MULTITECHNIQUE NON-DESTRUCTIVE TESTING: SYSTEMS AND APPLICATIONS

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The application of redundant non-destructive testing techniques has been carried out in critical situations without any specific methodology, when the importance of the inspection required the confirmation of the results. Nowadays, systems including multitechnique acquisition capabilities (ultrasounds, eddy current, electromagnetics, etc.) as well as evaluation systems which incorporate "data fusion" tools, open new perspectives from the point of view of reliability and performance of the test.

This paper presents some experiences and activities developed by TECNATOM, S.A. in relation to this topic. In particular, the results and conclusions of MIDAS project (multitechnique data acquisition and evaluation system, according to the most advanced concepts) and MISTRAL project (BE-96-3482: Data fusion analysis applied to the inspection by eddy current, ultrasound and X-ray) will be summarised below. *

INTRODUCTION

The complete analysis of an industrial component requires the use of different Non-Destructive Testing methods and even several techniques inside the same method. For instance, in the inspection of metallic components, ultrasounds (and/or X-ray) are employed for the detection of volumetric defects and eddy current for surface defects. In other cases, a combination of different ultrasonic techniques, like probes array and TOFD is used, providing complementary information about the same volume under analysis.

Although some years ago a second technique was only used in the re-test activities, since the present acquisition systems decrease the inspection time, handling huge amounts of data in real-time, the multitechnique approach is being applied from the beginning of the inspection and not as a confirmatory possibility. This supposes the modification of inspection procedures, above all when different sensors are used simultaneously and arranged ones next the others.

The new technologies and requirements, which impose the obligation of modifying the actual inspection procedures and operation modes, would influence in the next future the criteria and codes to be applied, based until now in a single technique. With regard to this, Tecnatom participates in standardisation committees at European level concerning several aspects of the NDT.

** Concepts and abbreviations: Multitechnique, data fusion, ultrasound (UT), eddy current (EC).*

The purpose of this paper is to summarise some Tecnatom's experiences in the design and development of multitechnique systems, both at acquisition and evaluation levels. Moreover, a general introduction about the new techniques of data fusion is presented as well as its application in the industrial field. Data fusion concept is interpreted as an intelligent combination of data produced for two or more different techniques to characterise the state of a component.

The aforementioned developments have been integrated in the following projects:

• *MIDAS:* Multitechnique data acquisition and evaluation system (ultrasounds-eddy currents). Three main modules compose the system:

- MIDAS: Integrated UT-EC data acquisition system.
- MASERA: Data evaluation system.
- MIDAS-RT: Ray tracing simulation system; it models the geometric ultrasonic propagation in a 3D space.

• *MISTRAL (BRITE-EURAM Project BE-96-3482):* In this project data fusion is applied to UT + EC and UT + X-Ray data combinations. From the point of view of the acquisition process, an advanced multi-sensor UT+EC is being designed. With regard to the second application, an inspection procedure has been designed to achieve spatial coherence between both acquisitions (UT and X-Ray) due to the simultaneous inspection is not possible. In relation to the evaluation process, advanced data processing techniques and data fusion algorithms are being implemented.

MULTITECHNIQUE SYSTEM

Depending on the inspection requirements, the features of the multitechnique system will be different: so, for a global analysis, each technique could be oriented to cover a different area. In other cases, in particular in the inspection of very critical components or areas, the same region would be inspected by different techniques to contrast the results.

With regard to the used techniques, the system will be considered "multi-technique" only in acquisition, only in evaluation or in both phases. For instance, the simultaneous application of ultrasounds, eddy current and visual inspection is possible (multitechnique system in acquisition) if the size and geometry of the component is not a constraint. However, ultrasounds and X-ray cannot be combined from the point of view of acquisition. In this case, it is necessary the generation of an inspection procedure to get a perfect overlap of the results. Data fusion will be performed later on at evaluation level. It is also recommended the use of a unified data format for the different techniques involved.

Anyway, some features should be common to any kind of multitechnique equipment:

- Integration capability for the data produced by the different techniques, from the Hardware and Software points of view.
- Whenever it is possible, the duplication of elements with the same objective will be avoided.
- Each technique will be interpreted and analysed using its own tools. The

style and use mode of these tools will be as much similar as possible for all the techniques.

Based on these objectives, the following benefits are expected:

- Reduction of the total inspection time: several functions, like sensors positioning, will be carried out only once.
- Total equipment reduction that supposes also a reduction of the communications between the different modules.
- Inspection quality increment: All the aforementioned factors deals to get a process with fewer errors, with a unique control over all the aspects of the system.

This type of architecture has been implemented in the multitechnique system developed by Tecnatom and called MIDAS.

MULTITECHNIQUE EVALUATION

To get a good data interpretation when several techniques are being used, it is necessary to build up advanced software packages. The introduction of the management of real geometries is one of the topics to be considered in order to obtain a good correlation between results. Actual computer capabilities make it possible. This is especially useful applying ultrasonic techniques, because it allows the reconstruction or simulation of the ultrasonic beam propagation inside the components, as well as the interaction with the elements that compose them: weld, defects, cladding, material interfaces, etc. When several techniques are used, also it will be possible by means of geometry handling to estimate the areas inspected by each technique to guarantee a full coverage of the critical areas. These were the main design targets of the evaluation packages named MIDAS RT and MASERA. These packages can handle complex geometries with a twofold objective:

- Inspection simulation (MIDAS Ray Tracing): The operators can select/calculate the optimised characteristics of the probes and test their performance in a real 3D volume as well as the coverage achieved by an inspection plan. Different defects can be easily introduced into the computer simulation.

- Data evaluation (MASERA): The behaviour of the ultrasonic beam with real inspection data is reconstructed in any kind of geometry.

In MISTRAL project, the geometry is also handled in a similar way, including the tri-dimensional representation and voxelisation.

MIDAS SYSTEM

This system has been totally designed and developed by Tecnatom during the last years. Thanks to the technological progress in personal computer market, the same system has been reproduced in a cheaper and friendlier environment, guaranteeing similar or higher capabilities.

F I - *MIDAS System*

The system has been tested on field inspections with excellent results, not only from the point of view of evaluation but for the considerable reduction of the total inspection time. Data transfer is made in MIDAS via FAST-ETHERNET. These are its most remarkable features:

- Storage velocity: higher than 4 Mbytes/second
- Processing velocity: 30 Mbytes/minute.
- Number of ultrasonic channels: 256
- Number of eddy current channels: 16.
- Advanced inspection and analysis techniques: TOFD, ADAPT, SAFT, etc.

These are some of the capabilities of MASERA (see fig. II):

- Data representation for different methods and techniques
- Local Maximum detection: This program detects automatically the local maximum in a selected sub-volume. This option is very useful detecting and sizing indications. Real depth is automatically computed. The program includes other tools related to the maximum response.
- Image Processing tools: interpolation, smoothing, filtering, etc.
- Variable colour palette (bipolar range, gray scale, etc.)
- Graphic editor: it is possible the introduction of text, lines, polylines, polygons, etc., to illustrate the images and include personal operator comments.
- Measurement tools, with lenses to help in the pixel selection.
- Automatic report generation, with a direct connection to the selected printer.
- Complex geometries handling, 3D visualisation and voxelisation.

The simulation module, MIDAS - Ray-Tracing (see fig. III), has the following capabilities:

- Ray tracing on complex geometry.
- Simulation of defects inside a defined geometry.
- Virtual execution of automatic or manual exam.
- Estimation of the optimum exam parameters: probe angles, location, sound path, scanning path, etc.
- Analysis of material changes from the point of view of ultrasonic response.

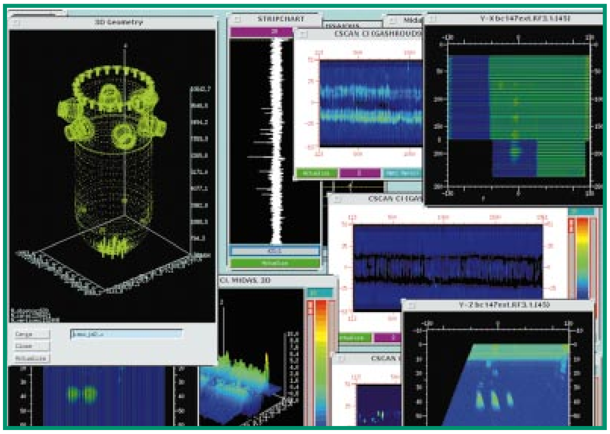
DATA FUSION TECHNIQUES

Sometimes, the information produced by different NDT systems and techniques is not complete and even contradictory if data are interpreted in a separate way. Regarding inspection, "Data Fusion" concept can be interpreted as a set of tools to combine the information from several NDT data sources being a help when the expert in each technique has to take a decision and reducing the human error in data interpretation.

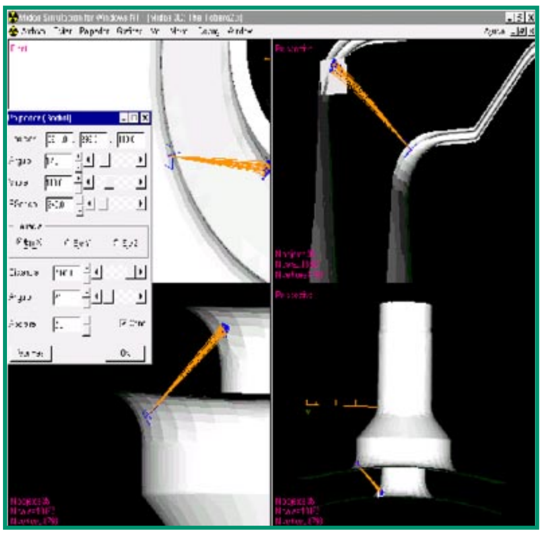
Making a simple and general description, data fusion is based in different statistical approaches in charge of combining the information. Their efficiency was assessed using statistical theories such as probability of detection and receiver operating characteristics curves. The NDT data fusion process implemented presents results in the form of probability associated with a measurement, which is used to make inference.

Before applying statistical methods, "data fusion" consisted on the overlap of the results produced by the techniques involved if this was possible.

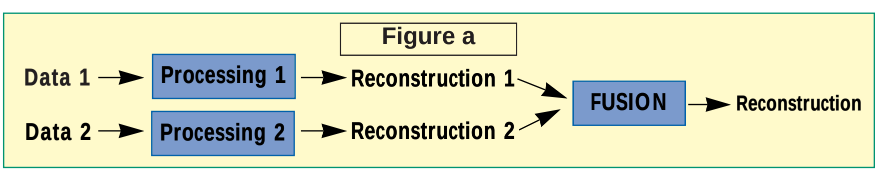
The first projects about data fusion corresponded to military applications. The technique was applied later in Robotics, Non-destructive Testing, Pattern Recognition and even in Finances.

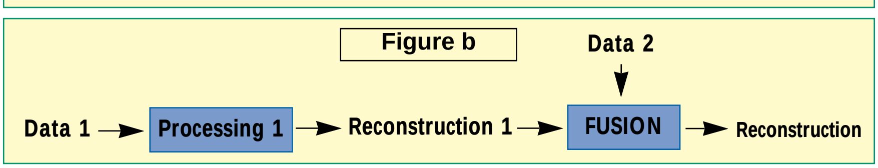


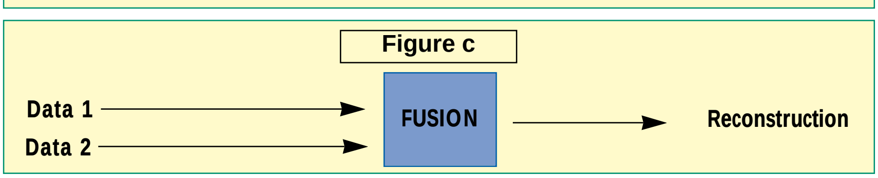
F II - *MIDAS Multitechnique System*



F III - *MIDAS RayTracing system*







There are three types of data fusion architecture:

• *Decentralised fusion:* In this model, data coming from different sources are first processed and reconstructed. Data fusion is applied later and fused data are reconstructed and represented. (see figure a)

• *Cascade fusion:* In this model, the first data set is processed and reconstructed and, later, the second set of data is introduced and the fusion is applied. (See figure b)

• *Centralised fusion:* original data are combined by means of the selected fusion algorithm. Data are reconstructed in further steps. (See figure c)

In MISTRAL, the data fusion algorithms selected have been the Bayes technique and the Dempster-Shafer evidence theory. In both cases, the result is a map of probabilities inside the component volume about the existence or evidence of the defect. The main objective of this project has been the application of data fusion techniques in nuclear and chemical sectors. Based on the estimations made by the different partners with regard to the improvements expected on field application, in comparison with the actual practice, it is possible to conclude the following benefits:

- Lifetime increment of several components: since the state of a component will be more accurately foreseen using these theories, remanent life will be also estimated with more precision (a 3.5% of life increment has been estimated for components such as heat exchangers). One of the added values of this project will be the application of Fracture Mechanics Code for defect assessment, once it has been detected and characterised.

- Inspection time reduction (3%): This aspect is extremely critical in the nuclear industry (where each shutdown supposes a high cost). This would contribute to reduce the total time spent in maintenance activities.

- Time increment between two consecutive stoppages and reduction of

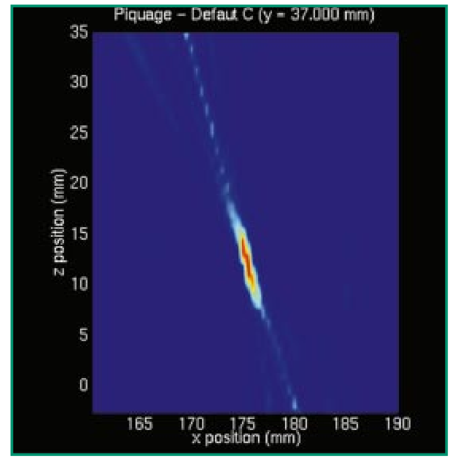


Fig. IV. *Vertical cut for the defect's mass of evidence obtained from the radiographs.*

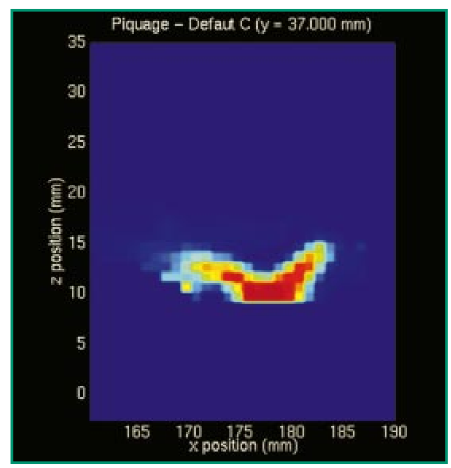


Fig. V. *Vertical cut for the defect's mass of evidence obtained from the ultrasonic data.*

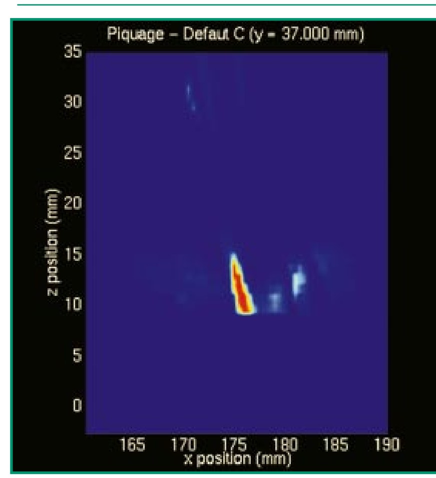


Fig. IV. *Vertical cut for the defect's mass of evidence obtained by the decentralised fusion process* the number of unplanned stoppages.

The data fusion technique based on the Dempster-Shafer theory, under decentralised fusion architecture, has been applied in particular in the inspection ultrasounds - X-ray. Figures IV, V and VI illustrate the results (images kindly provided by EdF).

Figure VII shows the relationship between MIDAS and MISTRAL systems. From the point of view of evaluation, MISTRAL can improve the features of MIDAS.

CONCLUSIONS

Following the actual industrial trends in inspection, it can be concluded the following:

1. Tecnaton has observed, among its main customers, the actual demand of integrated multitechnique systems with a twofold objective:

- The reduction of costs and inspection time.
- The quality improvement associated to the application of complementary techniques, to achieve an integral examination of the components and contrast the results obtained with several techniques in very critical areas.

2. An efficient multi-technique system has to be designed guaranteeing a high integration level.

3. The final goal to be achieved is the application of reliable and efficient data fusion algorithms to integrate the information even at data analysis level.

4. MIDAS and MISTRAL are goods examples of multitechnique systems (UT+EC) although the integration between them should be improved to take advantage of all their features.

Considering the progress achieved in fields like NDT data representation, Artificial Intelligence, Pattern Recognition, etc., it is evident that the NDT multi-technique and data fusion technology will have a fast evolution in the next future.

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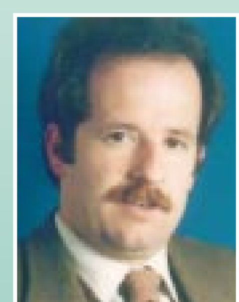

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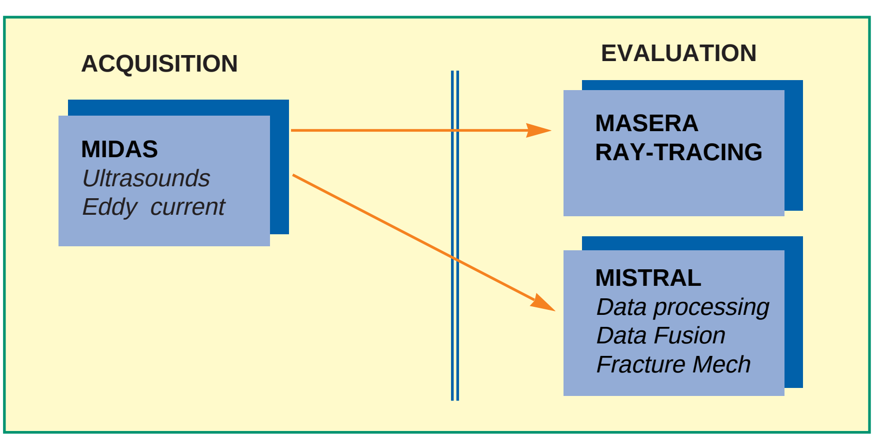

Fig. VI. *MIDAS-MISTRAL relationship chart*