PLASTIC PIPE DEFECT DETECTION USING NONLINEAR ACOUSTIC MODULATION

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Abstract -- *This project discuss about the defect detection of plastic pipe by using nonlinear acoustic wave modulation method. Nonlinaer acoustic modulations are investigated for fatigue crack detection. It is a sensitive method for damage detection and it is based on the propagation of high frequency acoustic waves in plastic pipe with low frequency excitation. The plastic pipe is excited simultaneously with a slow amplitude modulated vibration pumping wave and a constant amplitude probing wave. The frequency of both the excitation signals coincides with the resonances of the plastic pipe. An actuator is used for frequencies generation while sensor is used for the frequencies detection. Besides that, a PVP pipe is used as the specimen as it is commonly used for the conveyance of liquid in many fields. The results obtained are being observed and the difference between uncrack specimen and cracked specimen can be distinguished.*

Keywords: Nonlinear Acoustic Modulation, defect detection.

1. INTRODUCTION

Detecting, locating and repairing the leaks have become a painstaking task. In many cases, leakage receives a little or no attention from the consumers and there is always no proper management until an emergency occurs. Nowadays, different methods for the pipe defect detection have been developed and there are destructive method and non-destructive method. For the destructive method, force is applied to the structure until damage has happened in order for us to know the maximum force that the structure can withstand. Whereas for the non-destructive method, it includes 6 different methods such as dye penetration, magnetic particle, eddy current, radiography, ultrasonic and acoustic emission which allow to evaluate the structure without causing damage to it (Mpesha *et al.*, 2002).

The nonlinear acoustic modulation for pipe defect detection is done by the interaction between multiple waves. The two common types of wave that is introduced to the specimen are the low frequency excitation and high frequency of acoustic. According to P. Duffour et al, a modulation frequency is created by using an impact hammer and the frequency is used to actuate data acquisition system. On the other hand, the low frequency of vibration is recorded by using accelerometer which is placed to the other end of the hammer. A fast Fourier transform (FFT) can be used to transform the time domain signals to the frequency domain as well as to obtain the value of the sidebands and impact energy. In this project, the modal analysis is conducted to measure the most suitable values

for frequency of ultrasonic excitation (Duffour *et al.*, 2006).

2. METHODOLOGY

Nonlinear acoustic modulation has been studied by many researchers for the defect detection. This is because it is able to detect micro-cracking or early sign of damage and this method is also able to analyse the wave signal outputs which are irrelevant to the signal inputs. For instance, Sutin and Nazarov (1995) used nonlinear acoustic phenomena to detect defects in metal, Nagy (1994) used nonlinear ultrasonic characterization to detect fatigue cracks in his specimen and Van Den Abeele et al. (2000a) used the generation of harmonics and sidebands for damage detection on Plexiglass and sandstones. Besides that, it is known that the nonlinear effects are affected by the defects or damage appear in the specimen therefore it is most commonly used by researchers to determine the defect in the specimen. The examples of nonlinear effects are resonant shifting, side bands generation, amplitude dissipation and also harmonics generation.

In common understanding, we know that the nonlinear acoustic modulation is caused by the perturbation between high frequency of acoustic waves and low frequency of excitation. This method has been used by researchers for damage detection such as Van Den Abeele et al. (2000a) (2000b) have introduced nonlinear elastic wave spectroscopy (NEWS) technique which is to excite a test specimen with two frequency waves simultaneously and measure the harmonics and sidebands of the detected

frequency to detect damage. Later on, Parsons (2006) and Staszewski and Simondi et al. (2009) have used more advanced equipment for the damage detection which is the low-profile piezoceramic actuator and a piezoelectric transducer to generate both the low frequency vibration and high frequency ultrasonic waves simultaneously to the specimen. Therefore, the method by using piezo-electric generator or actuator to generate signals and using the DAQ software to interpret the data received will be used in this study.

3. EXPERIMENTAL SET UP

For the experiment set up, the first equipment that is needed to be ready is the plastic pipe. The plastic pipe is obtained from the store of Faculty of Mechanical Engineering and the length is modified to 120 cm by using the saw to remove the excess part. Basically, there are two set ups that are required for the experiment, one is the hardware set up while another one is the software set up. For the software set up, both the DasyLab software and the Ni-DAQ software are installed to the computer at which they are important to be used to interpret the data or signals obtained from the experiment. While for the hardware set-up, the foams are located at both ends of the pipes to hold the pipe and to isolate the pipe from the table. Next, the sensor is connected to the Ni-DAQ hardware and the amplifier is linked to the actuator. While for the subsequent step, the Ni-DAQ hardware is connected to the computer and the output of the Ni-DAQ is connected to the amplifier. This is to make sure that the data is able to be transmitted through and fro from the Ni-DAQ hardware to the computer. For the next step, both the actuator and sensor are fixed on the pipe by placing the plasticine behind the device as shown in the figure below. After the set up are ready, the experiment is ready to be conducted.

4. EXPERIMENT PROCEDURE

This part is mainly discussed about the procedure of the experiment conducted. First of all, a new task for output at Ni-DAQ is created which is to establish a virtual channel for the actuator. Next, another virtual channel is also created in order to form an input task for the sensor. The Ni-DAQ software is closed after saving all the tasks. For the next step, the DasyLab is opened and it is synchronised with

the tasks that have been saved in Ni-DAQ. Then, the DasyLab layout is produced by arranging in the module based on the module's function and the purpose of result.
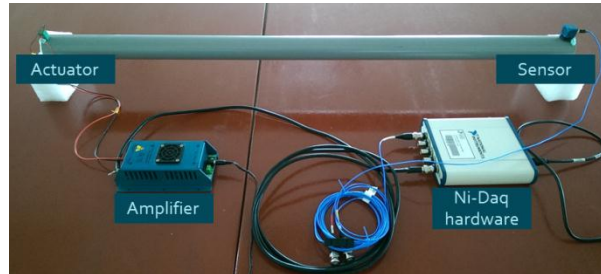

Figure 1. The Set Up of the Experiment

For the output channel, there are two generators each generate different frequency and are merged together by using 'arithmetic' while the purpose of the sliders is to adjust the frequency of the generator. It is then linked to a 'y/t' chart to show raw graph of the frequency and the frequency is then sent to the output which is the actuator through Ni-DAQ hardware and an amplifier. After the actuator released the signals, it is detected by the sensor and sent back to the DasyLab through Ni-DAQ hardware. Then, a 'y/t' chart is inserted to show the raw data of the signals and filters are inserted to eliminate noises. On the other hand, the purpose to include 'data window' in the layout is because it can produce various type of evaluation windows such as hanning, flattop, Poisson and so on which can be processed by 'FFT (fast fourier transformation)' to produce an amplitude chart. For the next step, the 'write' module is inserted to save all the data obtained in the computer and the function of the second slider is to adjust the frequency of the filter for both low pass filter and high pass filter. Lastly, the layout is being executed and the amplitude chart is shown. This process is repeated by altering the frequency generated as well as the frequency of the filters. The data for 10 cm, 50 cm and 100 cm distance between actuator and sensor is being obtained together with the frequency increment of 2000 Hz starting from 2000 Hz to 8000 Hz. The data and graph for each and every frequency and distance is being obtained and recorded in the computer. The example of amplitude graph obtained is shown in the Figure 2.
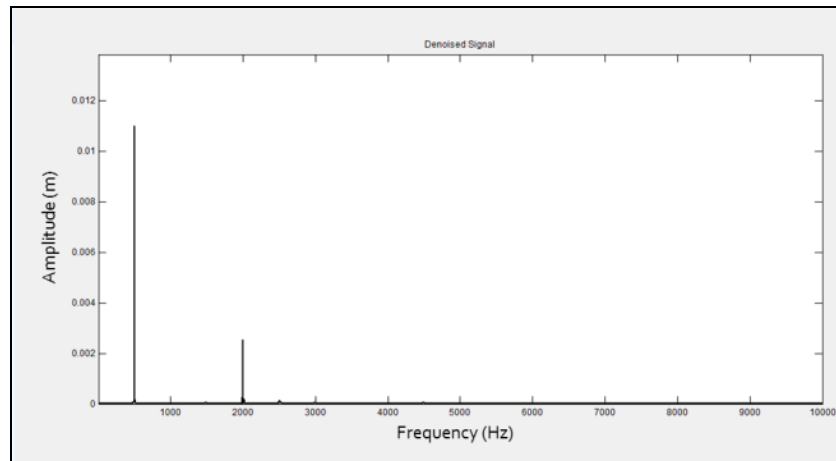
Figure 2. 2000 Hz of high frequency and 500 Hz of low frequency generated with 10 cm of distance between sensor and actuator

Subsequently, the experiment is followed by the testing on the cracked plastic pipe. First of all, single crack is introduced to the uncrack plastic pipe by using saw. Next, sensor and actuator are placed at both ends of the plastic pipe. The results are recorded for 2000 Hz, 4000 Hz, 6000 Hz and 8000 Hz applied. After that experiment for single crack is done, it is then proceed with the experiment of multicracks. The multicracks are applied to the specimen by using saw. Similar steps are carried out for the process of obtaining data for multicracks at which the frequencies are applied and results is being recorded down. All of the data obtained from DasyLab will be analysed by using Matlab de-noising package to omit the disturbances or noises.

This is because there are disturbance from the surrounding such as air conditioning, noises from the equipment itself and so on that are contributing effects to the results of the experiment and the wave generated is also being perturbed by cracks or defects. Therefore, the data obtained will appear to have more peaks or noises than expected. So, it is necessary to run the de-noising package to remove the noises that are contributing from the surrounding. After that, the spectrum of the response signals is studied and analysed to determine the condition of the specimen.

5. RESULTS

The results were analyzed by using Matlab after it was obtained and recorded down by using DasyLab. Meanwhile, Matlab is used to de-noise the disturbances captured during the experiment.

The experiment results will be shown in the form of graph which is produced by using Matlab. The results for same frequency but different length will be compared as well as the result for cracked and uncrack specimen. This can be done by observing the graph obtained and the changes of the amplitude. On the other hand, sideband is also used to distinguish the results that obtained from the experiment. The forming of sidebands for the nonlinear acoustic method of defect detection has been widely studied by many researchers such as Zaitsev, Cawley, Van Den Abeele and others. This nonlinear acoustic effect is able to detect various type of defect such as debonding, fatigue cracks, microstructural damage or materials corrosion.

In order to present the results, it is required to undergo Matlab de-noising package to eliminate the noise that is received during experiment. The example of the graph is shown in the Figure 3 where Figure 3 (a) shows the result obtained from DasyLab which is before de-noising and Figures 3 (b) shows the results after de-noising which is obtained from Matlab. From the results, the noises are being eliminated causing the amplitude of the generated frequency to be affected. The trend of the results remains unchanged although the amplitude value of the generated frequency is decreased. This de-noising process is applied to all the results obtained and the range of de-noising is maintained for each of the results. Thus, the decreasing in the amplitude value will not vary much for each of the graphs.
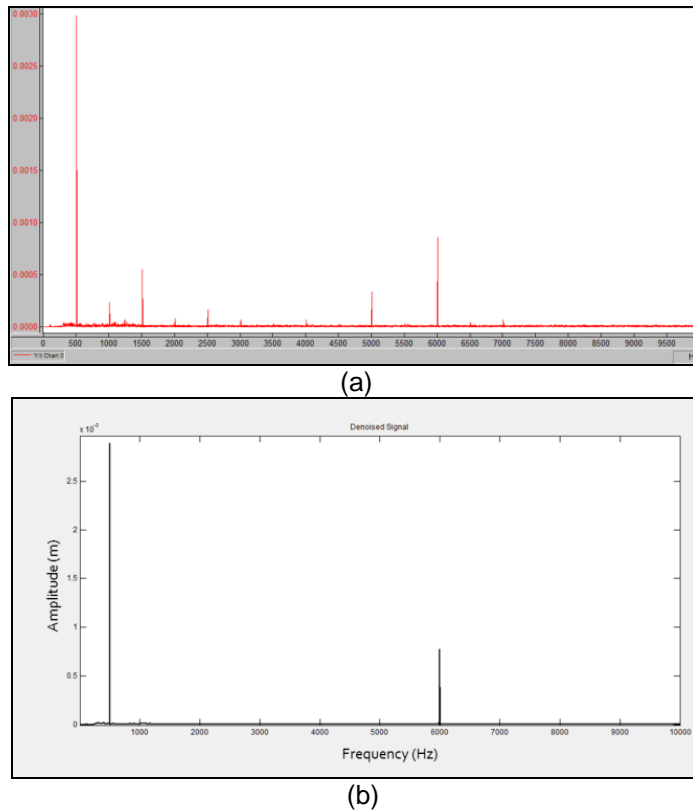
(a)

(b)

Figure 3. Graph of original and de-noised signals. (a) Result obtained from Dasylab and (b) Result obtained from Matlab which is after de-noising process

On the other hand, Figure 4 shows the result obtained from the experiment when 500 Hz of low frequency and 2000 Hz of high frequency are applied to the specimen through an actuator. There are two frequencies generated to the specimen because it is well accepted that low-frequency excitation triggers movement in crack surfaces such as opening/closing, slipping, or tearing actions, which causes wave distortion against the ultrasonic signal. Without low-frequency excitation, the ultrasonic wave distortion or wave modulation effect is nearly unnoticed. The results shown have undergone the Matlab de-noising package to reduce the unavoidable noises that are captured during experiment.
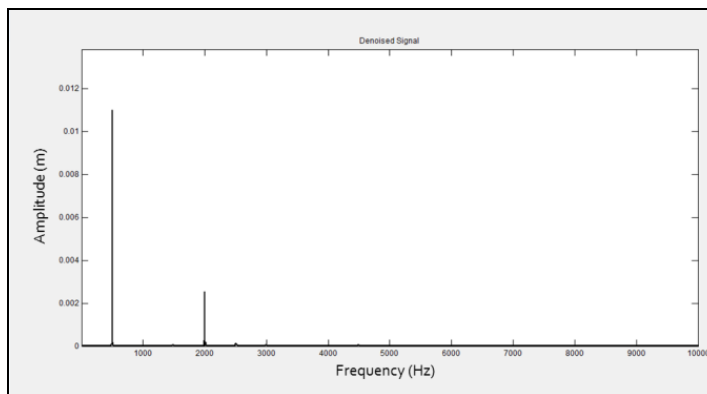

Figure 4. Results obtained for 500 Hz of low frequency and 2000 Hz of high frequency applied to the 10 cm of intact specimen

Table 1: Comparison of Amplitude Value for Each Spectrum at Different Distance between Sensor and Actuator

Distance	Amplitude	
	500 Hz	2000 Hz
0.10 m	0.011 m	0.003 m
0.50 m	0.0025 m	0.0024 m
1.00 m	0.0024 m	0.0002 m

According to Figure 4, the graphs contained two spectrums that are located at the original frequency applied which are 500 Hz and 2000 Hz. Besides that, it can be obviously seen that there is no extra sideband appear in the results obtained. This is because the wave that is generated by actuator is not being disturbed by any external force or crack. Therefore, the wave can maintain its formulation when it reaches the sensor. Meanwhile, Table 1 shows the comparison of amplitude value for each of the spectrum at different distance between sensor and actuator and it shows the value of the amplitude decreases as the distance between actuator and sensor increases. This can be deduced that the waves tend to dissipate more when the distance traveled by the wave is increased. So, the waves will become weaker when the distance is increased and this explained the reason for the value of amplitude decreases when the distance increases.
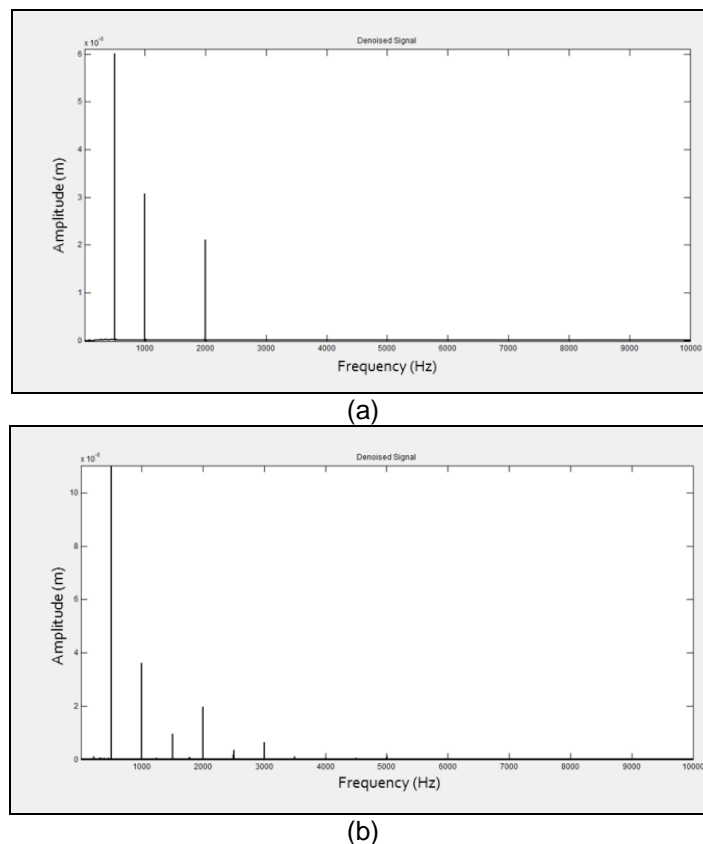

(a)

(b)

Figure 5. Results obtained for (a) single crack specimen and (b) multicrack specimen

Figure 5 shows the results acquired from the experiment for both single crack and multicrack specimen. It can be significantly observed that there is extra peak appear for the single and multiple crack specimen. This is because the opening-closing behavior of the crack changes the crack's cross section and subsequently changes the amplitude of the wave. On the other hand, the waves are travel in uniform wave formulation when they are first generated from the actuator. When the waves meet crack, the waves will meet several disturbances such as reflection, dispersion and even shorten of wavelength. These disturbances will affect the formulation of the wave and causing it to become inconstant, when all the waves or peaks are overlapping over each other, new peak will be formed and it will be the sign of crack that appear in the specimen. Therefore, same theory goes for the multiplecrack specimen. For multicrack crack specimen, this means that the waves are being disturbed even more and it will become more complicated as compared to the wave of single crack specimen. So, there are

more peaks appear for the results of multicrack specimen.

In addition, by comparing the results for uncrack and crack specimen. It is found that the high frequency wave is being modulated at the crack zone by the low frequency vibrations. In the frequency domain sideband appears around the high frequency component, as cracks of different sizes are unambiguously connected to a strong nonlinear response. If there is no crack present there will be no modulation and therefore no sidebands appear. One can imagine a vibrating crack. It will open and close. When the crack is open the high frequency wave is unable to be transmitted through the cracked area easily, the received high frequency amplitude is low. While the crack is closed, the high frequency wave is transmitted more easily and has higher amplitude.

6.   CONCLUSION

The result shows that the capability of using nonlinear acoustics modulation for the purpose of detecting defect in the specimen. The method used was based on the introduction of two types of waves which are probing wave (high frequency) and pumping wave (low frequency) to the specimen. The two types of waves will coincide with the resonance of plastic pipe and the characteristics of the specimen can be determined by analyzing the data obtained. The equipment used for this experiment is useful in collecting data. On the other hand, the data collected has proved the objective of distinguish the difference between the results of crack and uncrack specimen has succeed as well as the hypothesis of the experiment.

As a conclusion, knowledge and understanding about signal features can help to ease the defect detection process as the process requires large amount of time, money and effort to study. Besides that, information on the nonlinear acoustic effect can help to estimate the presence of damage in the structure. With the suitable type of equipment, different type of nonlinear acoustic effect can be studied and more details about the crack can be investigated. Therefore, nonlinear acoustic modulation is an effective way in detecting defect in the structure, the objectives is achieved and the hypothesis is accepted.

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