RESEARCH OF ACOUSTIC MEASUREMENTS OF BENDING FORCE ON HIGH VOLTAGE INSULATORS

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Abstract: The aim of this research was to research and verify the possibilities of using microphone to determine mechanical load acting on high voltage insulator. The insulator features a cable hole, which can be used for optical cables. Let's use this hole as a microphone mount in order to listen to sounds inside of an insulator. The cable hole and the insulator end holes were filled with insulating foam to insulate microphone from the external interferences. Acoustic measurements were performed on the outdoor post insulator C30-850-II. The insulator was placed in bending machine and was repeatedly mechanically stressed by bending forces. The results of this research verify the suitability of the selected method for future use in the proposed device for detection of mechanical overload of high-voltage insulators.

Keywords: high voltage insulators, bending force measurement, acoustic measurement, optical microphone, mechanical stress measurement.

1. Introduction

High-voltage insulators are used for electrical separation of high-voltage line components with different potentials. It also allows the transfer of mechanical forces between the components of the line. When mechanical forces are transmitted, the insulator is stressed, and the dielectric material gradually wears out [1, 2]. The aim this reserach was to research the possibilities of detection of mechanical overload of a high-voltage insulator.

Mechanical loads acting on high voltage insulators have a direct influence on their reliability and durability. Overstressing of these insulators can cause cracking and failure of insulators [3, 4]. Information about mechanical stresses of the insulator can be beneficial in increasing safety and reliability. Usage of electronic-based measurement methods is difficult due high electrical fields around these insulators in real-world scenario. To overcome this issue, let's focus on methods which can be implemented using modern optical devices such as optical microphones [4, 5].

2. Methods

Insulator was placed vertically into a bending machine. The microphone was placed into a cable hole and lower end of the hole was filled with foam. Later let's fill the upper end of the cable hole with foam to insulate microphone from the environment outside of the insulator. Insulator under test was loaded 21 times with different force and different bending rate. First, two tests were done with 50 % of the minimum bending failure load and bending rate of 10 mm/min. Then let's load the insulator ten times with 95 % of load and same bending rate. Next three tests were also done with 95 % load but with a slower bending rate of a 3 mm/min. We have continued by increasing load to 100 % and keep bending rate at 3 mm/min. Last three tests were again with 3 mm/min bending rate but bending force acting on the insulator was increased above the safe limit of 105 % of the minimum bending failure load. Insulator has withstood our tests without any noticeable changes or damage.

3. Results

The acoustic measurements were done with microphone Behringer ECM8000 [6] and external sound card Behringer U-phoria UMC204HD connected to laptop [7]. All signals were recorded with 96 kHz sampling frequency and 16-bit resolution; these signals were saved into PCM wav loose-less format.

Pre-analysis: All recorded files were analyzed with the Cooledit96 software for frequency components. It is found that all signals did not contain frequencies above 20 kHz (for –105 dB threshold to Full Scale). It has allowed to down-sample the signals to the new sampling rate of 48 kHz.

First measurement set was done with the microphone inserted into the upper end of the cable hole up to the microphone's connector. Top of the microphone was protected with acoustic foam. Microphone body was not acoustically insulated from the cable hole. The lower end of the cable hole was filled with thick foam. The upper end of the cable hole was left open, this allowed the microphone to pick up sound from the environment outside of the insulator and increase noise floor of the signals.

During the first measuring set, the insulator was mechanically excited by knocking of the metal rod on the its body. The direction of the knocking was perpendicular to the insulator axis. The measurement begins with no force on the insulator. Responses to five knocks approximately one second apart were recorded. Next, the insulator was loaded to 50 % and again five knock responses were recorded. This scenario was repeated again for 95 % load. Responses to knocks were individually normalized to have the same amplitude. On the **Fig. 1**, there are five normalized impulse responses and on **Fig. 2** their spectrograms. Spectrogram's Fast Fourier Transform has the following parameters: window size: 512 samples, windowing type: Blackmann-Harris [8–10]. Spectral components with high amplitude are mapped from red to bright yellow color. Responses and spectrograms of 4/5 knocks are similar, the second knock has high noise from the hydraulic bending machine. Detail of the forth knock response is shown in **Fig. 3** and its spectrogram is on **Fig. 4.**

By comparison of the knock responses with different bending load, it is possible to conclude that the response is independent of the bending load. There is no visible shift in resonant frequencies of the insulator. **Fig. 5** compares responses for 0 % load, 50 % load and 95 % of the maximum load.

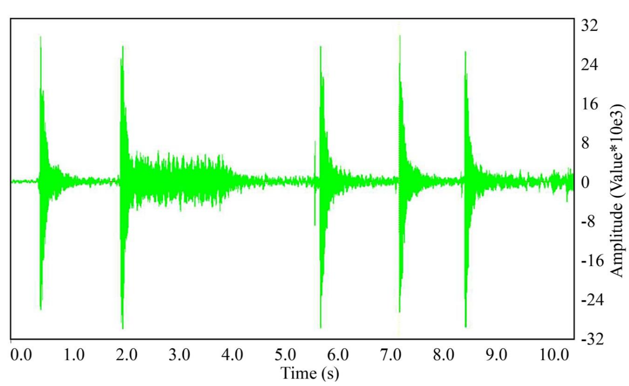

Fig. 1. Normalized recorded responses to five metal rod strokes, 50 % load

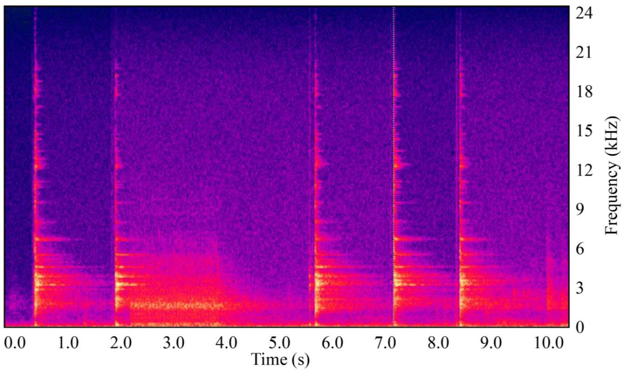

Fig. 2. Spectrogram of five knocks responses from **Fig. 1**. Window size: 512 samples, windowing type: Blackmann-Harris

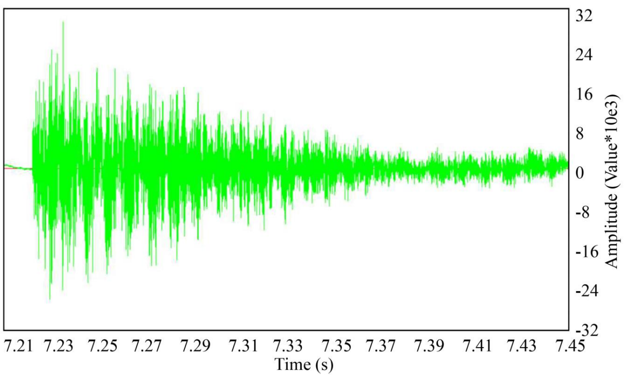

Fig. 3. Detailed view on the fourth response

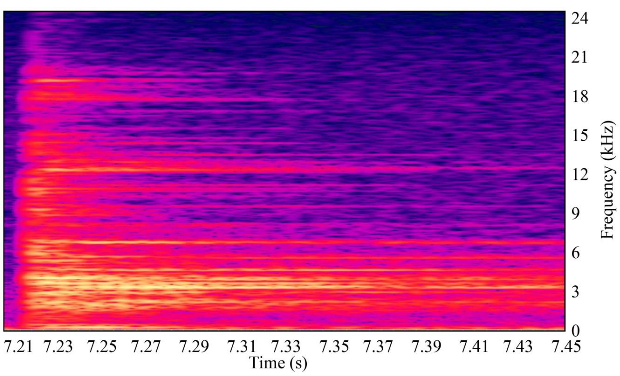

Fig. 4. Spectrogram of the individual response from **Fig. 3**

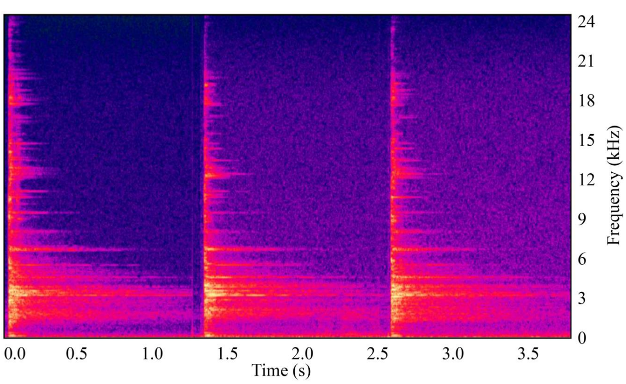

Fig. 5. Spectrograms of three responses captured at different loads, 0 %, 50 % and 95 %

The second measuring set. In order to reduce noise pickup of the microphone, we have used foam to insulate microphone body from cable hole and to plug upper end of the cable hole [12]. This reduced noise greatly. Let's change metal rod for a wood rod. During the second measuring set, let's knock on the insulator for every 3 kN increment of the bending force.

Recordings were down-sampled and normalized again in the same manner as above. Typical response waveform is in **Fig. 7** and on **Fig. 8** is its spectrogram. By comparing waveforms on **Fig. 3**, **6** it is possible to see a clear difference in noise performance. From spectrogram (**Fig. 8**) it is possible to see that low frequencies are dominant. To get a detailed view (**Fig. 6**) of the spectrum at low frequencies, we have had to change spectrogram parameters to the window size of 2048 samples, window type remained the same. There are three resonant modes at frequencies at 102.2 Hz, 186.3 Hz and at 303.5 Hz. These resonant modes are the result of closing both ends of the cable hole.

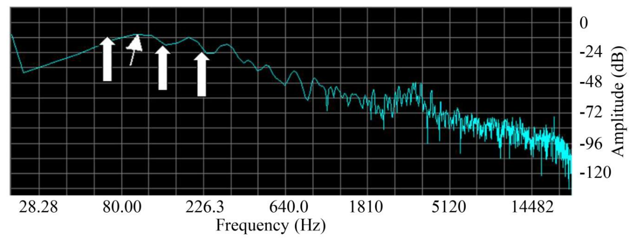

Fig. 6. Detailed view of the low part of the spectrum from the **Fig. 8.** Window size: 2048 samples, windowing type: Blackmann-Harris

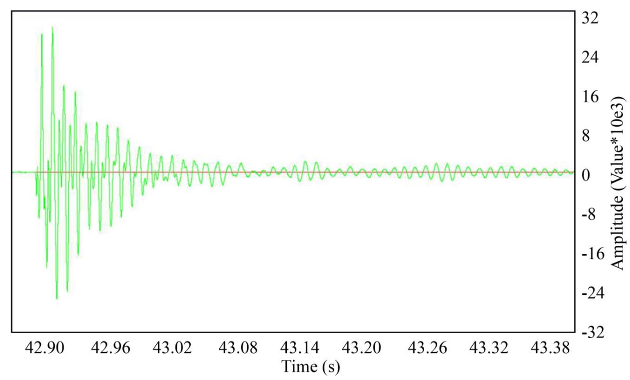

Fig. 7. The recorded waveform at 15kN

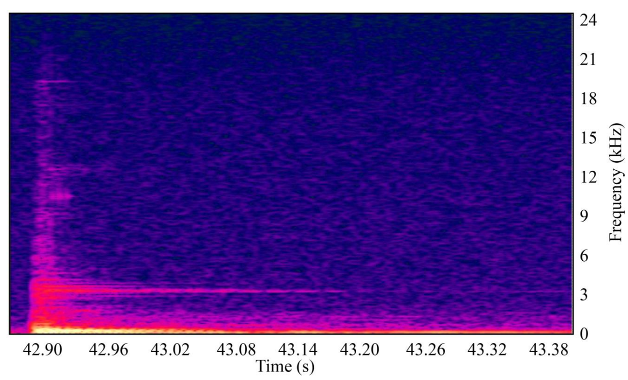

Fig. 8. Spectrogram of the waveform from **Fig. 7** Window size: 512 samples, windowing type: Blackmann-Harris

Both measurement sets show two groups of resonant modes (**Fig. 9**). The first group is around 3 kHz and the second group is single resonant mode at 18.85 kHz.

Table 1 summarizes resonant modes at the particular load values. It can be seen that the resonant modes do not vary

with load and cannot be used to determine load acting on the insulator.

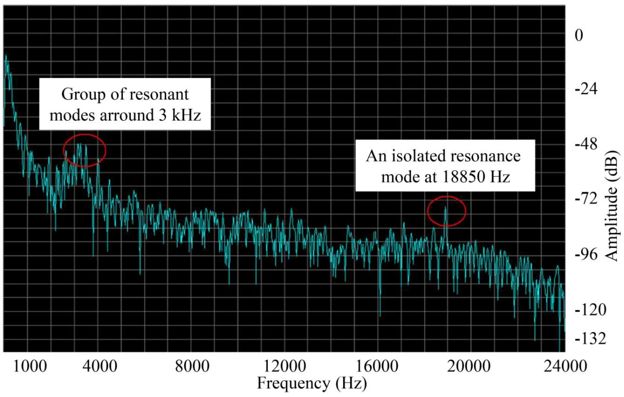

Fig. 9. The example of spectrum of resonant modes at 15 kN load. Window size: 2048 samples, windowing type: Blackmann-Harris

4. Discussion and conclusions

The aim of this research was to perform a series of mechanical overload measurements on high-voltage insulators using a microphone and to verify the use of this method for the development of a device for detecting the degree of mechanical wear of an insulator based on the optical microphone. This allows the damaged insulator to be replaced quickly, minimizing damage to the high voltage line and increasing its service life and reliability. Acoustic measurements of mechanical load were done on the outdoor post insulator C30-850-II [12]. The insulator was placed in a bending machine and stressed several times with different bending forces. Measurements were done on several pieces of insulators to verify that the differences between the insulators had no effect on the acoustic measurement results. We were unable to detect any dependencies between applied bending force and acoustic characteristics of the insulator. This would require further research.

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Table 1
Resonant modes at the particular load values

Load (kN)	3	6	9	12	15	18	21	24	27	30	31.5
Resonant modes (Hz)				2638				2670			
	3184		3152		3184			3184	3184		
	3313			3281	3281	3281		3281	3313		
			3442		3538						
						4021	4021	3989		3989	
				4117							
			4568	4600							
		4825	4825							4922	
							5211				
									8621		
			8911					8847			
				9072							
	10270	10320	10290		10230	10230				10260	10290
					12280						
									17270		
			17850				17850				
						18400					
	18850	18850	18850	18850	18850	18850	18850	18850	18850	18850	18850

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