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Educational Implementation of a Sound Level Meter in the LabVIEW Environment

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As a consequence of recent implementations of EU Directives related to noise protection more and more students of various AGH-UST programs are introduced to the basics of acoustic measurements. Students at various levels of theoretical background in the field of acoustic measurements are offered practical training in measurements using digital sound analyzers. The situation would be optimal if each student could have a device at his/her own disposal. Unfortunately, such a situation is not possible at the moment because of various reasons.

With the above problem in mind, a dedicated software package has been developed, implemented in the LabVIEW environment, which allows detailed studies of problems related to the acoustic signal measurement using sound level meters, as well as tasks in spectral analysis (1/1 and 1/3 band filters) and narrow-band (FFT) analysis. With such organization during the introductory laboratory classes each student is offered a direct individual contact with a virtual device that is properly pre-programmed for realization of a well-constructed learning process. It definitely facilitates understanding of the essence of acoustic signal measurements and provides a good basis for further laboratory work carried out as a team-activity.

Keywords: LabVIEW, acoustics, sound level meters, microphones, free-field investigation, frequency responses.

1. Introduction

Because of the recent implementation of EU directives, which put a special emphasis on the noise protection problems, there is a growing need for education and training of students in that field. At AGH-UST, in addition to the specialized classes for students of the Vibroacoustics program, there are many classes for students with a much weaker background in acoustics (e.g. from Mining or Geology Departments). Even after listening to the lectures on Acoustic Metrology, the practical measurements of the acoustic signal and their interpretation often seem to present serious problems for these students.

Laboratory activities related to acoustic measurements have to start from a general introduction covering the metrological features and functioning of sound level meters. Only after such introduction the student can start the routine acoustic measurements (e.g. in their work environment or external locations), or some more specialized tasks (e.g. measurements of the acoustic power, reverberation times etc.). It would be optimal if every student could have a separate measuring instrument at his/her disposal. Individual execution of the measurement exercises by each student adds much to the effectiveness of the learning process. Unfortunately, because of the rapid growth in the number of laboratory groups and the number of students in each group and because of considerable cost of professional devices for sound measurement such a situation is not expected to happen in the near future.

At present, in the Polish technical practice the predominant share of professional equipment for acoustic measurements consists of devices made by two Polish companies: Svantek and Sonopan, as well as two well-known global brands: Danish Brüel & Kjær and the Norwegian Norsonic. Most frequently those devices are digital sound analyzers with built-in sound level meters whose indivual cost is very high – ca. several thousands of Polish zlotys. The detailed price depends on the included software and the number of additional functions of the device.

A professional sound level meter must conform to the Polish standard PN-EN 61672 (2005) and is subject to legal metrological verification – obligatory type approval according to the regulation of the Polish Ministry of Economy (2007). At present, the cheapest professional devices conforming to the above-mentioned requirements are produced by the Sonopan company. It manufactures only sound level meters with a function set conformant to the function set required by the standard PN-EN 61672-1 (2005) and the government regulation by the Polish Ministry of Economy (2007). Still the cost of such a device exceeds many times the prices of non-professional devices made in China, like AZ8921 or Monacor SM-2. The Chinese devices include the manufacturer's declaration of conformity to the standard PN-EN 61672-1 (2005) which is printed on their cases. There are also companies that issue calibration certificates for such devices. The combination of price, declaration of conformity, and/or calibration certificate creates a situation when these devices are frequently purchased, used, and even applied for the teaching practice. Only those well aware of the regulations related to the legal metrology and professional measurement are able to evaluate the actual value of such devices. In practice these measuring devices do not conform to many standard and legal requirements and cannot be calibrated by standard methods (PN-EN 61672-3, 2007). Thus, one cannot ensure the reliability of the results obtained from such measurements.

The problems with the lack of availability of a sufficient number of professional sound level meters and that prevents an effective realization of laboratory activities have lead to the concept of implementation of an educational sound level meter in the LabVIEW environment. We decided to use LabVIEW because its functionality and exibility has been proved in many different research studies (Trojanowski, Wiciak, 2010; Barański, Batko, 2011). An attempt has been made to construct and implement a laboratory measurement setup which could offer the students a possibility to gain a thorough and more detailed knowledge of the problems related to the acoustic signal measurement using sound level meters, as well as frequency band analysis (1/1 and 1/3 octave filters) and narrow-band Fourier analysis (FFT). The software package written for the above-mentioned measurement setup has been labeled as LVSLM_EDU_v1 (shortened from: LabVIEW\Sound_Level_Meters\EDUcation\version1). The actual implementation is based on the solution presented on 15th International Conference Noise Control 2010 (Barański R., *Low Cost Sound Level Meter Based On LabVIEW*).

The software presented on 15th International Conference Noise Control 2010 has been subject (in combination with the soundcard of Dell E1405 laptop computer) to the tests that are routinely applied to professional sound level meters during their periodical check-ups, according to the standard PN-EN 61672-3 (2007) and respective measurement procedures used in the Laboratory of Vibroacoustics (Wszołek, Kłaczyński, 2008). The results of those professional tests for such an unprofessional measuring device have been found to be quite satisfactory and enhanced the authors' motivation to a further activity in the proposed direction.

The present paper describes the effects of adaptation of the above-mentioned software to the requirements of teaching practice and detailed investigations of microphones used for the computerized measurements. Due to implementation of the LVSLM_EDU_v1 software each student (each of 15 people in a laboratory group) will be able to have a separate device for his/her own use. Visualization of selected problems will definitely facilitate the process of assimilation of the necessary knowledge related to acoustic measurements.

2. The software concept – basics of acoustic measurements

After assimilation of the basic ideas related to the acoustic phenomena the students proceed to studying devices used for acoustic measurements and respective measurement methods. The basic concepts used in the introduction are: sound (and the related subjective impressions), acoustic pressure (and the decibel scale), sound spectrum, acoustic field and types of acoustic signals. The basic knowledge regarding measuring devices has to include the sound level meter, measurement microphone, and band filters. If this basic knowledge is purely theoretical the student, after laying his/her hands on the device (at present often an advanced digital sound analyzer), will carry out measurements without actually knowing what he/she is doing at the moment. There are some digits flashing on the display of the device that in most cases are rather hard to understand and properly interpret. Therefore, it is very important that the freshly acquired theoretical knowledge is instantly implemented in practice. Namely, the student should instantly "feel, hear, and see" the effects of the device's settings on the measurement results.

The practical teaching experience of the authors of the present work indicates that the best effects in teaching sound level measurements are achieved by a simultaneous presentation to the students of both analog and digital meters. In such a situation students more promptly acquire the proper way of configuring the device in the context of a specific type of measured signal.

The learning process referring to the scope of the basic ideas used in the acoustic measurements has to start from an introduction to the sound level meter and the following actions:

- switching the device on (various solutions in various device types by various manufacturers sometimes make the process not-so-simple),
- setting the proper measurement range,
- setting the proper frequency weighting (A, C, LIN/Z),
- setting the proper time weighting (Fast, Slow, Impulse),
- configuration of the measured (and/or read-in) parameters of the measured quantity (momentary effective value SPL, maximum sound level, minimal sound level, peak-value sound level, equivalent sound level, sound exposure level),
- setting up the measurement time,
- device calibration using a reference sound source (acoustic calibrator) to the sound level declared by the manufacturer of a given device, in its reference range (if the device offers more than one measurement range).

Understanding of the dependence between the measurement results of individual parameters shown by the device and the generated and simultaneously heard acoustic signal is more easily gained when the analog indicator scale is observed. Thus, students learn faster how to set up properly the time characteristics or the measurement range.

Also, a visual presentation of the spectral analysis of simple signals (noise) without any correction curve (LIN/Z) followed by the same presentation with specific frequency weightings (A, C) leads to a fast comprehension of the effects of frequency characteristics on the measurement results and the connection between the correction effects and the human subjective impressions.

The decibel scale and understanding of the dependence between an equivalent value of the sound level and a momentary measured value are also frequently difficult to grasp for students. This is much easier to understand if the knowledge is presented in a visual mode.

Only when the student comprehends the abovementioned basics of measurements, when his/her knowledge has been verified by practical measurements of various signal types under the supervision of a teacher, he/she is ready for the individual (in practice in a student's group) laboratory practice dedicated to specific types of measurements (e.g. traffic noise, industrial noise, acoustic power).

Implementation of the educational sound level meter in the LabVIEW environment (appended by the signal spectral analysis and FFT functions) allows the student to study in detail the properties of sound level meters and perform simple, evaluating measurements on his/her own using a dedicated computer setup.

3. Educational setup – VSLM_EDU_V1 software package

The main objective of the elaborated software for simulating functioning of a sound level meter, spectral analysis, and narrow-band frequency analysis is to prepare the user for working with real, professional measuring devices. Therefore, the program is equipped with the most frequently used measurement functions encountered in standard digital sound analyzers.

The student equipped with a PC computer with the LVSLM_EDU_V1 software, soundcard, microphone, and a set of headphones for monitoring the generated signals, can easily and without excessive costs study the basics of acoustic measurements and signal analysis. The software allows the analysis of exemplary acoustic signals selectable from a pull-down menu (e.g. real recordings of the traffic noise, industrial room environment noise) and the analysis of signals received by a microphone in the actual laboratory environment (e.g. signals generated by the extra equipment used by the supervising teacher).

Such a solution allows direct observation of the reaction and reading changes on the virtual measuring device caused by an arbitrary acoustic signal registered by the measuring system. Practical experience suggests that such a visual presentation provides the fastest progress in understanding the work of a professional sound level meter.

The authors of the paper, being aware of the errors occurring in the readings of the virtual meter, have carried out a series of tests concerning the accuracy analysis of the results obtained from a virtual instrument based on a low-cost soundcard and a microphone routinely used in standard measurement solutions. The results of the electrical tests executed by measurement procedures (Wszołek, Kłaczyński, 2008) conformant to the standard (PN-EN 61672-3, 2007) have been presented on 15th International Conference Noise Control 2010. The acoustic studies of low-cost, generally available microphones dedicated to the present measurement setup are described in Sec. 5 of the present paper.

4. Description of the LVSLM_EDU_V1 application

The LVSLM_EDU_v1 program has been developed in the LabVIEW 2010 (32-Bit) environment (LabVIEW 2010, Help, National Instruments Corp., 2010). Additionally, functions implemented in the Sound and Vibration Toolkit ver. 2010 (NI Sound and Vibration Measurement Suite, 2009) have been used. The main application window of LVSLM_EDU_v1 is shown in Fig. 1. Further-on the complete computer measurement setup together with the necessary software will be labeled as a single term "measuring device".

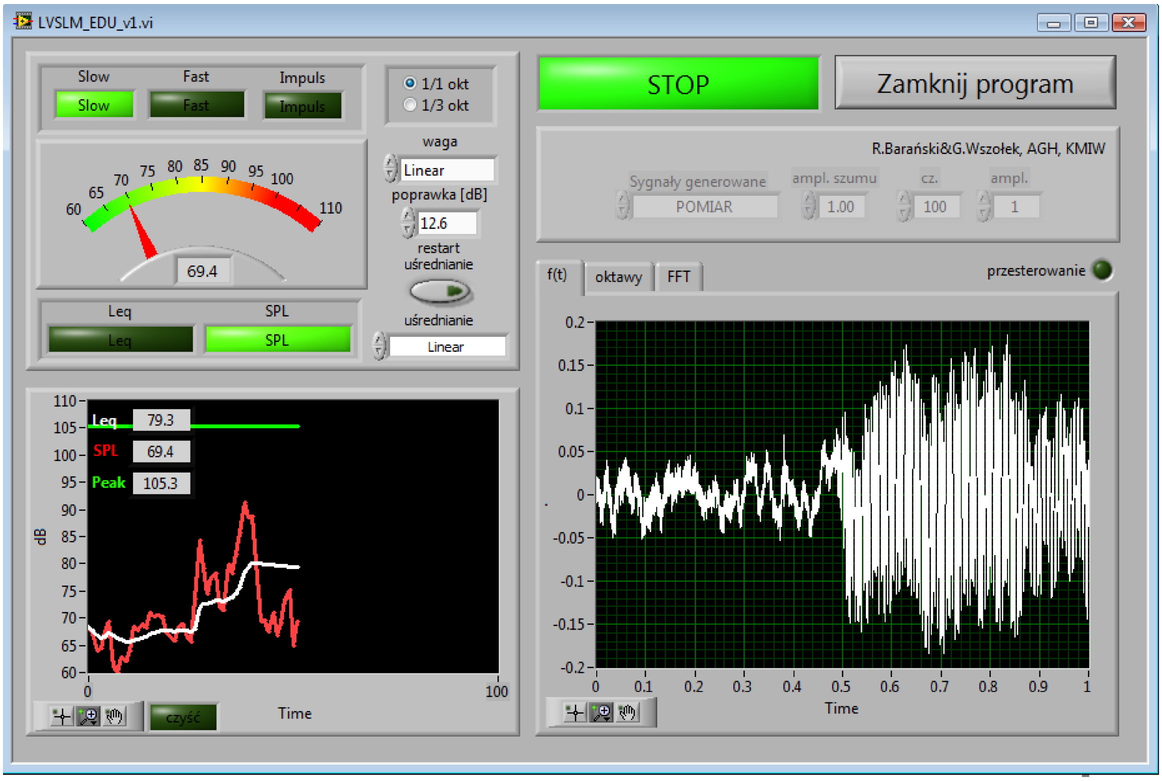

Fig. 1. Main application window of LVSLM_EDU_v1.

The main application window has been split into four sections: SIGNAL, SETTINGS, ACOUSTIC PARAMETERS, SPECTRA (see Fig. 1). Each panel (excluding the SIGNAL) reflects the basic measurement functions implemented in the sound level meter and its enhancements covering the spectral and narrow-band signal analyses.

Additionally, the main window includes two buttons executing respectively switching the meter on and off (START/STOP) and closing the main application window (Exit program).

4.1. The "Signal" section

In order to ensure the ability to simulate the functioning of a real device the virtual meter has been prepared to operate with several signal types, both simulated and real (Fig. 2).

Fig. 2. SIGNAL section.

The list of signal types that can be analyzed by the virtual meter looks as follows:

- sinusoidal signal,
- sinusoidal + pseudorandom signal (Gaussian noise distribution),
- pink noise,
- traffic noise (registered in the Mickiewicza alley in Kraków),
- industrial noise at a construction site (work of an excavator and pneumatic hammer).

For every generated signal type there is a possibility of changing the settings (parameters like amplitude and/or frequency).

The last option in the SIGNAL section is the MEASUREMENT. It allows registration of the sounds present in the local neighborhood, using the computer's soundcard and a connected external microphone.

4.2. The "Settings" section

The panel of the SETTINGS section is shown in Fig. 3. That section is used for a proper configuration of the measurement session i.e.:

- Setting the proper time weighting (Fast, Slow, Impulse),
- Selection of the measured and read-in parameters of the measured quantity (momentary effective value SPL, peak-value sound level, equivalent sound level),
- Activation of the proper frequency weighting (A, C, LIN/Z),
- Selection of the averaging type (Linear, Exponential),

- Calibration of the device using a reference sound source (acoustic calibrator),
- Selection of the frequency bandwidth for spectral analysis.

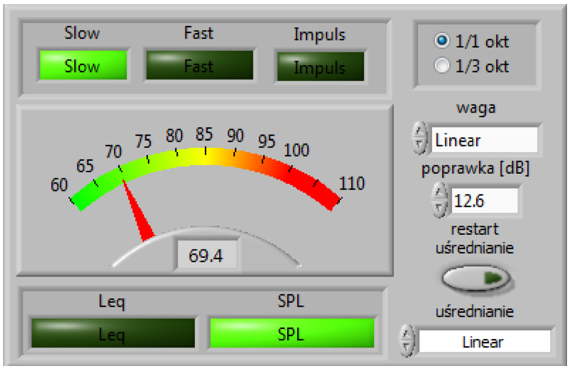

Fig. 3. Window of the SETTINGS section configuration.

In the central part of the SETTINGS section the analog and digital indicators are located, which is a direct reference to the indicators on the sound level meters – both in the analog (pointer on a scale) and digital (a window displaying the results in dB) versions. Such a visual presentation of changes of the measured quantity (by both pointer movement and changing digits) allows the students to observe the effects of setting the respective time characteristics (Fast, Slow, Impulse) on the measurement results. It also allows a direct observation of establishing the *equivalent level* (L_{eq}) or *momentary value* of *Sound Pressure Level* (SPL) for the analyzed signal.

An essential element is the averaging used in the process of calculating the L_{eq} value. The available averaging modes *Linear* or *Exponential* are restarted automatically after each initiation of the measurement or manually by using the *restart averaging* button.

Since the device offers the ability to perform measurements with an arbitrary type of a soundcard plugged into the computer, a dedicated element has been implemented, responsible for the calibration of the measuring system. For that purpose a special calibration correction, specified in dB, is taken into account in the signal processing line. During the system calibration, using a professional acoustic calibrator (e.g. B&K type 2231), the student specifies the proper correction value, so that the LVSLM_EDU_v1 software can adjust the result to the proper calibration value (e.g. 94 dB). In order to ensure a proper calibration of the signal processing line, a special matching adapter has been prepared, matching the atypical microphone size to the housing in the professional calibrators. The authors of the paper are fully aware of the importance of matching the proper adapter to the calibrator. It has been proved that the adapter directly affects calibration results. However, for educational purposes, the accuracy of calibration described above is quite sufficient. The calibration procedure itself is intended to develop in students the habits of professional measuring personnel – the awareness of performing the device calibration before and after measurements.

4.3. The "Acoustic Parameters" section

That section allows observation of the history of changes for the basic parameters used in the current acoustic measurement, like L_{eq}, SPL, or Peak (Fig. 4). Such a presentation offers the user the possibility to understand the differences in calculation of these three parameters. Additionally, by comparison it is easy to notice how the parameters influence each other and what the possible consequences of this are.

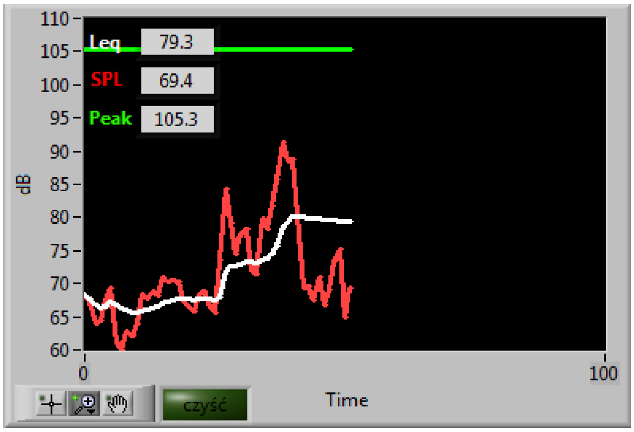

Fig. 4. Window of the ACOUSTIC PARAMETERS section.

The best example is provided by observation of the strong effects of a very high momentary SPL value on the values of L_{eq} and their changes in consecutive averaging results.

4.4. The "Spectra" section

That section allows observation of the history (Fig. 5). In order to introduce the student to identification of individual characteristic frequencies in the analyzed signals, a separate FFT tab allows observation of *Fast Fourier Transform* (FFT) analysis results. It is particularly useful in the analysis of signals with strong monoharmonic components like those during the calibration of the measurement system. Another tab called Octave allows presentation of the frequency spectrum of the analyzed signal using the octave filters (1/1 octave) or tertiary filters (1/3 octave).

The program allows presentation of the frequency spectra of the analyzed signal, calculated with various frequency weightings A, C, or LIN. The user is offered the choice to switch on/off an arbitrary frequency correction characteristic.

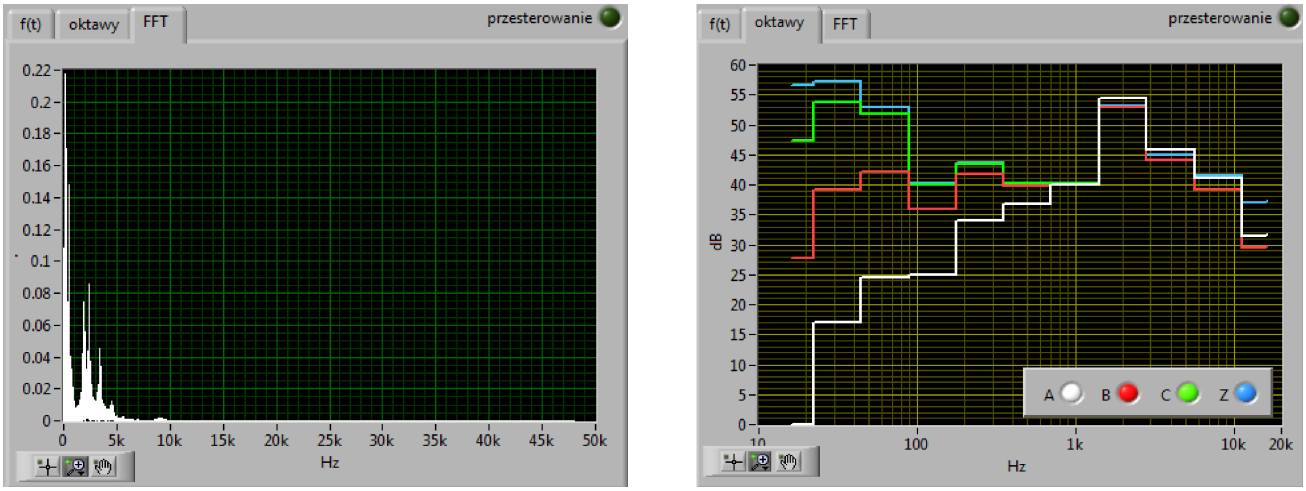

Fig. 5. Windows of the SPECTRA section for FFT and Octave tabs.

5. Examination of the microphones in free field

As mentioned before the tests of the implemented sound level meter SLM_LV_1.2c, which provided the basis for the development of the LVSLM_EDU_v1 software, have been presented on 15th International Conference Noise Control 2010. They have been carried out according to Sec. 3 of the standard PN-EN 61672 dedicated to the periodical check-ups. They did not include determination of the frequency response of the implemented device or examination of the microphones.

The present paper describes the examination of two types of widely available low-cost microphones that can be used in the described educational measurement setup. Because they are not measurement microphones, conformant to the standard – they cannot be examined using typical indirect methods (e.g. by electrostatic actuator method) according to the above-mentioned standard (PN-EN 61672-3, 2007) or dedicated standards for calibration of measurement microphones (PN-EN 61672-3, 2007). The microphones had to be examined in free field conditions (in anechoic chamber), by a direct determination of the frequency response of a given microphone or the whole meter. Examinations have been carried out for two types of microphones: MM10 and Digitus. Figure 6 presents the overall view of the whole measurement setup in the anechoic chamber.

The microphones have been tested according to professional rules applied for determination of device characteristics during acoustic measurements in free field conditions (Wszołek, Engel, 2004; Engel, Wszołek, 2004; Wszołek, Barwicz, 2007; Wszołek, 2008). During the tests, fully professional equipment has been used including a measurement system used for calibration of acoustic devices, based on the *PomAk* (Wszołek *et al.*, 2006) computer program. An LW2 class microphone – Brüel & Kjær type 4191 – was used as the reference (standard) one.

Fig. 6. Overall view of the measurement setup in the anechoic chamber.

In order to determine the "averaged" frequency characteristics for the examined microphones, 11 pieces of each microphone type have been examined. During the microphone tests the integrated soundcard of a Lenovo laptop computer has been used as a preamplifier. The installed ASIO drivers were responsible for transferring the signal to the headphone outputs where further analysis took place. The microphone characteristics have been determined for 0° wave incidence angle.

Figure 7 presents the average frequency response for both types of microphones. The figure also includes the tolerance limits for frequency characteristics of class 2 sound level meters, conformant to the requirements of part 1 of the standard PN-EN 61672 (2005).

The microphone characteristics can be subject to small changes due to the detailed features of its connec-

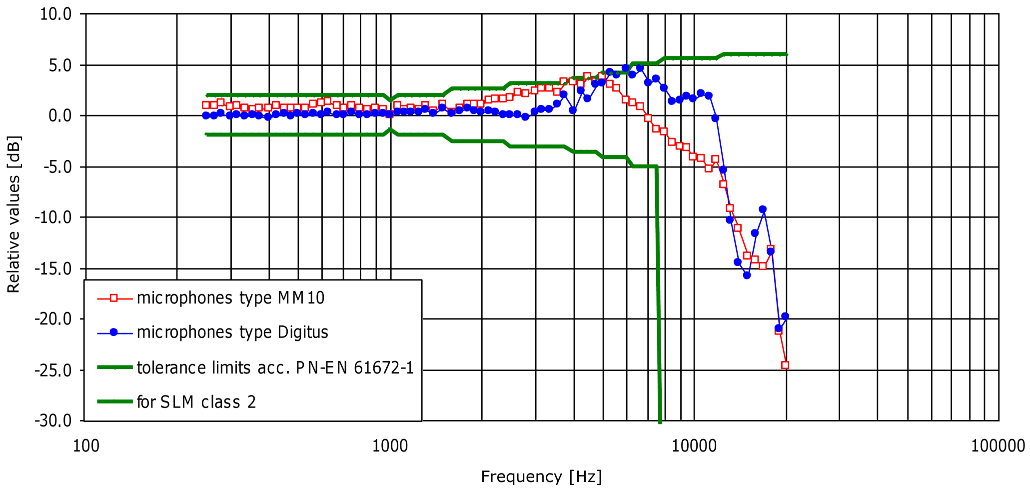

Fig. 7. Average frequency responses (typical characteristics) for MM10 and Digitus microphones, determined in free field conditions, for wave incidence angle 0°.

tion to the measurement system (the soundcard). However, the results of the study seem to be satisfactory and there are no objective arguments precluding such low-end microphones from being used in education-dedicated laboratory setups.

6. Conclusions

The present work is a continuation of the study presented on 15th International Conference Noise Control 2010. It describes the effects of adaptation of a specialized software developed in the LabVIEW environment for educational applications. The presented computer-based measurement setup is intended to offer the students a thorough and more detailed understanding of the problems related to acoustic signal measurements using sound level meters and frequency band analysis (1/1 and 1/3 octave filters), as well as the narrow-band Fourier analysis (FFT).

The concept of elaboration of such a virtual measurement setup has been born during the teaching activities in the Chair of Mechanics and Vibroacoustics, namely, during the laboratory classes with students with strongly varying levels of theoretical knowledge in the field of metrology and acoustics. Most frequently, the knowledge concerning the acoustic metrology is not sufficient for its correct implementation in practice. The flaws in proper understanding of the basic concepts and errors in a practical configuration of a sound level meter (setting the time constants and meter calibration) result in errors during execution of measurement and further interpretation of the results.

During the laboratory activities the actual number of students taking an active part in the measurement is limited because of the small number of available measuring devices, while the number of people in the laboratory groups is growing. In consequence, after completing the laboratory class, the majority of students still do not possess the necessary skills in operating the sound level meter at a competence level necessary for carrying out sound measurements (both routine and more specialized ones) and proper interpretation of the results.

Application of the LVSLM_EDU_v1 virtual sound level meter with the implemented additional measurement functions will allow a wider number of students to have an individual contact with the measuring device starting from the first introducing laboratory class. The educational scope of the described application covers the necessary knowledge in the field of acoustic metrology. Understanding and internalization of the concepts, practical knowledge of the device settings and its calibration will definitely have positive effects during the following classes and performing of specific sound measurement (e.g. in external environment, on a specific working post, determination of the acoustic power of devices etc.). The laboratory classes can be organized using standard PC computers available in the computer rooms used for teaching information technology.

The proposed software is dedicated purely to educational purposes. The important part is to inform the users that the software cannot replace any professional measuring devices in the same way as professional measuring devices cannot be replaced by low-cost, non-professional devices for sound measurements that do not conform to the requirements of the respective legal acts and standard regulations.

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