NEW ULTRASONIC ARRAY IMAGING OF CRACK-TYPE DEFECTS BASED ON SIMULATION-HELPED PROCESSING

Séverine PAILLARD, Ekaterina IAKOVLEVA, Sylvain CHATILLON and Pierre CALMON.
CEA, LIST, F-91191 Gif-sur-Yvette, France.

ABSTRACT Ultrasonic arrays provide improved flexibility and adaptability to complex configurations with comparison to conventional probes. Besides the usual application of focused beam, using electronic delays at emission and reception, more complete operating mode involving per-channel signals acquisitions are more and more encountered. Advanced ultrasonic array techniques provide considerable amount of data making possible by the use of suitable processing algorithms enhanced capability of defects imaging and therefore improved localization and sizing. To fully exploit this data, in order to localize and to characterize the defect, efficient imaging and reconstruction tools based on a direct modeling of the inspection are required. We present in this communication ultrasonic array 3D imaging tools developed in the framework of the French National Research program INDIAC.

INTRODUCTION The imaging technique presented here is based on the application of the FTP algorithm (French acronym for *Focalisation en Tous Points*) of CIVA [1] to data issued from Full Matrix Capture acquisition (FMC). A FMC acquisition is composed of as many shots as number of elements. One shot corresponds to one transmitting element, all the elements being active in reception. The reconstruction algorithm FTP consists basically in coherently summing the received signals at every point P in the sampled region of interest. Its output is a map of the summed amplitudes in this region which exhibits maxima at the defect location. To achieve the summation requires computation of the theoretical time of flights along the paths linking the transmitter the points P and the receiver. The connexion of the algorithm to CIVA forwards models allows to deal with non canonical situations. The objective of this communication is to present a new technique for imaging crack-type defects located closed to a backwall and giving rise to a multiplicity of possible echoes (tip diffraction, corner echoes and mode conversions) based on the generalization of the algorithm to multimodal echographies.

Experiments have been carried out in order to evaluate the performances of the method. We present results obtained on blocks containing various notches of different heights and orientations, simulating breaking or not breaking cracks. The results show that the technique allows to image the notch along its entire length. This is a quite remarkable result unreachable with classical inspection techniques and the results presented offer new perspectives for the characterization of crack-type defects.

ECHO DIFFFRACTION RECONSTRUCTION OF CRACK-TYPE DEFECTS

In a wide range of NDT applications crack-type defects are researched near a boundary of the part and are detected by exploiting a so-called corner effect involving one reflection on the defect and one on this boundary. In general [2], the FTP algorithm is applied assuming that for a given pair of elements, one scatterer gives rise to one echo corresponding to one direct path transmitter/scatterrer/receiver. Doing this, the possibility of reflections on the boundaries isn't taking into account.

In order to make the imaging possible for defects detected through a multiplicity of possible wave paths (involving tip diffraction, reflection, corner echoes, mode conversion,…) the FTP algorithm has been generalized to multimodal echographies following an approach similar to the one described in [3]. We define here one “mode” by the characteristics of the corresponding wave path: the succession of interactions with the defect or the surface and the polarization of the wave before between and after these interactions. Let us consider the general case where *M* modes denoted *m* can possibly give rise to an echo. The generalized version of FTP consists in 1) choosing one (or several) mode *m*; 2) computing the theoretical times of flights $T_{nP}^{(m)}$ along the wavepath defining the mode *m* and linking the transmitter, the point *P* in the Region of Interest (ROI) and the receiver; 3) extracting from the acquired signals the corresponding amplitudes $S_{nP}^{(m)} = S(T_{nP}^{(m)})$ and coherently summing the data. This leads to the following expression for the estimator output of the algorithm:

$$E^{(m)}(P) = \sum_{n=1}^{N} S_{nP}^{(m)} \quad (2)$$

Following this process from one set of acquired data *M* different images of the ROI may be displayed depending on the mode *m* selected for the reconstruction.

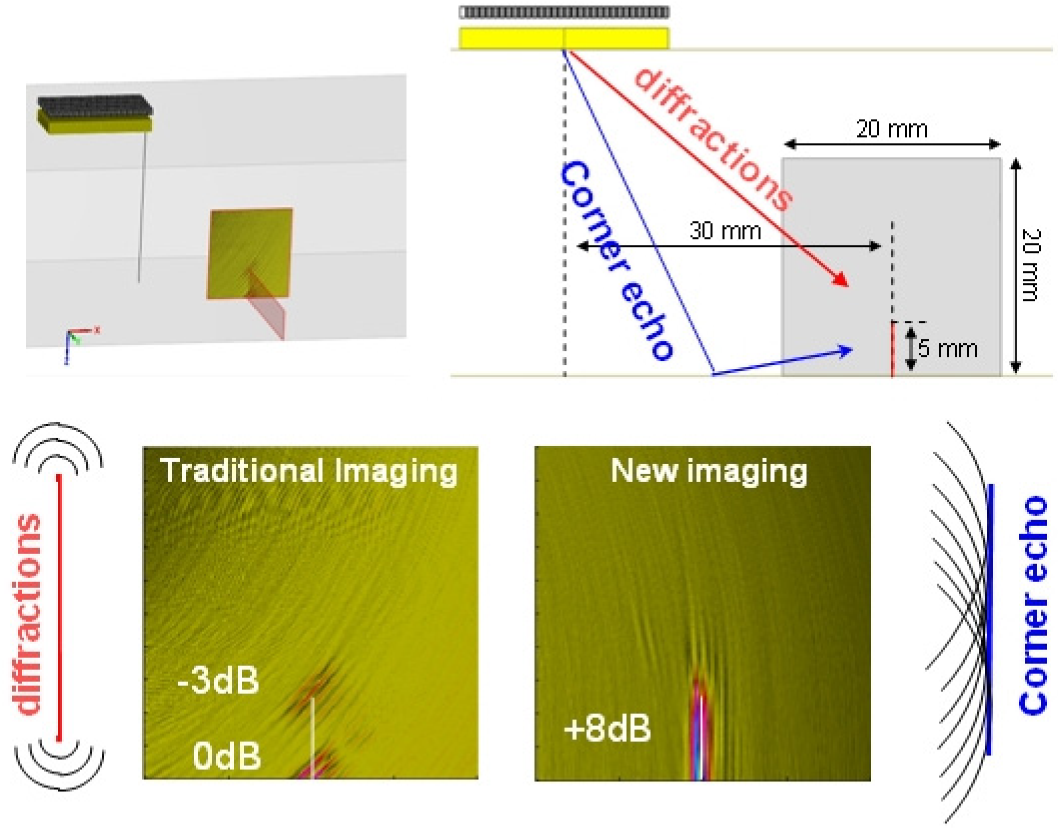

FIGURE 1. Imaging a vertical 5mm breaking notch. Geometrical configuration (up); diffraction reconstruction and corner echo reconstruction ;

EXPERIMENTAL VALIDATIONS ON NOTCHES

In the aim of evaluating the possibility of imaging crack-type defect located near a surface of the part and classically detected by corner effect, a first set of experiments has been performed on a steel planar block containing various notches of different heights and orientations, simulating breaking or not breaking cracks. Acquisitions have been carried out with a 32 elements 5MHz contact matrix array. We present here results obtained on two vertical defects one breaking and one non breaking the surface and one breaking surface tilted defect.

For one transmitter-receiver pair, one notch may give rise to numerous echoes corresponding to different modes. By applying arguments of reciprocity we consider here 3 direct modes (LL, LT, TT) involving no reflection on the backwall and 8 corner modes (LLL, LLT, LTL, LTT, TLL, TLT, TTL, TTT) involving 1 reflection on the backwall. In the notation adopted here for corner modes, the reflection on the backwall takes place between the first and second terms.

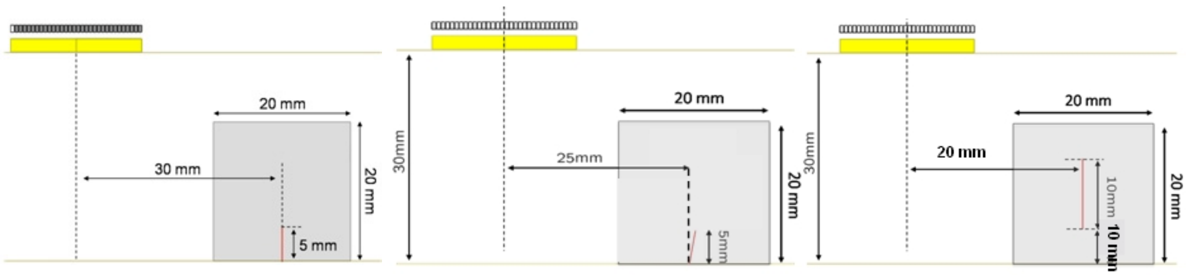

FIGURE 2. Experimental configurations

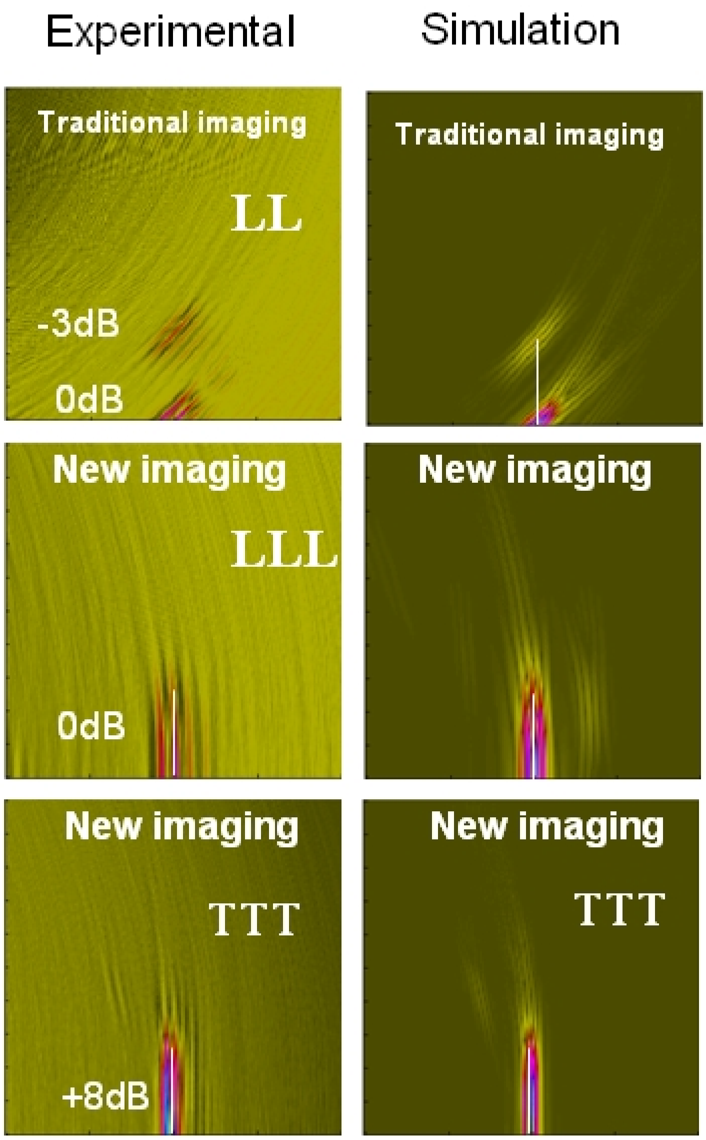

FIGURE 3. Imaging a vertical 5 mm breaking notch. Experimental (left); simulation (right).

Figure 3 summarizes the results experimental (left) and simulated (right) obtained on a vertical 5 mm breaking notch. The most significant images are reported on the figure. On LL image (first images on figure 3) we can see as expected the two spots corresponding to the two tips of the notch. More interesting are the others images corresponding to LLL and TTT reconstructions. With these modes the notch is imaged along its entire height.

The figure 4 summarizes the results obtained on a tilted 5 mm breaking notch. The relative positions of the probe and the notch are given (figure 4, up). Experimental data have been processed for the different possible modes what lead to a set of different maps of the region surrounding the notch. The most significant images are reported on the figure. On LL image (left down on the figure 4) we can see as expected the two spots corresponding to the two tips of the notch. More interesting are the other images corresponding to LLT and LTT reconstructions. With these modes the notch is imaged along its entire height. The tilt angle can be measured with accuracy. The both side of the notch allowed a good imaging. This is a quite valuable result unreachable with classical inspection techniques.

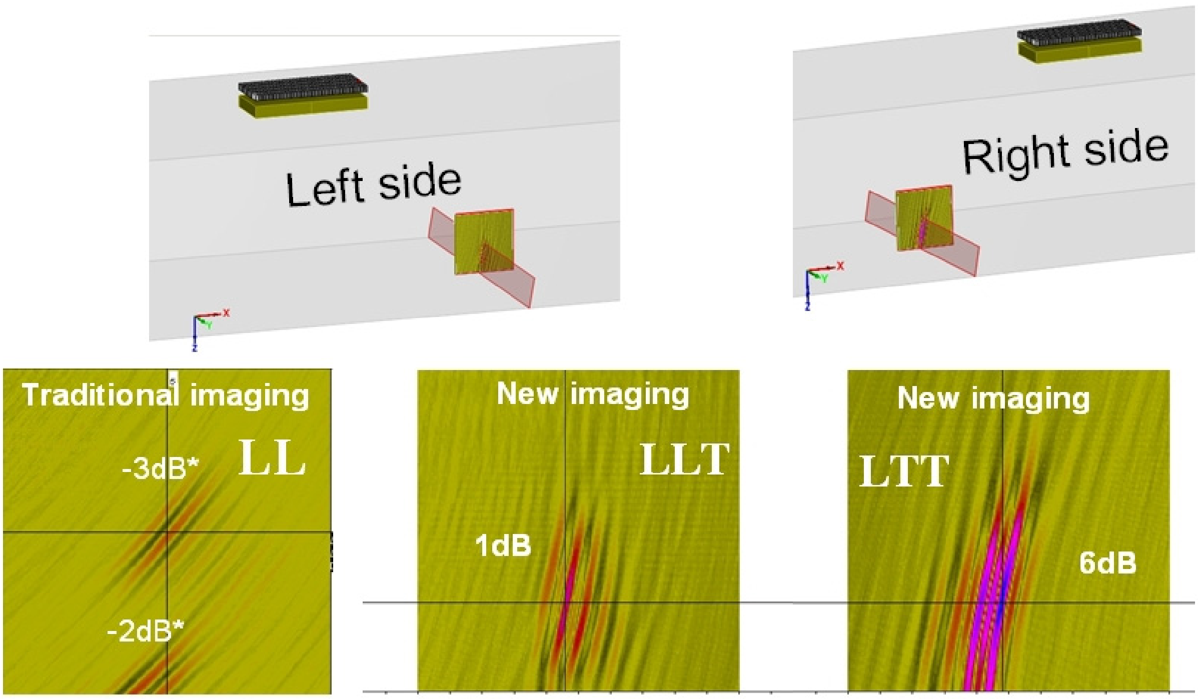

FIGURE 4. Imaging a tilted 5mm breaking notch. Geometrical configurations (up); diffraction reconstruction and two corner echo reconstructions, one with the probe located tilt side and one non tilt side.

In a similar way, figure 5 shows the most significant images obtained on a 10 mm skewed breaking notch. Due to the misorientation (skew) of the defect, in the LL image (figure 5, up), the amplitude of the bottom of the notch is weak. By using corner echo TTT the defect is well detected and imaged (other images in figure 5). These two different reconstructions are obtained with two different ROI box: one is placed at 5 mm from the x axis of the array and one at 10 mm, both in the XZ planes. We can notice that the shift of the defect imaged reflects the misorientation of the defect. In order to improve the imaging with corner echo to detect and measure skew angle, we had to go-on the 3D imaging.

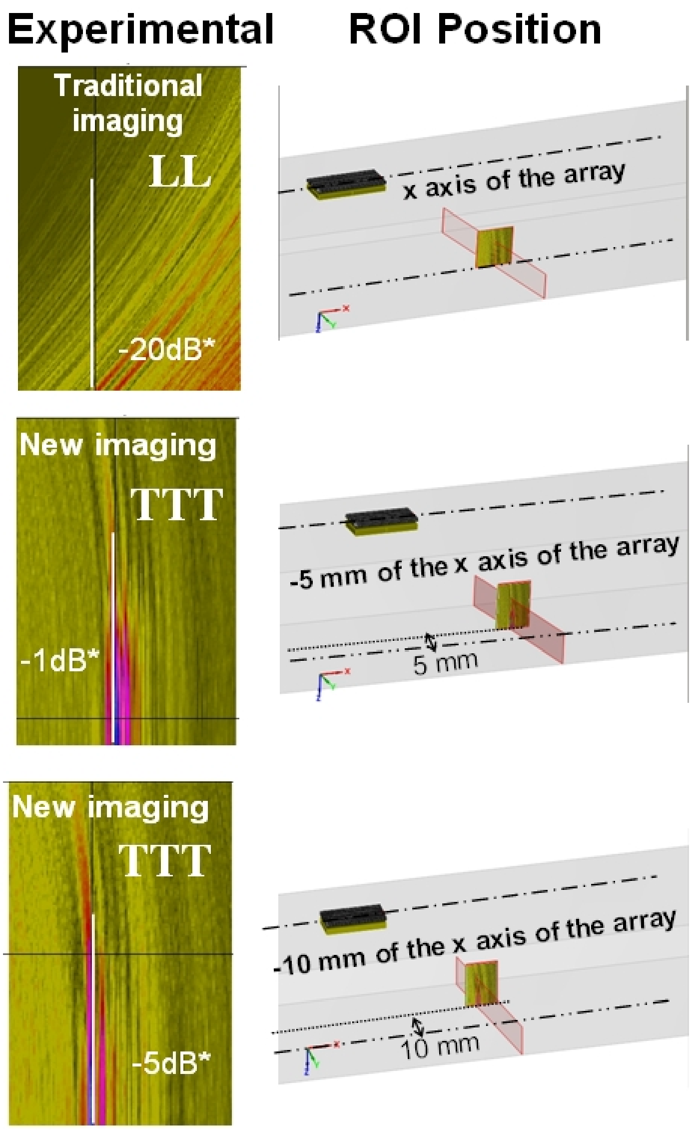

FIGURE 5. Imaging a 10° skewed 10 mm breaking notch. Geometrical configurations (right); Experimental diffraction reconstructions (left up) and two corner echo reconstructions, one with the ROI located at 5 mm of the x axis of the array and one at 10 mm.

IMPROVING IMGAGING CORNER ECHO WITH 3D IMAGING

In figure 5, the fact that the notch has a skew angle can nearly be detected. In order to improve the imaging we use 3D imaging. But, to get used to this 3D imaging corner echo, let's start with an easier example: a non breaking surface notch illustrated in figure 2 (right). On the left of the figure 6, the result is illustrated in the Region of Interest (ROI) and below, the result in the ROI box is in the 3D configuration. On the right, 2D views of TLL mode imaging, one experimental and one simulated are presented as shown in the previous figures.

In a similar way, figure 7 shows the most significant images obtained on a 10 mm skewed breaking notch. On the left, the 3D configuration is illustrated with the 2D view as shown in the previous figures, and on the right, a top view is presented of the configuration with a top view of the ROI box, where the skew angle can measured (10°).

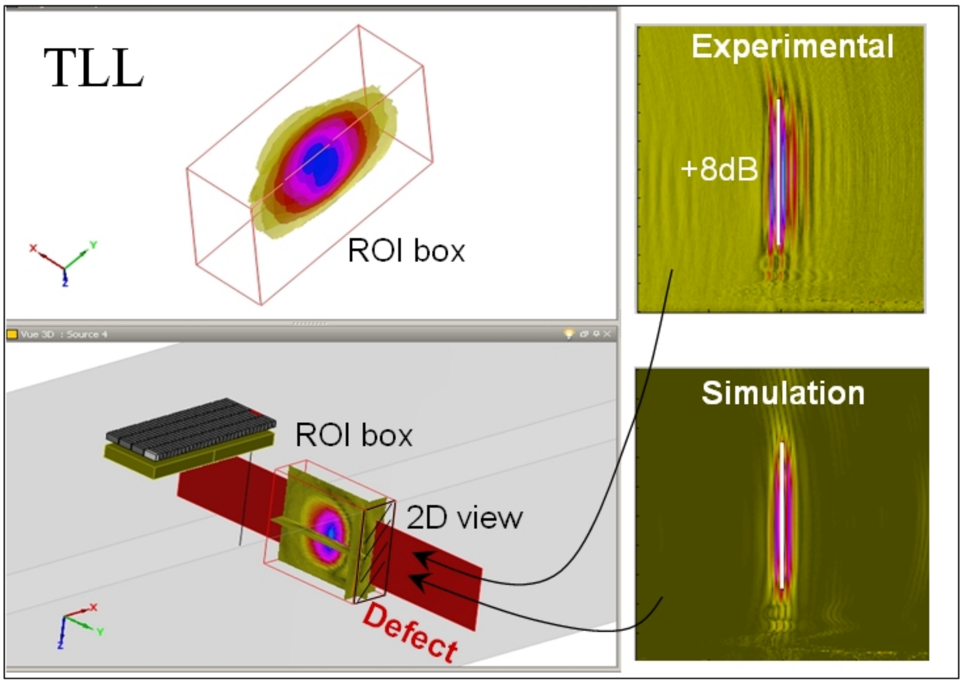

FIGURE 6. 3D imaging a vertical 10 mm breaking notch. Geometrical configuration with corner echo reconstruction replaced in the scene;

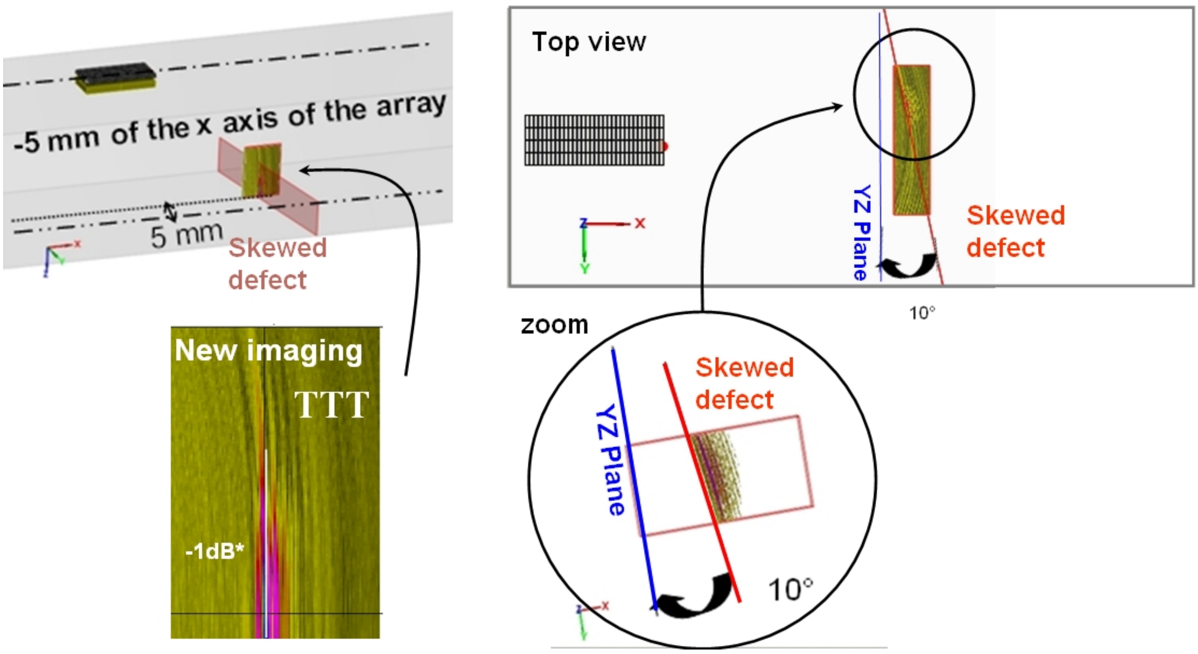

FIGURE 7. 3D imaging a 10° skewed 10 mm breaking notch. Geometrical configuration with corner echo reconstruction in the 3D configuration;

SUMMARY

The reconstruction algorithm FTP implemented in CIVA is coupled to forwards models allowing computing theoretical times of flights in non canonical situations. Applied to

FMC acquisition it appears quite efficient to detect, localize and characterize defects. We show in this communication why using traditional diffraction imaging is not always satisfying and why corner echoes and mode conversions can make the detection and characterization easier and with more accuracy. Results on both simulated and experimental data show how it offers a direct image of a breaking (or not breaking), vertical, tilted or skewed crack-type defect. 3D images are showed in order to improve the corner echo image to characterize particular defect such as skewed notches.

ACKNOWLEDGEMENTS

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REFERENCES

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