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ATOMIC FORCE MICROSCOPE DATA POST-PROCESSING ALGORITHM FOR HIGHER HARMONICS IMAGING

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Abstract: Previous works have proved that higher harmonics topography imaging using atomic force microscope (AFM) can significantly enhanced its measurement capabilities. Integrated tools dedicated to most of microscopes allow to visualize the investigated surface only by one selected harmonic. Because of the different characteristics of a sample, scanning tip and the environment, appropriate harmonic selection is time consuming and requires multiple scanning. In addition, repeated scanning guarantees no precise location of topographic formations, because the sample may be displaced. The author developed a system that allows simultaneous recording of the excitation signal, tips response signal from the photodiode and synchronization signal during typical surface scanning. The author presents an algorithm that allows higher harmonics surface imaging using these stored data.

Keywords: atomic force microscope, harmonics, imaging, algorithm

1. INTRODUCTION

The atomic force microscope (AFM) [1] is a versatile tool for precise topography investigations. The surface is visualized by a measuring the scanning tip - sample atoms force [2]. The force is non-linear and is connected with topography substructures with different physical properties [3]. So that, in non-uniform materials the non-linear force results in higher harmonics, which can be measured and give more information about the sample [12, 5]. It is noted, that at edges of a topography substrates occurs a significant increase in the higher harmonics level. Moreover, higher harmonics are more sensitive to even slightest changes in a texture of a sample. The same phenomena can be used during corrosion research, where an additional electrostatic force may be easily detected by higher harmonics and indicate the portable location of defects in a protective coating of metal.

During typical surface imaging higher harmonics imaging is mostly unavailable or requires a few scannings to detect, which harmonic will be the most effective. That may lead to errors in topography measurements caused by sample displacement.

Higher harmonics imaging with simultaneous measuring more than one harmonic mostly requires expensive equipment and specialist software [6, 7]. In previous works [8] the author have presented a system for simultaneous higher harmonics imaging using a measurement board (Fig. 1). The described system allows storing excitation and response tip signals data. The method gives an opportunity to process the data after recording and requires no specialist hardware.

A disadvantage of the method is large disk space occupancy by stored data and time consuming post processing. So that it is important to elaborate a fast and reliable processing algorithm.

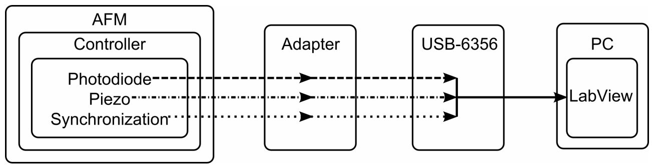

Fig. 1. Scheme of the measurement system [8]

2. DATA PREPARATION

Data recorded by NI USB-6356 and LabView software are stored in the Technical Data Management Streaming (TDMS) file format. The binary TDMS file format is an easily exchangeable, inherently structured, high-speed-streaming-capable file format that becomes quickly searchable with no need for complicated and expensive database design, architecture, or maintenance. Unfortunately, the format is incompatible with Matlab software. So that, files have to be converted into MAT type files.

During a typical measurement with 1 Hz scanning frequency, complete image takes about 34 files, each of 60,3 MB disk space. Converted files require in total 4 GB.

3. FOLDERS HIERARCHY

For faster further post-processing and better files organizing, a folder hierarchy presented in Fig. 2 was used.

The folder hierarchy is useful during files selection for subsequent processing steps, because it is possible to take all files from a proper folder without checking their names. That method is time saving and easier to implement than storing all files in one folder and choosing only proper ones for each processing step. Moreover, it gives an opportunity to postpone processing and resume it without no less of the data. The organization helps also debugging the program at each step.

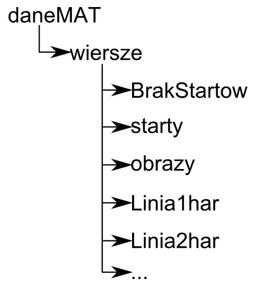

Fig. 2. Scheme of the folder hierarchy

4. ALGORITHM

The main program algorithm is presented in Fig. 3. At the beginning, user defines a processing folder (Step A). If any of the folders: *daneMAT*, *wiersze*, *BrakStartow*, *starty* and *obrazy* does not exist, is created (Step B). In Step C the first file from *daneMAT* folder is loaded and the synchro signal from the data is plotted (left graph in Fig. 4). Typically, the scanning frequency and the *synchro* state should be noted during a measurement, but if they are not, it is possible to read them from a plotted *synchro* signal. Moreover, the *synchro* signal can be offset. All the data are necessary to perform properly Step E and are saved in a file in *BrakStartow* folder.

Splitting and merging data files into row files are additional operations (Step E and F), which on first sight are redundant. It is possible to rebuild the program to skip this step, but during subsequent processing it turns out to be useful in data control (like number of rows) and merging rows during images creating (counting pixels for each row can be omitted).

In Step G all the moments, when *synchro* state is changing and indicates the start of pixel scanning, are detected and saved in *starty* folder for each row. If a processing error occurs and no starts are detected, the information is saved in a file in *BrakStartow* folder.

Step H is a main part of the whole program - for each pixel a lock-in amplifier procedure is performed (Fig. 5). As a result of the function, files with each chosen harmonics value for each pixel are saved in a proper folder (*Linia1har*, *Linia2har*,..., *Linia8har*). Each file is one row of the resulting image, so they are merged and plotted in Step K with user specified dimensions.

It is possible to stop the processing at each step, because all of them are independent. Before starting each function, the presence of a proper folder and files is checked.

Furthermore, not every harmonic image must be created during lock-in amplifier processing. For example, if the tip resonance frequency is too high relative to the sampling frequency. To prevent excessive processing, a user can select harmonics by checkboxes.

All images can be saved in *obrazy* folder in their original version or tailored to user requirements - after resizing and filtering. Application of each filter adds a name prefix to each saved image in order to distinguish it from the original one

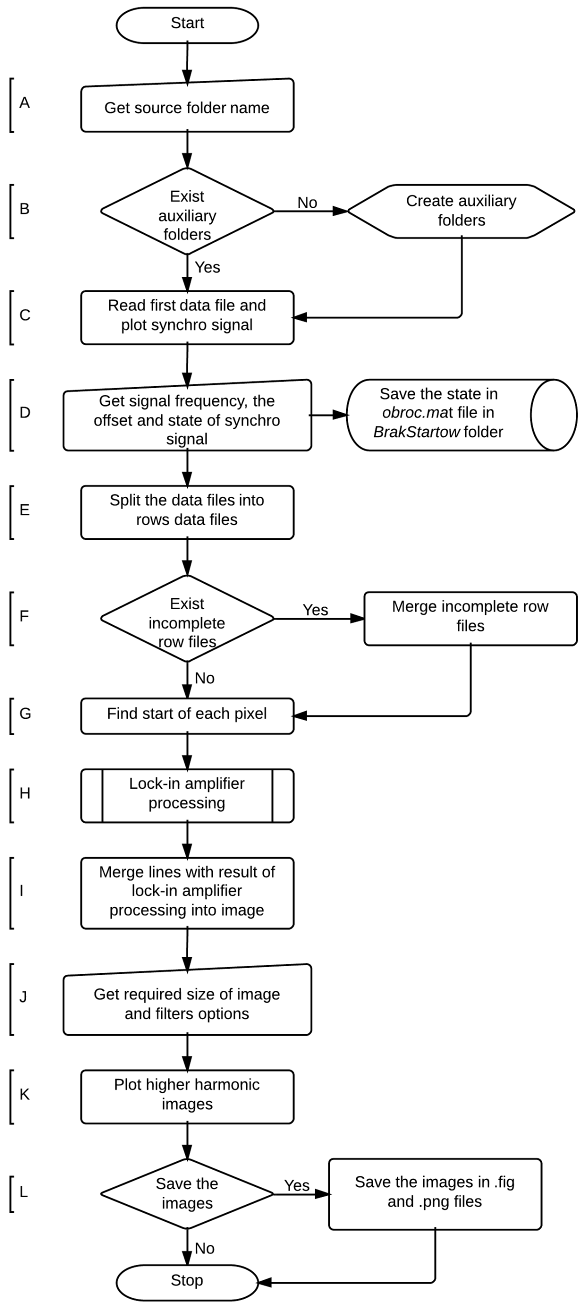

Fig. 3. Main algorithm

5. IMAGES

Secondary processing enables observation of the values of each row and column of the image (Fig. 6).

Data about the processing folder and user setting of the image size as well as used filters are transferred from the previous panel. If a user wants to change them, it is possible to do it by functions on top of the panel. In that case, the program validates the folders hierarchy and the presence of the appropriate files. If the higher harmonics images files are not present, the program informs a user about the fact. If only certain files are missing (for example they have not been created because of a too high tip resonance frequency), only existing images are plotted.

It is possible to analyze the same row and column in each harmonic picture and compare them. This may be a starting point for further research. Rows and columns images can be saved in *obrazy* folder with name prefixes denoting the row (or column) number.

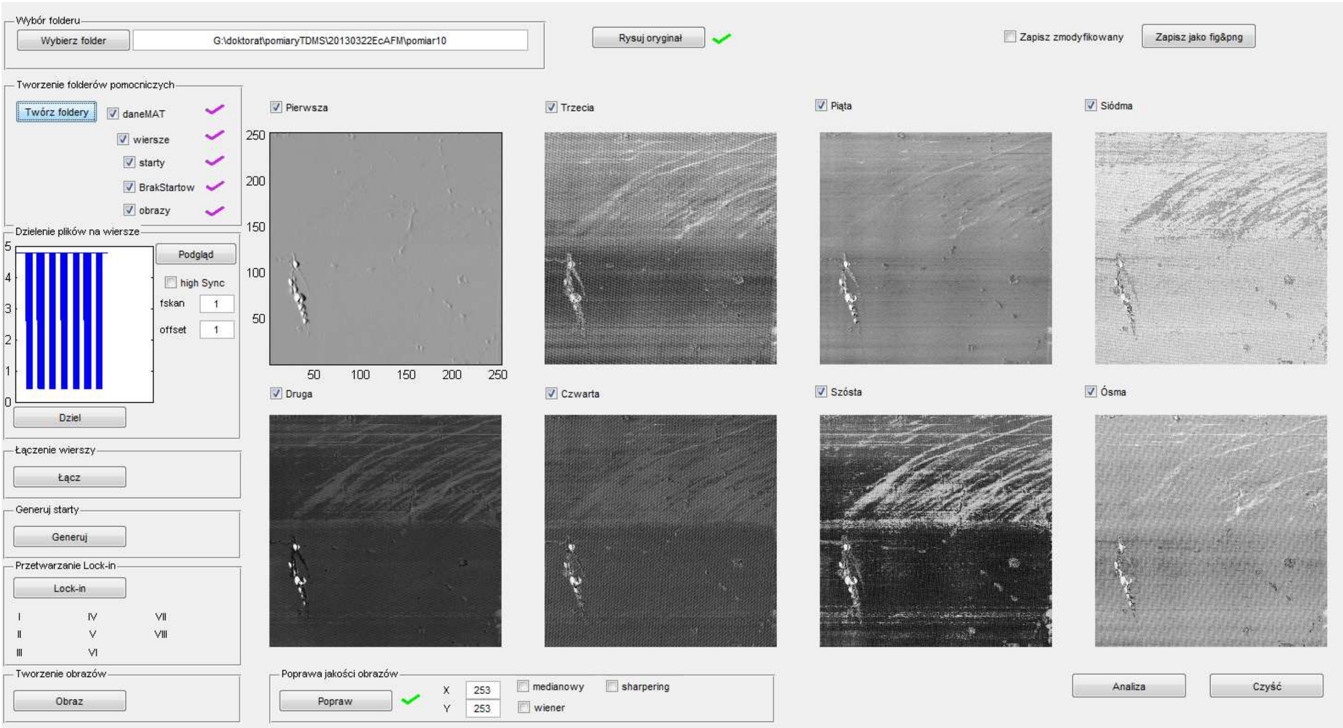

Fig. 4 Graphic user interface of main program

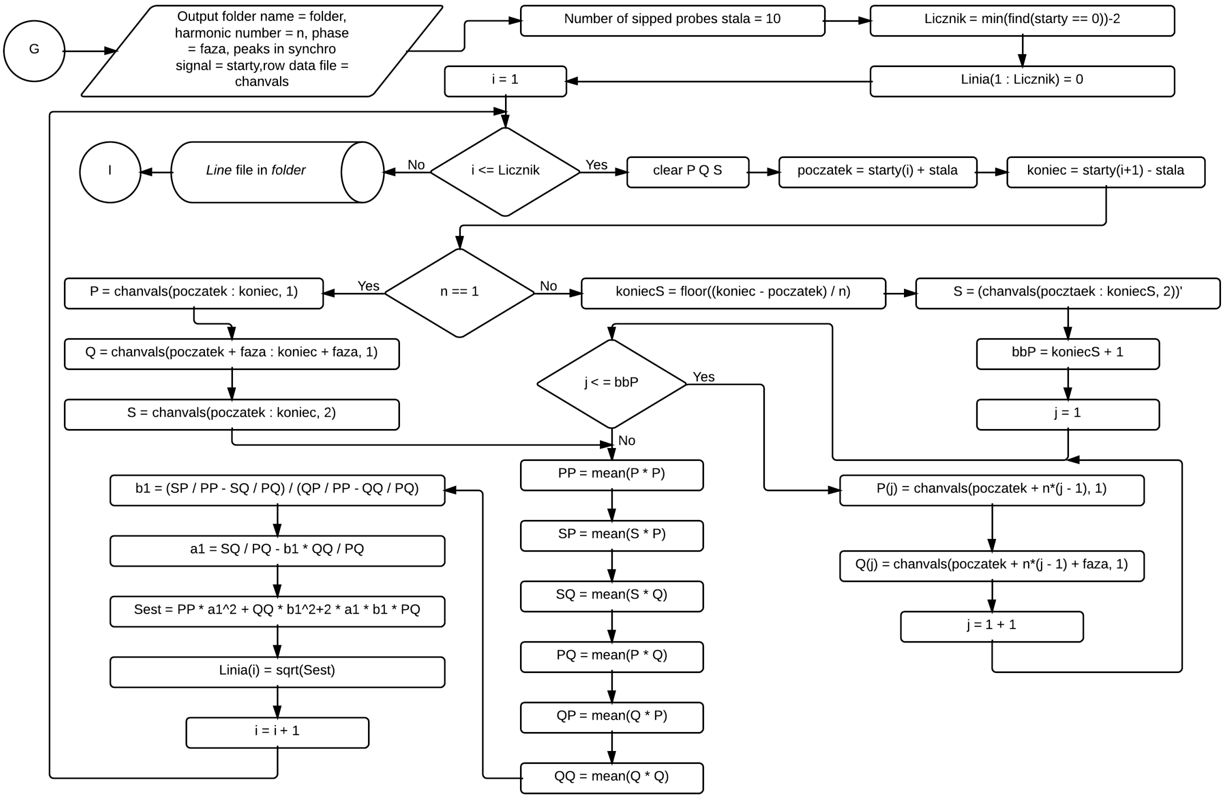

Fig. 5 Lock-in amplifier procedure algorithm

Higher harmonics images presented in Fig. 4 show a sample of AiSi304 investigated during corrosion process. It can be noticed, that some edges and topography substructures are sharpened.

6. CONCLUSIONS

The presented algorithm enables optimized processing of data recorded during AFM scanning in order to image the investigated surface by higher harmonics. Each step is independent, what simplifies debugging and gives an opportunity to stop the processing with no data lose. the program takes into account the different measurement conditions, like different states and offsets of the synchro signal, tip resonance and scanning frequency. The program also allows to preview each row and column and save them for future analysis.

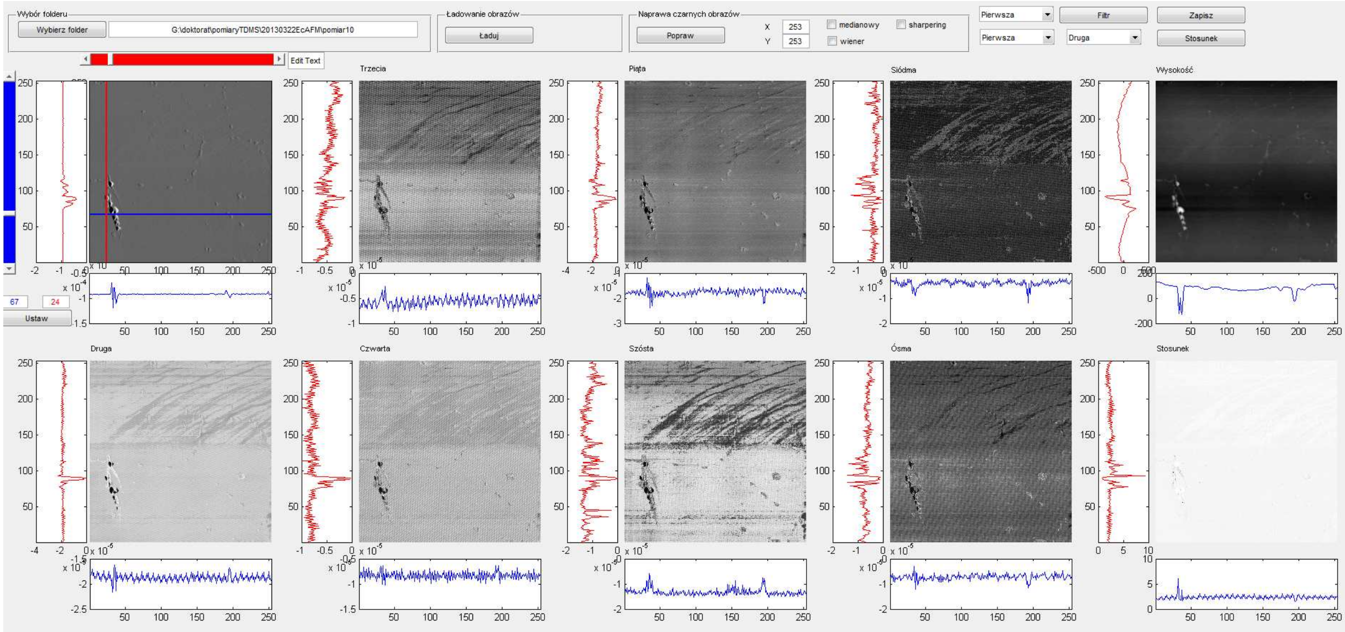

Fig. 6 Graphic user interface of the analyzing program

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ALGORYTM PRZETWARZANIA DANYCH REJESTROWANYCH ZA POMOCĄ MIKROSKOPU SIŁ ATOMOWYCH

Dotychczasowe badania wykazują, że obrazowanie topografii za pomocą mikroskopu sił atomowych (AFM, ang. *Atomic Force Microscope*) z wykorzystaniem wyższych harmonicznych może znacząco rozszerzyć jego możliwości pomiarowe. Z uwagi na różne właściwości próbki, igły skanującej i środowiska, w jakim jest przeprowadzany pomiar, dobór odpowiedniej harmonicznej jest czasochłonny i wymagałby wielokrotnego skanowania powierzchni.

Autor opracował system umożliwiający jednoczesną rejestrację sygnału pobudzającego wibrującą igłę skanującą, sygnału odpowiedzi igły z fotodiody oraz sygnału synchronizującego. Na podstawie tego ostatniego, możliwe jest precyzyjne określenie momentu badania danego obszaru próbki. Wykorzystując przedstawiony algorytm przetwarzania zarejestrowanych danych, autor obrazuje jednocześnie powierzchnię badanej próbki za pomocą wyższych harmonicznych oraz za pomocą dedykowanego oprogramowania AFM.

Słowa kluczowe: mikroskop sił atomowych, harmoniczne, obrazowanie, algorytm