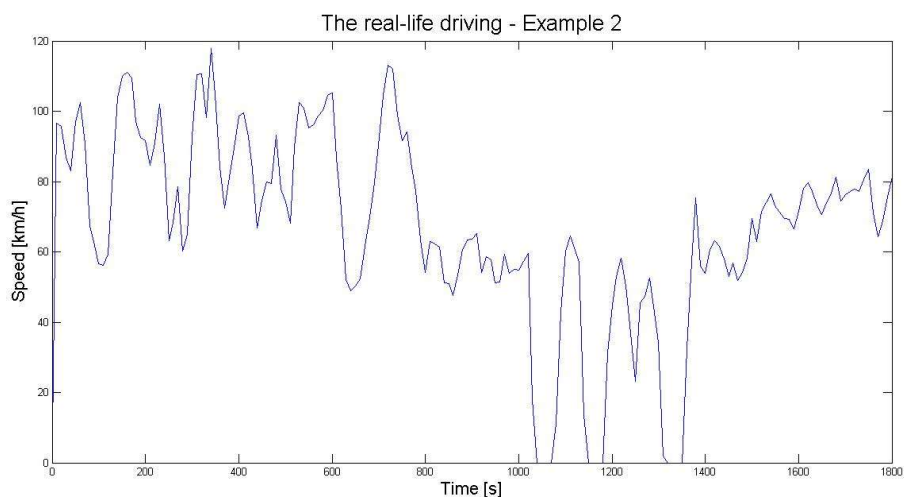
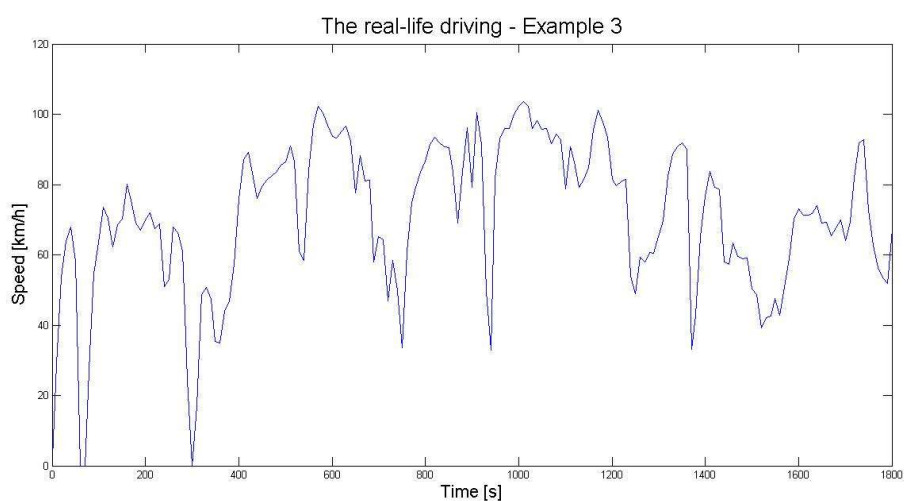


Figure 6. The Fast Fourier Transform - The reversed WLTP

Next, we wanted to verify, how well the WLTP test reflects the reality of real-life driving in every day car operation. We installed the necessary equipment into the car which allowed us to create the most valid conditions of random speed profile measurements. We recorded three rides and created graphs (Fig. 7, Fig. 8, Fig. 9).

**Figure 7.** The real-life driving - Example 1**Figure 8.** The real-life driving - Example 2**Figure 9.** The real-life driving - Example 3

After this we computed three FFT graphs (Fig. 10, Fig. 11, Fig. 12) and calculated the correlations between them and FFT of the original WLTP test (Fig. 5).

The correlation of the FFT example 1 was equal to:

$$r_{xy} = 0.7$$

The correlation of the second example was equal to:

$$r_{xy} = 0.59$$

The last one was equal to:

$$r_{xy} = 0.63$$

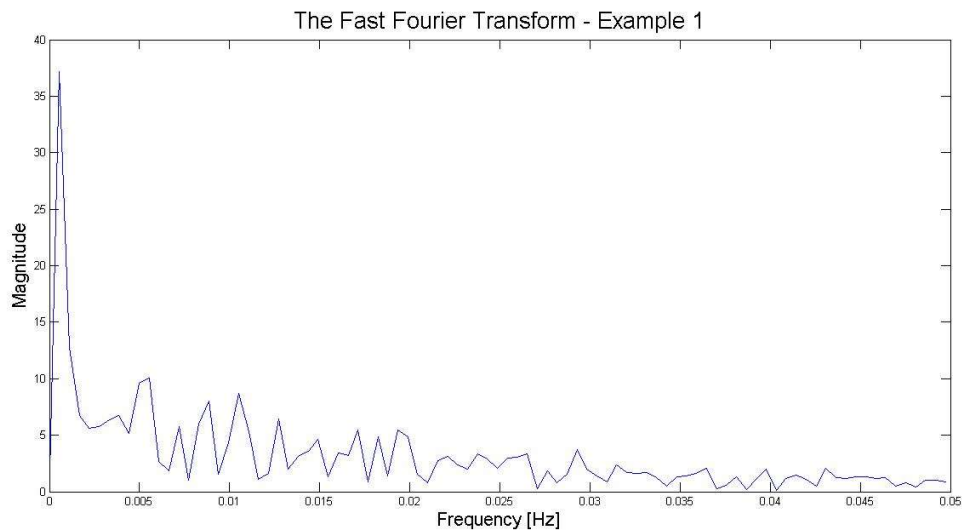


Figure 10. The Fast Fourier Transform - Example 1

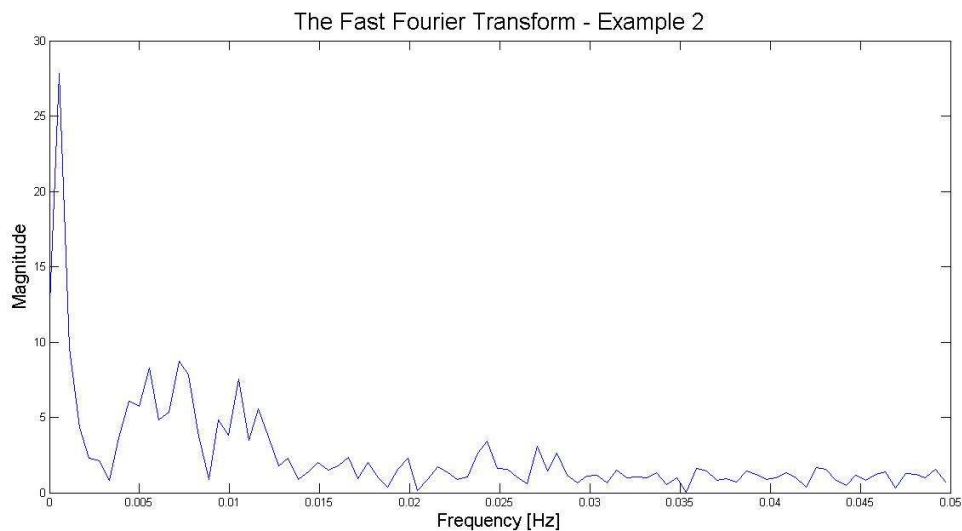


Figure 11. The Fast Fourier Transform - Example 2

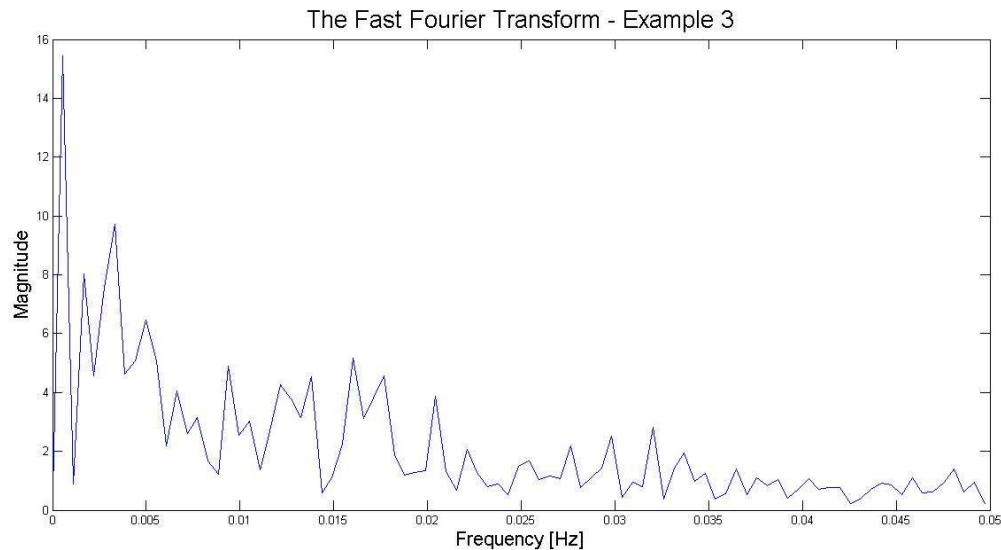


Figure 12. The Fast Fourier Transform - Example 3

5. Conclusions

This study shows, that there are still significant differences between current laboratory tests and real-life driving.

The Fast Fourier Transform can be used as an instrument for comparing speed profiles of different vehicles and is much more accurate than comparing speed profiles themselves.

The WLTP test made a huge step towards improving conditions of measurements, comparing to NEDC test, however it does not reflect the results in an entirely credible way, as it was shown on the examples.

Many of different variables are not considered by this test, such as: driving style, type of vehicle, type of road, change of altitude, therefore there is a need to include this in order to achieve correct results.

In the future studies we would like to develop a specific coefficients and predictors which would allow transferring laboratory test results into real-life driving conditions.

References

- [1] <http://wltpfacts.eu/from-nedc-to-wltp-change/>
- [2] https://www.dieselnet.com/standards/cycles/ece_eudc.php
- [3] E/ECE/324/Rev.2/Add.100/Rev.3 or E/ECE/TRANS/505/Rev.2/Add.100/Rev.3 (12 April 2013)
- [4] E/ECE/324/Rev.1/Add.82/Rev.4 or E/ECE/TRANS/505/Rev.1/Add.82/Rev.4 (26 April 2011)
- [5] "Vehicle Regulations": UNECE Transport Division/World Forum for Harmonization of Vehicle Regulations. Retrieved 30 April 2015.
- [6] "Global Technical Regulation No. 15 (Worldwide harmonized Light vehicles Test Procedure)": UNECE. UN. Retrieved 12 March 2014.
- [7] <https://www.mathworks.com/help/matlab/ref/fft.html>
- [8] Bracewell R 1999 *The Fourier Transform and its Applications*
- [9] Gray R. M., Goodman J. W. 1995 *Fourier Transforms: An Intorduction for Engineers*
- [10] Garson G. D. 2012 *Correlation*
- [11] Brigham E. O. 1973 *The Fast Fourier Transform: An introduction to Its Theory and Applications*
- [12] Brigham E. O. 1988 *The Fast Fourier Transform and Its Applications*
- [13] Sharma A.K. 2005 *Text Book of Correlations and Regression*