

## LAUS – Large Aperture Ultrasonic System – for Testing Thick Concrete Structures

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### Abstract

A Large Aperture UltraSonic (LAUS) system has been designed and built for testing thick concrete structures. The scalable system consists of twelve ultrasonic units, each hosting 32 individual shear wave transducers with mechanical dry point contact (DPC) to the concrete surface. The twelve units are attached to the concrete surface using a vacuum case which holds them in place during operation. Each LAUS unit can be placed individually depending on the surface condition and optimal ultrasonic condition, e.g. rebar position. Air pressure is supplied to each unit through an air hose.

The following extended abstract is a short version of an article to be published in the special edition of ASCE JIS that will describe the outline of the system, the principle of functioning, the data processing and adapted reconstruction calculation based on SAFT as well as the system performance during first applications.

**Keywords:** Ultrasonic imaging, Linear Array, Reconstruction calculation (SAFT)

## 1. Introduction

The main purpose of ultrasonic echo application for concrete elements is to determine the thickness of concrete slabs, to locate delaminations and to localize and investigate internal component (e.g. tendon ducts).

There are structures with concrete sections well in excess of 100 cm thickness, which cannot be tested with the existing ultrasonic equipment. Mostly, such constructions are only accessible from one side, further underlining the necessity for pulse echo measurements. Such structures e. g. can be found in foundations, dams, containments of nuclear power plants or waste storage containers. Especially for safety related structures such as nuclear containments the nondestructive investigation of thick and heavily reinforced concrete was identified as a primary research objective [1, 2].

## 2. System description, handling, and positioning

The LAUS system (full manufacturer name A1045 LAUS) is designed for the inspection of large concrete objects with ultrasonic pulse echo allowing the inspection of concrete structures with one sided access. The ultrasonic generation and sensing is based on dry point contact (DPC) transducers which have been introduced in the seventies [3].

The multi-static arrangement is realized by 12 identical and autonomous probe units which can freely be placed on the surface of the concrete test object. Each probe unit consists of three parts: (1) Ultrasonic (UT) module, (2) electronic module (EM) and (3) vacuum case (VC).



Figure 1: One ultrasonic unit of the LAUS system. Each Module consists of 32 dry point contact transducers which are spring loaded and ensure the mechanical contact to the concrete surface. Ultrasonic (UT) module, electronic module (EM), vacuum case (VC) (Photo BAM).

The UT module consists of 32 ultrasonic DPC transducers. They have each one electrical connector to the electronic unit, all 32 transducers simultaneously transmit or receive ultrasound.

The Electronic modules (EM) are designed for the generation of the electric pulse to generate the ultrasonic impulse. The managing process of sending and receiving data from the electronic modules is installed on an external computer, all communication is by using WiFi in an ad-hoc network. The EMs operate in parallel, one unit being assigned by the controller software as master unit.

Synchronization of the ultrasonic signal operates on a radio channel in the ISM band (868 MHz), ensuring a time lag of less than  $1 \mu\text{s}$  between units. The synchronization works over large distances (several meters) if the units are within line of sight. Alternatively, synchronization by electrical wire is also provided.

The probes are attached to the concrete surface using a vacuum case, custom designed and built at BAM. For each of the UTs a vacuum case (VC) was constructed which allows to mount the unit using atmospheric air pressure. The bottom of transducer units are sealed with sponge rubber material to the surface of the specimen (shown in figure 1), low air pressure is generated utilizing venturi nozzles.

In the simplest position configuration the transducer units are mounted equidistant along a line, forming a regular 1D aperture. For this and the regular 2D grid, data analysis and reconstruction procedures exist, e.g. those which have been developed for the analysis of multiple MIRA measurements [4].

In a non regular arrangement, the position and orientation of the transducers must be determined as this information is needed as input for the Inter-SAFT program. The top side of the EMs is outlined using retro reflective labels and individually labeled with a number or a character using the same paint. From digital photographs those features are extracted, applying a software module. The result of this preprocessing step is then used in the Inter-SAFT program for the analysis and visualization of all 132 A-scans acquired in the measurement sequence.

The best configuration of the shear wave transducers to produce the sound field is their alignment in a perfect line. Deviations from such a line may be enforced by surface condition, accessibility or reinforcement location. Such deviations may be tolerated if 2D reconstruction is required.

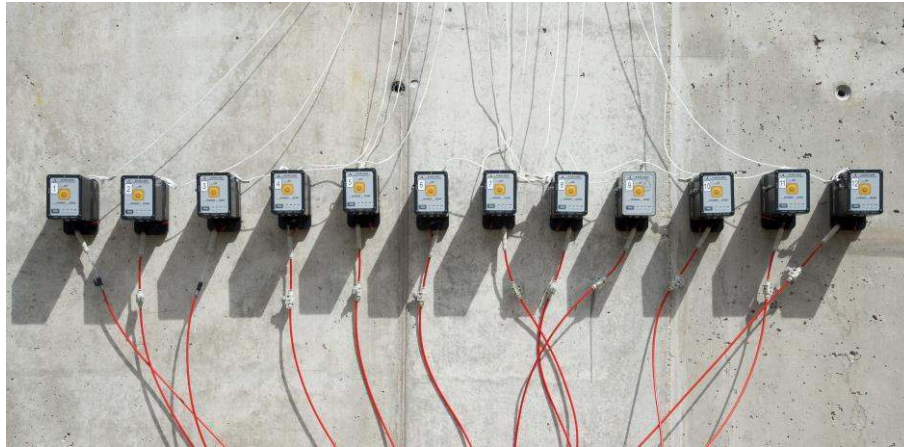


Figure 2: LAUS system mounted on a concrete wall. Hoses supply air pressure for vacuum generation. Controller manages measurement using WiFi connection. No electric cables required between LAUS modules or to controller (Photo BAM).

### 3. Data processing and system performance

The system is equipped with data processing software which is derived from the Mira Linear-Array device of the same manufacturer. It allows to control the system, capture data, displays A-scans from any transmitter-receiver configuration and does SAFT reconstruction on the basis of equidistant and linear probe positions.

For interactive data processing a software package InterSAFT (K. Mayer, University of Kassel, InterSAFT Imaging Software System, jointly developed between University of Kassel and BAM, 2008-2015, unpublished data) was extended to include the flexible configuration possibilities of the freely place able transducers of the LAUS system. In challenging experimental situations this package allows to react on difficult measurement conditions by interactive parameter optimization in the chain - data preprocessing, data filtering, reconstruction technique, post processing and visualization. The software package consists of different modules, which can be applied separately or in the processing chain to the data. This is necessary to optimize measurements results through optimization of the experimental arrangement on site.

One test measurement is presented here. A foundation slab was used to determine the depth range for measurement on very thick concrete. The slab is 4000 mm x 4000 mm with a height of 600 mm (max aggregate size 32 mm, heavily reinforced). The LAUS unit was mounted on one front side of the slab parallel to and in the center of the 4 m axis. The aperture length was kept at a minimum (LAUS units next to each other). The position of the LAUS system is indicated in figure 3.

The data from the measurement is transferred to the InterSAFT reconstruction software. Processing includes filters and adjusting the velocity to  $c_v = 2700$  m/s. The result of the SAFT reconstruction is included into the drawing of the foundation slab in figure 3. The echo from the opposite side of the slab at a distance of 4000 mm is clearly imaged at 4000 mm. Under certain conditions even the first multiple is visible in a depth of 8 m.

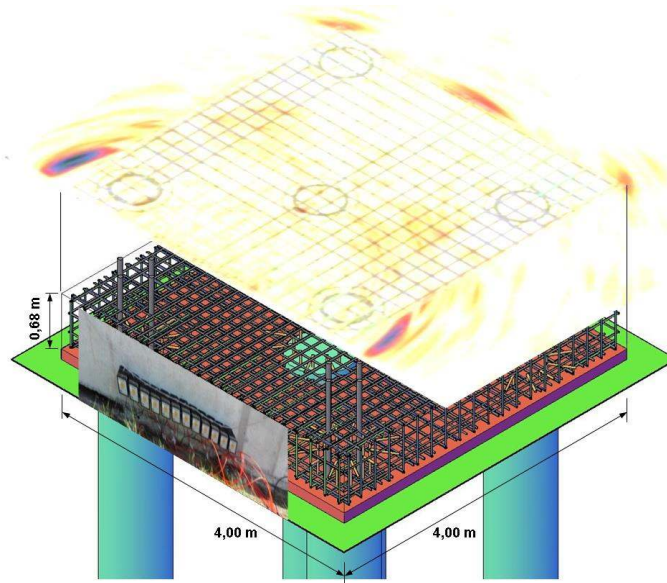


Figure 3: LAUS results on large foundation slab of 4000 mm x 4000 mm and 680 mm thickness. The LAUS system was mounted on one front side of the slab (shown by photomontage). The opening angle for the SAFT reconstruction was set to  $180^\circ$  to collect all echoes from all directions. Clear echoes are detected from the opposite front side at a distance of 4000 m, from edges of the slab on the opposite side (distance 4470 mm), and from the embedded pile top at 1300 mm. Additional echoes are visible to the side of the measurement plane behind the pile heads due to reflections of surface waves.

## 4. Conclusion

First results of measurements with the LAUS system confirmed a depth range for thickness measurements of more than 4 m in laboratory specimens (aggregate size 32 mm). Geometric resolution is comparable with the MIRA system under optimum conditions. In heavily reinforced areas, backside detection was possible at a depth of 1200 mm.

The LAUS system has been developed to test thick and highly reinforced concrete as it is common in industrial environments and large infrastructure installations. The design supports this through the compact size of the array, independent transducer units and data analysis with arbitrary aperture. Transducers can be positioned in tight spaces, good surface condition and when circumstances enforce transducer positions where interference with reinforcement is low.

## References

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