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SIGNAL PROCESSING OF EDDY CURRENT THREE-DIMENSIONAL MAPS

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SIGNAL PROCESSING OF EDDY CURRENT THREE-DIMENSIONAL MAPS

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ABSTRACT

Digital processing of eddy current three-dimensional maps improves accuracy of detection : flattening, filtering, computing deconvolution, mapping new variables,.., give new possibilities for difficult test problems. With simulation of defects, probes, probe travels, it is now possible to compute new eddy current processes, without machining defects or building probes.

KEYWORDS

eddy current ; three-dimensionnal mapping ; signal processing ; deconvolution ; probe simulation ; defect simulation ; travel simulation.

INTRODUCTION : SURFACE TESTING AND SIGNAL MAPPING

Eddy current three-dimensional mapping arises out of the necessity of point probe use in surface inspections. From that time onwards, probe orientation and travel create problems, and the signals must be displayed in an appropriate way. A previous paper [1] described how CEA developments result in the mapping of signals delivered by an absolute probe, which is the only procedure for obtaining data truly independent from operating conditions (e.g., probe orientation, travel, etc...).

Because it provides a clear overview of the phenomena involved, while improving the selectivity of signal detection, three-dimensional mapping of eddy current signals has found immediate applications.

The mapping technique has been used by the Saclay Laboratory as a basic tool for the past three years ; applications include problems which have arisen within the CEA, at Intercontrôle, at EdF, at the Indret Naval , Establishment, a.s.o...

Signal processing has been the key factor in developing the unique capabilities of the technique to its present degree of maturity.

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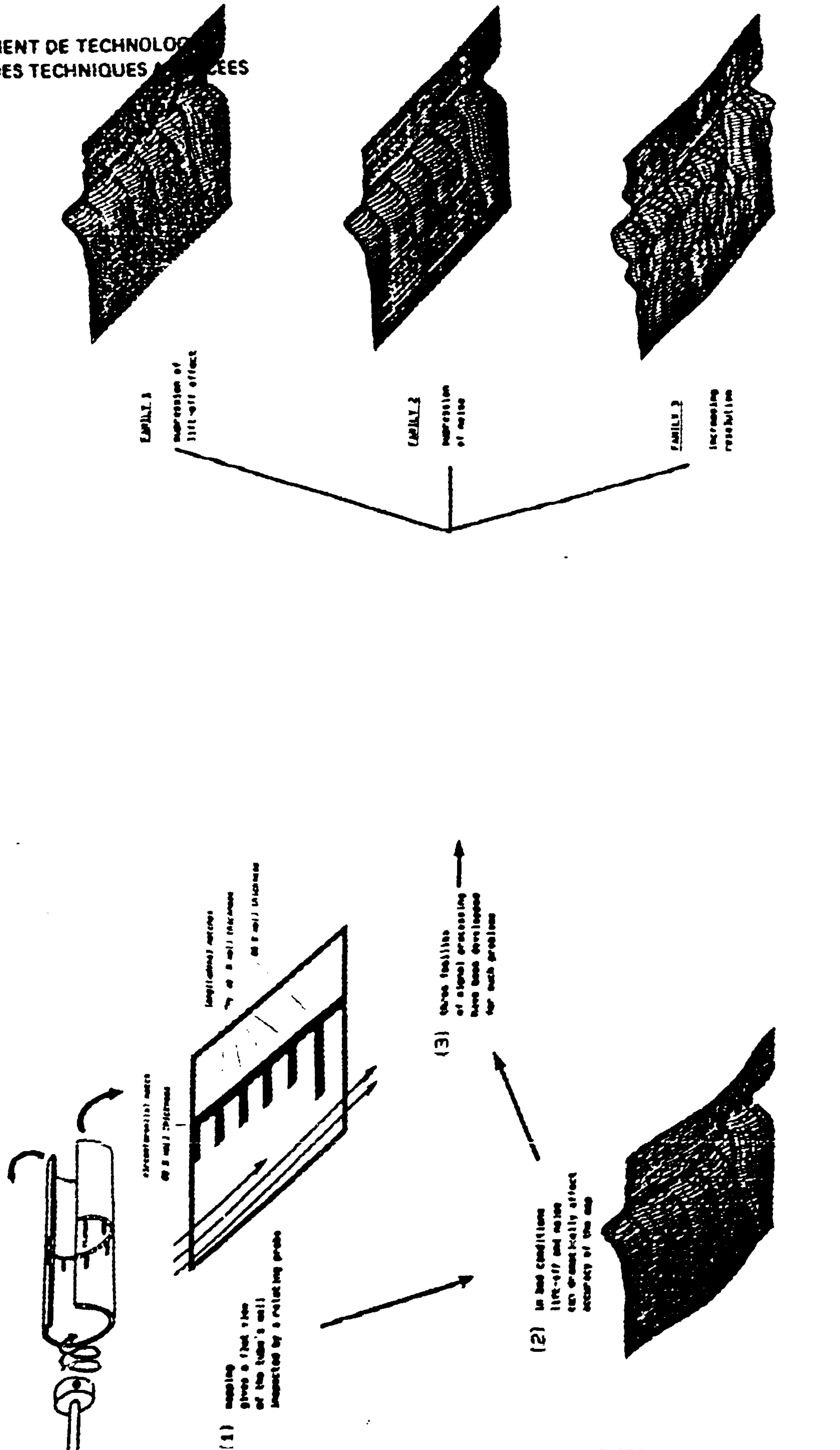

FIG. 1 INCREASING MAP'S ACCURACY:

THE THREE FAMILIES OF SIGNAL PROCESSING

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IMPROVING THE IMAGE

The first group of processing tools is directed at the improvement of picture quality. The example shown in Fig. 1 illustrates three major processing steps :

A PWR tube showing a ramified defect is examined using a rotating absolute point probe. The defect consists of a circumferential notch, with depth equal to 60 % of the wall thickness, and six longitudinal notches : notch depth is 40 % for five of them, and 60 % for the last one. The defect is located on the inner surface of the tube.
The map on the left side of Fig. 1 shows the result of an acquisition in voluntarily bad conditions.

First step : map flattening

The image curvature is due to the fact that an absolute probe was used for data acquisition ; this type does not compensate for lift-off effect. Although this basic 3-D effect may be desirable in certain cases, it must sometimes be eliminated. Two techniques have been developed for image flattening.

The first one is based on map contour only : the perimeter is taken as being at zero level, and the elevations on individual points are corrected as a function of their distance to the four edges of the image. Where the curvature is uni-directional, flattening is readily achieved through a simple linear interpolation in one direction ; this is the case of the example shown Fig. 1 in which the only problem is due to lift off effect as the sensor head revolves. If the map is truly warped, one must use a succession of crossed interpolations, or, better, two-dimensional interpolations.

The other method for image flattening consists of high-pass filtering, which eliminates low fluctuations of signal. Although this method is the simplest, it results in deterioration of signals from long indications. But, uni-directional high-pass filtering modifies only one direction on the map : a combination of the two images obtained through crossed high-pass filtering yields a flat map of relatively good quality.

Second step : noise suppression

As in the previous step, one may proceed in one direction, or in the other, by crossed filtering in successive stages or by two-dimensional filtering. The latter is by far the most satisfactory, because it covers all the points of the surface which makes up the filtering window, whereas crossed filtering only covers the points along two lines. (Fig. 1 right, middle).

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Third step : improving resolution

To that end, a de-convolution process is now used, either in line or through crossed de-convolutions. Fig. 1 (right, bottom) shows the effect of crossed de-convolutions on the indications mentioned earlier.

The de-convolution algorithm restores, on an estimated basis, the high-frequency information which has vanished because the measurement channel (especially the probe) has low-pass filter characteristics. Its behaviour is in a way, similar to that of an electrical circuit which is on the verge of oscillation, delivering the fastest possible transient signals as part of a compromise based on certain assumptions relating to the signal being processed, the noise level, etc... This accounts for the slight undulating patterns visible on the map.

IMAGE TRANSFORMATIONS

There are cases where the image fails to show defect indications in spite of all the improvements achieved through the use of imaging techniques. One case in point is the examination of the butt welds in the Superphenix 1 steam generator tubes (Fig. 2).

Expected indications are micro-cracks, located in the thermally affected zone, and oriented along the seam on the inner surface of the tube.

In this case also, a rotating probe is used for acquisition, and the display clearly shows the welded seam.

Unfortunately, the seam is highly irregular in shape ; its width, height and even its orientation vary, which is enough to make the healthiest of welds look suspicious, and further, might draw attention away from a small indication quite similar in appearance to the others (fig. 2 left).

Three groups of processing methods have been developed to cover problems of this kind.

First group : knowledge of healthy test-piece pattern

The first group involves the most exacting requirements : it calls upon prior knowledge of the characteristics of the weld under examination. Two procedures of this kind have been applied in the case of the Superphenix welds : a baseline comparison of the welds, and a comparison with an assumed shape of the weld signal. The baseline comparison consists of substracting the baseline acquisition from the acquisition at date "t". Problems arise from the necessity of restoring the proper amplitude scale and position for both images, and accounting for the spread which may have resulted from the use of different probes. In view of the minuteness of the defects under investigation, image resetting requires interpolating between measurement points, leading to a huge amount of computing which is not the best solution (Fig. 2 right top). Comparisons with pre-determined shapes eliminate the requirement for baseline data, which are replaced by a form of adaptive synthesis : at any point, the amplitude and centerline of the signal are re-aligned with those of the measurement signal. In this case, recordings have shown artifacts unconnected with the defects investigated in this example.

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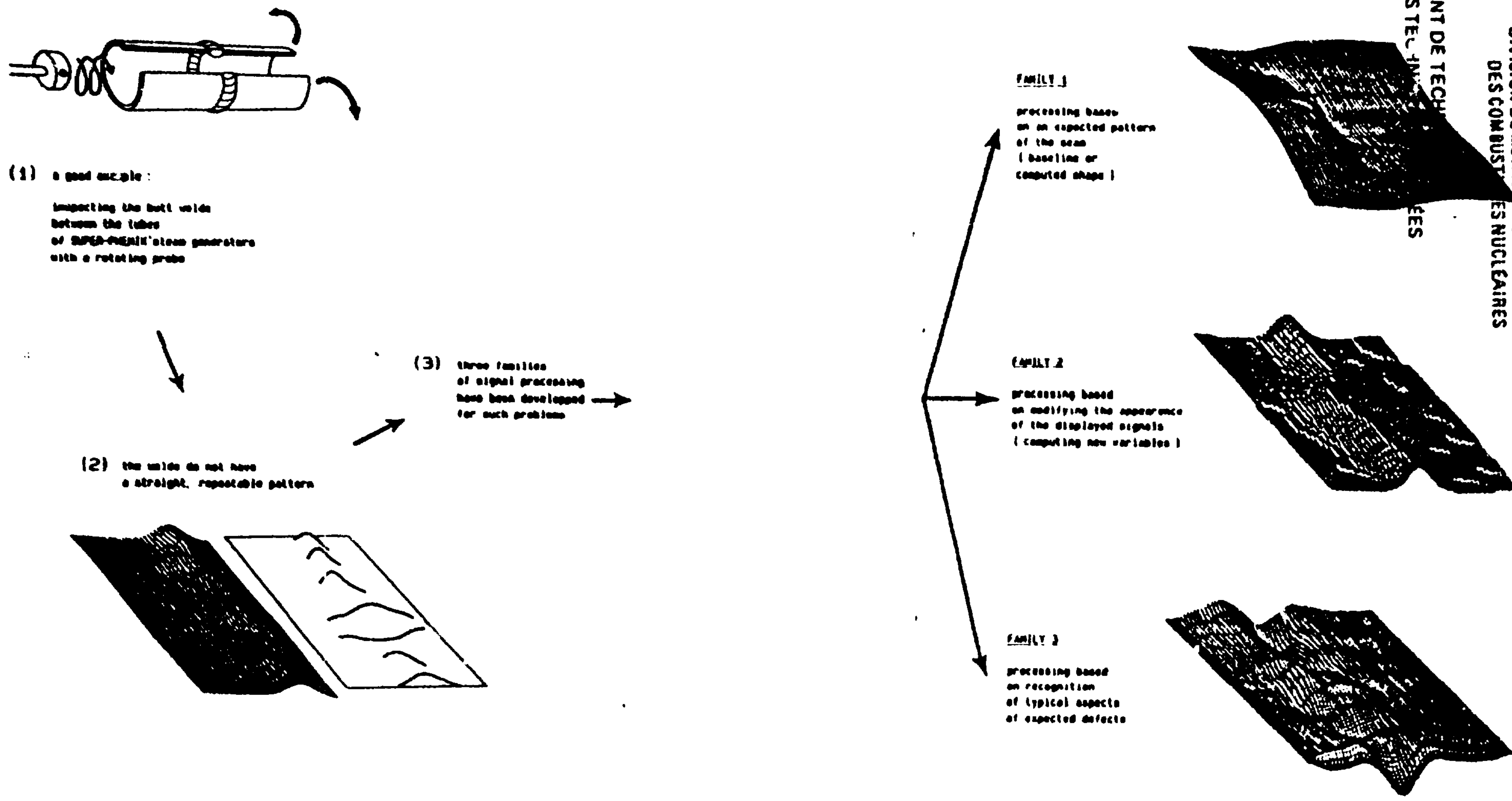

FIG 2 MODIFYING MAP'S ASPECT : THE THREE FAMILIES OF SIGNAL PROCESSING

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Second group : modification of the appearence of the displayed signals

The second group of processing procedures aims at modifying the appearance of the displayed signals to exhibit new features. Thus, a display of normalised amplitude in discrete levels improves detection based on level contours (Fig. 2 right, middle). Plotting the geometrical axis of the weld profile, the amplitude-to-width ratio of the signal, etc... also yields new images showing different properties from the standpoint of fault detection.

Last group : knowledge of defect pattern

Last, the third procedure group is not based on any prior data on the weld, but instead on prior knowledge of the features of the defect under investigation. In this case, signals from the weld are eliminated inasmuch as they lack the specific features relating to the defect, not on the basis of their relation with weld characteristics (baseline condition, assumed appearance, etc...). This type of processing presents difficulties because most of the signals have rounded shapes which are very close to one another, and the adjustment of spectrum analysis facilities for maximum selectivity is not a simple matter. However, a method of this type, called "self-processing" gave the best results in the case use in our example (Fig. 2 right, bottom).

SIMULATIONS

The purpose of simulations is quite different. Their objective is not to display acquired signals, but rather to create images representing acquisitions not yet made. Current simulations are of three types, i.e., defect, probe, or travel simulations [2].

Defect simulation

The principle of defect simulation is the following. The laboratory has compiled a library of defect signals which can be superimposed, as required, on the mapping obtained from a sound part (Fig. 3). It is no longer necessary to have test pieces containing actual defects ; as a result, investigation time is shorter, cost is reduced, and, most important the incidence of defect shape, size or location can be investigated at no extra cost. As an example, Fig. 3 (right, top) shows how the different elements of the left page have been combined : the hole and the longitudinal notch appear on the expansion zone of a steam generator tube.

Probe simulation

This synthetic map of the tube expansion zone with defects is a good illustration of the simulation tools of the second type, i.e. probe simulations. The expanded part of a tube is a critical area, and, for that reason, frequently inspected with differential point probes, which requires selecting the orientation of the coil pair with respect to the track. There are several schools of thought on this subject, and coil orientation is subject to periodic changes following the latest test results : this because it would be expensive to build and test several probes with different orientations, and, mainly because differences may be caused by manufacturing tolerances rather than by probe design. Simulation brings a solution to this problem. A single acquisition is made using an absolute pro' · one then simulates differential probes with various orientations, ne coils remaining identical. Any difference can thus be ascribed to sensor design, and not to manufacturing tolerances. Fig. 3 (right, middle) shows how the absolute map (top) yields maps corresponding to various orientations of the differential probe.

Although the effect of the transition zone may be eliminated by making the differential pair parallel to that zone, signals from circumferential defects will be subject to strong disturbances. A 45° orientation is a compromise between longitudinal and transverse detection. If oriented axially, defferential probes respond poorly to longitudinal indications.

It will be readily appreciated that simulation provides a way to examine all possible solutions, using an ideal sensor. To account for manufacturing differences between the two coils in the sensor, we may go one step further and introduce various degrees of unbalance to analyse their consequences.

Travel simulation

The previous maps give a good global vision of probe performance. But in some cases, it is important to know how the response is on the screen of the eddy current device (impedance plane). The first reason is to predetermine actual response without mapping devices, the other to measure the phases of indications in order to estimate defect depth. Fig. 3 (right, bottom) shows the simulated impedance plane indication for the simulated differential probe on the simulated hole of the expansion zone ! As can be seen here, there is a great variety of simulation levels and combinations.

CONCLUSION : FUTURE TRENDS

Three years of intensive 3-D image processing in eddy-current testing have shown the exact field of application of the method.

In survey work, map processing following absolute acquisition is a tool with unmatched performance for surface examination. Performance, however, is achieved to the detriment of operating speed, and image reading must remain visual.

In process investigations or qualification, simulation is used at the laboratory stage, where it has demonstrated its capabilities to the full, making it possible to undertake a comprehensive study of defect and probe parameters.

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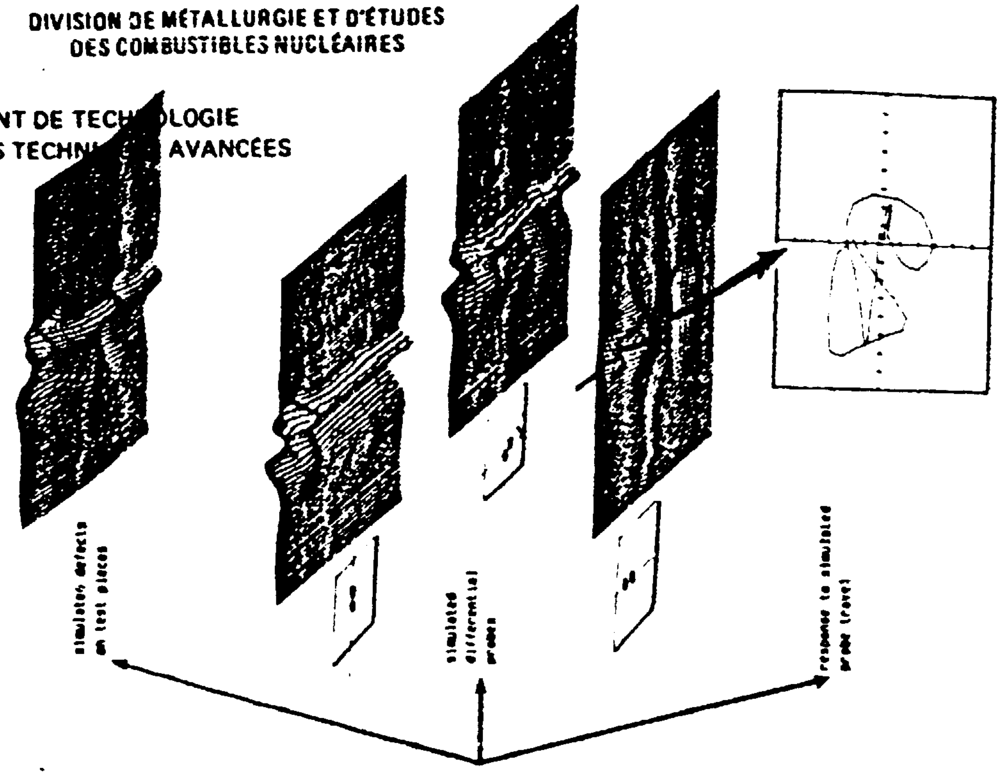

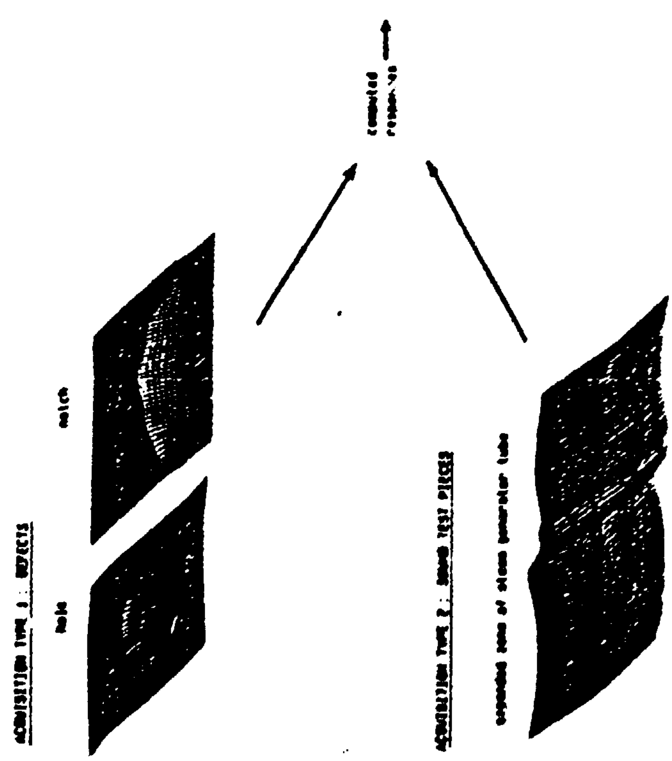

FIG 3 THE TWO TYPES OF ACQUISITIONS AND THE THREE FAMILIES OF SIMULATIONS

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