NEW POSSIBILITIES TO INCREASE SENSITIVITY OF THE ULTRASOUND NONLINEAR MODULATION METHODS

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Abstract:

The ultrasound nonlinear modulation spectroscopy has two basic variants of realisation. The ultrasound excitation can use harmonic signals with relatively near or distant frequencies as using of mixing or modulation principle. This paper presents comparison of these two basic methods and asks new possibilities for rising of sensitivity. Especially a necessary time for the exciting and sensing signals are compared and further it discusses possibilities of lowering of a dynamic range of the measured signals by using of analogue linear prefiltration for suppressing of excitation signals.

The second part discusses possibility of using of the pulse exciting mode for these methods. First, the excitation by phase coupled pulse signals is derived for obtaining of result long time signal without wasting of its useful energy. Nevertheless this output long time signal consists from more time separated pulses and therefore the analogue prefiltration cannot be used for suppression of excitation signals. Therefore the new variant of mixing method is derived, where such exciting frequencies are used, that result signal with difference frequency has a relatively high frequency and a shorter period then the exciting signal. On the other hand, the frequency difference between this resultant component and exciting signal is sufficient for using of LC filters with sufficient attenuation of exciting signals.

Keywords: non-linear spectroscopy, modulation, ultrasound, cracks, pulse exciting, noise

1. INTRODUCTION

Non-linear ultrasonic spectroscopy is new progressive NDT technology with various methods ([1], [2] etc.). Especially modulation methods with two exciting signals appear as very perspective methods for NDT. Their main advantage consists in creation of the new frequency component with different frequency than exciting signals. Therefore it is not sensitive to reflected and spread exciting signals and a theoretical sensitivity is very high.

Nevertheless the practical sensitivity in cases of published results ([1], [2] etc.) is considerably lower than theoretical one. This fact has more reasons. One of the main reasons consists in the limited dynamic range of currently used systems for signal processing and high dynamic range of measured signal. The usable dynamic range can be risen (ultra-low noise amplifiers, 16-bit AD converters etc.) but more effective way consists in suppressing of exciting components in measured signal by linear analogue prefiltration.

This problem is more complicated in the case of pulse excitation. It is necessary to say that pulse mode has advantage in minimisation of problem with standing waves and it enables a localization of cracks. On the other hand the pulse mode offers lower energy of detected signal, the time of pulse can be shorter than period of result signal and it is problem to use frequency filters for suppression of exciting signals.

2. COMPARISON AND CHOICE OF METHODS OF NONLINEAR ULTRASONIC MODULATION SPECTROSCOPY

Nonlinear ultrasonic modulation spectroscopy uses an excitation by two harmonic signals with frequencies f_1 a f_2. In a nonlinear environment this excitation creates new signal with frequency components by this equation:

$$f_r = \left| \pm m f_1 \pm n f_2 \right| \quad \left| m, n = 0, 1, 2..\infty. \right. \tag{1}$$

This general equation can be used for two typical examples:

1) Relatively distant values of frequencies f_1 and f_2 (as amplitude modulation)
2) Relatively closed values of frequencies f_1 and f_2 (as mixing)

The first variant with relatively distant values of excited frequencies (for example low value of f_1 and high f_2) produces signal with the most interesting difference components that corresponds to side bands of classical amplitude modulation

$$f_r = f_2 \pm f_1, \tag{2}$$

as it is shown in Fig. 1 in time and frequency domains.

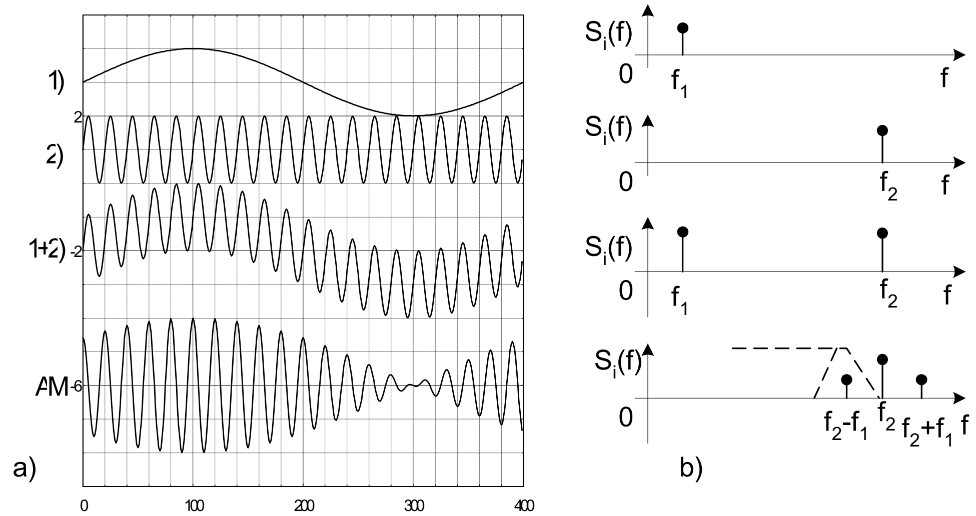

Fig. 1. A creation of amplitude modulation in case of excitation of nonlinear system for relatively distant values of frequencies f_1 and f_2 (AM): a) time domain, b) frequency domain with marked possibility of filtration

The second variant uses the excitation ultrasonic signal with relatively closed values of frequencies f_1 and f_2. In this case we receive the new frequency component created according to relation

$$f_r = f_2 - f_1 \,. \tag{3}$$

This case is usually named mixing and it is shown in Fig. 2. Except of difference component the additive component is created similarly as for AM, but we don't use it for preferable properties of difference component.

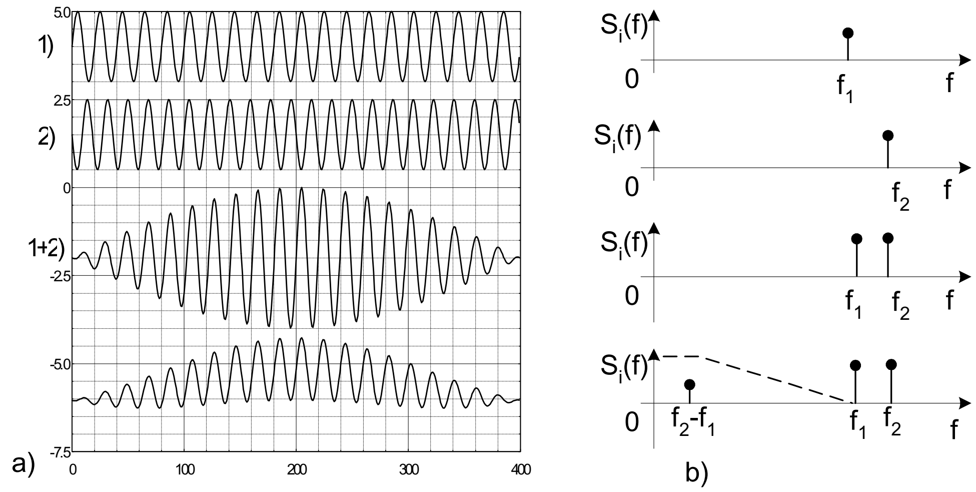

Fig.. 2. A creation of differential component in case of excitation of nonlinear system for relatively closed values of frequencies f_1 and f_2 (mixing): a) time domain, b) frequency domain with marked possibility of filtration

We can compare both cases from two important points of view as possibility of suppression of excitation signals by filters and necessary time for evaluation of result signal. It is necessary to have in mind that differential and additive components carry the usable information and they are much lower than carrier excited component f_2. The lowering of dynamic range by suppression of exciting component f_2 is very difficult especially if we have to use linear LC filters. If we compare both discussed principles (Fig. 1 and Fig.2), we can see that first case with AM need non-realisable filter whereas in case of mixing principle the suppression is easy feasible.

A comparison of the necessary time for evaluation of resultant signal looks like different on the first view because detected components $f_2 - f_1$ and $f_2 + f_1$ of AM case have a higher frequency and shorter period in comparison with mixing principle. The more detailed discuss shows dissimilar result. As the time dependency of AM signal shows (Fig. 1a), a period of this signal takes the same time as differential component $f_2 - f_1$ in mixing case (Fig. 2a). We can say that both principles are equivalent from this point of view.

3. PULSE EXCITATION WITHOUT WASTE OF ITS USEFUL ENERGY

This task has antagonistic aims. Therefore the solution it more complicated and it is necessary to use digital signal processing (DSP). The basic principle consists in distribution of exciting signals from Fig. 2a to discrete parts (as radio pulses), which are separated by zero laps with sufficient length for solution of problems with reflections and interferences of signals. It is shown in Fig. 3. the zero laps are shorted in this figure for simple displaying. It is necessary to say that this time isn't important for the signal processing.

On the other hand, it necessary to remark, that the changing phases of exciting signal have to be complied in separate pulses for regular sum exciting signal as it show Fig. 3. If we adhere this phase synchronisation, we obtain the resultant signal with the envelope form as a beat note similarly as in the continual wave mode (Fig. 2a) by the superposition of both pulse exciting signal pulses. The nonlinear environment changes this summed pulse signal according (1) and the result pulse signal will contain the asked differential frequency component. Further it is necessary to select the separate result pulses and leave out zero laps for result solution. This task is quite simple because we know the time of pulses and zero laps.

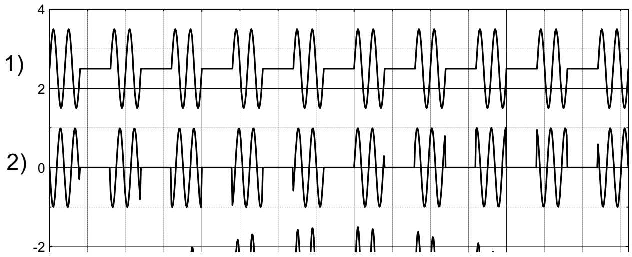

Fig. 3. A dividing of exciting signals to phase synchronized short pulses and summed excited signal with effect of envelope beat note.

It is evident, that in practical use we obtain partly different signals. First, the selective properties of a transfer path spread the edge of impulses. It is not so much important for detecting in the case of a limited time of spreading because the sum energy of low frequency useful signal is the same. On the other hand this effect lowers an accuracy of localization.

Second, the real measured signal will be delayed for limited velocity of propagation of ultrasound signals in tested sample. Therefore it is necessary to use the variable delay between of both generators with phase synchronisation. It is evident that we obtain the right result signal with a correct phase shift in the place of crack and therefore we have to compensate the difference between transfer shifts of both signals by additional delay shift.

Because we don’t know the difference time t_1 between transfer shifts (Fig. 4), we have to add to basic phase shift gradually short time sifts for obtaining of asked differential component $f_2 - f_1$. It is simple time scanning and it offers value of unknown time difference t_1. For quick process of scanning we can use of two-step scanning when first we use a raw scanning with a greater shift and after obtaining of estimative value t_1 we can use a fine scanning for the localization with higher accuracy.

Further time shifts as a propagation time to place of defect (t_2) and subsequently a propagation time from place of defect to sensor (t_2) can be detected in addition as a shift of demodulated signal and it is the second information for localization. A method of computing for localization depends on the form of tested object and on placement of sensor and transducers.

General block diagram of testing system is shown in Fig. 4. There the way for generation of signal is very important. It is necessary to use defined phase and delay shift for both harmonic signals in the frame of separate impulses with high accuracy. Further it is necessary to accurate define time intervals between pulses for scanning. It cannot be realised by two controlled standard generators, but it is necessary to use a system with finely digitally controlled generators with control unit that is synchronised with system of DSP.

The optimum analogue pre-processor and A-D converter with high resolution have to be also used. The system of DSP realizes a detection of the useful signal and computing for localization.

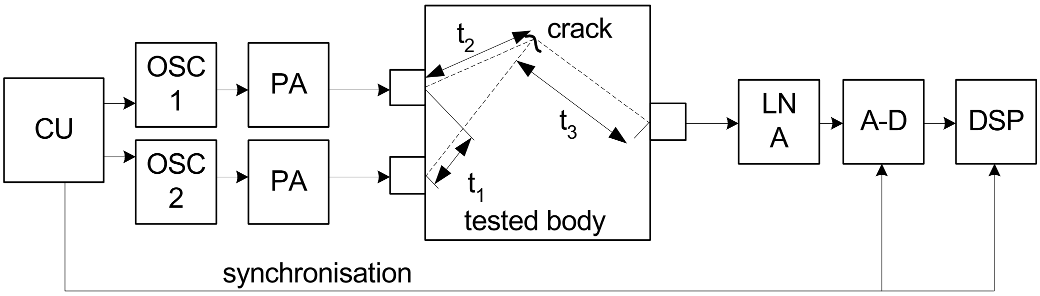

Fig. 4. Block diagram of the system for pulse testing for modulation spectroscopy.

4. PULSE TESTING SYSTEM WITH HIGHER DYNAMIC RANGE

As it was discussed above, the system with pulse excitation cannot use the filter suppression of exciting components because the time constant of the filter is longer than pulse duration. It is the great disadvantage and therefore we try to solve this problem. The special compromise can be used as a solution of this problem. It is necessary to use such values of exciting frequencies f_1 and f_2 that the differential frequency component will have sufficiently higher frequency f_2- f_1 for result pulse response with some periods of this signal. On the other hand this differential frequency of result signal has to be so lower than exciting frequency, that realisable LC low-pass or band-pass filter can be used for sufficient attenuation of exciting components without non-permissible spreading of result pulse. As our experiences shows, the ratio f_1 /(f_2- f_1) has to be equal or greater then 2.

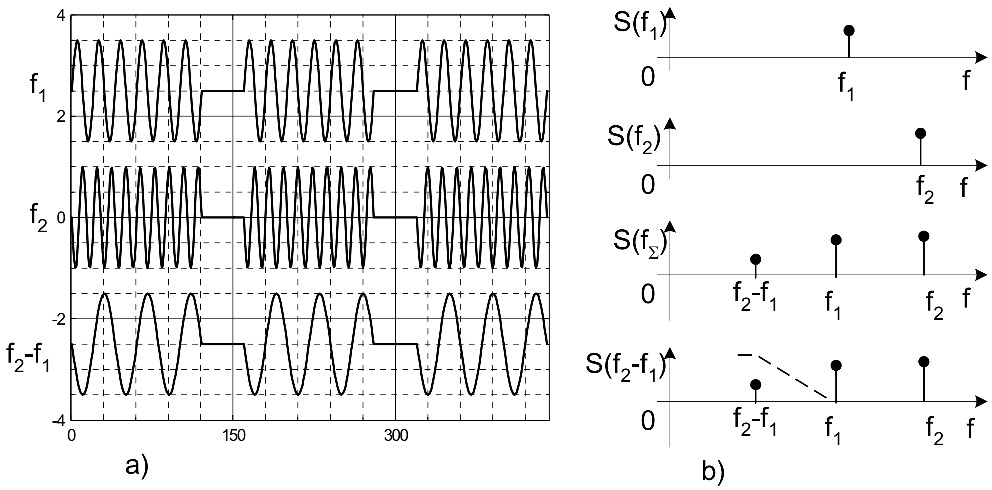

Fig. 5. The pulse excitation signals with possibility of the use of the linear passive filters for attenuation of exciting components: a) time domain with result pulse signal, b) frequency domain with marked possibility of filtration

These relations are shown as an example in Fig 5. We can chose the f_1 = 1 MHz and f_2 = 1.5 MHz. Then the different frequency is 500 kHz. In this case it is used the pulse with duration 6 μs and the result pulse will have three periods of differential signal and it can be filtered for suppression of exciting components.

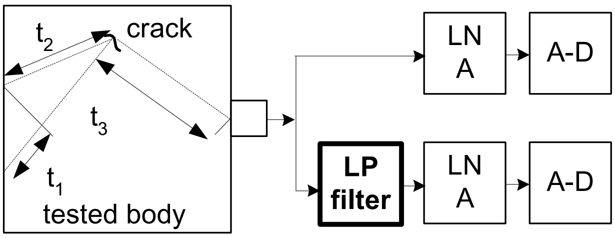

Fig. 6. A modification of the block diagram from Fig. 4 for suppression of the exciting components by linear frequency filters.

It is necessary to remark that a design and realisation of such filter is rather complicate because it is necessary to ask of optimum compromise between sufficient steepness (attenuation in stop-band) and quick time response for minimisation of spreading of pulse. On the other hand it has to be considered the loading and matching to impedance of sensor. Therefore it is necessary to use suitable program for this filter design. Also the use of the filter elements with high linearity is very important.

The result modification of pulse testing system from Fig. 4 is shown in Fig. 6. There we can see not only addition of passive low-pas (or band-pass) filters, but also the second channel without filtration has to be used for obtaining of direct excitation pulses for determination of the time $t_2 + t_3$. The transfer delay of the filter has to be considered in comparison wit direct signal way without filters.

5. CONCLUSIONS

This paper showed problems, comparison and possibility of improving of two basic methods of nonlinear ultrasonic modulation spectroscopy that can be marked as amplitude modulation method and mixing method. The comparison of these methods for continual wave excitation shows these two basic findings:

- They needs the same time of detection of useful result signal.
- The mixing method enables simplier filtration of result signal by higher attenuation of exciting frequency components. Therefore this method enables to obtain lower dynamic range of measured signal and the higher result sensitivity.

Further this paper shows a way for use of pulse excitation for the case with longer response of result signal. This solution is usable for localization of defects. It needs a use of special excitation system with two digitally controlled pulse generators with phase synchronisation and added time shifting for a time scanning. On the other hand the distribution of response pulses between the zero response laps doesn't enable using of the analogue prefiltration for rising of sensitivity. The block diagram of this testing system is also described.

Therefore the new variant of the pulse excitation was designed, where the optimum compromise of a differential frequency of the exciting frequency components is used. This relatively high value of differential frequency enables not only use a response pulse with more cycles of result signal and use of filtration by low-pas or band-pass filter, but also the sufficient ratio f_1 /(f_2- f_1) for feasibility of this filtration and attenuation of the exciting frequency components. The necessary change of the pulse testing system is also described.

In further work we will direct our effort to realization of phase synchronised two pulse generators and consequently all system.

Acknowledgement

This work was supported by the Grant Agency of the Czech Republic under Grant 102/06/0866, 106/07/1393 and project VZ MSM 0021630503.

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