APPLICATION OF PRECISION CLOSE RANGE PHOTOGRAMMETRY FOR QUALITY CONTROL AND DOCUMENTATION IN POWER STATION CONSTRUCTION

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ABSTRACT

In connection with the manufacture of component parts for a nuclear power station there was a need for an independent final inspection. As the condition of the component parts should be documented simultaneously, application of photogrammetric methods was ideal. For the present 70 about 500 points of each part have been determined photogrammetrically. On demand further points can be determined with minimal effort. As there was extraordinary accuracy demands photogrammetric equipment from WILD/Heerbrugg has been used. Thus the project could be finished successfully. The papers describes the most important steps of the photogrammetric process.

INTRODUCTION

The industrial fabrication of component parts for superpower stations does not mean a difficult problem from a technical view today. Modern CNC-machine tools allow a fast, precise and economic manufacture of the wanted parts.

A rather disadvantage however of this method is that there is no manufacturing inspection which is independent from the production process so that some surpassings of tolerances may not be detected. Such tolerance surpassings can be caused for instance from shakes or changes in temperature while manufacturing, from deformations of the machine tool as consequence of the component parts' own weight or from many other reasons. For these reasons and with regard to the possible consequences of manufacturing defects the component parts must be controlled by an independent measuring method after production process has been finished.

This inspection can be done easily by precision close range photogrammetry as well as by geodetic methods (Fritsch et al., 1984). But it is significant that geodetic methods yield only the coordinates of selected points while photogrammetry documents the total condition of the component parts at the moment of exposures. Beyond this measuring of photos is temporally independent from taking photographs so that it is possible to decide later about the extent of measurings and computations. It is even possible to renounce of measuring for the moment until specific circumstances take place, for instance in connection with rights of recourse. With that photogrammetry proofs to be a very flexible method because there are measurings and computations - and with that: costs - only then, if there is a real requirement for it.

The paper describes the most important steps when inspecting the reactor pressure vessel of a nuclear power station with precision close range photogrammetry methods.

MEASURING PROBLEM

The reactor pressure vessel (Fig. 1) has a height of about 14 m and a diameter of about 8 m. Inside there are the interesting component parts with either plain or spherical surface. As it can be seen from Fig. 1, every component part has approximately 500 vertical boreholes for the later mounting of the fuel elements. Further 20 boreholes for the mounting of the control rods take an oblique and wind-tipped course. Manufacturing and mounting of the single component parts must take place in such a way, that the axes of corresponding boreholes are exactly on a straight line, when the reactor has operating temperature.

The task was to ascertain the actual condition of the single component parts in working position with photogrammetric methods; above all the coordinates of the borehole axes had to be determined. For the purpose of a powerful manufacturing control there was a required uncertainty of photogrammetric coordinates of only 0,2 mm.

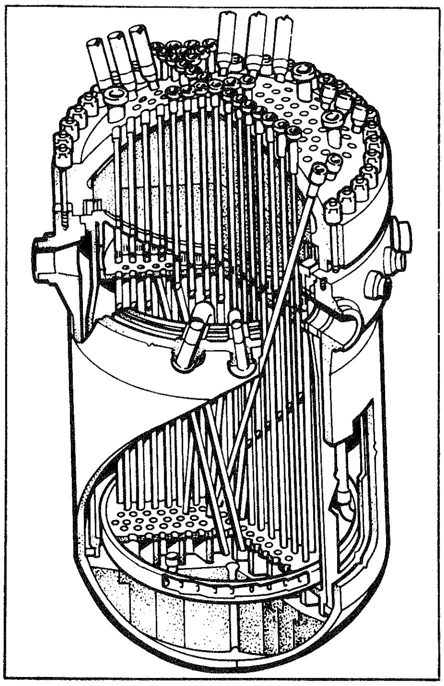


Fig. 1: Cross section of reactor pressure vessel

PLANNING PHOTOGRAMMETRIC EXPOSURES

First of all an important problem had to be solved. The borehole axes could not be measured directly because they did not exist physically. Visible, and with that measurable were only the edges of the boreholes.

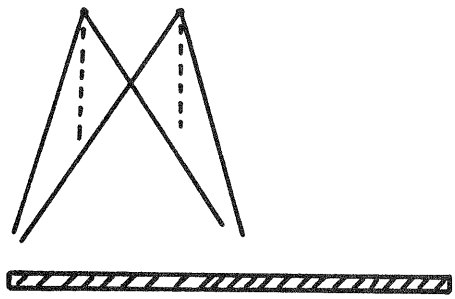
In principle it would have been possible to measure - for instance in a photogrammetric model - several points of the borehole edges and to ascertain the respective axis by computations, for instance as center of an adjusting circle. Using a computer integreted measuring system like an analytical plotter, this would have been possible even on-line. But as the boreholes had chamfered and not sharp edges this proceeding was not favourable.

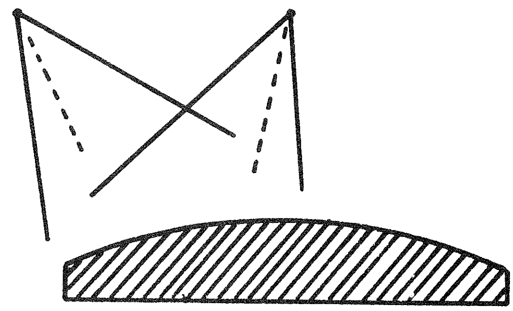
Therefore it has been decided to manufacture special cylindrical measuring pegs which could be inserted into the boreholes concentric with the borehole axes. At the upper side these black coloured measuring pegs had centric white targets which could be measured in the photos very well. As it would have been to expensive to provide every borehole with a measuring peg only a random test of casually distributed boreholes has been signaled in the specified way. By changing pegs between the exposures it could be achieved that at all about 15 percent of the boreholes have been provided with measuring pegs.

The selected photogrammetric camera was a WILD P31/10 cm focussed on 4 m. This camera has an acceptable image field (4 in. x 5 in.) which can be applied very flexibly because of its displacement of principal point. The change of standard focussing by intermediate rings is a warranty for a good stability and repeatibility of inner orientation. Beyond it because of its steady construction the P31 is very sturdy and safe to operate. In order to minimize systematic errors because of unflatness of plates there have been used ultra-plan plates from AGFA-GEVAERT.

Oblique photographs could hardly be realized because of the relative small depth of focus when focussing a camera to low ranges. An optimized disposition of photographs (Fig. 2 and 3) finally could be found by computer simulation.

The fundamental element of this disposition are two exposures which have - because of the displacement of principal point - an overlap of 100 percent. This basic element has been repeated eigth times in symmetric positions. Thus a lateral overlap of 60-70 percent could be realized. In order to improve the height accuracy of selected points some zenith distance measurements have also been included. According to the definitive disposition of photographs every borehole can be measured in average seven and at least in four photos.





Disposition of photographs

Fig. 2: Component part with plain surface

Fig. 3: Component part with spherical surface

TAKING OF PHOTOGRAPHS

The photogrammetric survey happened simultaneously with a test mounting of the component parts. This was possible, because the time for taking photographs is relatively small so that the mounting works have been distributed only undiscernible. For fixing of scale some prepared invar rods supplementary have been mounted on the component parts. Fig. 4 shows a typical measuring photo.

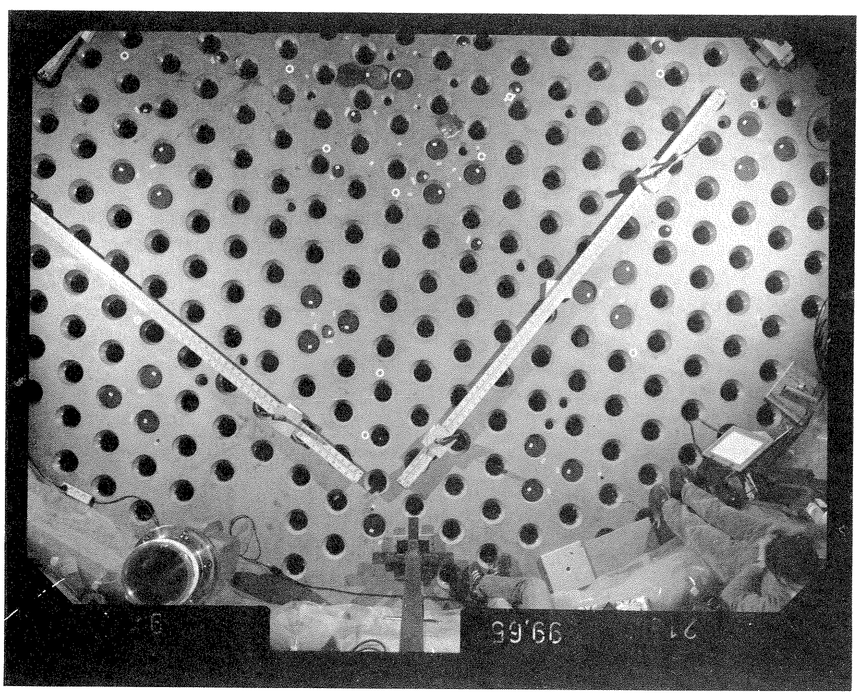


Fig. 4:

Typical measuring photo (plain component part)

MEASURING OF PHOTOS

The photos have been measured with the analytical plotter WILD Aviolyt AC1. It can be stated without any doubt that the AC1 is suited for many precision close range photogrammetry applications as well as no other analytical plotter: the AC1 combines the accuracy of measurement of a precise monocomparator (Steigerwald, 1985) with the manifold possibilities for automation and accelaration of measurement of a computer controlled measuring system.

Measurement of photos has been done by assistance of a special measuring program which has been developed at the Institut für Photogrammetrie und Kartographie of Technische Hochschule Darmstadt (Weisensee, 1985). This program is based upon the WILD-software. The required input data are the approximate coordinates of all object points and the approximate data of inner and outer orientation of all photos. Thus already in the first measurement passage all points can automatically be set approximately. The operator's job is only the fine setting. Beyond this there is an effective control of measured photo coordinates during the second measuring passage: if the difference between first and second setting is greater than a selected boundary value there is a warning signal from AC1. By the aid of repeated measurements the operator can come to a decision, for instance to delete one ore more single measurements of the concerning points.

This special method of computer supported measurement has several advantages: the speed of measurement is essentially greater than with classical single point measurement methods; and likewise the quality of measurement can be improved, above all the danger of making gross errors (for instance mix-ups of points) can be reduced.

Because of the simple and similar shape of the measuring points it even would have been possible to completely automate the measuring process using well-known digital image processing techniques.

COMPUTATION

The suited method in order to compute the coordinates of the wanted object points is the combined photogrammetric-geodetic bundle adjustment with additional parameters (Düppe, 1984).

In the best case, a component part with plain surface, adjustment yielded mean residuals of photo coordinates of only 1.5 µm for x and y which among other things confirms the high precision of measurement of the AC1. Fig. 5 gives a good survey of size and local distribution of the residuals.

The resulting standard deviations of the object point coordinates were from 0.03 to 0.05 mm for X and Y and from 0.09 to 0.13 mm for Z. By addition of the zenith distance measurement and combined adjustment the block could be stabilized and homogenized: the standard deviations were from 0.03 to 0.05 mm, in part even from 0.02 to 0.03 for X, Y and Z.

In the most unfavourable case, a component part with a spherical surface, the resulting standard deviations were from 0.07 to 0.09 mm for X and Y and about 0.12 mm for Z. By addition of zenith distances the accuracy in Z likewise could be improved to the same level as in X and Y.

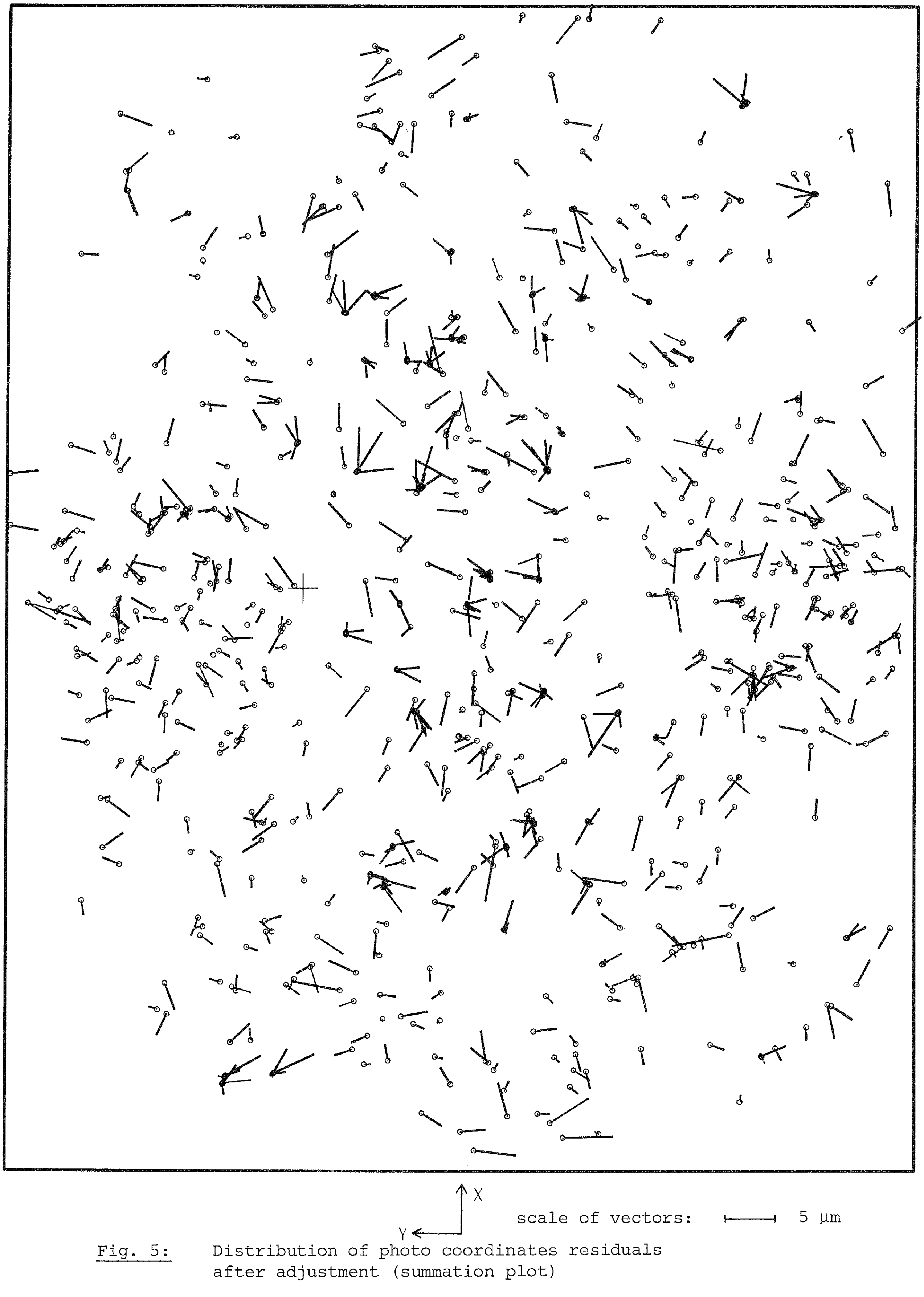


Fig. 5: Distribution of photo coordinates residuals after adjustment (summation plot)

CONCLUSIONS

The efficiency of low range photogrammetry as an indirect measuring method for the fast and precise recording of engine building objects has been demonstrated once more. The obtainable accuracy is equal to that of so called industrial measuring systems as for instance WILD/LEITZ RMS 2000 (Bill et al., 1985). But in contrast to these systems the photogrammetric method has the great advantage that the complete object is recorded and not only selected points of it. With that photogrammetry simultaneously is useful for the purpose of documentation so that at any time further points of the object can be determined.

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