MONITORING OF CONVERTERS FOR STEEL PRODUCTION

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Summary

Non disturbed fabrication of unchanged high quality is decisive for the efficiency and the productivity of modern industry. The monitoring of the installations in modern industrial plants by the application of geodetic and photogrammetric methods will help to avoid damages and to keep the production on a high level of quality. As an example a combined geodetic/photogrammetric monitoring of a steel converter in a German steel plant is shown.

1 Introduction into the problem

The steelmaking process is divided into two steps. The first step is the production of the raw iron in a furnace. In the second step carbon and other pollutions has to be removed from the raw material to receive high quality steel. This process takes place in a steel converter, which is a vessel with approximately 10 m height and a diameter of 8 m made of steel with an inner surface of incombustible fire bricks with a width of 1 m. The converter is filled with the smelted raw iron (>1600°C), additional scrap metal, and alloy. To receive high quality steel the rest carbon and pollution particles are eliminated out of the hot metal by the injection of oxygen. During this decarbonisation process the temperature in the reaction centre reaches 2500-3000°C.

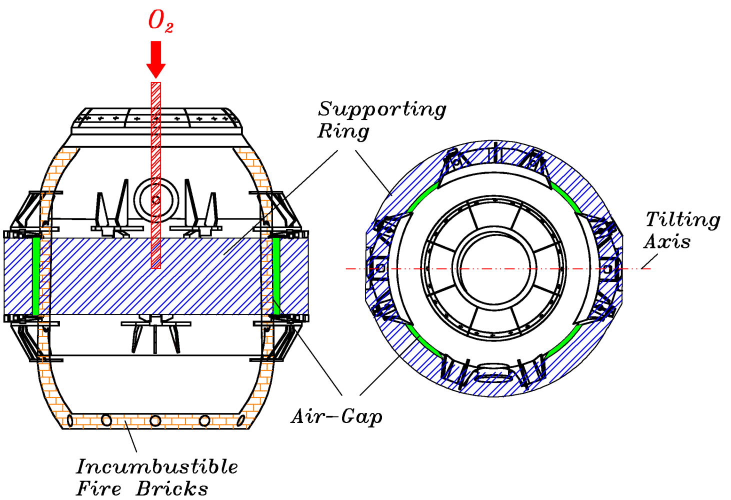

Fig. 1: Principle sketch of a converter for steel production

One converter has a capacity of up to 400 t. The vessel itself is holded by a supporting ring. Between the outer surface of the converter and the supporting ring an air-gap of 15 cm for cooling the vessel is situated. For filling or voiding the converter may be tilted with its supporting ring around a horizontal axis. The whole construction is installed upon a working platform inside the steel-mill.

One process of filling the converter, oxygen blasting, and voiding of the converter takes approximately 45 minutes. During this process the converter has to stand hereditary taints. After 2-4 weeks the incombustible inner surface of the converter has to be renewed. During the renewing the production process has to be interrupted for about 3 days. This means an economic lost for the steel works. To minimize this lost the renewing usually has to be delayed until the security of man and material is endangered.

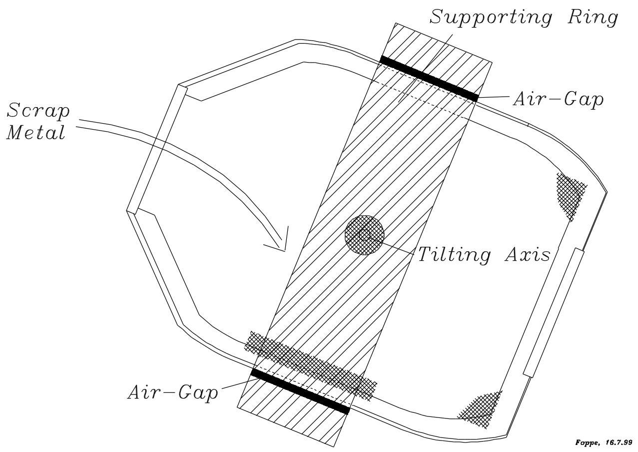

Fig. 2: Critical zones of the converter

The most critical part of the converter is the width of the air-gap between the vessel and the supporting ring, which is very important for the cooling of the converter. The vessel is deformed by striking of scrap metal against the inner surface, by thermic stress, and by its own weight at the suspension of the tilting axis (fig. 2). If the width of the air-gap becomes significant smaller than the nominal space of 15 cm, the vessel gets red hot and may brake during running production.

There is no direct access to the air-gap to enable optical measurements of the deformations. To determine the interesting actual state of the air-gap two digital object models (DOM) of the geometrical shape of the converter and of the shape of the supporting ring were derivated out of a combination of geodetic and photogrammetric measurements. By computing the differences of these two surfaces the air-gap at its actual state is to be achieved. The air-gap-DOM can be compared with the initial state after the construction. Information about ongoing deformations are to be derivated out of following epochs.

Another aspect in the monitoring was the determination of the clearance of the converter brackets with respect to the tilting axis.

2 Planning of the measurements

For the realization of a measurement campaign the two main conditions „access“ and „duration“ had to be considered. The outer surface of the vessel is armed against splashing hot metal and therefore not accessible. Furthermore there is no direct access to the air-gap. That means that the shape of the vessel has to be derivated from the inside after removing the incombustible fire bricks. Because of economic aspects the time window for the observations had to be minimized.

The chosen way to realize an economic determination of the inner surface of the vessel was the application of photogrammetric methods. On the other hand observations of discrete points on the supporting ring were carried out by tachymetric methods. So the model of the supporting ring was derivated out of geodetic observations. Furthermore the determination of the control points inside the vessel is also realized by geodetic methods (tachymetry).

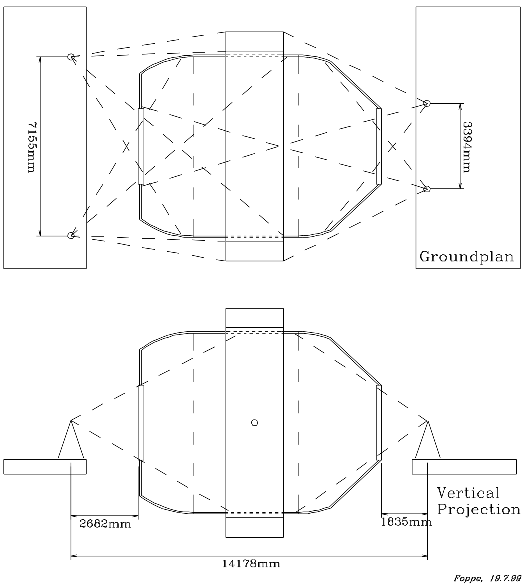

Fig. 3: CAD supported planning of geodetic observations

Due to visibility constraints the different observations were planned in three different converter positions. The tachymetric observations outside and the photogrammetric observations inside the converter were planned in upright („normal“) position. To determine the control points inside it was planned to turn the converter in horizontal positions („face I“ and „face II“).

For the planning of the geodetic observations the construction plans of the converter were digitized. Within a CAD software the visibility of all necessary points in- and outside the converter was checked for different configurations of the different instruments (fig. 3). Finally, the optimal instrument stations for the tachymetric observations inside the steel mill were determined on the basis of simulation studies with an adjustment software.

At the beginning of the project the photogrammetric observations were planned by conventional methods (fig. 4). Meanwhile an automatic planning system for close range photogrammetry is developed and verified hereafter with the data of the converter. In [Pollak 1999] it is shown, that the planning of photogrammetric surveys can be optimized under economic and accuracy aspects by the application of an automatically planning system.

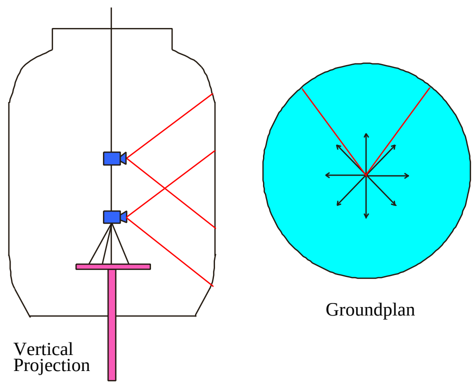

Fig. 4: Photogrammetric Planning

The time slot for the monitoring of the converter was restricted to approximately nine hours (including the signalling of the converter) during the regular renewing of the fire-bricks. To hold the time schedule four tachymeters were used simultaneously.

3 Establishment of a reference frame

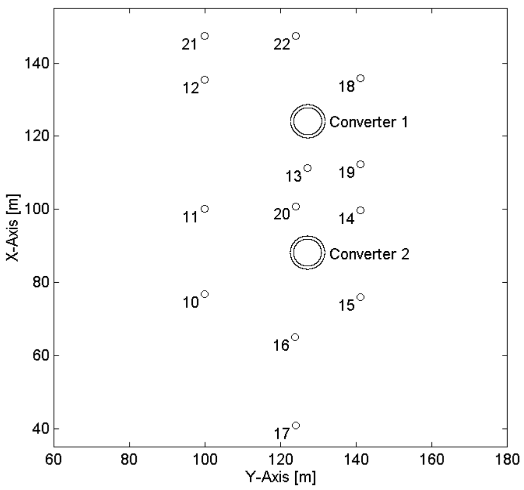

Fig. 5: Frame of reference points in the steel mill

For combination of the photogrammetric and the geodetic surveys a geodetic monitoring network of high accuracy with an extension of 70x120 m was installed as reference frame inside the steel mill (fig. 5). It consists out of 13 reference points, whose benchmarks were constructed as consoles for standard reflectors. The coordinates of the reference points were determined in a free network adjustment with mean standard deviations s_x, s_y, s_z better than 1.5 mm. The geodetic network serves as the reference frame for the two converters in the steel-mill, especially for the transformations among the several observed converter positions („normal“, „face I“, „face II“).

4 Signalling of the converter

Three main parts of the converter had to be equipped with optical target points: the inner part of the converter after removing the firebricks, the outer part of the supporting ring and the ends of the tilting axis. Only temporary marks could be mounted. They were fixed by the assistance of a lifting jack, because the converter is not assessable in another way (fig. 6). This rather time-consuming method lasts up to six hours including interruption periods because of other renewing works at the converter.

Fig. 6: Signalling the converter by the assistance of a lifting jack

Self-pasting and magnetic-fixed retro-reflectors were used for tachymetric and photogrammetric measurements. In addition painted marks serving as photogrammetric control points were depicted inside the converter because of the contrastless surface.

5 Geodetic observations and data processing

The geodetic observations for the determination of the points inside the converter and at the supporting rings were carried out by using four tachymeters simultaneously beside the running production process of the respectively other converter. The four observation stations are to be seen in fig. 3. Some of the target points were observed in at least two of the three converter positions. At each converter position („normal“, „face I“, „face II“) the actual positions of the tachymeters were determined with respect to the visible points of the reference frame.

The measurement of the electro-optic distances was not easy to realize because of the short distances in connection with the use of retro-reflectors that reflect the electro-optic signals direct and not parallel shifted like standard reflectors. The only available instrument solving the problem was the Geodimeter 422, because the reflected signals found their way into the receiving system of the electro-optic instrument. The reason for this possibility is the large divergence angle of the transmitting system.

Additionally the points at the ends of the tilting axis were observed; also with respect to the visible points of the reference frame. The observations of a fifth tachymeter strengthen the geodetic network by connecting the tachymeter positions for the determination of the object points. All the observations last about four hours.

The constraint adjustment of the observations leads to accuracies for each coordinate better than 0.8 mm in each position of the converter. Besides the three different coordinate sets the position of the tilting axis was estimated using an adjustment of condition equations with unknowns. The three coordinate sets were combined with the help of the estimated position of the tilting axis and some 3-D-HELMERT-transformations (without scale parameters). The translation parameters of the HELMERT-transformations yield the evidence about the clearance of the converter brackets.

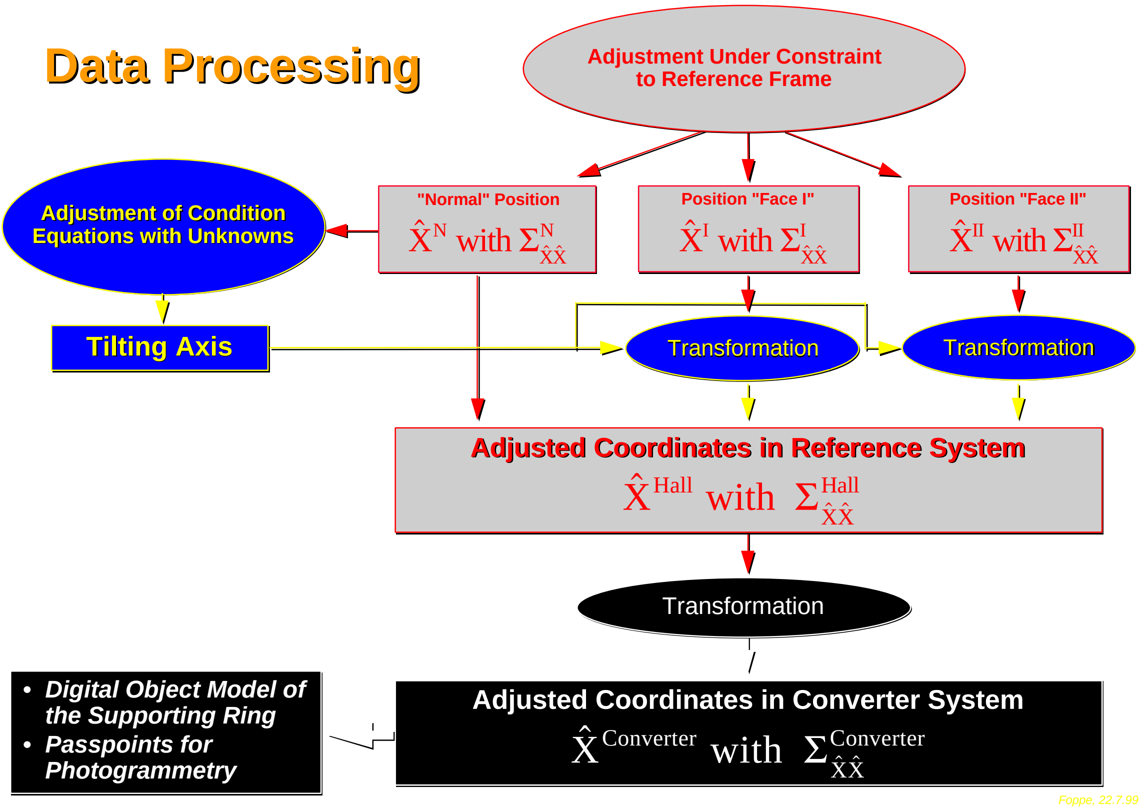

Fig. 7: Processing of a common solution for the geodetic observations won in three converter positions

Finally all necessary coordinates were given in the converter system with the origin inside the converter, x-axis as tilting axis, and z-axis as vertical axis. This converter system is the basis of any further computations, especially the DOMgeneration and the control point determination for the photogrammetric evaluation. The described geodetic evaluation steps are presented in fig. 7.

6 Digital Object Model (DOM) of the supporting ring

The DOM of the supporting ring for each converter is created by using 16 known geodetic points on the outer surface of the ring (fig. 8). The supporting ring is constructed as a cylinder with upper and lower plane sides. The mantle thickness is known from the construction plans. In an adjustment of condition equations with unknowns (GAUSS-HELMERT-Model) the evenness and circularity of the planes are analysed. The remaining residuals with respect to a circular and a plane are shown in fig. 8. With respect to the centre points of the upper and lower circle the DOM of the supporting ring is computed. The result is given by fig. 9. The presented deviations reach some mm. The implications of these deviations on the production process in the steel-mill are not discussed within this paper.

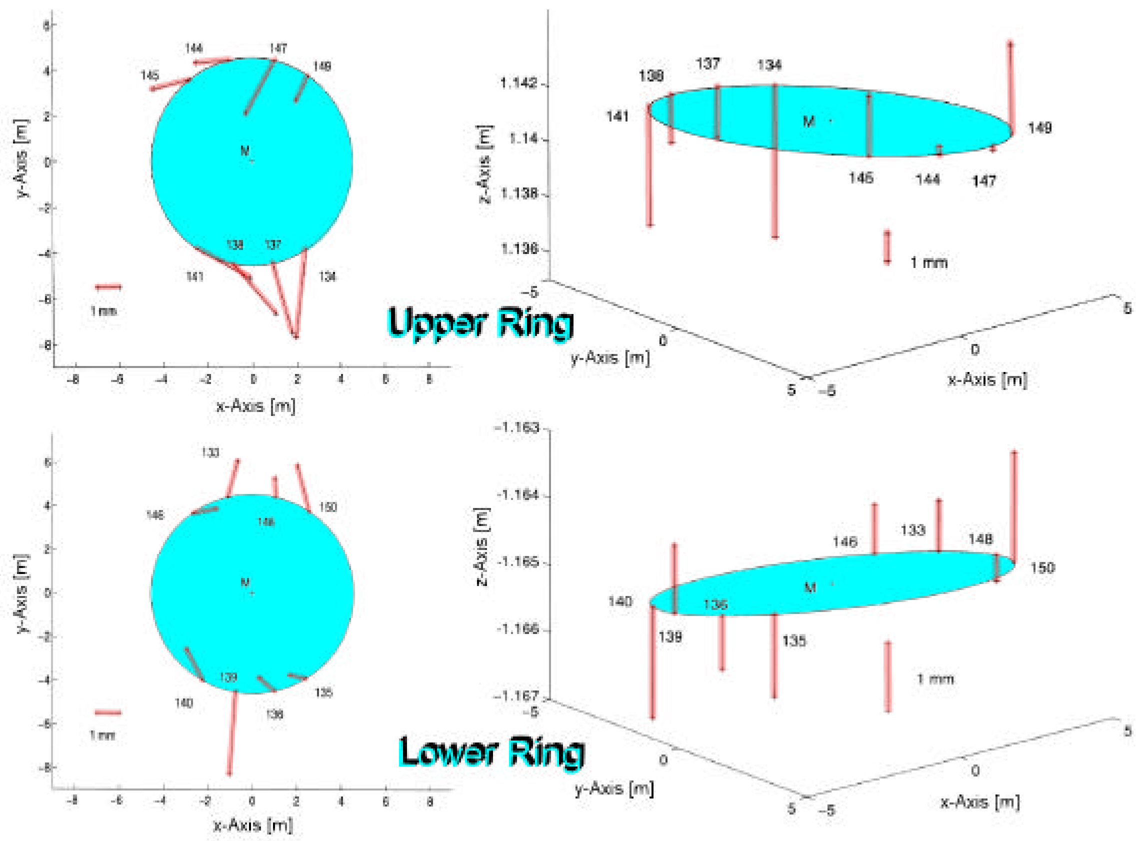

Fig. 8: Adjustment of condition equations with unknowns to model the upper and the lower part of the supporting ring as circular planes

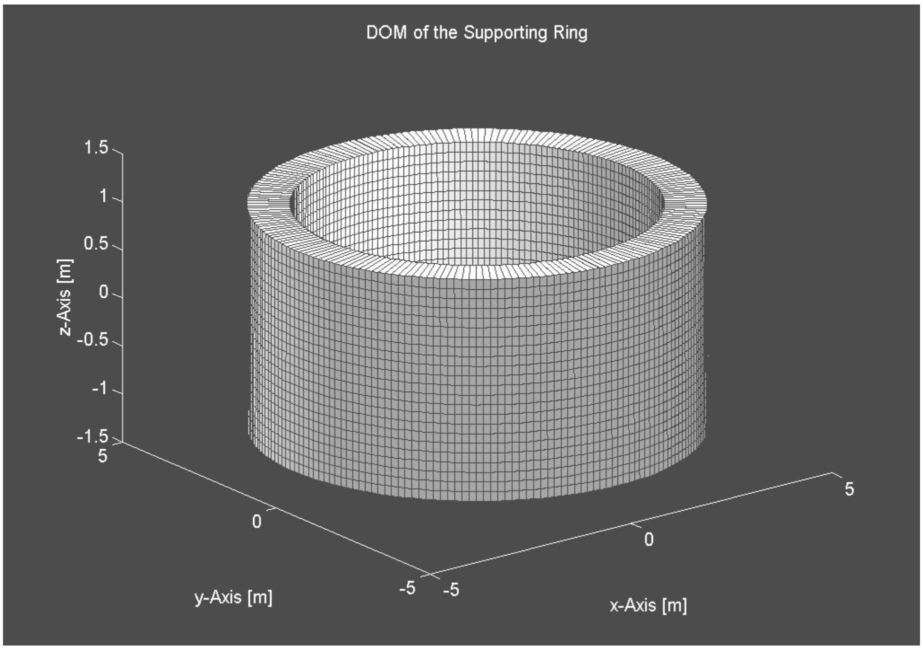

Fig. 9: DOM of the supporting ring

7 Photogrammetric Shape Determination

To describe the real shape of the steel converter it is necessary to determine a lot of object points on its surface. In case of a grid distance of about 20 cm more than 4000 targets have to be measured. To do this in a short time, photogrammetric methods are the most proper solution.

The task was to achieve an accuracy of less than ± 5mm standard deviation on the surface of the converter. The time for preparations (e.g. target signalization) and image acquisition had to be minimized.

Due to handling and time reasons a Rollei 6006 metric camera with a Zeiss Distagon 1:4 / 40 mm wide angle lens was chosen. Additionally the camera was equipped with a 70 mm film cartridge for up to 80 images. A digital camera would have had some advantages but was not available.

The placement of the camera inside the converter was realized with an existing platform, which is normally used to prepare the converter for steel production. With this device it is possible to move the camera along the vertical axis of the upright positioned converter (fig. 4). Eight images on nine vertical levels were taken, using an overlap of 60% in the direction of the converter axis and one of about 40% inside a level. This arrangement supplied the image stereo basis, which is necessary for the 3D point determination, only along the vertical converter axis.

Special problems arose from the surface structure and the light conditions inside the converter. In order to reduce preparation time, additional lighting was realized by only two photo lamps (1 kW each) fixed at the camera mounting on the tripod. This direct light caused irregular reflections on the object surface, depending on whether the scratches on it showed blank metal or not. Also for different images of the same object point this effect varies. For this reason an additional signalizing of targets in an about 80 cm wide grid was done.

The photogrammetric evaluation process is shown in fig. 10. The total time for taking the images was about 1.5 hours. The most critical component was the very slowly moving platform. Another factor was the swinging of the platform in combination with long exposure times down to ¼ second, which leaded to delays while waiting for a stable situation.

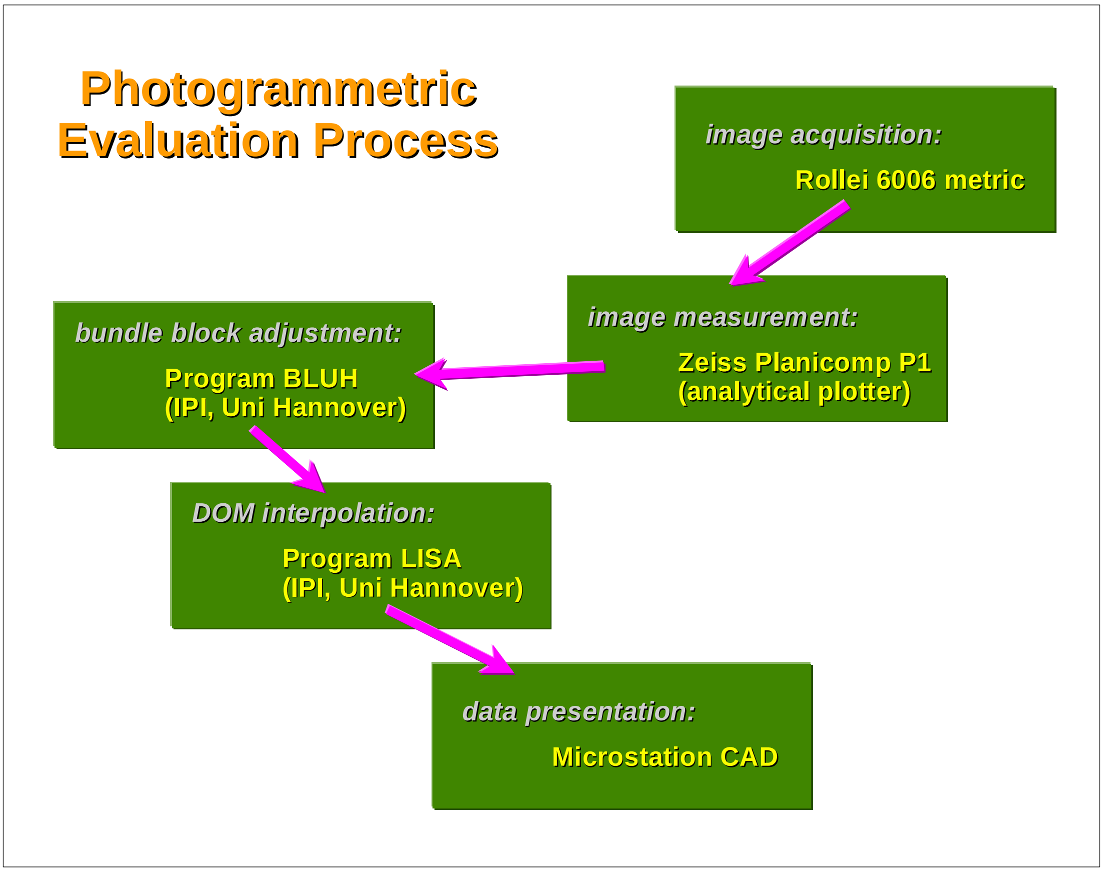

Fig. 10: Photogrammetric evaluation process

The image coordinate measurement was done with the analytical plotter Zeiss Planicomp P1. A first approach was done using the standard techniques of generating digital terrain models (DTM) from aerial images: Control- and tie points were measured in a single image mode and then computed with a bundle adjustment. The resulting image orientation parameters were used again in the Planicomp to determine 3D object coordinates in stereo mode. Because of large y-parallaxes and the disturbing reséau grid of the Rollei camera while using the stereo mode, resulting in low accuracy, a second approach has been made with measuring all object points in the single image mode and handle them completely in a bundle adjustment. The bundle adjustment was calculated using the program system BLUH (Jacobsen, IPI Hannover). Approximate coordinates of all points could be obtained with BLOR (part of the system BLUH). The systematic errors of the Rollei images were corrected in an online calibration using additional parameters e.g. for the focal length, the principle point and the lens distortion. The resulting standard deviation of unit weight was about 16 µm. This is below the potential of the camera system and is caused by difficulties in the identification of homologous points in different images, as mentioned above. Nevertheless, due to the large image scale the object point accuracy is sufficient. The mean square error at the control points with $s_x = \pm 2$ mm, $s_y = \pm 3$ mm and $s_z = \pm 1$ mm indicates that.

8 Combined Digital Object Model (DOM) and final results

The raw object data generated by BLUH had to be transformed into a digital object model (DOM). Also profiles for certain predefined orientation angles and a model of differences between the converter and its surrounding supporting ring (combined DOM) were required.

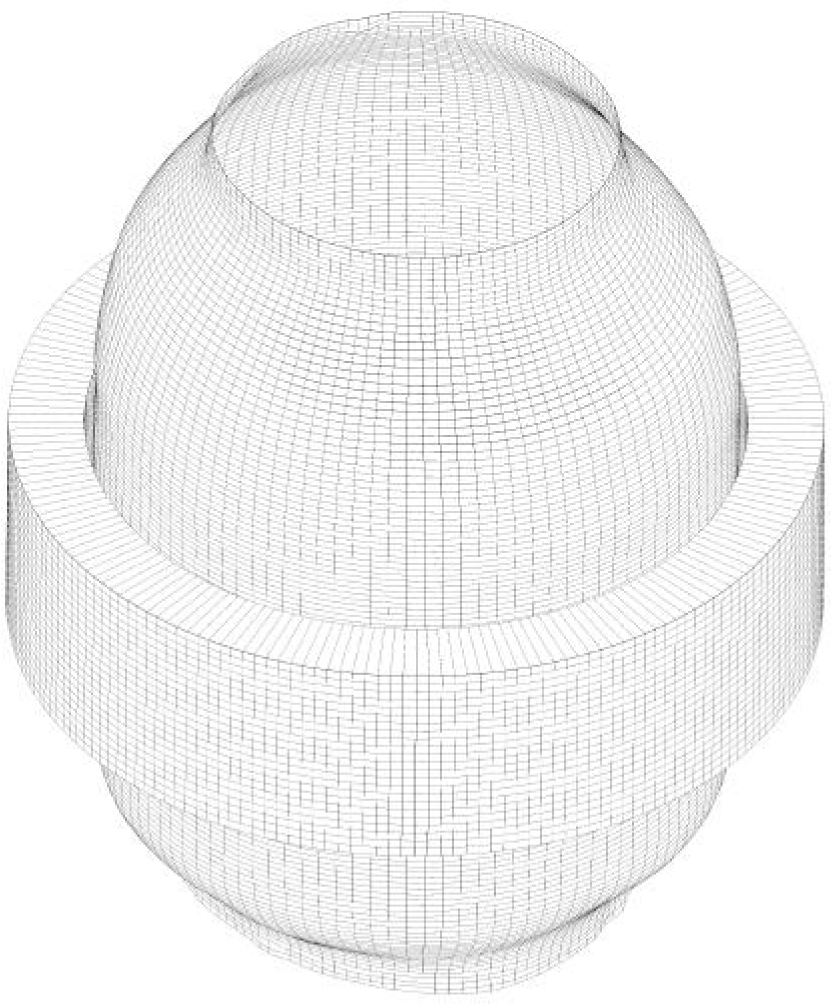

Fig. 11: Combined DOM of converter and supporting ring

The interpolation of a regular grid, representing the DOM, was done with the program LISA (Linder, IPI Hannover). Profiles were generated and a format conversion of the 3D converter model to Autodesk DXF was realized with especially developed programs. This data set was imported into the Bentley Microstation CAD system, were visualisation and data consistency checks could be performed (fig. 11).

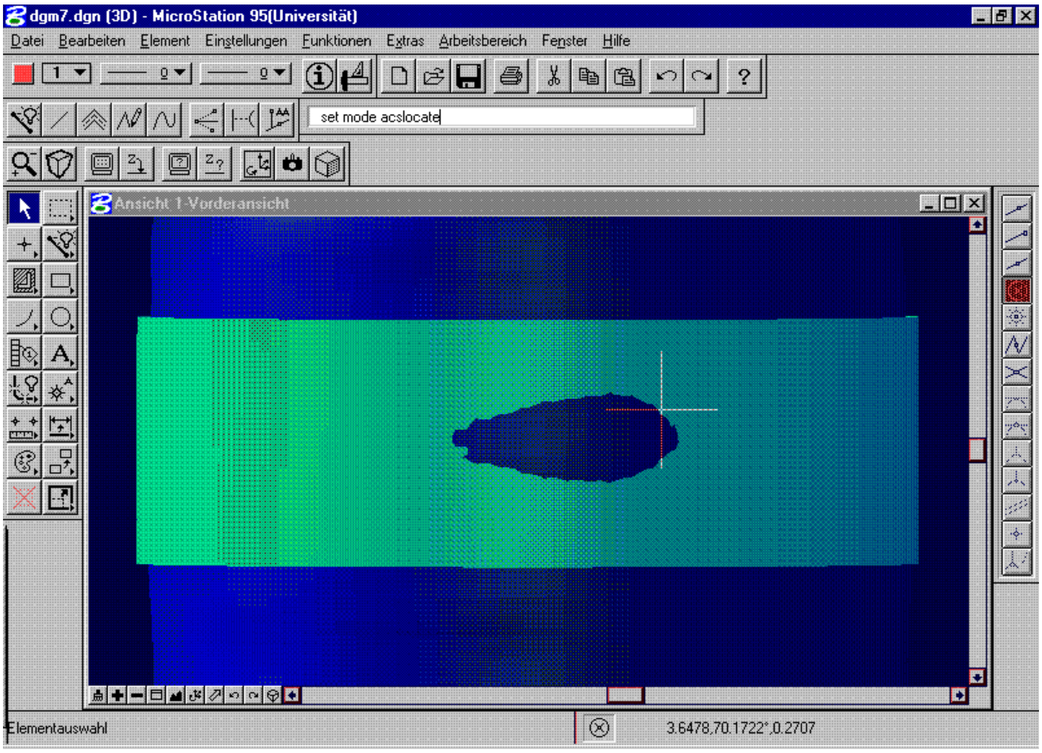

Fig. 12: Critical deformation error

The comparison of the inner dimensions of the supporting ring with the outer converter shape was done after the correction of the photogrammetric results with a constant factor of 70 mm, which was representing the material thickness of the converter. Each object point was shifted in perpendicular direction using an curvature interpolation between neighboured points. A model of differences was calculated between these two data sets with an interpolation along the vertical converter axis perpendicular directions. Critical deformations could be shown using the Microstation CAD system (fig. 12).

9 Conclusion

The highly accurate determination of the shape of a converter may be realized by a combination of photogrammetric and geodetic measurements. The high accuracy is guaranteed by the usage of different adjustment models like the adjustment of condition equations with unknowns. This application of combined geodetic/photogrammetric methods is a successful example for the support of economic industrial production processes.

10 References

BOEHM, S.: Gerätetechnische Realisierung eines digitalen photogrammetrischen Aufnahmesystems am Beispiel eines Stahlkonverters. Diploma thesis, University of Hannover (not published), 1998.

POLLAK, B.: Ein rechnergestütztes Planungssystem für die digitale Nahbereichsphotogrammetrie. Wissenschaftliche Arbeiten der Fachrichtung Vermessungswesen der Universität Hannover, No. 232, 1999.

REINKEN, A.: Automatisierung in der digitalen Bildverarbeitung. Diploma thesis, University of Hannover (not published), 1998.

RIETDORF, A. / SCHULZE, A.: Untersuchungen zur geodätischen Vermessung von Konvertern der Stahlwerke Bremen GmbH. Diploma thesis, University of Hannover (not published), 1998.

WENDELN, H.: Ergebniskontrolle und Ergebnisdarstellung von photogrammetrischen Aufnahmen am Beispiel eines Stahlkonverters. Diploma thesis, University of Hannover (not published), 1998.