Ultrasonic Testing With Matrix Arrays, Applications in Non-Destructive Testing

Thomas HECKEL, Gerhard BREKOW, Heinz MRASEK, BAM, Berlin, Germany

Abstract. Using matrix array probes for non-destructive materials testing offers the ability of electronic steering of the sound field through a test block almost without limitation. This provides a lot of new possibilities for testing applications on components with complicated geometries and structures such as used in the public transport and energy industry. In the BAM a laboratory scale test system has been built up which can handle two matrix array probes containing up to 64 elements each. The system is now available for practical tests in the field.
In parallel several matrix array probes have been simulated, developed and constructed. A newly developed software package handles all test functions on a real-time basis for the controlling of the probes. It enables processing of high amounts of measured data which are delivered by the measurement system and the display of testing results.
When using matrix array probes in combination with image processing algorithms adaptation to in-field applications becomes easy. In this article the first results with the matrix array test equipment are introduced for different test applications.

Introduction

In recent years a clear increase in ultrasound automated testing equipment in the non-destructive testing branch has been observed. Sinking investment costs for the device technology and rising requirements with regard to the testability of the components have favored a trend towards the introduction of phased array systems to the market. Hence, requirements to modern test systems are growing constantly. This refers, on the one hand, to very limited accessibility to the components which should be tested, for example, in repetition check and also as in in-service inspection. On the other hand the complicated geometry of the components becomes a big challenge, for example in the field of transport security, especially for railway systems. In addition, marginalized conditions are created by an increase in the number of available axes for the test robotic systems required, the number of probes to be used, the high test volumes and the test speed to be realised. These trends require the development of phased array systems with electronic sound field steering possibilities in more than one direction, which are optimized for the respective test application. Using a matrix array probe offers the ability of electronic steering of the sound field through the test block with minimal limitations.

1. Operational Principles

In non-destructive materials testing with ultrasound, piezoelectric transducers are the central tool converting the electrical pulse into an acoustic wave. When partitioning the transducer by slots into many small individual elements, the acoustic properties of the transducer can be varied by the electronic control of the single elements. Similar to the radar technology this process is referred to as phased array principle. This time delayed triggering of the elements is based on the point source synthesis. An adaptation to a huge number of test applications by variation of these delay times becomes possible.

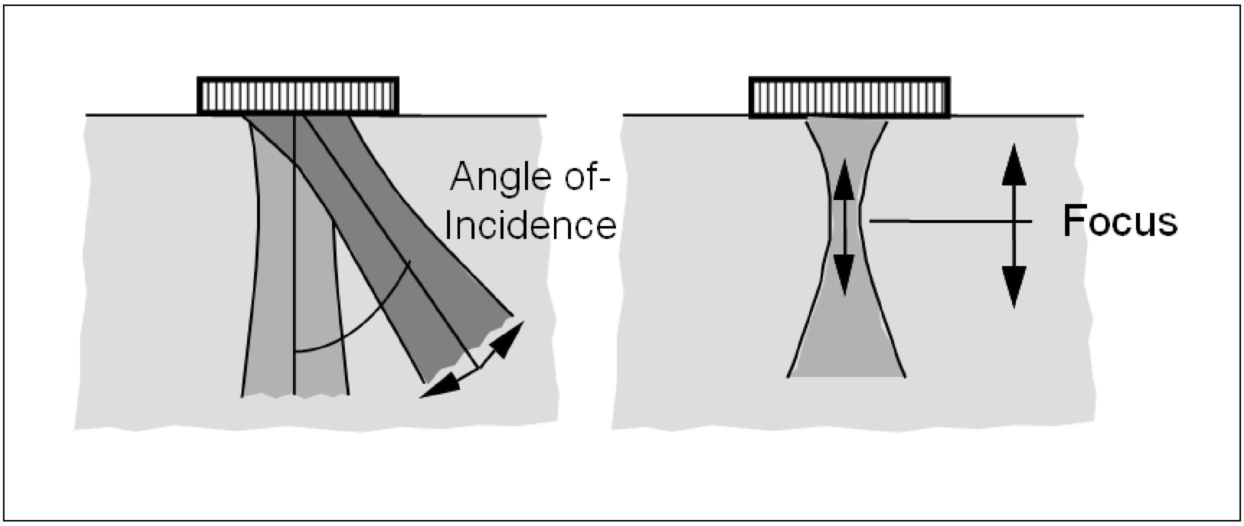

Figure 1 Phased Array Principle

If it is necessary to vary the sound field in two directions, the transducer needs to be slit vertically in both these orthogonal directions. The transducer is thereby divided into a lot of small square elements. This transducer design is designated as a 2D-matrix-array. For a matrix array probe with 8 times 8 elements, 64 coupled flaw detectors are required. The construction of a matrix array testing system is a big challenge compared with conventional testing systems.

Meanwhile non-destructive testing can face this challenge itself thanks to the progress in the electronics, in particular miniaturization. Today the modern electronic devices allow an uncomplicated use of ultrasonic testing systems equipped with multi dimensional steering of sound fields at a moderate price.

2. Ultrasound Hardware

To maximize the potential of the ultrasonic array a specially adapted electronic which can treat each element independently is required. For the operation of a 64 element probe a total of 64 ultrasonic transmitter and receiver stages are required at the same time.

Especially for this application the testing system MATRIX64 was newly developed by the BAM. It consists of an ultrasonic transmitter and receiver electronics of the COMPAS phased array system, a newly developed control electronics with digital signal processing units and a measuring data logging system supplied by National Instruments. The ultrasonic subassemblies and the control electronics are accommodated in the so-called matrix ultrasound frontend electronics.

In figure 2 the ultrasonic subassemblies can be recognized in the foreground: The patch field for the matrix array probe, the SMD equipped receiver-board and the transmitter-board (below). The control electronics (background) consists of several printed circuit boards with CPLD and DSP technology. The connection between the matrix frontend electronics and the data logging system occurs through a network link.

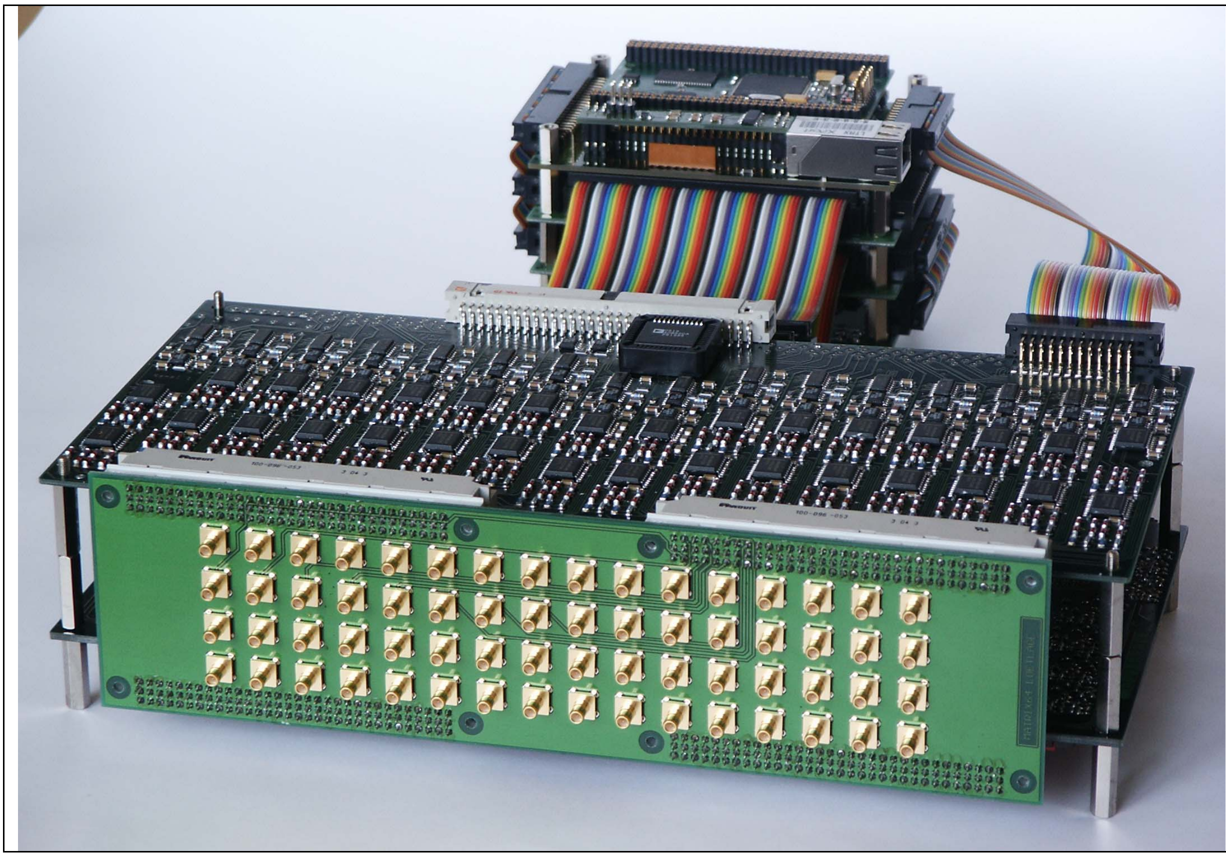

Figure 2 Ultrasonic Subassembly of MATRIX64 Testing System

Additional interfaces are available on the PXI bus for the control of the axes of the test robotic systems and coordinate register and capturing system.

3. Illustration of Results

The user interface of the entire system is realised in LabView under Windows XP. The measured data are displayed as A-, B- or C-scans. For a three-dimensional presentation of the measurement results special image formats are under development.

The evaluation algorithms are the main focus of software developing activity. Large amounts of data are recorded from the matrix array probe according to its variable set of testing possibilities. With image reconstruction and processing algorithms this flood of data must be transformed into a few expressive ultrasound images. Thereby the optimized presentation of the result data and their evaluation corresponds directly with the respective application. At the moment algorithms for different application sets are under development.

4. Probe

In contrast to conventional probes a transducer in a matrix array probe consists of many small elements. A matrix array with 8 times 8 elements each about 2.5 mm² would fit into a conventional transducer with a size area of about 20 mm². Hence, for the technical realization of a matrix array probe unit suitable to in-field operation, the unit will have to be customized in the manufacturing process for the transducer, especially with regard to transducer itself, electrical contacts, wiring, materials etc. .

In the early development stage the future test situation must be analyzed to determine the desired or necessary sound field and unit properties. The basic parameter set can be derived by analyzing roughly specific test situations. A basic model can be calculated from these properties. The model calculations occur on the basis of the point sources synthesis. In the final development stages the parameter set is optimized by recursive model calculations according to the specific planned application.

One such example is described below using a matrix array probe with following properties, which has been optimized and built as a test prototype.

Test frequency: 1.5 MHz
Transducer size: 17 x 17 mm^2
Element size: 2 x 2 mm^2

For the transducer a composite material was used. The cutting of the transducer into single elements was carried out with the aid of laser processing techniques. The element sizes and slot width are adapted during the production process. The production process guarantees that all elements have reproducible electric and acoustic properties. For the connection of the transducer elements a special adapter PCB is required. A unique soldering technique is necessary, so that the acoustic properties of the small elements will not be influenced by the soldering process itself.

5. Example 1:

The automated testing (conventional transducers) of components with multiple curved faces in immersion technique requires a very accurate mechanical positioning system. The optimum probe position is always vertical with respect to the components face which means that the component face and probe position have to be aligned with each other uphold verticality.

With the help of a matrix array probe some of the necessary movements of the probe can be replaced by electronic sound field steering. Therefore the probe unit can be mounted in a simple x-y-z- positioning system without need for any additional rotation axles.

The goal of this development is that the automated test equipment computes the exact position and geometry of the component by itself, using data from a coarse scan. After calculating the optimal test parameters for the actual component the automated testing starts. With this setup, only coarse positioning of the component will be necessary.

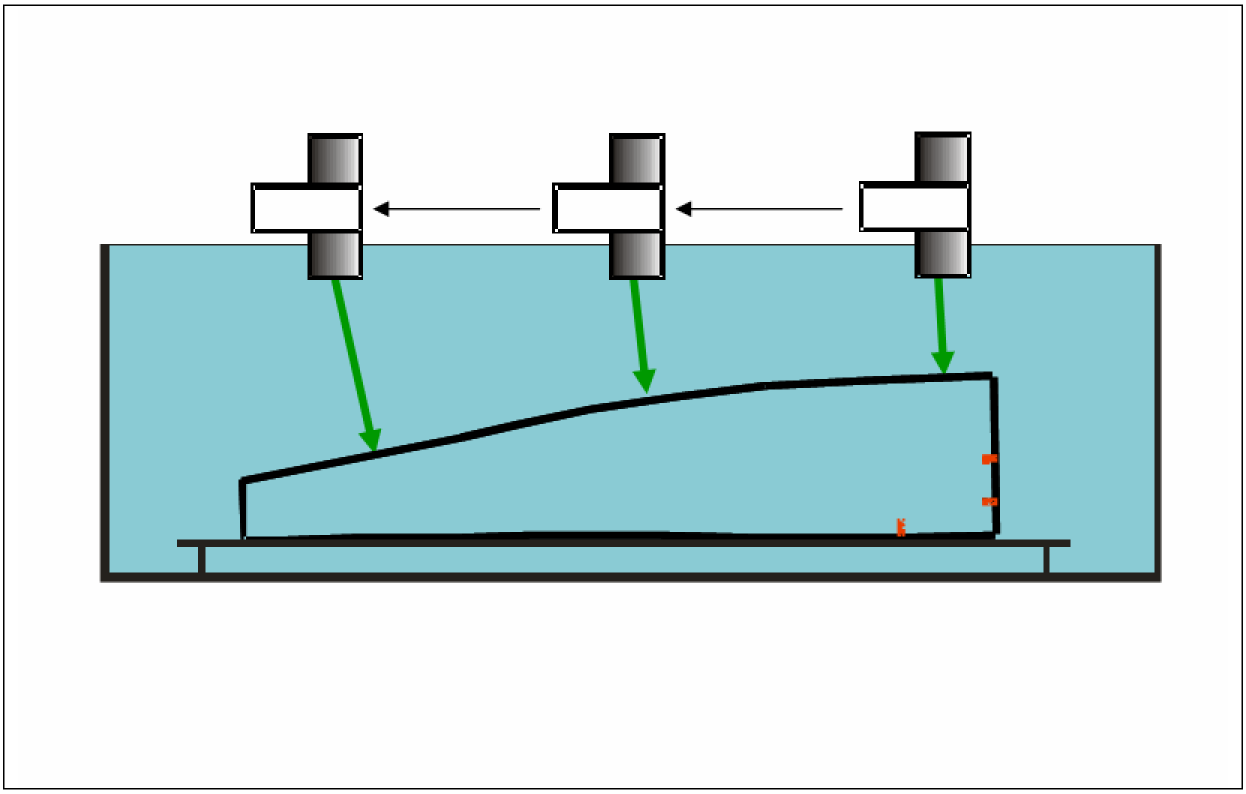

Figure 3 Exampe 1 - Immersion Technique Using Matrix Array Probe

In a test block with a unilaterally spherical curved face contouring investigations have been carried out. Objective was to measure the angle of slope to the surfaces-normal of the curved face as a function of the probe position and to determine the optimum test parameters for the array.

The measurement setup is shown in figure 3. Using the z axis the point of focus could be adapted to the depth position of the test reflectors in the CFK test block. Test reflector drillings with a diameter of 1 mm and flat bottom drillings with diameters of 1 mm and 3 mm are used.

6. Example 2:

In the railway industry the testing of wheel set is, due to aspects of technical safety, critical particularly as only non-destructive testing may be employed. Only mechanized ultrasound test systems are capable of achieving the necessary short inspection cycles. The potential for reducing inspection time centres on in-service inspection. Because of limited in-situ accessibility, a special V-sound path with coupling on the tread is employed for the testing of the disc faces.

The geometry of engine wheels are especially complex, because their discs have several specific drillings and cross section crossing. Cracks in the discs which may occur are expected to start from the radial face and run tangentially and tend to occur in particular close to drillings and cross section crossings.

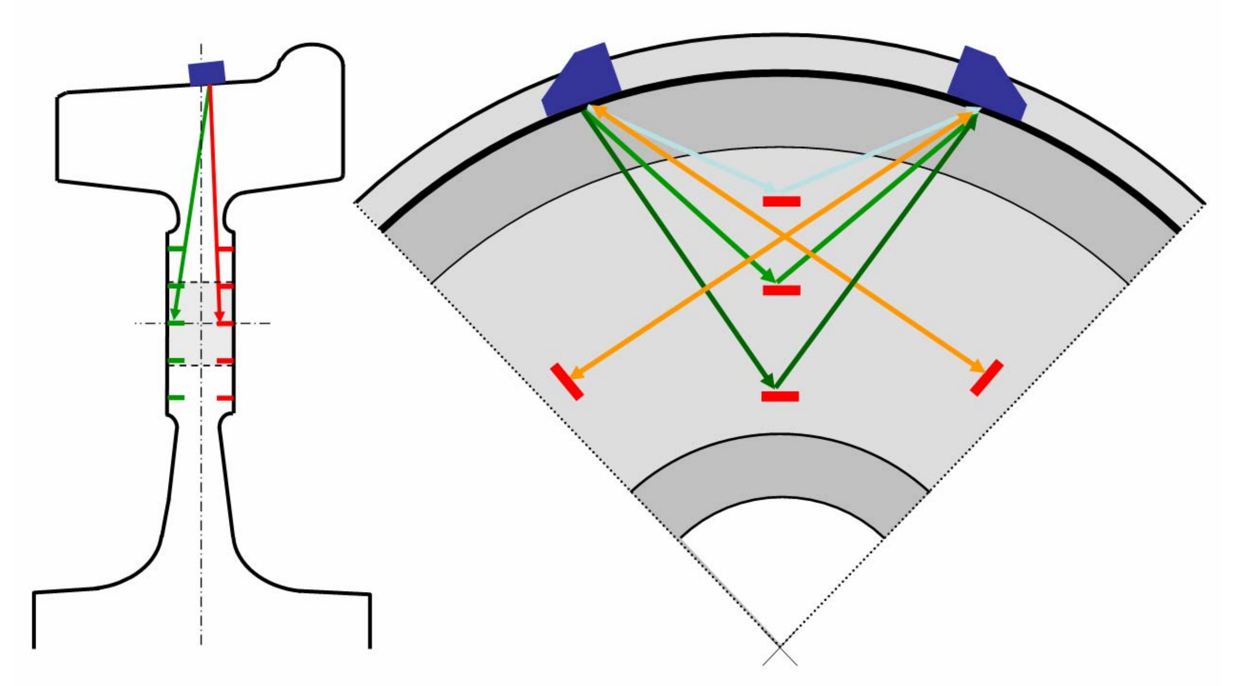

Figure 4 Example 2 - Testing of Discs Using Matrix Array Probes

Two probes, in transmitter-receiver configuration are positioned facing each other on one line on the tread. For the detection of the reflection, the reflected signal from the test reflectors shaft is employed. To steer the sound at different depths on the respective disk face, the sound field of the probe has to be moved in two independent directions. Using two matrix array probes in this setup means every position on the disc can be accessed.

Notches with depths of about 2 mm are used as test reflectors with radial and tangential orientation. The notches are sickle-shaped and have a width of about 1 mm. For the presentation of the results echotomography algorithms are used. The basic measuring setup is shown in figure 4.

7. Conclusion

Automated non-destructive ultrasonic testing of components with complicated geometry and limited accessibility pose high qualification requirements on the mechanical positioning of the ultrasonic probes. By replacing mechanized investigation using conventional transducer heads with matrix array probes certain mechanical movements become obsolete and can be replaced by electronic control of the sound field. This is a huge advantage especially for testing problems with limited accessibility.

For the operation of matrix array probes a special phased array ultrasonic test equipment with a large number of parallel channels is required. In the BAM a test system has been built on a laboratory scale to examine a range of field applications. It facilitates the connection of two probes with up to 64 elements each. This system is named MATRIX64 and consists of ultrasound frontend electronics and data logging system based on an industrial PC.

For measurements in immersion a 64 element probe has been optimized and a prototype has been constructed.

When using matrix array probes in combination with signal processing algorithms and image processing the adaptation to a huge number of complicated test applications and geometries in the field becomes much easier. For a range of specific applications, different problem specific algorithms are under development which when necessary can be customized to customer specifications.

Two application examples have been shown.

References

[1] R. Boehm, A. Erhard, Simulationsgestützte Entwicklung von Ultraschallprüfköpfen, DACH – Jahrestagung 2004 in Salzburg