

DIGITAL ULTRASONIC IMAGING SYSTEM: THE SOFTWARE CONCEPT

Vytautas DUMBRAVA, Rymantas KAŽYS,
Liudas MAŽEIKĀ, Linas SVILAINIS

Ultrasound Measurement Laboratory,
Theoretical Radioengineering Department,
Kaunas Technical University,
3028 Kaunas, V.Juro St.50, Lithuania

Abstract. The paper is devoted to analysis of the software peculiarities of the computer based ultrasonic imaging system for non-destructive testing (NDT) applications. The developed software enables 1, 2, and 3-dimensional imaging of the intrinsic structure of the materials and measurement of their parameters.

Key words: ultrasonic imaging, image processing, ultrasonic digital NDT.

An ultrasonic imaging gains the wide application in an industry, especially for the non-destructive testing. The developed systems (see, e.g., Neumann and Barbian (1983), Smith (1986), Mark at al. (1987), Generazio at al. (1988)) enables to determine the spatial position of flaws, to obtain their images and in some cases to measure their dimensions. The operational possibilities of such systems strongly depend on a developed software. In this paper the main concept and peculiarities of the software developed for the ultrasonic imaging system IZOGRAF-2 are described.

Fig. 1 shows the block diagram of the whole system. It consists of the two coordinates electromechanical scanner, the

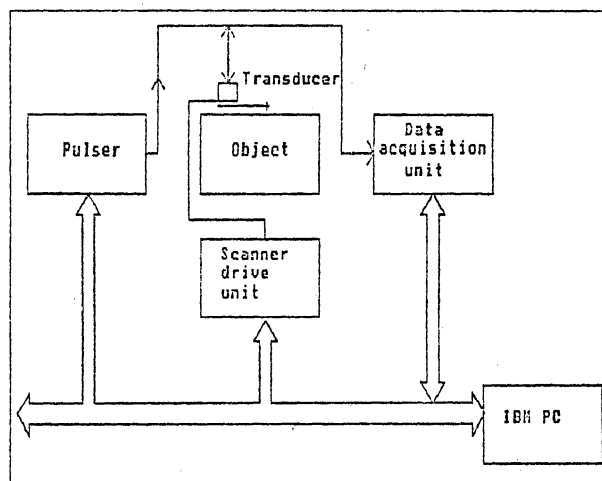


Fig. 1. Block diagram of the ultrasonic imaging system IZOGRAF-2.

scanner drive unit, the data acquisition unit and a personal computer compatible with IBM PC/AT. All main units of the system are controlled by a personal computer via MULTI-BUS-1. The system can be operated in pulse echo, tandem and transmission modes in the frequency range (0.5 ÷ 25) MHz. An acoustic image is obtained using a raster scanning technique. For this purpose ultrasonic transducer is scanned along the surface of the object under test. The microprocessor based scanner drive unit is controlled by the personal computer. The minimum scanning step is 0.1 mm, the scan area is 310 × 260 mm. The detailed description of the hardware of this system can be found elsewhere (see Kažys et al. (1991)).

The operation of the system is completely predetermined by the developed software. The menu driven software has a multilevel structure (Fig. 2). The first level program package SYSTEM STATUS VIEW, INITIALIZATION, VISUALIZATION, MEASUREMENT, COPY, PROCESSING and SELF-TESTING programs, each of which consists of others lower

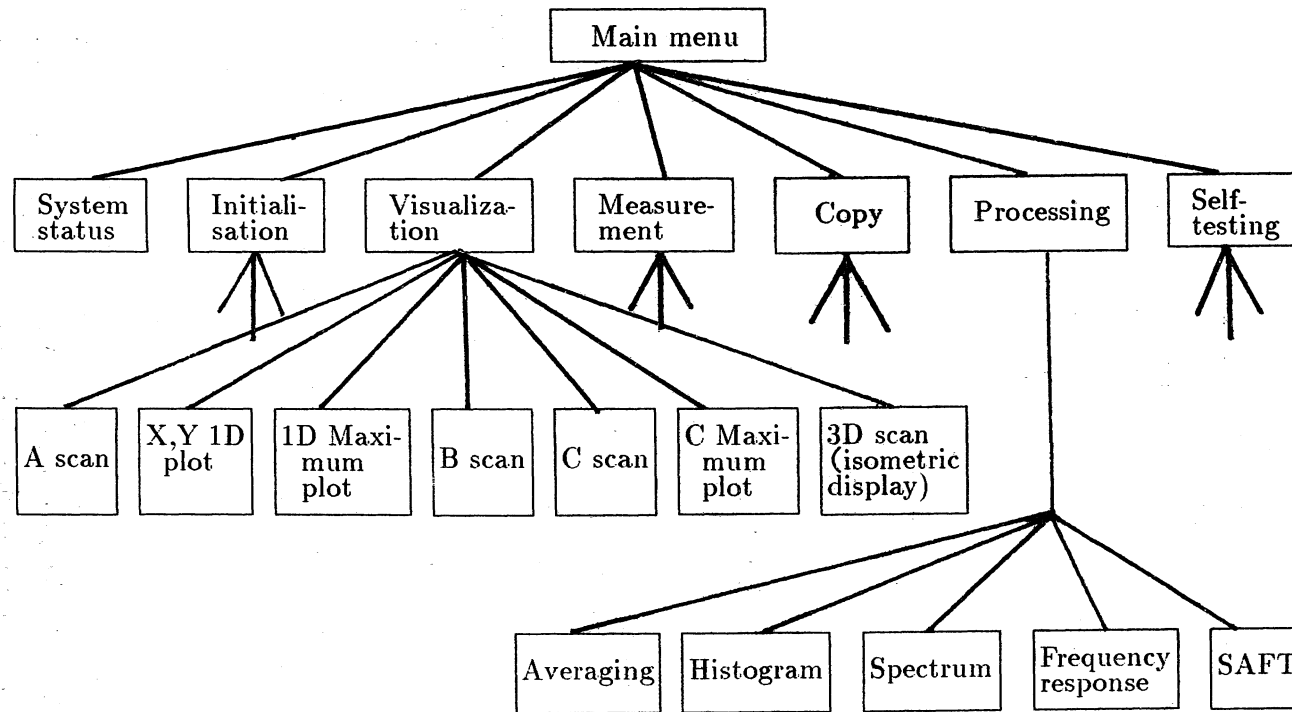


Fig. 2. Bloc diagram of menu driver software.

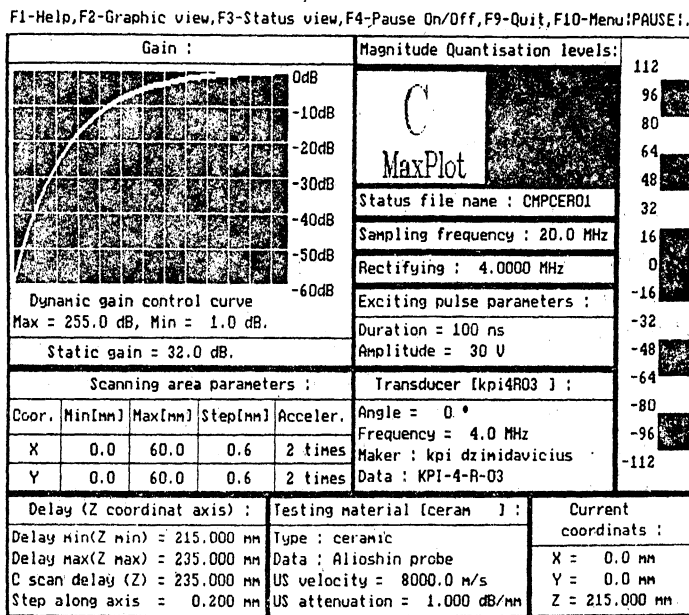


Fig. 3. Display of the system status.

level routines and sub-routines. Some of them are shown in Fig. 2. The program SYSTEM STATUS VIEW displays the parameters of all main units of the system (Fig. 3). The program INITIALIZATION enables the operator to set required values of these parameters. For example, it is possible to choose the scanning area coordinates, the amplitude and the duration of the excitation pulse, the gain value, to present the time varying gain curve and so on. The time varying gain needed for a compensation of a signal losses in a medium can be chosen in two different modes. The first is based on the calculation of the gain versus time control curve from the relevant ultrasonic transducer and the material data: diameter, resonant frequency, ultrasound velocity and absorption. In order to reduce the computation time the simplified model is used. The second way is based on a construction of the re-

quired correction curve which fits the experimentally collected echo data from the series of reflectors at the different distances from the transducer.

The structure of the program VISUALIZATION is given in detail in Fig. 2. It enables the operator to choose the required scanning mode and the appropriate display format of the collected data on a high resolution graphics screen. This program package includes well known A, B and C scanning and displaying modes as well as less known 1D X and Y plot, 1D and 2D maximum plot and 3D isometric visualization modes. 1D X or Y plot mode enables to obtain the distribution of the instant amplitudes of non-rectified signal at the preset z coordinate along x or y direction. It means that it is possible to display on the screen the spatial distribution of inhomogeneities in the tested material at the given depth along the specified direction i.e., in the layer of the finite thickness (Fig. 4). For the comparison in Fig. 5 the B scan image of the same test object is presented. Contrary, maximum plot mode presents the projection of one inhomogeneity located in the layer of the finite thickness causing maximum reflected signal (Fig. 6). It means that in the case of a few flaws located on the same line oriented along z -axis only one creating maximum signal will be displayed on the screen. The signals reflected from the smaller flaws will be neglected. For example if the Y maximum plot mode is used on the screen is generated the curve

$$u(y_j) = \max \operatorname{mod} u(y, z) \Big|_{x = \text{const}}$$

$$z_{\min} \leq z \leq z_{\max}$$

where y_j is the coordinate of the j -th scanning point, z_{\min} , z_{\max} are the boundary coordinates of a selected layer. The thickness and the spatial position of the layer from which reflected signals are collected can be chosen by an operator.

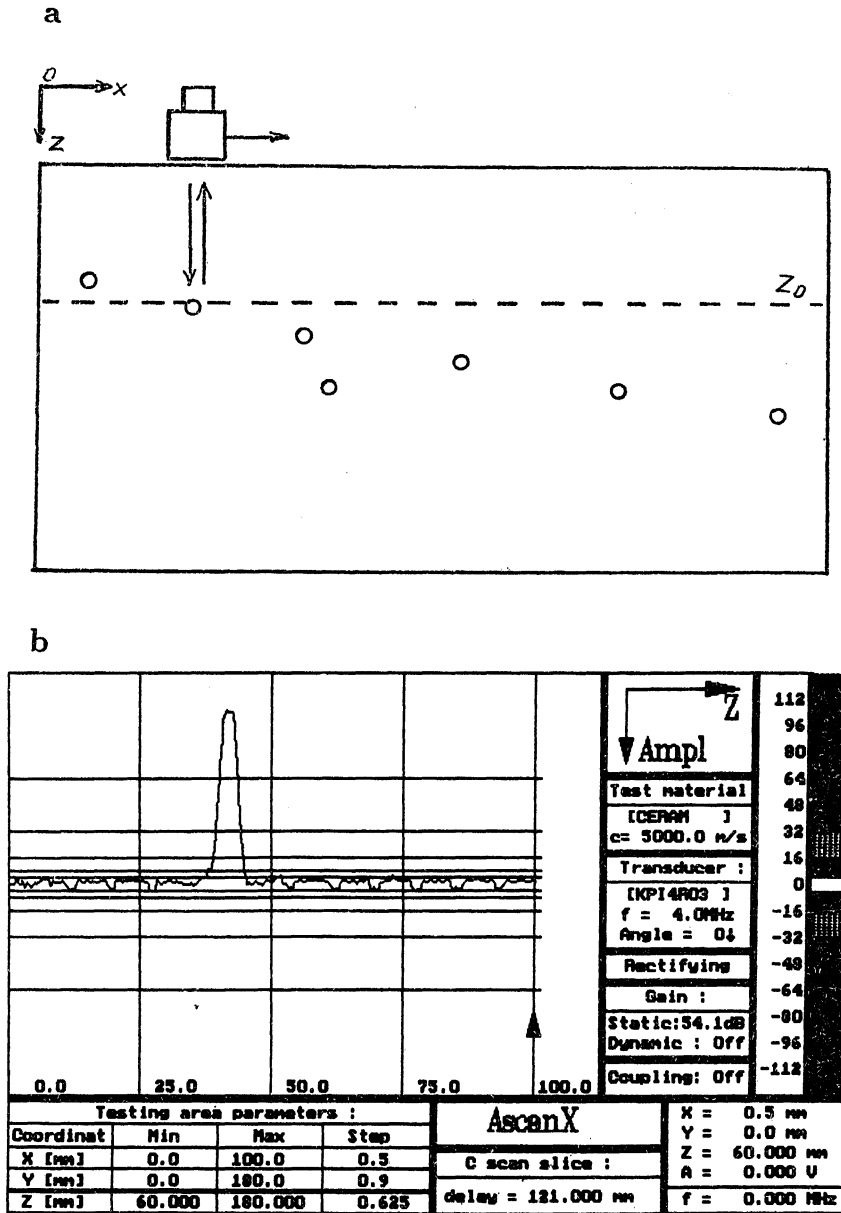


Fig. 4. 1D X or Y plot mode: a – principle of image formation; b – example of 1D image.

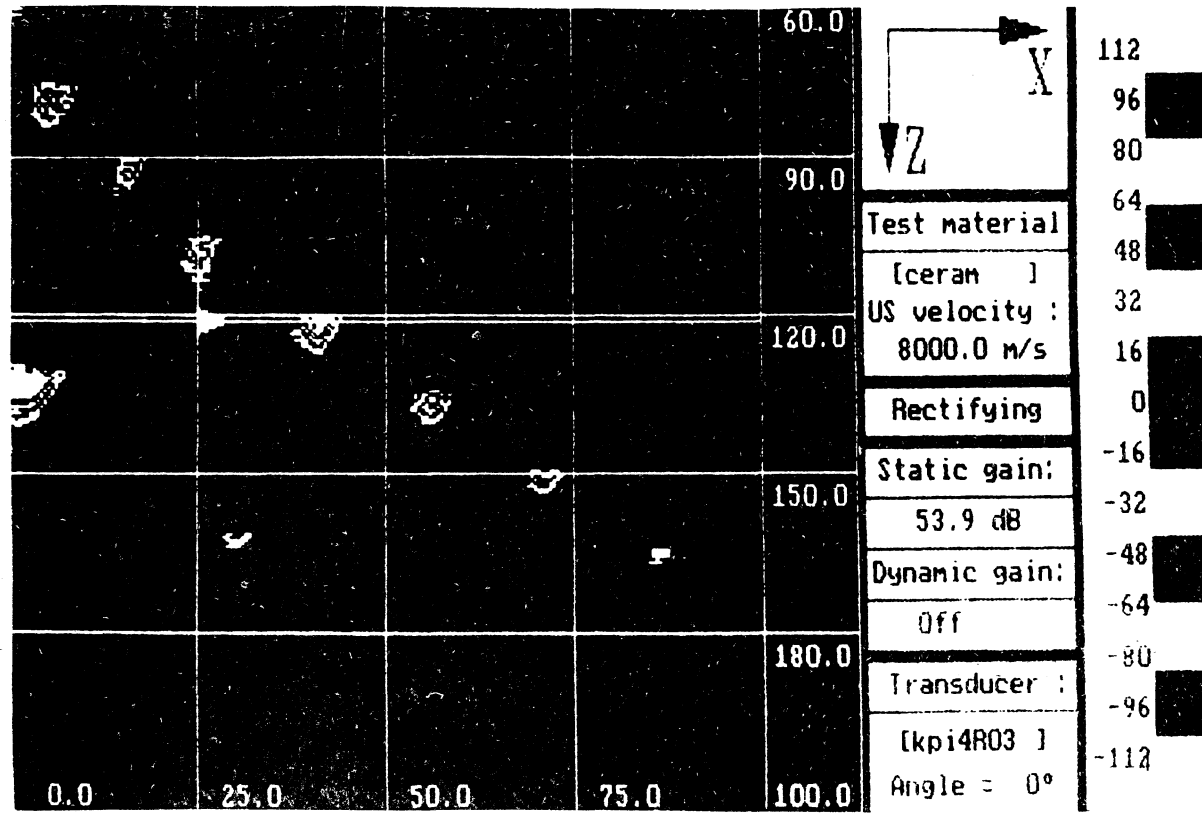


Fig. 5. B scan image of the test object No.1.

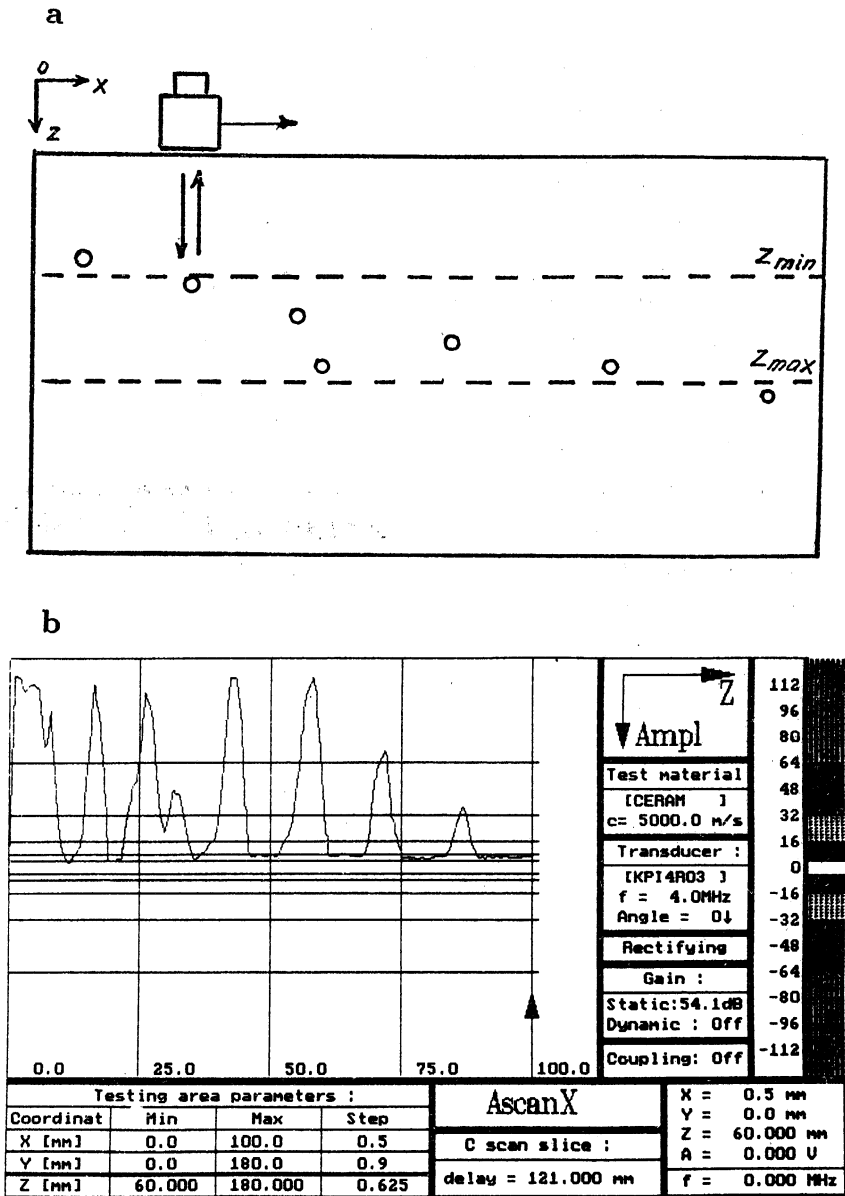


Fig. 6. Maximum plot mode: a – graphical explanation; b – example of 1D image of the test object with 1mm drilled holes.

The maximum plot is possible in 1D X, Y and 2D C scanning modes. It allows the fast collection of echo data from the object under test. The more detailed analysis of the selected regions can be provided by means of conventional 1D X, Y or 2D C plot modes.

It is necessary to point out that in 2D pictures color coding is used. The 16 freely chosen amplitude levels are represented by different colors. It allows to enhance image details or highlight small signal variations. Some standard amplitude scales are generated by the software: linear, logarithmic and others.

According to the images formation principle, the consists of pixels the shape of which depend on the used interpolation procedure. The simplest is 2D interpolation by rectangular elements. In this case the image consists of rectangular pixels coded by different colors (Fig. 7a). The quality of the picture mainly depends on the number of pixels which is predetermined by the number of scanning steps. The image quality at the same number of steps may be significantly improved using 2D smoothing filters, or in other words, smoother interpolating function. Fig. 7b shows the same image as in Fig. 7a, but obtained using 2D linear interpolation. The interpolation was performed using Bresenham's algorithm.

In some cases the presentation of 2D images by isolines instead of a color coding is more preferable. The isolines can be obtained from the conventional color image using the developed algorithm.

Let us denote the 2D image by $K \times L$ dimensional matrix $[I]$. There K corresponds to the number of rows and L is the number of columns in the image. The isolines $[K]$ are obtained by means of logical operation

$$[K] = [I'] \oplus [I''] \vee [I'] \oplus [I'''],$$

where \oplus denotes the summing by mod 2, and \vee is the logical

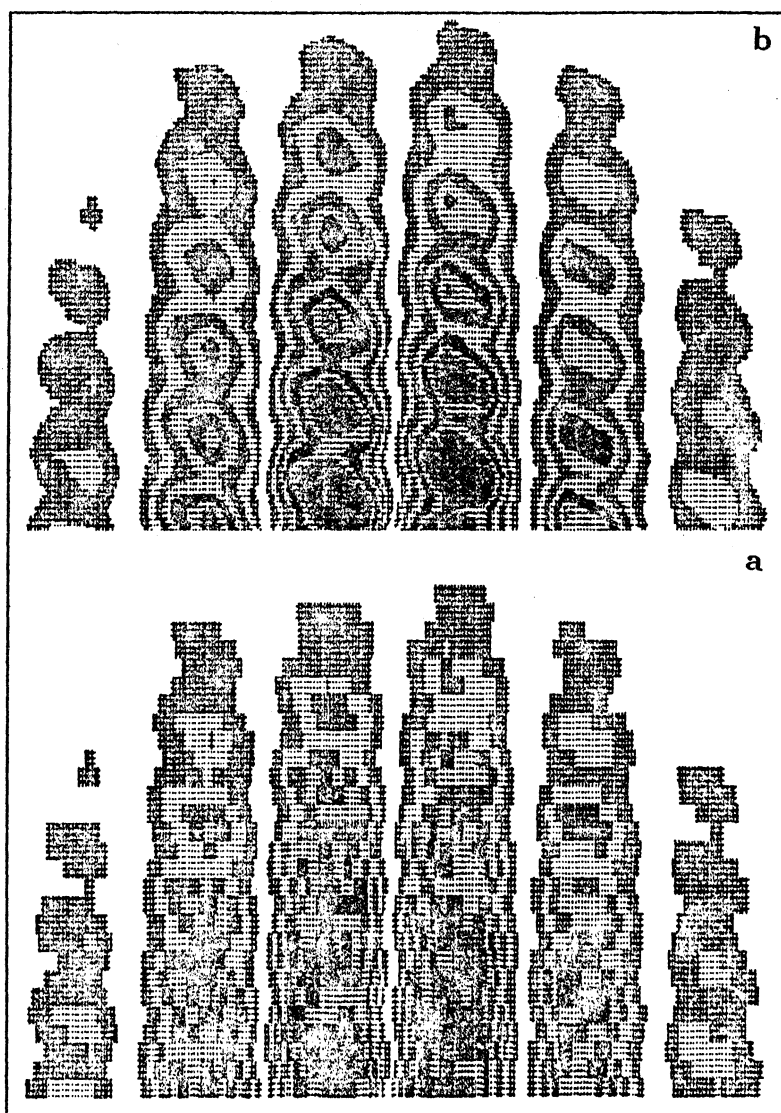


Fig. 7. Presentation of the 2D image by different interpolation techniques: a - rectangular interpolation; b - linear interpolation.

function 'OR'. The elements of matrixes $[I']$, $[I'']$, $[I''']$ are determined from the image matrix $[I]$ as follows:

$$\begin{aligned} I'_{kl} &= I_{kl}, \\ I''_{kl} &= I_{k+1,l}, \\ I'''_{kl} &= I_{k,l+1}, \end{aligned}$$

where $k = \overline{1, \dots, (K-1)}$, $l = \overline{1, \dots, (L-1)}$. The latter restriction means that after such a processing the dimensions of the image are reduced by one row and one column. The examples of the 2D image with isolines obtained according to the described algorithm are shown in Fig. 8.

The formation of 3D image is based on the isometric projection of slices obtained in xOz or yOz planes (Fig. 9). The signals reflected from the flaws are represented in 3D space projection on the screen. The amplitude of the signal is usually coded by colors. Such a technique has some disadvantages: the image is too motley and difficult to understand. For this reason binary coding is preferable: the pixel of the image is displayed only when the signal exceeds the chosen threshold level. In this case image consists of isolines corresponding to the threshold level. For the better understanding of the image the boundaries of the object can be outlined together with the displayed data (Fig. 9).

The measurements in all kinds of images are provided by means of the program MEASUREMENT. It enables to obtain the spatial or temporal coordinates of the selected point in a image, to determine the instant amplitude of the ultrasonic signal. The measurements can be performed semi-automatically using a cursor, generated by a special subroutine on the screen. When the position of the cursor is selected by means of the specified keys on the keyboard, the digital value of the measured quantity is displayed in the special window. The on-line processing or post-processing is performed

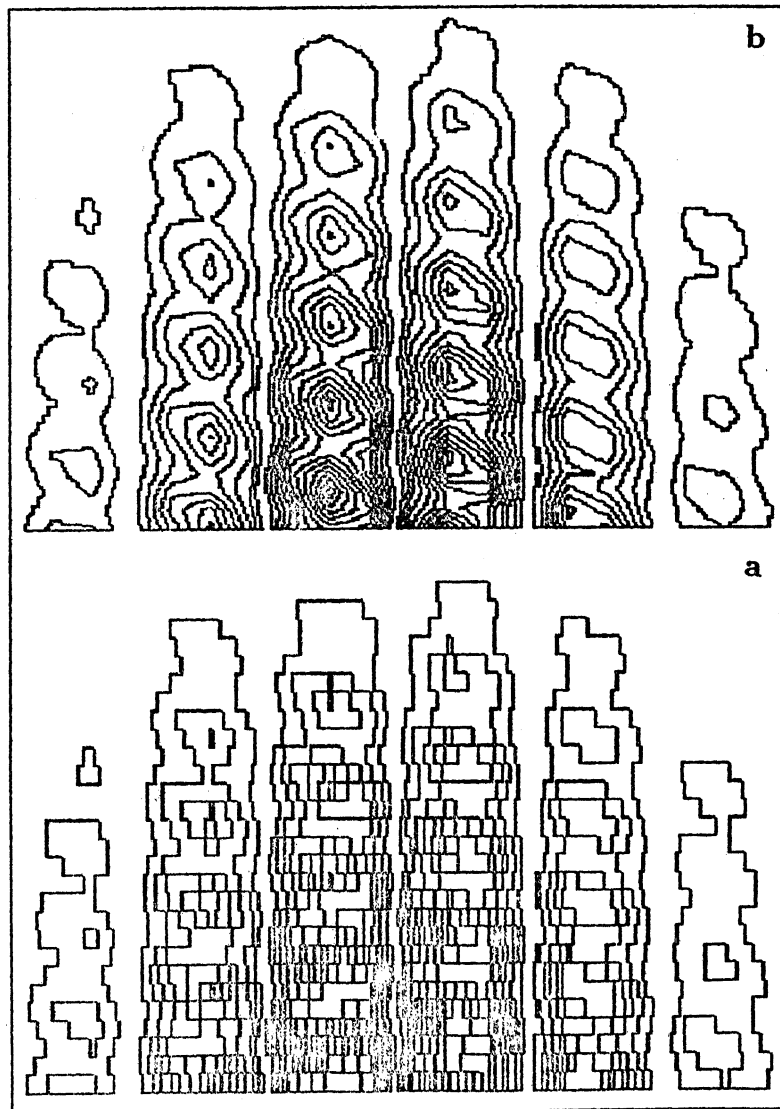


Fig. 8. Presentation of the 2D image shown in Fig. 7 by isolines: a – rectangular interpolation; b – linear interpolation.

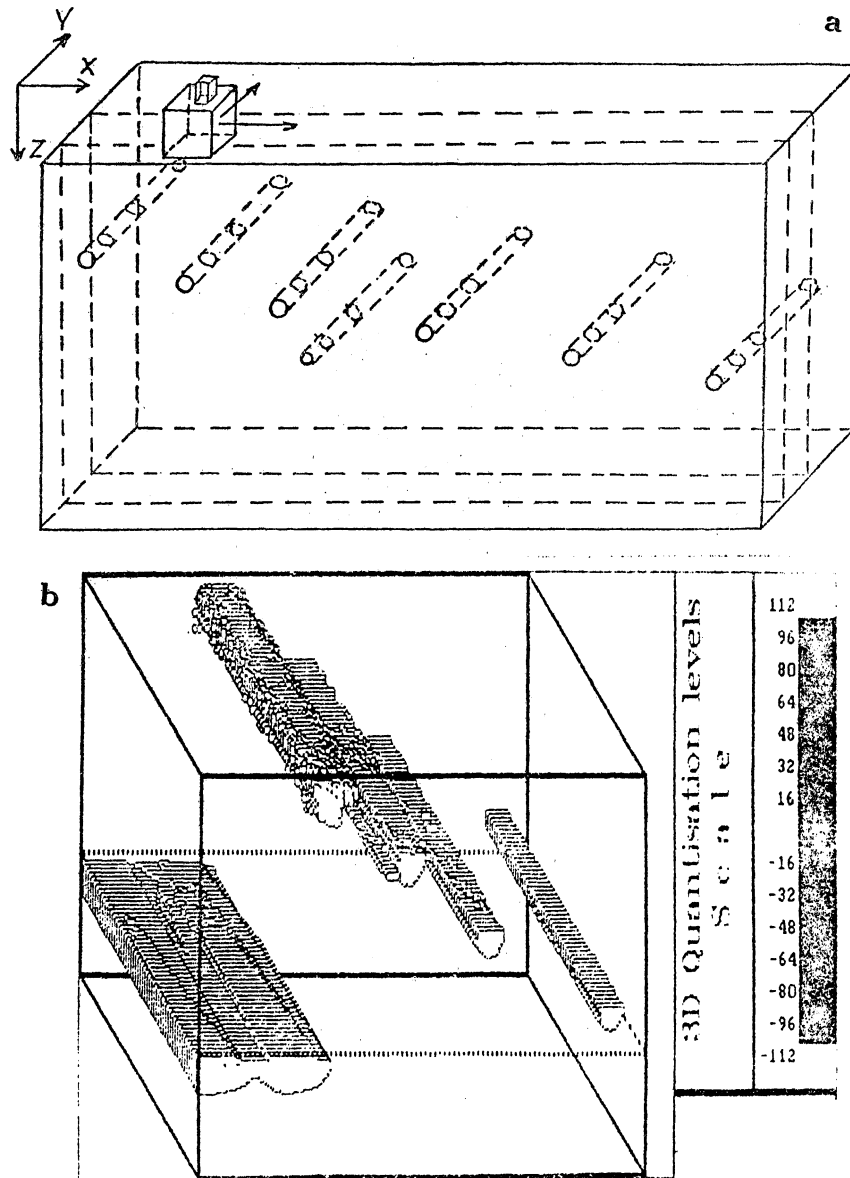


Fig. 9. 3D image mode: a – principle of image formation from the slices; b – example of 3D image of the test object presented in Fig. 7.

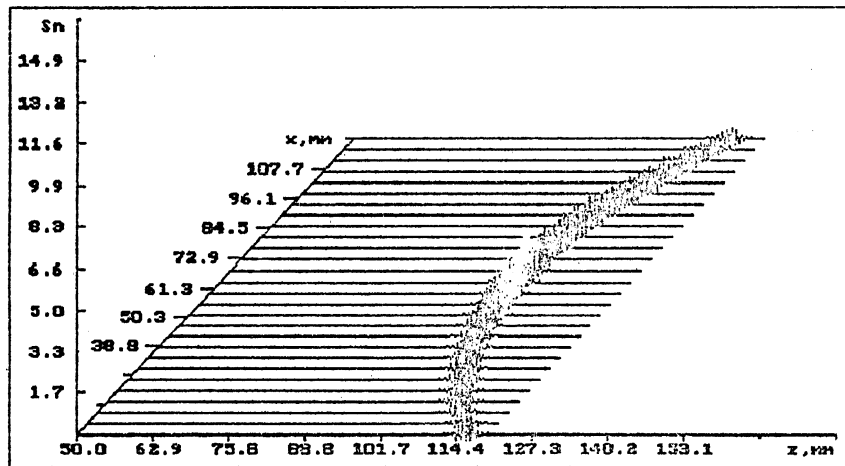
using program package PROCESSING (Fig. 2). It enables to carry out statistical analysis, spectral analysis, frequency response measurements and to enhance the spatial resolution of the images by means of Synthetic Aperture Focusing Technique (SAFT). The processing program SAFT was checked using the simulated data. During the simulation it was assumed that the ultrasonic beam spread angle was 90° and the central frequency of the Gaussian pulse was 2MHz. Fig. 10 shows quasi 3D image of a point type reflector in a water before and after SAFT procedure. The focusing was performed at the $z_0 = 100\text{mm}$. The transducer was scanned along x axis with the step 1mm. It means that the SAFT procedure was performed using 100 adjacent lines of the primary image. The presented results show a significant enhancement of the lateral resolution. The main drawback of a such type processing is that this procedure is a rather time consuming.

The developed ultrasonic imaging system IZOGRAF-2 has been successfully applied for a solution of various NDT tasks: weld inspection, defects visualization in metals, engineering ceramic and composite materials examination, visualization of the ultrasonic fields, radiated by piezoelectric transducers. Fig. 11 and 12 are hard copies of images obtained with the described system.

Fig. 11 shows the acoustic image of a silicon nitride material obtained in C maximum plot mode. The disk shape sample was tested using an immersion technique. A few different signals levels in this monochrome picture are coded by the same black color. The coding scale is shown on the right side of the picture. The layer from which reflected signals were collected was chosen to be half of the disk thickness. The presented image shows a very non-uniform intrinsic structure of this sample. Non-uniformities in the image are represented by dark regions inside of the disk rim.

Fig. 12 gives the image of aluminum composite material

a



b

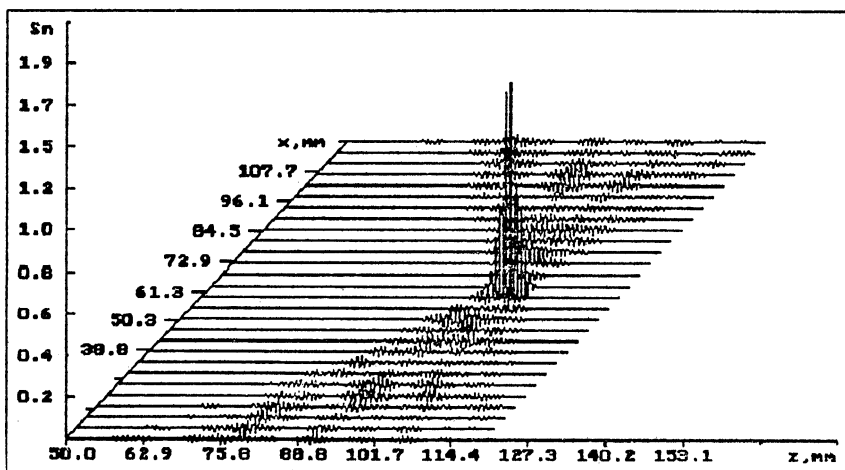


Fig. 10. B scan image before (a) and after (b) soft processing.

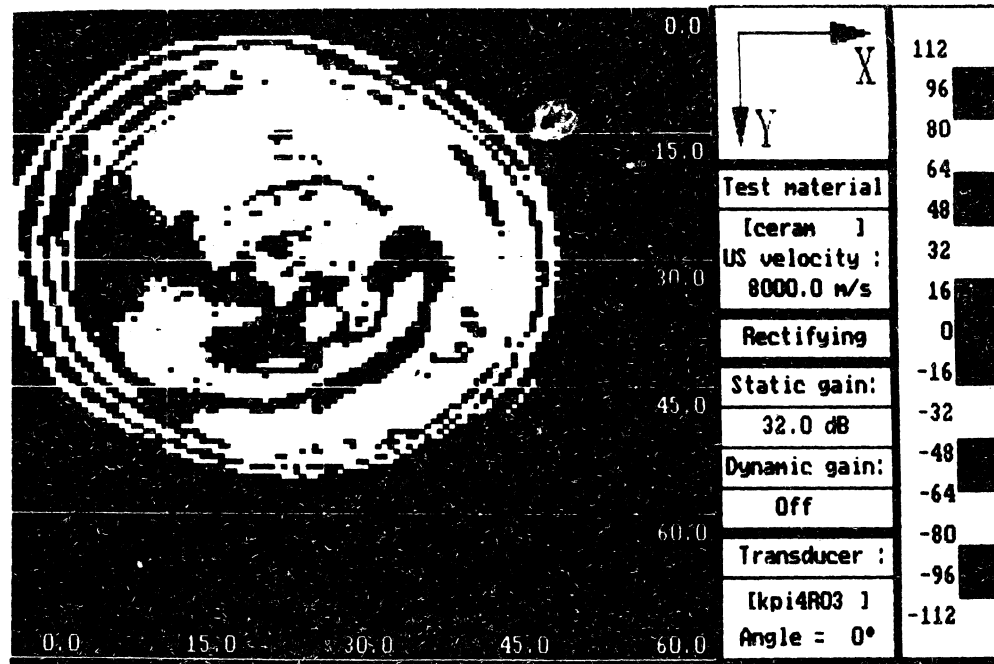


Fig. 11. Acoustic image of the disk produced from a silicon nitride obtained in C maximum plot mode.

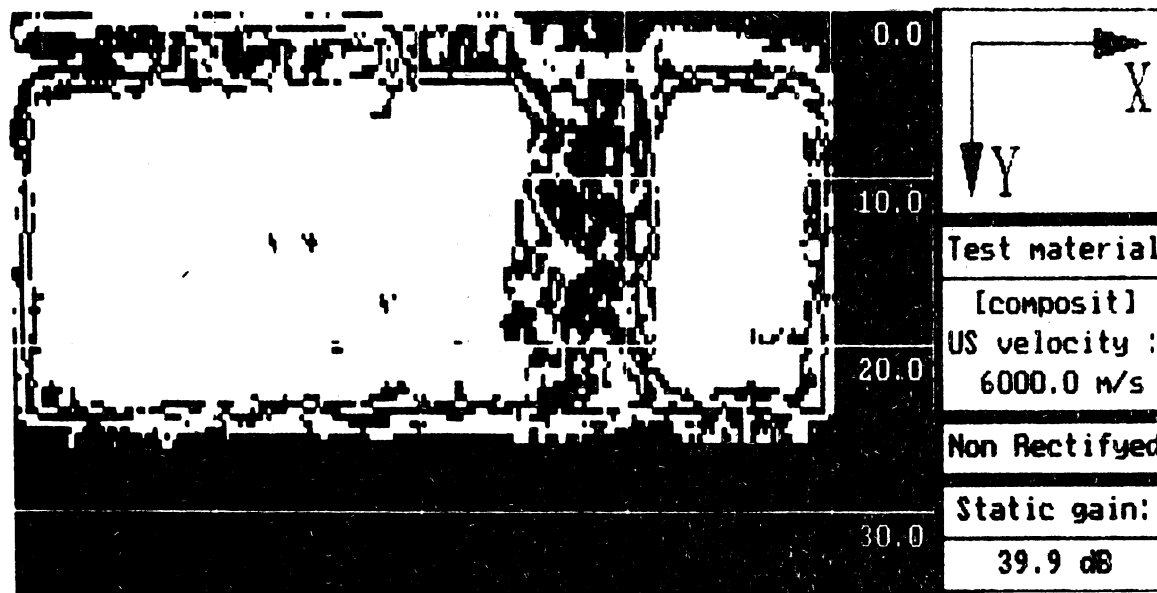


Fig. 12. Acaustic image of the aluminum composite material with boron fibers (C maximum plot mode).

with boron fibers obtained in C maximum plot mode. The tested sample was a sheet with a thickness 5 mm. The dark region shows the artificial defect produced during manufacturing process. This defect was a delamination of neighboring aluminum layers. The similar experiments carried out with carbon fibre composite materials have shown feasibility to detect disbonds at the carbon - glass fibre interface with a high reliability too.

The presented results show a great variety of the application fields of the developed ultrasonic imaging system. It is worthwhile to remind that due to MEASUREMENT mode it is possible to obtain not only quantitative images, but to carry out measurements of ultrasound velocity, absorption and scattering coefficients, to obtain impulse and frequency responses of the objects under test. For this reason IZOGRAF-2 can be used for the detailed studies of materials microstructure or investigation and mapping of pulse ultrasonic fields.

REFERENCES

- Neumann, R.K., and O.A.Barbian (1983). Hardware-equipment for automatic ultrasonic inspection by the ALOK-technique. In P.Holler (Ed.), *New Procedures in Nondestructive Testing*. Springer-Verlag, Berlin-Heidelberg. pp. 13-25.
- Smith, B.J. (1986). ZIPSCAN: a new concept in ultrasonics instrumentation. *British Journal of Non-destructive Testing*, **28**(1), 9-16.
- Mark, D.K., M.Macecek and A.Kovacs (1987). Ultrasonic defect visualization in a metal block. *Acoustic Imaging*, Proc.15 International Symposium Vol.15. New York-London. 503-509.
- Generazio, E.R., D.J.Roth, G.Y.Baaklini (1988). Acoustic images of subtle porosity variations in ceramics. *Materials Evaluation*, **46**, 1338-1343.

Kažys, R., V.Dumbrava, L.Svilainis, V.Puodžiūnas, L.Mažeika and N.Eidimtas (1991). 3D digital ultrasonic imaging system for NDT applications. *Proc. of the Higher Schools of Lithuania Republic, Ultragarsas*, **23**.

Kažys, R.-J., L.Mažeika, A.Vladišauskas (1989). Axial focusing of ultrasonic beam under pulse excitation. *Defektoskopija*, **5**, 71-78 (in Russian).

Received June 1990

V. Dumbrava graduated from the Kaunas Polytechnic Institute in 1977. He is senior lecturer of Theoretical Radioengineering Department, Kaunas Technical University, Kaunas, Lithuania. His research interests include a computer aided hardware design.

R. Kažys received the Degrees of Candidate and Doctor of Technical Sciences from the Kaunas Politechnic Institute in 1970 and 1981, respectively. He heads the Theoretical Radioengineering Department and Ultrasound Measurements Laboratory of Kaunas Technical University, Kaunas, Lithuania. His research interests include ultrasonic imaging, signal processing and ultrasonic transducers.

L. Mažeika is an associate professor of Theoretical Radioengineering Department, Kaunas Technical University, Kaunas, Lithuania. He received the Degree of Candidate of Technical Science from the Kaunas Polytechnical Institute in 1986. His research interests are in the field of digital modelling.

L. Svilainis is an assistant professor of Theoretical Radioengineering Department, Kaunas Technical University, Kaunas, Lithuania. He graduated from the Kaunas Polytechnic Institute in 1988. His research interests include a software design.