Development of a multichannel pulser for acoustic scanning microscopy

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Abstract

Modern ultrasound imaging techniques use arrays to manipulate an ultrasound beam and to gather additional information out of the reflected sound field by analysing the received signal of each channel. For further wide-ranging applicability it is required to achieve a higher resolution by increasing the frequency of excitation signals and improvement of the signal to noise ratio. Actually neither electronic hardware nor high-frequency arrays are available that meet these requirements, so that a further development of the control-electronics is indispensable.

Therefore the ultrasound pulser presented in [1] was improved with respect to the generation of various excitation signals. A unit consisting out of 16 channels has been developed containing the technology to control these channels as well as to record and to process the received signals. It provides different types of excitation-functions with an excitation-frequency stepwise increasable up to 40 MHz. Additionally the modularised layout allows an extension to control much more elements.

All presented improvements are realised in a new ultrasound pulser that offers emission of arbitrary signals on each single channel. Of course the raw data of measurements are accessible and different optional data processing functions are selectable.

Keywords: high frequency; high resolution; focusing and steering; arbitrary waveform
1. Introduction

Scanning acoustic microscopes are used on the one hand to show hidden structures inside of optically opaque objects and inspect them with regard to delaminations between two layers and inclusions inside the objects. For quality management of electronic devices, this application can be used to control and optimize the production processes. On the other hand, they are used to characterise unknown materials and substances regarding to their physical properties like sound velocity and damping to get information about their mechanical behaviour.

Commercial microscopes are working with single-channel transducers with a centre frequency up to 240 MHz. They consist of an excitation unit to emit short pulses to an ultrasound transducer, an amplifier to gain received ultrasound signals and a digitizer to convert the analogue signals for the further evaluation. Especially novel methods need transducers based on segmented annular arrays to obtain further information from the received ultrasound field and to offer electronic focusing and steering of the ultrasound beam. These multichannel microscopes are commercially not available, so that the scanning acoustic microscope presented by Gust [1] represents a first approach. It establishes the basis for further developments discussed in this paper, like enhancement of the operation frequency for a better resolution and increase of channel count to control segmented transducers. Additionally the new measurement methods make it necessary to improve the SNR of the hardware to enhance the accuracy.

2. Characterisation of the current setup

In contrast to the system of Gust [1] two new ADC-cards (125 MS/s, 8 channels, 14 bit) are used, so that all 16 channels can be read simultaneously. Additionally anti-aliasing filters and termination resistances are applied to each of the used channels. By means of the digitalised signals demands on the pulser specification are formulated.

A measurement method for simultaneous determination of thickness and sound velocity in layered structures, presented by Kümmritz [2], is considered. Hereby the measurement system and a focussing transducer are used to determine both unknown parameters of a specimen-material without displacement of the ultrasound transducer. It works by focusing on the surface, the internal interfaces between different layers and the backwall of the specimen and calculating the searched parameters afterwards by using the different focal-positions and times of flight.

Expected signals will be discussed in advance. At the first method by Kümmritz [2] the focus of the transducer is located on the interfaces. This is resulting in good identifiable peaks in the received signal. The test is executed by using two different voltages for the excitation of the transducer with a resonance-frequency of 3 MHz. The results are shown in figure 1.

![Figure 1: Measurement of the received signal from a solid metallic specimen with an excitation voltage of 10 V (a) and 100 V (b). Both figures show the raw-data (green) as well as a 100 times averaged signal (blue).](image-url)

Figure 1a shows the test with an excitation voltage of 10V. The raw data of the measurement (green) contain several peaks that need to be separated in a first part caused by front and back wall echo of the aluminium plate and a second part caused by noise of the system. To demonstrate the difference between distortion and useful signal the averaged signal (100 times – blue) is shown. After that post-processing the localisation of the two peaks, caused by the surfaces of the specimen (Fig. 1a, b: 1 and 2), in the receive-signal becomes obvious. Next to them, there are visible other peaks that occur random in time and although before the peak of the front wall. These peaks reach similar amplitude like the surface echoes and are not caused by any interface or particle in water, so that a consideration about the accuracy of the measurements as well as electromagnetic compliance will be necessary. A main criterion for the accuracy is the effective resolution that on the one hand is limited by construction of the card,
on the other hand by its noise level. One bit of effective resolution is marked in figure 1a (red; resolution 14 bit, ENOB 11 bit). It shows that the effective resolution of the used ADC-cards is small enough, so that the measurement inaccuracy can be excluded as a reason. The second approach is the consideration of EMC. It is proved by changing and extra-shielding of the system interconnections. The examinations show, that these peaks disappear when the coupling of signal-ground from transducer to the pulser-/receiver unit is enhanced. So an improvement in shielding and signal coupling results in a higher accuracy of the measurement results. Another possibility is to increase the excitation energy by a higher excitation voltage. This leads to a significantly larger signal, compared to the noise-level of the system (figure 1b).

Another method is the non-invasive and locally resolved measurement of sound velocity presented by Wolf [3]. It uses scattering particles instead of the reflected signal of an interface. The sound velocity is determined by the evaluation of the time of flight to the focus position, together with the usage of calibration curves. The resulting echo by 1000 times averaging is about 1 mV. This lies under the noise of the receiving system of 2.5 mV, containing 2 mV noise of the system and 0.5 mV digitalisation noise of the ADC-card. With a high number of averages these signals can be measured, because the useful signal becomes identifiable by noise elimination.

3. **Results for the development of the new microscope**

After the analysis of the raw-data and the examination of the whole setup and hardware the following critical points concerning essentially the amplifier and electromagnetic compliance of the system can be named.

The hardware of the amplifier has to be improved, because the minimal variable gain results in 1 mV additional noise. In comparison, the useful signal of a scattering particle at 1000 averages results also in 1 mV. This makes an improvement on the amplifiers necessary.

Furthermore the electromagnetic compliance of the measurement system has to be revised. The cable connection from transducer to pulser and receiver unit, where the signal ground is transmitted over the shielding of the cables proved to be the main problem. The usage of double-shielded cable is not possible, because of the limited space for the bonding of the cable to each single element of the segmented annular array. An improved coupling of transducer to the signal ground of the measurement system shows a significant enhancement of the received signals SNR. Therefore the focus is on the improvement of the coupling from transducer to signal-ground.

Further changes will affect the structure of the system. So a higher grade of modularisation will be realised (fig. 2) with the aim to simplify the routing of the electric traces and to avoid the capacitive coupling of high frequency signals between crossing traces in stacked layers. This will be reached by separating the whole pulser and receiver unit in single modules, each containing four channels (channel count of the used pulser circuit). Additional advances of this step are the simplification of maintenance and further system extension up to a higher number of channels.

The structure is improved with the aim of reducing the amount of external connected components to minimise signal reflections at junctures. So the anti-aliasing filters and termination resistors that are applied as external components between the output of the amplifier and the ADC card, will be integrated in each channel of the modules ahead the output.
Functional enhancements of the arising system will be the possibility to match the excitation pulse length to the centre frequency of the used transducer. This will result in the reduction of the necessary excitation voltage by maximising the excitation energy at the same time. Additionally the displacement system will be extended by goniometers. This will improve the adjustment of the transducer to the used specimens, especially if they contain inclined interfaces.

References

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