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Band Analysis For The Determination of Noise Characteristics

KEYWORDS
noise, method of determination of noise, internal combustion engine.

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ABSTRACT *Band analysis for the determination of noise characteristics. The great number of data during the determination of noise characteristics of internal combustion engines, and the subsequent mathematical operations for their processing require significant resources in respect to time and technical appliances. During the processing with one and the same technical appliances, the use of multidimensional massifs for the structure formation of data in frequency bands is one of the ways for the acceleration of calculation process. These methods of approach leads to significant acceleration of data processing, and to analysis extend of the investigated process. The use of frequency bands unifies the analysis of results got at different operation modes of the engines.*

Introduction

During the high-speed recording of periodical processes running with high frequency a certain derivation in periods' length of the single cycles is marked. This derivation is mainly due to a certain unevenness of process running, caused by factors of different origin. When a quantitative evaluation of the signal is done this unevenness leads to a derivation in the values of amplitudes and noise levels in cycles, while during the spectral analysis significant derivations in the amplitudes values of low-frequency harmonics are available. For the subsequent synthesis of the functions it is necessary the harmonics of higher order for all processes to be examined which leads to significant increase of their total number.

For the goal of this working out it is investigated that the distinctions in these results are minimum at number of examined diagrams greater than 4, thus 6 diagrams for a certain process are processed during the calculations. The use of greater number of diagrams multiplies the experimental data for processing, and increases the length of the primary vectors.

Presentation

The goal of this study is the use of algorithms for the simultaneous processing of recorded data in order the process of calculations for the noise characteristics determination of internal combustion engines to be accelerated. This method of approach allows grouping of data in frequency bands with set in advance parameters and analysis intensification of measurements data, because the presence of possibilities for operating with integrated massifs and transposed matrices. After each processing the large number of calculations results has to be kept also in integrated massifs, which elements in common case have different dimensions.

A point of the method

The harmonic analysis of the data is done simultaneously for all processes and elementary diagrams. The input massifs of sound pressure and the range of the harmonics $m_{\min_j} \div m_{\max_j}$ subject to examination are determined. The range is necessary for the drawing up of the frequency spectrum of the signal investigated in the set frequency range.

$$\begin{array}{l} \mathrm{Fd1} := \text{for } j \in 1..\,\mathrm{last}(M) \\ \qquad \text{for } k \in 0..\,T_j - 1 \\ \qquad\qquad \mathrm{Fd1}_{k,j} \leftarrow K_{\mathrm{druck}} \cdot \left(M_j\right)_{k+\mathrm{nula}_j,\,1} \end{array} \quad (1)$$

The frequency analysis of the sound pressure is done by harmonic analysis of discrete functions according to the method of Fourier represented in [5]. This method is worked out in this study for processing with massifs as program cycles for the processing of multidimensional incoming arrays are used.

$$\Delta\alpha_j := \frac{360}{T_j} \quad (2)$$

$$\begin{array}{l} \alpha_j := \text{for } k \in 0..\,T_j - 1 \\ \qquad \alpha_{k,j} \leftarrow k \cdot \Delta\alpha_j \cdot \dfrac{\pi}{180} \end{array} \quad (3)$$

The graphic change of the sound pressure of internal combustion engine is a strictly periodical and a high-frequency process. For its examination it is necessary the parameters of harmonics of extraordinary high order to be determined so that the sound level in the frequency range of the anthropogenic reception of noise to be measured. Because of the circumstance that the recording of the experimental data is executed individually for each measurement point on the embraced surface, the length of the sound pressure recordings in the input massif data is different in the common case. This necessitates in the program cycles for the determination of Fourier's coefficients to be introduced variables, which have to draw the investigation limits of harmonics individually for each measurement point. The minimum and maximum orders of the harmonics, which are subjected to study, are determined by the conditions (4) and (5):

$$m_{\min_j} := \mathrm{floor}\left[f_{u\left(n_1\right)} \cdot \frac{\mathrm{end}_j - \mathrm{nula}_j}{f_{sk_j}} \right] \quad (4)$$

$$m_{\max_j} := \mathrm{floor}\left[f_{o\left(n_{\mathrm{last}(n)}\right)} \cdot \frac{\mathrm{end}_j - \mathrm{nula}_j}{f_{sk_j}} \right] \quad (5)$$

In the upper equations $f_{u(n_1)}$ and $f_{u(n_{last(n)})}$ are the lower and the upper limited frequencies of the first and the last frequency bands in the chosen frequency range, respectively. The vector n contains the geometrical mean frequencies of the frequency bands with a set constant relative width.

The determination of the cosine and sine coefficients, the constant member as well as the function synthesis is a process which needs a significant source in respect to time and computer facilities. The length of the massif $\text{Ħ}\ 1_{k,j}$ and the maximum order of the studied harmonic M_ν are significant at low-frequency regimes of working. This imposes an optimization of the experimental investigations and a subsequent preliminary preparation of the data for the harmonics analysis.

```
$a1 := $ for $j \in 1..\mathrm{last}(M)$
    for $m \in 1..M\nu$
        $a1_{m,j} \leftarrow \left(\frac{2}{T_j}\right)\cdot\sum_{k=0}^{T_j-1}\left(Fd1_{k,j}\cdot\cos\left(m\cdot\alpha_{k,j}\right)\right)$        (6)
```

```
$b1 := $ for $j \in 1..\mathrm{last}(M)$
    for $m \in 1..M\nu$                                                                           (7)
        $b1_{m,j} \leftarrow \left(\frac{2}{T_j}\right)\cdot\sum_{k=0}^{T_j-1}\left(Fd1_{k,j}\cdot\sin\left(m\cdot\alpha_{k,j}\right)\right)$
```

```
$a0 := $ for $j \in 1..\mathrm{last}(M)$
    $a_{0,j} \leftarrow \left(\frac{1}{T_j}\right)\cdot\sum_{k=0}^{T_j-1} Fd1_{k,j}$        (8)
```

A synthesis of the function is done for each process in the *j*- measurement point in program cycle (9). By means of this synthesis the correct action of the determination of the harmonics components of the discrete functions is checked. If some disturbances or not characteristic values in the experimental data are available, the synthesis of the functions can be used as a digital filter for the removing of these quantities.

```
$Fdd1 := $ for $j \in 1..\mathrm{last}(M)$
    for $k \in 0..T_j - 1$
        $Fdd1_{k,j} \leftarrow a0_{0,j} + \sum_{m=1}^{M\nu}\left(a1_{m,j}\cdot\cos\left(m\cdot\alpha_{k,j}\right) + b1_{m,j}\cdot\sin\left(m\cdot\alpha_{k,j}\right)\right)$
                                                                                                  (9)
```

In equations from (6) till (9) *m* is the order of the studied harmonic. Its quantity is in the range $m_{\min j} \div m_{\max j}$, in which the amplitudes of the studied harmonics in the massif $Ampl_{m,j}$ are determined:

$$\mathrm{Ampl}_{m,j} := \sqrt{\left(a1_{m,j}\right)^2 + \left(b1_{m,j}\right)^2} \qquad (10)$$

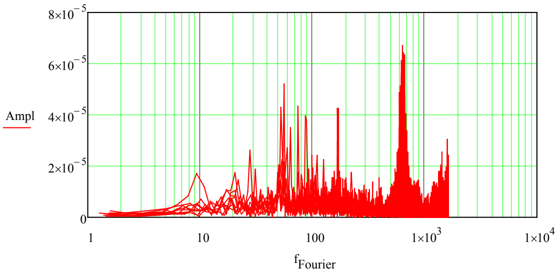

Fig. 1. A spectrogram of harmonics amplitudes for all measurement points

The spectrum of sound pressure level in accordance to the methods for determination of sound power level is composed in octave or third-octave frequency bands. In Ref. [5] are developed methods for determination the parameters of frequency bands with set relative width, which is chosen from program, and gives the opportunity a narrow-band analysis to be executed. The total sound pressure level determined by the harmonics amplitudes is calculated from the expression (11):

```
$L_{number} := $ for $j \in 1..\mathrm{last}(M)$
    $fsig_j \leftarrow f_{Fourier_{1,j}}$
    $s \leftarrow 0$
    for $kk \in 1..10\cdot n + 1$
        $s \leftarrow 0$
        for $mm \in 1..m_{max_j}$
            $s \leftarrow s + 1$ if $fu_{kk} \le mm\cdot fsig_j < fo_{kk}$
        $L_{number_{kk,j}} \leftarrow s$                                                    (11)
```

The sound levels in the frequency bands are calculated from the program cycles (12) and (13):

```
$L_{terz} := $ for $j \in 1..\mathrm{last}(M)$
    $fsig_j \leftarrow f_{Fourier_{1,j}}$
    $s \leftarrow 0$
    for $kk \in 1..10\cdot n + 1$
        $s \leftarrow 0$
        for $mm \in 1..M\nu$
            $s \leftarrow s + 10^{0.1\cdot L_{mm,j}}$ if $fu_{kk} \le mm\cdot fsig_j < fo_{kk}$
        $b \leftarrow 1$ if $s = 0$
        $b \leftarrow s$ otherwise
        $L_{terz_{kk,j}} \leftarrow 10\cdot\log(b)$                                          (12)
```

```
$Ls_{Ampl} := $ for $j \in 1..\mathrm{last}(M)$
    $s \leftarrow 0$
    for $m \in 1..M\nu$
        $s \leftarrow s + 10^{0.1\cdot L_{m,j}}$
    $Ls_{Ampl_j} \leftarrow 10\cdot\log(s) - 3$                                              (13)
```

The total sound pressure level in the frequency bands is determined from (14):

$$L_{sum_j} := 10\log\left(\sum_q 10^{0.1\cdot L_{terz_{q,j}}}\right) - 3 \qquad (14)$$

The results from the calculations are arranged in integrated multidimensional massif composed of the basic calculated quantities. The main characteristic of this integrated massif is that it is composed of elements which themselves can also be multidimensional massifs or vectors containing text or digital data. It gives the opportunity in one massif to be kept data for the sound harmonic analysis, and also data for the sound pressure levels in the third-octave bands. Such massifs are significantly distinguished in its length, and in another organization of the data a large number of zero values of the massif elements could have be obtained. The expression (15) shows the structure of an integrated multidimensional massif, which contains data for the sound pressure levels in third-octave bands and the coefficients of the harmonics analysis.

$$\mathrm{DATA} = \begin{pmatrix} \{6,1\} \\ \{32,10\} \\ \{6,10\} \\ \{1,10\} \\ \{1001,10\} \\ \{1001,10\} \end{pmatrix} \qquad \mathrm{DATA}_0 = \begin{pmatrix} \text{"vector and matrix names"} \\ \text{"Lterz"} \\ \text{"Ls"} \\ \text{"a0"} \\ \text{"a1"} \\ \text{"b1"} \end{pmatrix} \tag{15}$$

Conclusion

The developed algorithm for determination of sound pressure levels in frequency bands is based on the use of multidimensional massifs. The experimental data arranged in input massif are processed simultaneously. The data from all measurement points on the embraced surface for a given operation mode of the examined target are processed in uniform programme cycles. Each elementary cycle of operation is examined by its amplitude and frequency, while the calculations data are arranged in frequency bands with preliminary set parametres. This method of approach gives the opportunity by changing the limits of the frequency range and the bands numbers during noise analysis to be realized different frequency filters for the prognostication of the noise emission from internal combustion engines.

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