GEODETIC INVENTORY OF A COOLING TOWER USING REFLECTORLESS TECHNIQUE

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ABSTRACT

The technique of reflectorless measurements finds more and more applications in geodetic practice. Its new stage is video-tacheometry. It is quite a new measurement technology combining tacheometric measurements and digital photogrammetry. On the one hand, it ensures perfect metricity of a set of spatial points (XYZ), on the other, it offers “continuous” image representation of an object surface. The combination of these data into a uniform measuring system and the ensuing result processing allow us to obtain unprecedented effects.

This article presents inventory measurements of the surface of a cooling tower taken with a precise Leica TCRP 1201+ tacheometer and a TOPCON Image Station 03 video-tacheometer. Video-tacheometric measurements were carried out in the SCAN AREA and LINE modes.

The obtained results were confronted with the design values of the cooling tower and accuracy measurements taken with a TCRP1201+ measuring system. The results of the research allow us to see all the flaws and merits of the new technology and make its accuracy assessment.

1. INTRODUCTION

Thin engineering structures require special care to ensure that their stability is appropriate and by the same token their safety. Engineering structures of this type are cooling towers. The study of static stability of these structures requires precise recognition of their real shape in relation to the design surface. The size of these structures and a large number of points required to represent the structure as well as difficult access to survey points have always been a major problem for surveyors.

Various methods and technologies have been used earlier to carry out these measurements. They have been mainly based on the construction of angular intersections to control points. It has also been required to signal measurement points. The surveying has been exceptionally arduous and the point representation of a structure limited, due to these difficulties.

Some hope was raised by the introduction of photogrammetric methods. Photogrammetric techniques ensured the required density of area “sampling” but obtained accuracies were limited and often inadequate.

After the introduction of electronic theodolites and laser eyepieces, it was possible to meet accuracy requirements as well as those concerning information density about a particular structure. The above technology called Remote Measuring System (RMS) involved very precise field measurements, demanding intense concentration on the part
of many observers making observations. Personally, I have taken measurements of many cooling towers by the RMS method, using Wild T2002 theodolites and the related experience has been recorded in the literature [1]. The possibilities as well as the quality of this technology should be appraised highly.

Technological progress, especially in the field of geodetic instruments is constantly providing new solutions. The introduction of reflectorless rangefinders, starting from a DI 3000 DIOR produced by Wild, opened up possibilities of making an RMS survey in the “polar measurement” mode. One of the first systems of this type is APS Leica and MONN MOS Nokia. Increasing the speed of observation made it possible to construct scanning theodometers and ground laser scanners.

Currently, measuring systems are being developed, based on scanning tachometers and digital cameras built into one instrument. They are the so-called video-tacheometers. They combine the technology of precise polar measurements (Automatic Polar System) and that of digital area imaging.

This article presents the experience involving experiments with the application of reflectorless tacheometric technology and video-tacheometry to make an inventory of the external area of a cooling tower. In video-tacheometric technology the image and geometric features of a structure are registered in one coherent study and constitute an objective material source. It enables high fidelity presentation of a structure with all its external features and thus making the right decisions after analyzing these data. Registered images can be also instrumental in the selection process involving characteristic points of a structure.

Reflectorless measurements have a number of flaws connected with geometric synchronization of the theodolite-rangefinder system [2]. It is mainly due to the geometry of the rangefinder system and the phase shift of a measuring wave.

![Image of a laser beam of various instruments from a distance of 42 m and distance changes caused by the eccentric effect of a beam for a TCRP1201+ for equal angles of beam incidence.](image)

The values of measurement errors change approximately in a linear way in relation to the length of sight. The adverse impact of the beam incidence angle becomes particularly prominent in the case of structures in the shape of solids of revolution, especially on oblique surfaces. That is why one should avoid such conditions while making observations. This question, along with research on the subject, has been reported in the literature [2].
To ensure the proper level of confidence in the results of experimental measurements concerning a cooling tower, a number of studies on measuring systems have been done. The research results for measurement errors in the reflectorless mode for a TCRP 1201+ are shown in Fig.1. These results confirm high accuracy standards of the instrument. Its readings can be the reference point for assessing the precision of the Image Station 03 system.

2. MEASUREMENTS ON A COOLING TOWER

The subject of the experiment was the inventory of the external surface of a cooling tower 130 m tall and 100 m base diameter. In the middle part of the structure the thickness of the concrete shell did not exceed 14 cm. Hence there were exceptional accuracy requirements concerning geodetic observations determining the geometric properties of such a structure. To ensure a uniform system of coordinates for defining the position of all structure points observed from different stations, an appropriate 30-point geodetic control network was designed and measured: 10 station points, 3 points of basic network of the structure, 7 connecting points stabilized by signals on tripods and 10 points of the structure’s direct network (see Fig.2). It is the points of the direct network that were the framework of reference for individual measurements taken with a video-tacheometer.

![Sketch of the geodetic control network.](image)

Building constructors carrying out a static analysis of the cooling tower demanded a detailed assessment of the outer shell of the cooling tower in 10 vertical profiles with a vertical density of 2 m, i.e. about 70 points for a vertical profile.
Geodetic observations with a precise tacheometer TCRP 1201+ were made on 10 station points. Along with the geodetic network observations, observations were made to all individual points. For every profile observations were made to about 200 profile points. The measurements were taken in the reflectorless mode. The solution character was that of a block network concept. All observations were adjusted as a spatial network in the Leica Geo-Office program, obtaining very high accuracy in defining the positions of all points (±1-1.5 mm). Video-tacheometric technology enables even denser representation of the structure’s area and much faster measuring work as well as supplements geodetic data with a photographic panorama of the structure. It also enables fast automated result processing.

Using a video-tacheometer IS 03, the following measurements were made from 10 control network-oriented stations:

- measurement in the SCAN LINE mode defining the measuring density at the level of 2000 points for every profile (every 6 cm),
- scanning measurement carried out in the SCAN AREA mode for about 15-20 % of the cooling tower surface, containing 8000 individual points.

At every station an appropriate number of photographs were taken with a digital camera of the instrument, ensuring a complete panorama of the registered area (Fig.3).

![Image](image.png)

Fig. 3. View of control points covering the surface of the cooling tower in the Image Master system.

In total, 85 000 individual points were registered for the shell of the cooling tower. These points constitute a very dense representation of the structure for constructing a model of the external surface of the cooling tower.

3. SCANS PROCESSING

On the basis of the results of inventory measurements with a video-tacheometer, we obtained a record of individual points and images, carried out in definite space directions. Subsequently read-in scans are automatically added in the Image Master system as successive fragments of a point-represented model of the structure. Next,
there are Triangular Irregular Networks (TINs) created for individual “clouds of points”, according to Delaunay’s algorithm. As a final effect, we can obtain the whole structure as a set of appropriately combined points (see Fig.4).

Fig. 4. View of an Image Master editing window with a TIN network of the structure's surface.

Individual networks are built for individual stations and combining them to form a coherent whole is made possible, e.g. by separate “sampling”. At a further stage of analysis we can cover the TIN network with an appropriate texture (Fig.5).

Fig. 5. View of an Image Master educational window along with a surface model of the structure.

In standard studies of cooling towers, vertical profiles are made in chosen places as well as their horizontal cross-sections for selected heights of the structure. Deviations from design values are presented for individual places. These deviations are calculated by comparing an adjusted set of points measured in the design model of the structure.
In the present case, the adjustment was made by the approximation method of least squares only of the points of the lowest part of the cooling tower, assuming that the direction of the vertical (the z-axis) was to be maintained. Such an approach is required for the right assessment of the structure stability. The standard form of measurement data processing by using TCRP observations, in the AutoCAD system is illustrated in Fig. 6.

Fig. 6. Typical report drawings with deviations from the design made in AutoCAD.

Video-tacheometric technology provides us with a much greater number of data and the structure model obtained therein can be the basis for creating any sections and profiles required, as well as any contours of the model surface (Fig.7). Additionally, digital photos of the structure are noted, which can be used for texturing the model.
It is also possible to process measurement data more thoroughly, e.g. according to one’s own algorithms in different analytic and graphic systems, e.g. in MatLab (Fig. 8). Many measurement deviations can be easily observed here, especially on the edges of partial mapping? Compilations? caused by worsening surveying conditions or local identification mistakes (lamps, ladders, wires, etc). These defects should be removed from the study with appropriate data filters, adjusted to the situation and features of the analyzed surface, accounting for the properties of the existing deviations.

Fig. 7. Contours for two TIN surfaces, determined from different stations.

Fig. 8. Graphic representation of scanning data for the cooling tower surface in the MatLab system, with a marked plane of the section axis in azimuth 324° (section 10).
A detailed analysis of data measured several times in chosen profiles, obtained by LINE and AREA mode scanning allows us to assess the accuracy of the measurement made for the structure. An array of measurement results for one of the vertical profile lines, determined on the basis of experimental measurements made for the cooling tower, is presented in Fig. 9. The figure shows not only the trace of precise TCRP profiling, a profile interpolated from the TIN network, but also two independent graphs showing the values obtained in the LINE mode.

![Graph showing measurement results](image)

**Fig. 9.** Registered individual points as compared to the design model of the surface.

The analysis of observation results obtained with a video-tacheometer showed discrepancies between precise observations, even reaching, under the worst of conditions, 50 millimeters. As shown in figures 8 and 9, these discrepancies become more prominent with greater incidence angles of the measuring beam and with considerable distances. In addition, the analysis of scanning results shows dramatic, zigzag changes in the graphs representing profiling results. These changes result, on the one side, from the lack of synchronization of individual constituent observations of the guiding vector to the point, as well as the incidence of errors related to the distance measuring system and the direction of “in motion” measurements. A rise in positioning accuracy can be easily noticed for points measured in the STOP mode in relation to the NON STOP mode, as well as in the case of a constant vertical angle of the telescope when a series of measurements is made.

The presentation of results of the study based on precise TCRP measurements can be presented in the form of axonometric projections and contour drawings in a cylindrical projection (Fig. 10). These illustrations visualize deformation effects of the structure surface in the assumed graphic projection.

Numerical magnitudes of these deformations are the subject of analyses and assessments made by building constructors.

Surveying in the STOP mode under good pointing conditions allows us to obtain accuracies of a few millimeters. Bad measuring conditions and the SCAN mode show...
distinctly lower accuracy, abrupt changes in successive results and likely incidence of other disturbances, e.g. unambiguous target identification.

Fig. 10. Contour and projection rendering of structure surface deviations from the design model.

4. CONCLUDING REMARKS

Steel shell structures require special treatment to ensure their safe and long functioning. To determine the deformations of these structures and the contractor’s poor workmanship newer and newer, advanced surveying technologies are used. Earlier it was geodetic measurements that were often very painstaking in practice. Contemporary electro-optic teodolites do not require reflex reflectors and the surveying is done directly to the surface of the structure. It is a great advantage but also a drawback of such measurements, due to the ambiguity of the reflection place. It is
particularly visible in the case of a complicated surface of the structure or a partially obscured measurement beam. That is when different disturbances occur, which are difficult to eliminate, undermining the accuracy effect obtained.

Reflectorless surveying technologies used in modern tacheometers are not devoid of synchronization errors in time-space observations of directions and distances. This element becomes exceptionally prominent during measurements in the scanning mode. The introduction of video-tacheometric technology supplements geodetic observations still by another element, which is a digital image. In this case, it is possible to use the analysis of this image as support in making detailed measurements. This technology, apart from making observations, contains a complete method for processing these observation results in an automatic way. It speeds up considerably the final outcome of the study, eliminating mistakes in combining observations, and enables to conduct fast the successive stages of data processing. The constructed virtual model of the structure can be the subject of an indefinite number of analytical-graphic transformations.

New forms of graphic presentation enable better perception of the final outcome of the studies and, due to automatic data processing, make these studies more objective and reliable.

REFERENCES
