Geodetic Networks of Special Purposes in Hydropower Industry

Nestorović, Ž.1, Gospavić, Z.2, Božić, B.2 and Delčev, Š.2

1 PD "HE DJerdap" d.o.o., HE DJerdap I, Trg kralja Petra 1, Kladovo, Serbia
Web site: www.djerdap.rs, E-mail: zarko.nestorovic@djerdap.rs

2 University of Belgrade, Faculty of Civil Engineering, Bulevar Kralja Aleksandara 73, 11000 Belgrade, Serbia, Web site: www.grf.bg.ac.rs
E-mail: zaga@grf.rs, bozic@grf.rs, delcev@grf.bg.ac.rs

Abstract

Geodetic networks utilization in hydropower industry applications is close connected with considerable limitations. Demands in accuracy and reliability of geodetic data are very high while shape and design of geodetic network is limited by the shape and dimensions of the measured machinery structure and its environment. Measured machinery structure dimensions and geometric relationships of its elements determination in such conditions are sometimes possible only by using geodetic networks with very short distances. In this paper the results attained by using geodetic networks for dimensions of big machinery structures determination in hydropower industry are shown. Special attention was devoted to analysis of accuracy and reliability of attained results. Based on these results adequate conclusions will be given about the achievable accuracy of such networks with classical geodetic instruments.

Key words: Geodetic networks, accuracy, reliability, machinery structures

1 INTRODUCTION

Hydro energetic industry is very important for modern civilization because it produces electric power from renewable sources and because that energy is considered cleaner than produced from the other conventional sources. The task for engineers who are working in hydro energetic industry is to maximize the utilization of potential water energy in process of its transformation to electric power. In that sense, the geometry of electric aggregate is of big importance.

Having in mind that, parts of electric aggregate can be of big power and dimensions the role of geodetic measurements in dimensions, geometry and geometric relationships of its parts determination is inevitable. The main issues for geodetic work are the very high accuracy and limited conditions for realization of geodetic measurement. High accuracy is needed because of necessity to match it with the accuracy of electric aggregate elements production. Aggregate elements are produced on the lathes of big dimensions and in technological processes which ensure geometrical shapes with, in geodetic sense, very high accuracy. Very high accuracy during the machinery elements production is necessary because of constructive and functional conditions which must be satisfied in order to assemble them.
into the whole and in order to assure that the whole will work properly. It is possible that different parts of electric aggregate could be produced in different factories and if the accuracy of its parts is not adequate the probability of proper parts assembling and proper functioning is quite small. According to the fact that price of these machines is high every mistake will cause the further costs. Consequently, geodesists must take every reasonable action in order to achieve the maximum accuracy in limited conditions. The possible solutions of that problem are: to use the geodetic instruments and equipments of maximum performances, to have the big number of redundant measurements and to make rigorous analysis of measurement results. In this paper some solutions with using classical high accurate geodetic instruments and equipment are considered.

2 GEOMETRY DETERMINATION ISSUES IN HYDRO ENERGETIC INDUSTRY

Geometry determination of big machines in hydro energetic industry is characterized by:
- High accuracy demands for dimensions of parts and their relationships;
- Very limited conditions for geodetic networks;
- Difficult measurement conditions;
- Short lines of sight;
- Limited time interval for measurement and
- Other working processes could be provided simultaneously impeding or slowing down geodetic measurement process.

High accuracy demands of electric aggregate elements and their relationships means that errors of measured values must be in the interval of few tenths of millimeter. Limited conditions for geodetic network establishment means that fixed geodetic points cannot be established on the positions which are most suitable for best network geometry from aspect of accuracy of searched dimensions and values.

Measurement conditions are difficult because it is not possible to provide equal visibility for each point. Consequently, different points are determined from measurement results which are of different quality (different accuracy). That means that we can hardly talk about homogenous accuracy of measurements and that it is possible to estimate the accuracy of a certain measurement objectively. In some cases the efforts for objective estimation of measurement results are senseless.

Sometimes the needed line of sight is shorter than it is the minimum line of sight of a certain geodetic instrument. It can cause extension of time for geodetic measurements.

Limited time for geodetic measurement is defined by other technological processes. Consequently, geodetic measurement must be provided in technological pauses of other processes for aggregate production.

Other working processes provided simultaneously can impede geodetic measurement process by slowing it down, breaking it for a while or to cause some changes in working place which can affect results of geodetic measurement.

It can be a case that needs for geodetic measurement arise in time which not allows detailed analysis of all possibilities for problem solution. Consequently, the best possible solution is cannot be found making geodetic measurements further difficulty. In that case the solutions satisfying needed accuracy and are technically feasible should be found.
Intuitively appears the question how to eliminate or reduce these influences during the measurement process or during the measurement results processing. One of possible solution is based on:

- Using geodetic instruments and equipments of maximum possible performances;
- Big number of redundant measurements and
- Rigorous analysis of measurement results.

Geodetic instruments and equipments of maximum possible performances needs considerable investments which is not always possible and even not needed with proper combination of possibilities of classical geodetic technology.

Number of redundant measurements is limited by time available for measurement. Automated geodetic instruments, of course can provide more data per time unit.

Rigorous analysis of measurement results means that criteria for quality of geodetic networks (accuracy and reliability) must be applied and that quality of final results must be estimated.

3 CHARACTERISTICS OF GEODETIC NETWORKS FOR SPECIAL PURPOSES IN HYDRO ENERGETIC INDUSTRY

Geodetic networks for special purposes in hydroenergetic industry have further characteristics:

- Fixed points establishment is dependent on site conditions (points should be visible as much as possible and to be stable during the measurements process etc.);
- Points should be established in way to make the measurement process as efficient as possible i.e. they must fit the demands for values determination;
- After moving, it is almost impossible to establish points to the same position;
- Success of measurement is strongly dependent on geodesist's experience and ability to estimate if conditions and number of redundant measurements satisfy demands;
- It is almost impossible to make additional measurements after finishing measurements because the conditions on the site are changing rapidly and
- Final judgement about quality of measurement and searched values can be made a posteriori i.e. after data processing when it is usually too late to provide certain measurement again.

Fixed points of geodetic networks should be stabilized on tripods or on the other secure positions on adequate adapters. They should be good illuminated avoiding need for additional illumination during the measurement process. Also they should be affordable because it can increase efficiency of measurements. On the other side, these points should not impede the other processes, work security and they should be placed where they probably will not be damaged.

Fitting the points of geodetic network to searched values means that the points should be established on the positions which enable the determination of searched values.

Impossibility of establishing points on their positions after moving causes impossibility of checking measurement. Consequently, if measurements are not good they will be lost.

Geodesist’s experience is of big importance because some decisions must be done during the measurement process. Geodesist is to be able to estimate if measurements are on the adequate level of quality to provide needed quality of searched values.
Because of other processes proceeding simultaneously with geodetic measurements it is impossible to provide additional geodetic measurement. Those processes almost always change the measured elements out of time interval dedicated for geodetic measurements. Mentioned characteristics for special purposes in hydro energetic industry often cause that planning and realization of geodetic measurement must be done on the site. Consequently the available time must be used for collecting data of highest possible quality.

4 CASE STUDY: GEODETIC NETWORKS OF SPECIAL PURPOSES IN HYDROENERGETIC INDUSTRY ON HPPSS „DJERDAP 1“

Here, two geodetic networks used for geometry of aggregate on Hydro Power Plant and Shipping System (HPPSS) „Djerdap 1“ (Fig. 1) will be considered. Hydroelectric Power Plant and Shipping System was being built upon a Danube between Serbia and Romania and it is placed on the 942nd kilometer away from the Danube’s mouth at Black Sea. Electric power is producing in 12 aggregates – 6 on Serbian and Romanian side each. Aggregates are of 180 Mw power each and their dimensions are huge (diameters of some parts are greater than 16 m). The aggregates are 40 years in exploitation and they are in revitalization. In that process geodetic measurements are unavoidable whenever it is needed to determine dimensions of their parts and geometric relationships. Demands for accuracy are very high and they reach the maximum accuracy of geodetic methods in certain conditions.

The following approach was used:

- Automated total station with characteristics MPE = 0.5 mm for lengths less than 120 m and MPE=0“.5 for directions;
- Big number of redundant measurements and
- Detailed analysis of results was made.

Figure 1 Panoramic view on HPPSS „Djerdap 1“
4.1 ADJUSTMENT MODELS

Adjustment of geodetic networks was done using following least squares model (1), (2), (3), (4), (5):

\[ \mathbf{y} = \mathbf{A} \mathbf{x} + \mathbf{f} \]  
(1)

With conditions

\[ \mathbf{P} \mathbf{y} \mathbf{y} = \text{minimum} \]  
(2)

\[ \mathbf{x}^T \mathbf{x} = \text{minimum} \]  
(3)

Stochastic model is

\[ M(\epsilon_i) = 0 \]  
(4)

\[ M(\epsilon_i^2) = \sigma^2 \]  
(5)

These models were accepted because all points were considered as stable during the measurement process.

4.2 UPPER RING OF DIRECTING MECHANISM

Upper ring (Fig. 2) of directing mechanism for water flow in Kaplan’s turbines is one of the most critical parts for its proper functioning. Accurate determining of geometry of this element is necessary because it is affected by strong forces during exploitation and because it should be positioned into the other parts of Kaplan’s turbine and in certain position in space to allow turbine functioning at all. Tolerances for upper ring are quite small and they are 0.2 mm or smaller for some parts of it. It means that maximum of possible accuracy is needed for determining searched values. Having in mind that outer diameter of ring is 12.5 m and its constructive characteristics it makes geodetic task considerable difficult.

Searched values are: coordinates of 64 points placed on inner and outer surfaces of upper ring.

Figure 2 Upper ring of directing mechanism
Characteristics of geodetic network for upper ring (Fig. 3) are:

- four fixed points visible for inner and outer side of upper ring;
- from outer side of ring there were 8 points of geodetic network;
- from inner side of ring there were 3 points of geodetic network;
- directions were measured in two sets;
- distances were measured only between points of network;
- automated total station was used which allowed efficient measurements;
- measurements were lasting 10 hours without pause and done by one surveyor;
- total number of unknowns in adjustment was 166;
- minimal line of sights was 2.75 m, and maximum was 20.16 m;
- maximum semi-axes of error ellipses are: \( a=0.90 \) mm and \( b=0.32 \) mm;
- average semi-axes of error ellipses are: \( a=0.35 \) mm and \( b=0.13 \) mm;
- minimum semi-axes of error ellipses are: \( a=0.11 \) mm and \( b=0.06 \) mm;
- unit standard deviation from adjustment is \( \sigma_0 = 4.58 \);
- there were 309 directions and 92 distances measured and
- measurements were done in field and the weather was suitable for measurement.

4.3 STATOR AND SHAFT FLANGE

Geometric relationship between stator and shaft flange is of critical importance for water energy transformation to electric energy. These two parts of aggregate (Fig. 4) must be put in projected position very precisely (the tolerance is less than 1 mm) before the rotor of generator assembly because of complexity of that process and errors in that phase can affect the aggregate functioning very negatively. Inner diameter of stator is over 16 m and outer diameter of shaft flange is over 2 m.

Searched values: coordinates of points placed on the stator (36 in total) and coordinates of points placed on the shaft flange (25 in totals).
Characteristics of geodetic network (Fig. 5) for geometric relationship between stator and shaft flange determination are:

- three fixed points of geodetic network;
- directions were measured in two sets;
- distances were measured both to fixed points and to points on object;
- automated total station was used which allowed efficient measurements;
- measurements were lasting 9 hours without pause and done by one surveyor;
- total number of unknowns in adjustment was 144;
  - minimal line of sights was 2.10 m, and maximum was 13.36 m;
- maximum semi-axes of error ellipses are: $a=0.48$ mm and $b=0.22$ mm;
- average semi-axes of error ellipses are: $a=0.32$ mm and $b=0.15$ mm;
- minimum semi-axes of error ellipses are: $a=0.17$ mm and $b=0.10$ mm;
- unit standard deviation from adjustment is $\sigma_0 = 5.62$;
- there were 406 directions and 154 distances measured and
- measurements were done in closed area and under artificial illumination.
5 CONCLUSION

Geodetic networks in hydro energetic industry for dimensions and geometric relationships determination are realized under extremely high (in geodetic sense) demands for accuracy and in limited space conditions for its realization. Decisions must be done in the conditions of time deficit having in mind that accuracy must not be lost. It is shown in two examples that utilization of classical geodetic instruments can fulfill accuracy demands. That was proved by process of assembling and during the aggregate exploitation.

Acknowledgement

This paper was realized as a part of the project "Using GNSS and LIDAR technologies in infrastructure and terrain movement monitoring" (36009) financed by the Ministry of Education and Science of the Republic of Serbia within the framework of technology development research for the period 2011-2014.

REFERENCES

MIHAIOVIĆ, K. - ALEKSIĆ, I.R.: Deformation Analysis of Geodetic Networks Faculty of Civil engineering, University of Belgrade, Belgrade, 1994 (Deformaciona analiza geodetskih mreža, Građevinski fakultet Univerziteta u Beogradu, Beograd, 1994)


PEROVIĆ, G: Least Squares Method, Faculty of Civil engineering, University of Belgrade, Belgrade, 1994 (Metod najmanjih kvadrata, Građevinski fakultet, Univerzitet u Beogradu, 2005)

PEROVIĆ, G: Least squares, Faculty of civil engineering, University of Belgrade, 2005

CASPARY, W.F.: Concepts of network and deformation analysis, School of surveying, The University of New South Wales, Kensington, N.S.W., Australia, 1987