

PHOTOGRAMMETRY : a method for three-dimensional inspection of equipment inside nuclear installations.

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Industrial photogrammetry is a method of dimensional inspection whose main advantages are : rapid acquisition of elementary data (photos), inspection without contact and deferred analysis. Its basic principle means that photogrammetry is well suited to work in hostile environments, and particularly for maintenance of nuclear power stations.

Since 1983, FRAMATOME has been developing various applications of photogrammetry for its three-dimensional inspection needs and for expert evaluation with a view to preparing repair work.

Up to now, three different types of applications have already been regularly carried out (see figure 1)

- . inspection of tube sheets of steam generators,
- . dimensional inspection of steam generator nozzle support rings,
- . inspection of positioning pins of fuel elements for Upper Internals in the reactor vessel.

The first two applications were performed in air in a restricted and confined space (1/4 of a sphere of 1.6 m radius), the third application on the 10 m of contaminated water.

In all three cases, the radiation level was such that :

- . the human operator could in no case remain near the equipment while the photos were being taken,
- . positioning had to be as quick as possible to avoid having a shadow on the film,
- . as many operations as possible had to be by remote control,
- . in no case was it possible to go back to take the photos again in case of failure while the shots were being taken.

These extreme operating conditions required rigorous preparation, purpose made tools, operator training beforehand and in order to ensure the quality of the measures taken, work with Quality Assurance.

It must also be noted, that in all cases only photogrammetry was enable to make possible these inspections with acceptable precision.

#### 1 - Inspection of steam generator tube sheets

This is in order to determine the damage caused by a "loose part" over a tube sheet (a plate drilled with 3388 holes to which are welded the exchanger tubes - 1/2 circle of 1.6 m radius).

As the loose part had squashed in the ends of the tubes, inspection enables in particular, the following to be determined:

- . inside tube diameter - this data is necessary to perform routine inspection of the state of these tubes,
- . the excess height of these tubes in order to know, to what extent they may be machined without deteriorating the component,
- . the profile of the most deformed tubes to be able to justify the harmlessness of this damage to the components (see figure 2).

The operating principle consists of :

- . using a non-metric camera calibrated to medium size
- . a manipulating arm which positions the camera in 12 different positions,
- . the mosaïque thereby created enables a stereoscopic view of all the tube sheet to be obtained,
- . metrology is performed on each tube at about 20 points,
- . inside diameter and residual height is deducted by means of an optimization calculation,
- . on request, a profilometry can be performed as indicated in figure 2 in order to characterize the most impacted tubes.

This application has already been performed on more than 10 tube sheets in France and in Europe, allowing :

- . in less than 8 hours, usable photos to be obtained,
- . in approximately 48 hours, the most appropriate means of repair to be indicated,
- . in one week, a photographic and dimensional file indicating the state of the tube sheet to be supplied to the utility, thereby making it possible to request the safety authorities to authorize the startup of the reactor.

The accuracy of the measurements are :

- . 0.2 mm for the tube diameter, (7/8")
- . 0.2 mm for the residual tube height ( 5 mm nominal value)

## 2 - Dimensional inspection of steam generator nozzle support rings

The role of these rings is to accommodate a plug which allows work to be carried out in the steam generator, while the power station is shut down for its annual refueling, at this time obligatory movements of water, associated with loading and unloading operations, would prohibit any activity within the steam generator were it not for the presence of the plug.

Whenever a reactor has never been fitted with such plugs, it is necessary to check the generator nozzle support rings to check that :

- . the plug can really be clamped to the ring by means of 20 screws in the 20 holes which are tapped around the ring,
- . the levelness of the ring will be acceptable for the kind of plug joint and that water tightness at a pressure of 0.2 MPa will be guaranteed.

Depending on the results of this inspection either the standard plug will be compatible with the ring, or it will be necessary to adapt it to the ring, or finally a plug will have to be specially designed for that ring.

The operating principle is as follows :

- . the ring is prepared by fixing studs into the tapped holes, by making the lodging stand out and by placing reference in the field of vision (see figure 3). To do this, an operator works in the steam generator for a maximum of two minutes.
- . the photo is taken from the outside with the help of a manipulating arm which places a medium size metric camera in two positions.

The process gives (see figure 3) :

- . the ring drilling plan
- . levelness defects of the lodging at about 200 points.

The operation lasts about :

- . 4 hours for the photo,
- . 24 hours for the analysis.

This operation has been performed on around 20 rings in France and in Europe. Its use can be extended to checking levelness of flange lodgings for various components.

The accuracy obtained for a 1 m diameter ring taking into account the environment and the medium sized apparatus is 0.3 mm.

### 3 - Inspection of the fuel rod positioning pins in the Upper Internals of the reactor vessel

The positioning pins of the Upper Internals are used to keep the fuel rods in place in the reactor vessel.

During maintenance operations of the upper internals in the reactor cavity during refuelling, it may happen that these pins become damaged if they come in to contact with part of the cavity, in this case they can no longer carry out their function and they may, if badly bent, damage the upper flange of the fuel rod. Although this damage does not bring about any safety problems, it is very expensive, since the fuel rod is itself damaged and must therefore be replaced. When such an incident becomes known therefore, it is important to be able to quantify the pin defect in order to determine the most appropriate kind of repair work : machining, straightening, or removal.

As the upper internals are in contact with the reactor fuel rods, it is impossible to remove them from the water (this acts as a screen against radiation). To perform this inspection it is therefore necessary to take all the photos under water, moreover as the pins are situated under the upper internals, the operations must be guided by an underwater video system.

The photo equipment consists of :

- . 2 underwater metric cameras of medium size, coupled to obtain a base of 0.5 m for 1.2 m shooting distance,
- . a system of flash lighting set up on the camera support,
- . a set of reference scales linked to the camera support,
- . a video camera which acts as a viewfinder to correctly position the cameras on their objective,
- . a set of poles and brackets to position the set as desired under the upper internals.

Following the operation, the analysis enables the state of the pins to be seen as shown in figure 4 : each pin's distortion and positioning are given.

This information is then used as a guide to repair work on the pin. During the first operation, with pins showing a distortion of about 3°, they were using the photogrammetric indications to direct the effort which was to be exerted. During the second operation, the distortion reached 10° and was judged excessive for the mechanical resistance of the pin, which was simply cut off. In both cases, the inspection enabled, within 48 hours approximately information of prime importance on damages to be given and to help in the choice of the means of repair.

Accuracy with medium sized cameras and mediocre operating conditions is about 20' for distortion values.

In all the applications described above, photogrammetry has been a great help for maintenance work on nuclear power stations. It can be seen that ease of use is a prime factor in the choice of photogrammetry as a method of inspection. It must however be noted that two handicaps remain to be overcome :

- . the accuracy obtained is only just sufficient for the needs of repair operations,
- . process delay may be a reason for rejecting the method.

In the majority of cases however, photogrammetry is obligatory as it is the only possible method taking into account working conditions in a very hostile environment. These are the reasons which have enabled FRAMATOME to perform its inspections on more than 30 installations in France and in Europe in 4 years.

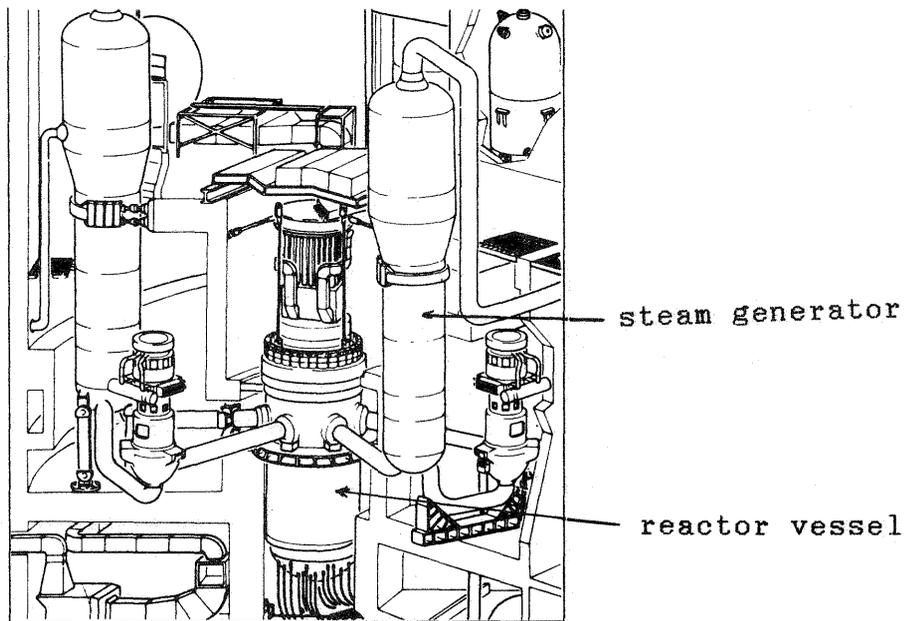


Figure 1

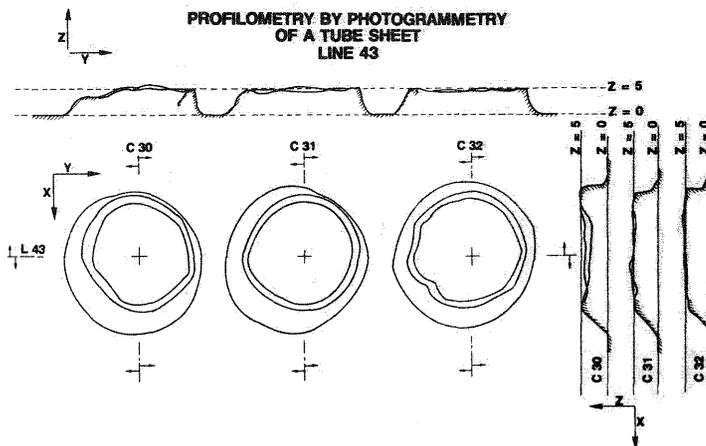
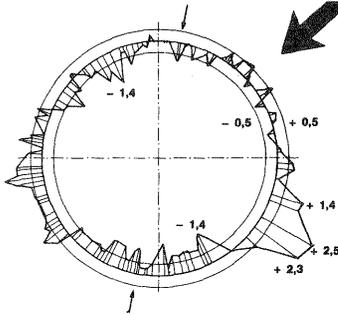
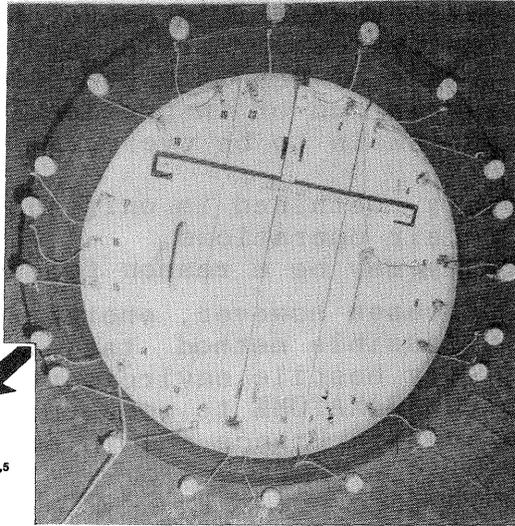


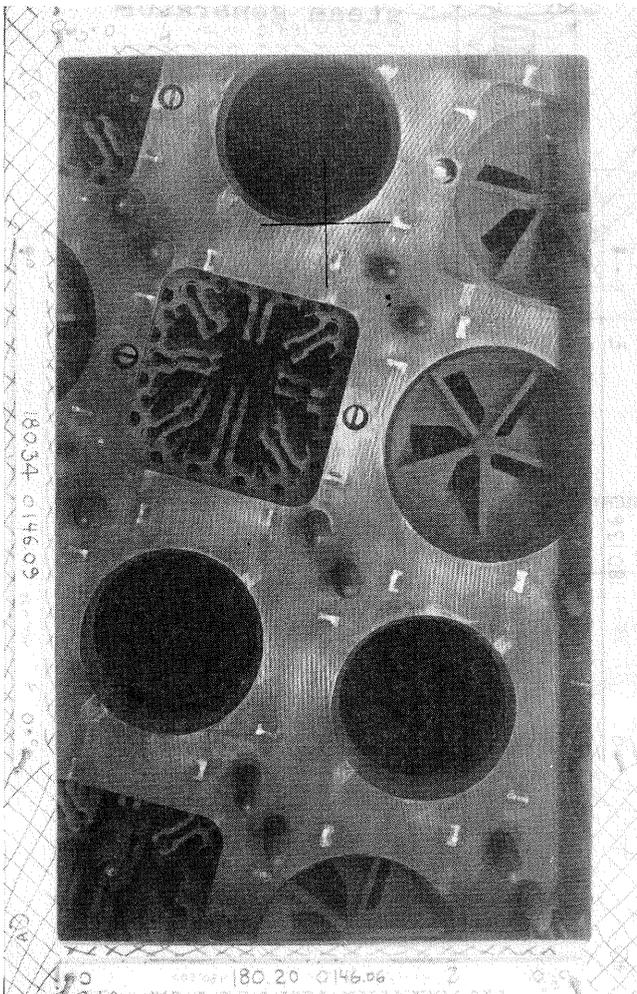
Figure 2

Dummy S.G. nozzle dam  
for measuring  
the ring flatness defect  
and hole dimensions.  
Note the reference scales  
and the target studs  
fitted into the holes.



Example of photogrammetry application :  
View of flatness defect in S.G. nozzle dam  
holddown ring (folded away in the drawing)

Figure 3



PHOTOGRAMMETRY OF UPPER INTERNALS

GRAPHICAL REPRESENTATION OF PIN DISTORTION

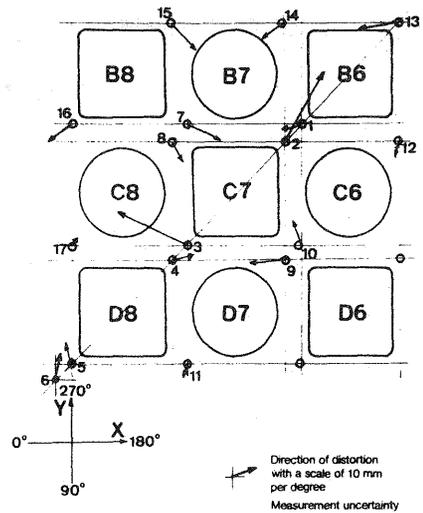


Figure 4