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The vibration registration system with the use of a seismic sensor and a real-time spectrum analyzer in the room intended for the TERS-STM system installations

***Abstract**. Modern measurement techniques such as STM and TERS-STM offer the possibility of imaging with atomic resolution, but at the same time they are extremely sensitive to vibrations. The authors of the article proposed a vibration registration system using a seismic accelerometer and a real-time spectrum analyzer, allowing for long-term vibration recording. Appropriate presentation and analysis of the collected data allow for the optimal selection of the room with the lowest level of vibration.*

Streszczenie.** Nowoczesne techniki pomiarowe takie jak STM i TERS-STM oferują możliwość obrazowania z rozdzielczością atomową, ale jednocześnie są niezwykle wrażliwe na wibracje. Autorzy artykułu zaproponowali system rejestracji drgań wykorzystujący akcelerometr sejsmiczny i analizator widma w czasie rzeczywistym, pozwalający na długoterminową rejestrację drgań. Odpowiednia prezentacja i analiza zebranych danych pozwala na optymalny dobór pomieszczenia o najniższym poziomie wibracji.* (System rejestracji drgań z wykorzystaniem czujnika sejsmicznego i analizatora widma czasu rzeczywistego w pomieszczeniu przeznaczonym na instalacje systemu TERS-STM***)

Keywords: vibration measurement, seismic accelerometer, real-time spectrum analyzer, TERS-STM.
Słowa kluczowe: pomiar drgań, akcelerometr sejsmiczny, analizator widma czasu rzeczywistego, TERS-STM. Słowa kluczowe:

Introduction

Among the many problems associated with the use of precise measuring equipment, one of the most important is to provide a room with a low level of vibrations.

An example of such a precise optical measurement technique is TERS-STM (Tip Enhanced Raman Spectroscopy - Scanning Tunneling Microscope), which is based on the strong enhancement of inelastic Raman scattering with the use of the STM tip illuminated with focused laser light [1-3].

The STM microscope itself is an extremely sensitive measuring instrument. It enables in the real space imaging of the atomic [4] and molecular structure [5], based on the measured tunnel current between the investigated sample and the probe tip.

Typically, the distance between the STM tip and the sample surface during the measurement process is less than 1 nm [6,7], and the tunnelling current changes tenfold for a 0.1 nm change in distance [8]. For this reason, it is important that the measuring system is not exposed to external vibrations coming from building. Otherwise, vibrations may not only affect the tunnel junction, but also cause the probe to crash the sample surface uncontrollably.

Measuring systems are usually equipped with active and passive external vibration elimination systems. The STM head is also isolated inside the system from vibrations by suspension on springs and the use of eddy current damping system.

If possible, vibration-sensitive measuring equipment should be installed in a specially designed and built facility that provides single or double separation of the ground on which the equipment is located from the foundations of the building [9]. If such a solution is not possible, it is very important to check the vibrations of the building and to choose a suitable room with the least possible vibration.

In the article, we present a solution to the problem of vibration detection and registration based on a seismic accelerometer and a real-time spectrum analyzer. The research was conducted in the building of the Faculty of Physics and Applied Informatics of the University of Lodz. The building is located 100 meters from a very busy street with tram traction.

Considering the high weight of the STM system and the lower level of vibrations in the lowest floors of the buildings, the choice of rooms was narrowed down to those located in the basement and on the first floor of the Faculty building.

The assessment of the impact of vibrations on buildings and on people in buildings is regulated by two Polish standards: PN-B-02170 and PN-B-20171 [10,11]. The methods of measuring vibrations affecting people in buildings differ from the methods of measuring the impact of vibrations on buildings, therefore, during data recording, the analogy of the impact of building vibrations on the sensitive STM measurement system was adopted, as on a person in the room. The measurement points were located in the center of the room, exactly where the equipment would be installed. The RMS (root mean square) value of vibration acceleration (ms^{-2}) or vibration velocity (ms^{-1}) in the frequency range from 1 Hz to 80 Hz is most often used to evaluate vibrations.

The authors of the solution wanted the possibility of long-term study of possible disturbances. The proposed solution allows for continuous recording of the vibration level lasting from several minutes to several days.

Measuring system

The measuring set is shown in Fig. 1, it consists of:
- Wilcoxon Model 731A seismic accelerometer,
- dedicated P31 power supply/amplifier,
- Tektronix RSA3408A real-time spectrum analyzer with measurement data output module (Option 05),
- data acquisition card PCI64-HPDI32A General Standards Corporation,
- a PC with a 64-bit PCI slot

The seismic sensor is equipped with a piezoelectric sensor, with a dedicated amplifier offers a frequency response of 0.05 Hz - 450 Hz in the accelerometer mode and 1.5 Hz to 150 Hz in the vibration velocity measurement mode. For our purposes, we chose the second mode where the output signal can be amplified to 10 V/in/s. Importantly, the amplifier is powered only from two 9V batteries, ensuring that the interference from the power supply network is not transferred to the signal spectrum.

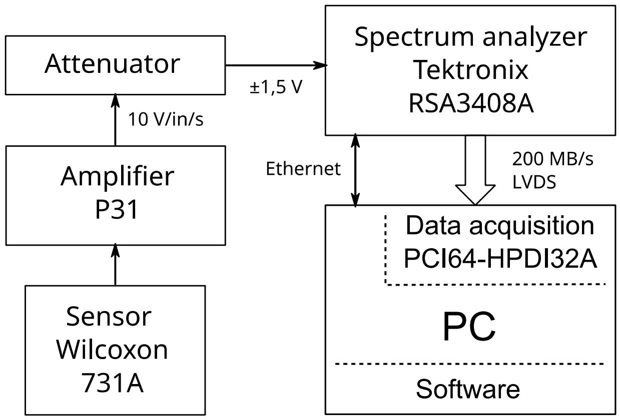

Fig.1. Diagram of the measuring system

The Tektronix RSA3408A real-time spectrum analyzer can analyze signals with frequencies in the range from 0 Hz to 8 GHz and is designed for radio applications. The 50 Ω signal input allows a voltage range of ±1.5 V, so it was necessary to use an attenuator.

The spectrum analyzer is equipped with an extension "Option 05", enabling the export of data in the form of digital samples. Two 16-bit samples are sent to the acquisition card simultaneously via Low-Voltage Differential Signaling interface (LVDS). Such a connection enables real data transfer to PC at the level of 200 MB/s.

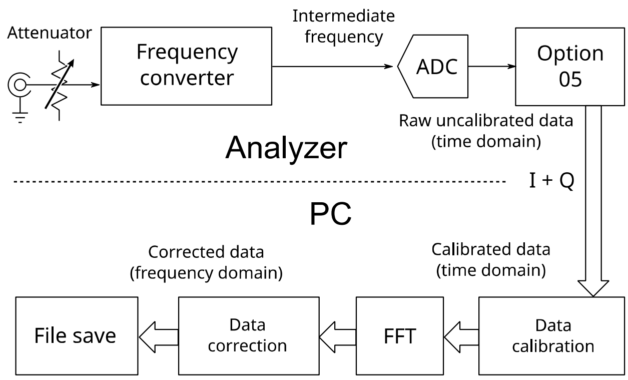

Fig.2. Signal processing

An additional connection to a PC via the Ethernet interface is necessary to simulate the virtual GPIB (General Purpose Interface Bus) interface, which is used to download calibration and correction parameters from the analyzer.

Signal acquisition and data correction

The RSA3408A real-time spectrum analyzer is capable of sampling a 36 MHz intermediate frequency signal at 102.4 MSps with a resolution of 14 bits. This data is then digitally converted to 16-bit "I" and "Q" samples depending on the span. Such uncorrected time-domain signal samples are stored in the internal memory of the analyzer and can be transferred to a PC. Raw data must be corrected by certain calibration values (in the time domain) and correction values (in the frequency domain). These values are unique for each analyzer. The built-in analyzer software automatically performs corrections before the spectrum is calculated and displayed on the screen, however, when we download raw data, these procedures must be done by the user's software. The signal processing method is shown in Figure 2.

When recording slow-changing signals representing vibrations, the span used was 100 Hz, the sampling time of the data set was 8 s and with this interval the PC software downloaded, processed and saved the data file.

In each of the selected rooms vibration data has been collected continuously for a period of about 5-8 days.

Collected data and its presentation

A single collected spectrum is shown in Fig. 3 (graph "a" - black). Attention is drawn to the marking of the Y axis (scale from -140 to -60), where we read the signal intensity from the spectrum analyzer scaled in dBm power units, instead of the vibration speed.

In order to check the reliability and to calibrate the collected spectra, a professional vibration meter Svantek SVAN 958A with the SV84 sensor was borrowed. For a week, both measuring systems have been simultaneously collecting the same vibrations from the same measuring points.

The presented spectra (Figure 3, graphs "a" and "b") overlap, and the only visible differences may result from different vibration acquisition times: 8 seconds for the RSA3408A spectrum analyzer and 10 seconds for the SVAN 958A vibrometer. The Wilcoxon sensor measures the "z" axis only, while the Svantek sensor is triaxial, and for comparison only the "z" axis measurement data is presented. For the "b" spectrum scaled in decibels, the reference level is 1 nm/s. Spectrum "c" shows the same data as graph "b", but in a linear scale in µm/s.

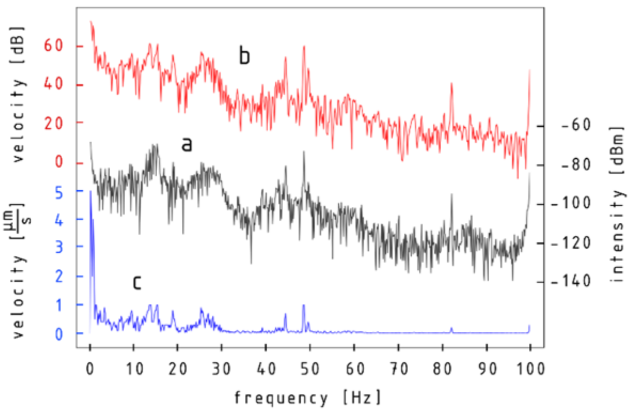

Fig.3. Comparison of spectra measured with the RSA3408A analyzer (graph a - black, dBm units) and the SVAN 958A vibrometer (graph b - red in decibels). The blue color (c) indicates the spectrum (b) drawn in a linear scale in µm/s.

In dedicated rooms, the measuring system collected a total of over 500,000 spectra. In order to visualize such a large amount of data, dedicated software was developed to enable the presentation of spectrum changes over time, e.g. in the form of a waterfall spectrogram.

Figure 4 presents data collected from four different rooms. The horizontal axis represents the time from 0:00 to 23:59:59. Graduations mark the start of full hours (every two hours). The ordinate axis of each spectrogram represents the frequency from 0 Hz to 100 Hz. The intensity scale of all presented spectrograms is the same and is presented in the left part of the figure.

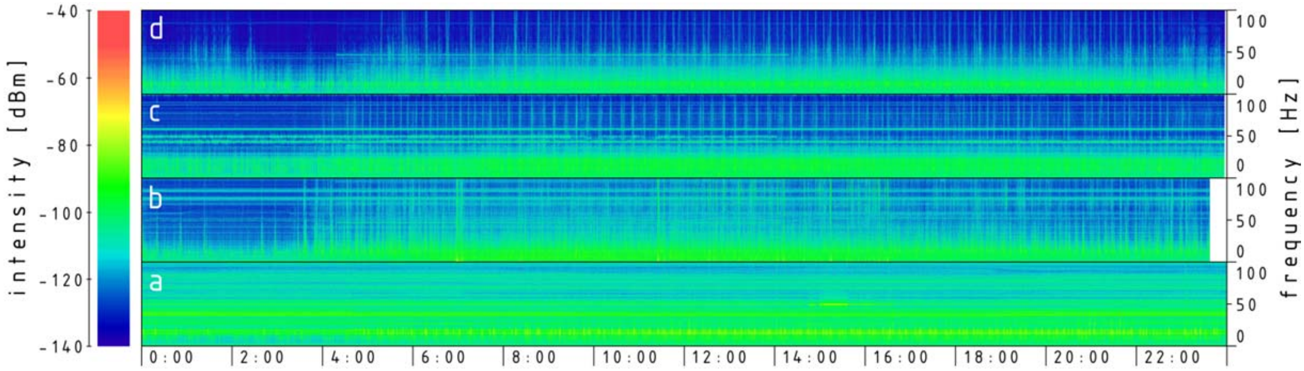

Fig.4. Waterfall spectrograms representing rooms "a", "b", "c" and "d". Based on the recorded vibrations, it is possible to observe the different character of the rooms

The spectrograms clearly show the different nature and level of vibrations in selected rooms:

- Room "a" located on the first level of the building - data collected on April 18, 2022 (Easter Monday). The spectrum is almost uniform around the clock, which is related to the fact that the data was collected on a holiday. Staff and students were absent and there was little traffic on the streets. However, the spectrogram is characterized by the highest level of various vibration frequencies. This is most likely due to the location of the room in the building and is confirmed in Figure 5.

- Room "b", also located on the first level of the building - data collected on April 5, 2022 (Tuesday, working day). The spectrogram around 7:00 a.m. shows an increased level of vibrations in the entire frequency range, which may result from the cleaning service entering the room. Slightly increased periodic vibration intensity until 4:30 p.m. may be related to the presence of students near the room (there are laboratories nearby).

- Room "c" located in the basement of the building - data gathered on May 28, 2022 (Saturday), the room is located under the laboratories with UHV equipment, where preliminary vacuum rotary pumps or aggregates may operate periodically, which is visible by the presence of components with frequencies from 43 Hz to 58 Hz and around 90 Hz.

- Room "d", also located in the basement of the building, under room "b" - data collected on May 15, 2022 (Sunday, no classes on the floor above). The spectrogram is characterized by the lowest level of vibration, especially above 50 Hz.

On most of the spectrograms shown, the reduction of vibrations during the night hours is clearly visible. Public transport starts at around 4:00 a.m. and lasts until 11:00 p.m. The cyclical disturbances visible for this reason most likely come from the tram or truck rolling stock [12, 13, 14] and are of a similar nature throughout the day. The impact of the movement of lighter passenger cars is imperceptible.

The signal with a frequency of 47 Hz is also interesting, it appears every day in most rooms at 4:20 a.m. and disappears after 2:00 p.m., which is related to the operation of forced internal ventilation in the Faculty building.

Data analysis and comparison

Presentation of the collected data as a waterfall spectrogram gives qualitative information about the nature and level of vibrations in the room. However, it is difficult if we want to compare data collected from several rooms over many days. For this reason, it was decided to aggregate the data for each room in the form of one chart. Each spectrum contains intensity information for a defined set of frequencies. Having a set of spectra, it is possible to calculate the intensity occurrence histogram for each frequency separately.

Figure 5 presents a collective history of vibrations based on all collected data for the presented rooms. The colour depends on the number of occurrences of each intensity for a given frequency. The figures also show the maximum recorded vibration intensity.

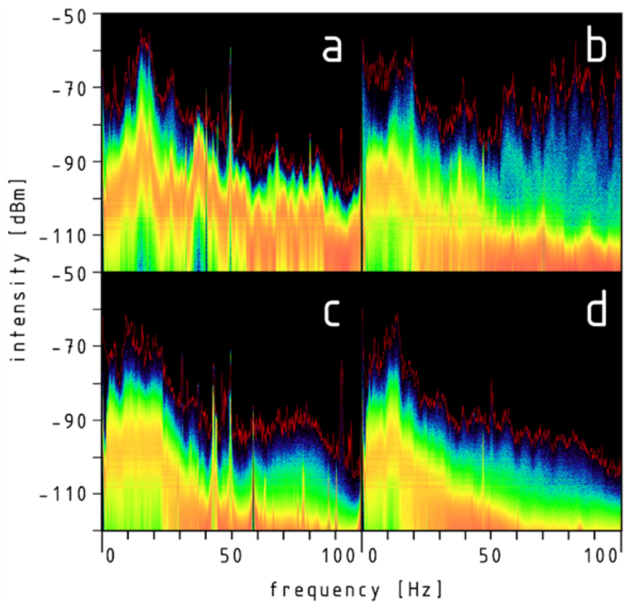

Fig.5. Summary information on registered vibrations for selected rooms

Figure 5 confirms earlier observations of vibrations presented as one day spectrograms, on the basis of which the following conclusions were drawn:

- Each chart can be divided into two parts: the frequency range up to about 25 Hz, and above 25 Hz. Each building has a specific natural frequency, usually from single Hz to 28 Hz [15,16], the natural vibration of our building is clearly visible on all charts and is about 13 Hz - 16 Hz.
- The source of vibrations visible in the shape of peaks is the equipment operating in the nearby rooms and in the further part of the building.
- Spectrum components distributed more gently, especially in the range of higher frequencies, represent interference from traffic and human activities in the building.

The presented system for recording floor vibrations together with the method of presenting the collected data allows for a clear assessment of the usefulness of available rooms in terms of location for the vibration-sensitive measurement system installation. Among the rooms mentioned above, room "d" is characterized by the lowest long-term level of disturbances, both of the building's own vibrations, as well as vibrations from the apparatus and the activity of employees and students.

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