Automatic control of working car engine vibrations using multi-stage discrete Fourier transformation

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Abstract. There are questions connected with work of automotive internal combustion engines quality control digitalization. The research goal is formalization of necessary and enough condition of automatic control of such engines’ vibration levels by discrete Fourier transformation digital methods without completing hardware-intensive multiplication operations. During research there are used methods of mathematic and hardware-intensive modeling of digital algorithms of discrete Fourier transformation work and differential filtration on programmed logical integral devices. There are principals of this engine vibrations’ level by digital methods of multi-stage discrete Fourier transformation, which does not require completing algorithmic multiplication operations. There are given formulas of such digital signals’ transformation of differential digital filters by only algebraic addition of timing counts of these signals. The research results have shown and confirmed a possibility of lowering hardware costs with hardware and software realization of digital algorithms of working automotive internal combustion engine vibrations on programmed logical integral devices.

1. Introduction
Constant improvement of microelectronics’ element base necessarily provides gradual hardening of automotive internal combustion engine automatic control in terms of their serial production and further exploitation. Diagnostics of technical condition of automotive internal combustion engines allows estimating their running condition and, if necessary, timely take precautions for providing prophylactic works for elimination possible defect.

One of the workable methods of automatic control of such engines’ quality is still periodical examination of accordance of these engines’ vibration level to European quality standards criterion. Such examination must and has to be made by digital methods of digital signals spectral analysis on the basis of discrete Fourier transformation (DFT) [1]. These methods are successfully realized on the programmed logical integral device (PLD) [2, 3].

Usage of PLD in digital spectral analyzer stimulates development of DFT methods and algorithms on the basis of digital filtration, which does not demand multiplication operations completing. One of the most perspective methods of such DFT must and has to be considered multi-stage DFT (MDFT) of digital signals on the basis of differential digital filtration (DDF). MDFT of digital signals comes as sequence of recurrent procedures of multilane filtration of these signals, using differential digital filters after their specters separation on the lanes row by Coordinate Rotation Digital Computer (CORDIC).
method on each stage of such digital signals processing (DSP) [4, 5]. This DFT development of digital signals came as further development of their multi-speed theory and methods [6, 7].

2. Research goal and methods
Research goal is formalization of necessary and enough condition of automotive internal combustion engine automatic control by digital methods of DFT without completing hardware-intensive multiplication operations.

The research materials became calculative algorithms DDF of different procedures of varieties and CORDIC algorithms [4].

During research there were used methods of mathematic and hardware and software modeling of DFT digital algorithms work and differential filtration on PLD.

3. Research task
Research task is defining of necessary and enough condition of hardware costs minimization with hardware and software realization of digital algorithms of automotive internal combustion engine automatic control on the basis of MDFT digital signals without completing hardware-intensive multiplication operations on PLD.

4. Theoretical basis
Research theoretical basis must and has to be considered CORDIC method and method of terminal variation accordingly to forming amplitude-frequency characteristic of digital filtration for exchanging its coefficients with differential coefficients DDF of different varieties procedures [4, 8].

Usage of CORDIC method provides hardware and software realization on PLD of all procedures of digital signal spectral components transfer only by using elementary adders and hardware shift registers [8].

With hardware and software realization on PLD of finite difference method for building calculative algorithms DDF it is possible to reduce the needed number of memory cells for keeping filtration coefficients through significant decreasing the number of these coefficients and considerable reduction in their bit depth.

5. Practical importance and novelty
Research practical importance consists of defining the necessary and enough condition of digitalization the vibration level of automotive internal combustion engine automatic control on the basis of MDFT digital signals by differential digital filters.

Research novelty consists in formalization of necessary and enough level of minimization software costs with hardware and software realization of digital algorithms of such control on PLD.

6. Research results
Research results have shown and proved that necessary and enough condition of vibrations level of automotive internal combustion engine automatic control on the basis of MDFT digital signals by differential digital filters must and has to be considered as the integer value of their difference coefficients.

Danger of appearing the undesirable vibrations of automotive internal combustion engine determines actuality of quality increasing of their diagnostics and increasing the informativeness of used control methods of these vibrations.

MDFT is suggested to be used for digitalization of such control, because vibration of worked automotive internal combustion engine are difficult hesitations, which can be shown as summary of harmonic hesitations.

Essence of hardware and software realization of vibrations level of working automotive internal combustion engine automatic control on the basis of MDFT digital signals by differential digital filters with integer difference coefficients DDF consists in the fact that by MDFT controlled signals by method
of their multi-lane filtration by differential digital filters is made calculation of indicators \(y(\Omega, nT)\) of levels of harmonic components of these signals.

By making the research there was developed a modified algorithm MDFT, which provides on PLD analysis of measured meanings of controlled parameters of amplitude-frequency vibrations characteristics, which appear in the process of automotive internal combustion engine work. Recording and digital processing of acoustic signals of working automotive internal combustion engine vibrations was made by microelectronic devices on the basis of PLD.

Research results have proved the possibility of using MDFT vibration digital signal \(x(nT)\) with the period of sampling \(T\) by method of its \(L\)-lane filtration by differential digital filtrations \(K+M\)-th order with \(k_M\)-th differential coefficients of \(M\)-th difference order \(h_p(M, k_M, l)\) for calculating indicators \(y(\Omega, nT)\) of levels \(l\)-th harmonic components of this signal by formula (1) with \(k_M=0, 1, 2\ldots K+M-1, \ m=1, 2, 3\ldots M\) and \(n=0, 1, 2\ldots N-1:\n
\[
y(\Omega, nT) = \sum_{k=0}^{K+M-1} \sum_{k_0=0}^k \sum_{k_1=0}^{k_0} \cdots \sum_{k_{M-1}=0}^{k_{M-2}} \sum_{k_{M-1}=0}^{k_{M-2}} \sum_{k=0}^{k_M} \sum_{k=0}^{k_{M-1}} \sum_{k=0}^{k_{M-1}} \sum_{k=0}^{k_{M-1}} h_p(M, k_M, l)x(nT). \tag{1}
\]

“Saving effect” with DDF of temporary selections with the length \(N >> L\) by the formula (1) constantly neutralizes undesirable impact of uncorrelated acoustic interference such as "white noise" on results of \(L\)-point MDFT digital vibrations’ signals.

Frequency of vibrations’ signals discretization \(\omega_d\) was taken as typical and made 44,1 kHz for providing the needed step by frequency \(\Omega\) by formula (2) [9]:

\[
\Omega = \frac{\omega_d}{2L}. \tag{2}
\]

Moreover, \(k\)-th coefficients of \(l\)-th lane filtration \(h(k, l)\) with \(k=0, 1, 2\ldots K-1\) and \(l=1, 2, 3\ldots L\) are formed on the basis of \(k_m\)-th differential coefficients of \(m\)-th difference orders \(h_k(m, k_m, l)\) by the formula (3) with \(k_m=0, 1, 2\ldots K+m-1\) and \(m=1, 2, 3\ldots M\) [4]:

\[
h(k, l) = \sum_{k_0=0}^k \sum_{k_1=0}^{k_0} \cdots \sum_{k_{M-1}=0}^{k_{M-2}} \sum_{k_{M-1}=0}^{k_{M-2}} \sum_{k=0}^{k_M} \sum_{k=0}^{k_{M-1}} \sum_{k=0}^{k_{M-1}} h_p(M, k_M, l). \tag{3}
\]

This is why necessary and enough condition of completing of MDFT of such signal is only by calculating its temporary counts is integer difference coefficients \(h_p(M, k_m, l)\), by formula (4) with \(l=1, 2, 3\ldots L:\n
\[
7. \ h_p(M, k_M, l)x(nT) = \begin{cases} 
    x(nT) + x(nT) & \text{if } h_p(M, k_M, l) = +2; \\
    x(nT) & \text{if } h_p(M, k_M, l) = +1; \\
    0 & \text{if } h_p(M, k_M, l) = 0; \\
   -x(nT) & \text{if } h_p(M, k_M, l) = -1; \\
   -x(nT) - x(nT) & \text{if } h_p(M, k_M, l) = -2
\end{cases} \tag{4}.
\]

8. Discussion

Suggested idea of working automotive internal combustion engine vibrations automatic control digitalization by MDFT digital signals of its vibrations using PLD must and has to be considered as further development of the diagnostic idea of automotive internal combustion engines technical condition through their vibroacoustic parameters [10].

Results of mathematic and programmed modeling in terms of made research satisfy the demands of confirmation of the accordance of the quality of automotive internal combustion engines to European quality standards.
9. Conclusion
Research results became a further development of theory and methods of digital signals’ deductive processing [4].
Veracity of research results is proved by their accordance well-known results of perspective processing of digital DFT methods and algorithms for diagnostics automotive internal combustion engines by their vibroacoustic parameters [9].
Suggested formalization of necessary and enough condition of vibrations of working automotive internal combustion engine automatic control by digital MDFT methods without completing multiplication operations allows lowering software costs with hardware and software realization of calculative algorithms of such control on PLD.

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