

3D MEASUREMENTS FOR DIMENSIONAL CONTROL OF A SHIP UNIT USING LEICA TDRA6000 LASER STATION TECHNOLOGY

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Abstract: *From international point of view, the improvements made to development of technologies implemented in metrological instruments such industrial total stations are, have made them to be preferred for dimensional control operations of construction elements from various industry sectors. This article aims to study and to experiment the possibilities offered by Leica TDRA6000 sensor in shipbuilding industrial area. The analysis of these possibilities was performed based on some 3D experimental determinations having as object of study an sub-assembly – block unit of a vessel – for which were performed 3D measurements to determine the actual coordinates of the characteristic points of the unit. Based on these measurements were drawn graphical and textual comparative reports between the designed and actual values, reports which are required within the quality assurance operations.*

Keywords: *Laser station, 3D measurements, shipbuilding, quality assurance*

1. Introduction

Taken in consideration that the modern shipbuilding companies consider, as a feasible solution, the concept of modular construction, which are now receiving the benefits associated with this method of construction, further improvements of productivity can be achieved if these modules are accurately realized by avoiding the excessive material that is usually cut during the mounting process.

The measurement and obtained results analysis tasks are two important steps within general activity of dimensional control. In order to obtain accurate and consistent results, standard procedures of dimensional control must be developed and customized for each stage of production.

These checking procedures is one of the most important part of the manufacturing process, and without it, further operations can be affected in terms of achieving quality construction works, production time and therefore the costs of manufacturing.

Dimensional control job typically includes five major phases, each of them including several sub-tasks which shall be performed:

A. Preplanning (in the office) which includes dimensional control goal setting, definition of measurement stages and of the design data which will be used (points of interest), specification of the reports form, planning the measurement procedures, planning the adjustment procedures for the instruments.

B. Measurement preparations (inside the office) that contains compiling of the measurement worksheets (files), extraction and downloading design data from the project, typically from point information from 3D CAD systems and transfer of the files (including the design data) to the measuring site, for example: upload design data to the instrument.

C. Measurement procedure (on shipyard) which includes system setup and instrument orientation of the Object Coordinate System, point measurements and data collection, quick measurement control based on Actual/Design measurement differences.

D. Dimensional Analysis (in the office) which contains download of the design/actual data from instrument to PC, numerical and graphical analysis of the measured *sub assembly*, creating dimensional control DC reports, saving and storing the design and actual data for future use.

E. Process Analysis (in the office) includes numerical and graphical analysis and assessments of the specific manufacturing processes, stages, object types or manufacturing lines, producing accuracy reports of the whole process, exploration of the possibilities in order to improve manufacture and design processes.

The various dimensional control tasks are performed based on measuring position of a point in a gaved 3D coordinate system. It is advantageous to use the Object Coordinate Systems (OCS) as the measurement system, so that the actual/design coordinate comparison can be real-time obtained.

The principle of the method is to bring the CAD data to the production site in order to compare the manufactured structure with the design values from the project. The differences between the measured actual data and the design data is obtained immediately during the construction process.

After the field stage, the actual and the design data will be processed with dimensional analysis software that illustrates the results both graphically and numerically.

The DCP – TDRA is a single sensor 3Dimensional Control and Analysis System for shipbuilding and similar industries. The system includes three components as following:

- LEICA TDRA6000 – a high accuracy industrial Laser Station as the measuring device;
- A.M.S. DCP05 – a powerful on-board dimensional control program installed into the Laser Station and used for the dimensional control tasks at the production site,
- A.M.S. DCP100 – a dimensional analysis program run on a PC and used to present the results graphically and numerically

2. Hardware description

Among the instruments that contain electronic measuring sensors can be reminded the tachometers and total stations which contains extremely precise modules for measuring distances. By replacing conventional prisms with sighting marks the reflective sheets, the points of the measured object can be marked directly and sustainable, which extends the system's field of usage.

A brief overview of this industrial measurement system is necessary to highlight the technical facilities and multiple possibilities for using in various fields: building vessels, aircraft, automotive constructions, robotics, etc.

Leica TDRA6000 Laser Station (figure 1) is a portable system for 3D checking measurements created to achieve accuracy measurements of extremely high structures and offers the following features:

- introduction and storage of all measurement data and information relating to measured objects;
- integrated checking and adjustment options, that can function during the measurements;
- computing functions;
- displaying and visualization of the coordinates of station point and target point;
- free station;

- calculation of the distances between two measured points;
- generation of a very precise reference line for aligning a machinery or its components under different given angles;
- generation a reference surface for determining flatness of parts or subassemblies;
- centralized quadruple compensation on 2-axis for correction of the position of the instrument axes;
- reticular wires system specially designed for use in industrial measurements;
- software package which allows the instrument orientation, conduct automatic measurements (motorized) and analysis measurement results;

With a laser spot, whose size does not exceed 0.25 mm at the 30 m distance, Leica TDRA6000 is the most accurate total station designed for industrial use. The standard accuracy for distance measurement is 0.6 mm+1 ppm and for vertical and horizontal angular measurement is 0.5 ".

Automatic target recognition module, with the positioning accuracy of ± 0.5 mm and the angular one of 1 ", enable the sensor to perform automated deformation studies and to track automatically a target which allows measurements by one person.



Fig. 1. Leica TDRA6000 Laser Station

The system operates on the principle of determining 3D coordinates through polar coordinates method and the reflective environment consists of Leica prisms or reflective tapes (figure 2).



Fig. 2. Leica prisms and reflective tapes

3. Software description

The dimensional control and analysis software products have been especially created to meet the requirements of the real-time dimensional control tasks, analysis, simulation and reporting in large scale assembly processes such as shipbuilding, steel construction and similar industries.

The onboard DCP05 has various measuring and control functions to process effectively the 3D coordinate measurements for on-line surveying of parts and assemblies and for guiding the building and assembling processes based on comparison of design and measured actual 3D data.

The DCP05 field software include special measuring functions such is that to measure the 3D coordinate values of a hidden point with using a hidden point bar. The X or Y or Z function is advantageous, when measuring points of which only one or two coordinates values are important e.g. points laying on the edge of a thin plate.

The stake-out function combined with the pointing red laser allows to locate and to visualize 3D points of the object for building and inspection of manufacturing parts. Additionally, the circle measurement and analysis and the 3D-Front-Back point pair measurement with their support on 3D-file brings new aspects in effective use of total stations in large-scale assembly.

The DCP05 software contains calculation features for real-time dimensional analysis. The position of a measured point can be compared to any other measured point, reference line or plane. The references are calculated from the set of measured points defined by the operator.

It is important to know that the 3D measurement instruments (total stations, 3D-sensors, etc.) are primarily measuring in their own coordinate system called sensor coordinate system. Therefore, in real-time measurements there is the ultimate need to have different procedures to align the 3D measurements from sensor coordinate system to the object coordinate system.

4. Procedure and principle of coordinates measurement

4.1. Principle of 3D Point Measurement in Sensor Coordinate System

The location of a target point of an object is measured using the polar coordinates method. The coordinate of the points are calculated using three measured elements: horizontal angles, vertical angles and slope distances (figure 3).

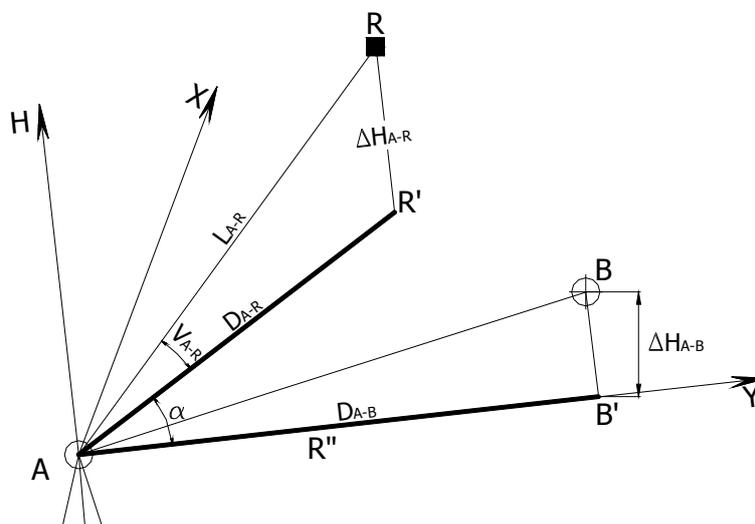


Fig. 3. Measurement principle used to determine coordinates through polar method

The system coordinate origin is located on point A, the OY axis is located among the direction of the reference point B and the measured elements are:

- Horizontal angle α
- Slope distance L_{A-R}
- Vertical angle V_{A-R}

Principle of a method consists in measuring from point A contained on the support edge AB, of the horizontal angle α and slope distance L_{A-R} to the point P, whose we will determine the 2D rectangular coordinates based on the known coordinates of point A and field measured elements:

$$\begin{cases} \theta_{A-R} = \theta_{A-B} - \alpha \\ D_{A-R} = L_{A-R} \cdot \cos V_{A-R} \end{cases}$$

- in the XAY rectangular system, generated by the reference AB:

$$\begin{cases} X_R = X_A + D_{A-R} \cdot \cos \theta_{A-R} \\ Y_R = Y_A + D_{A-R} \cdot \sin \theta_{A-R} \end{cases}$$

- in the three-dimensional system generated by the coordinates and height of the point A which is the origin of this system:

$$H_R = H_A + D_{A-R} \cdot \operatorname{tg} V_{A-R}$$

The results are calculated and shown in a Cartesian coordinate system (X, Y, H) called Sensor Coordinate System (SCS). The origin of SCS (figure 5) is located in the center of the sensor at the intersecting point of the optical axis (line of sight), vertical axis (H-axis) and tilting axis.

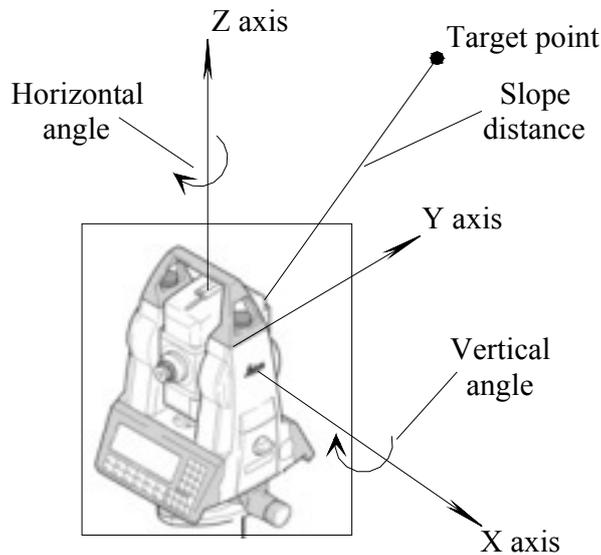


Fig. 5. The origin of sensor coordinates system

4.2. The Object Coordinate System

The object coordinate system (figure 6) is a 3D coordinate system, in which the object geometry is represented. The object is typically designed in a CAD environment offering the design 3D coordinate values in object coordinate system.

Two different methods provide the orientation of the sensor to the object coordinate system, so that the measurement results are represented in the same system, providing real-time actual/design comparison of the results.

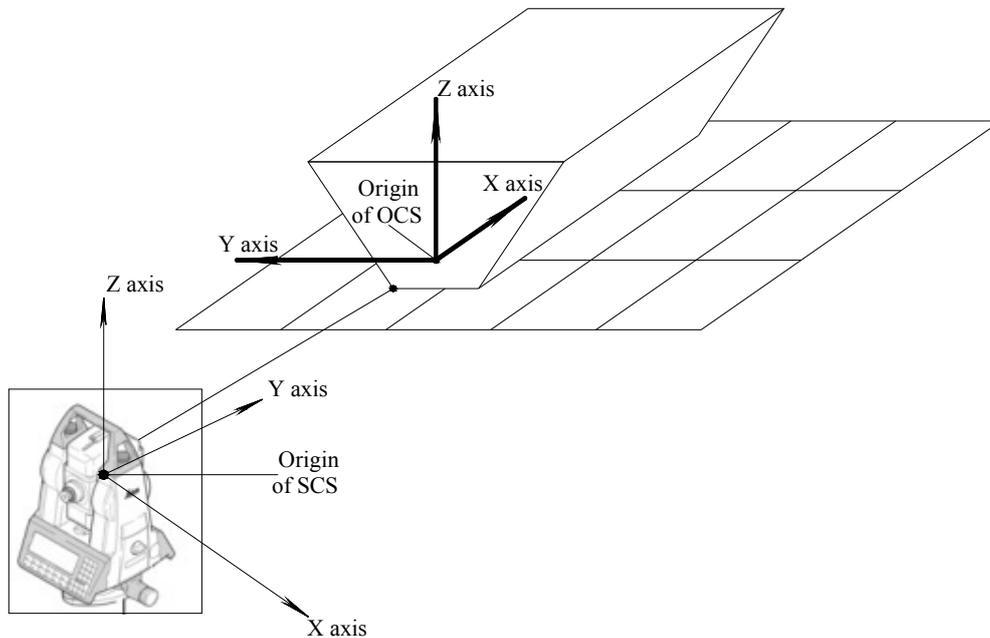


Fig. 6. The object coordinates system and the relation with the sensor one

4.3. Direct Orientation Method

The method is based on defining the direction of the axis of the object coordinate system and is realized in three steps:

1. *Defining a reference plane* - The reference plane can be selected to be (X,Y), (X,Z) or (Y,Z). The selected plane is specified at least by three points which will be measured in sensor coordinate system. The described points will define the positive direction of the plane (normal) or parallel to the horizontal plane, for ex. the normal is along the Z axis (figure 7).

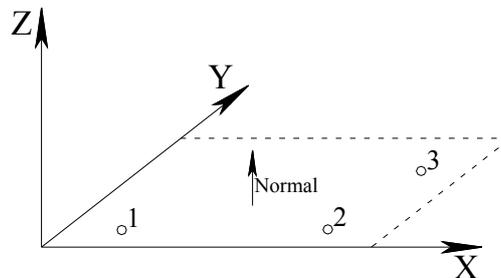


Fig. 7. Defining a reference plane

2. *Defining a reference line* - After the direction of the plane has been defined, the direction of the corresponding axis on the plane is selected and defined. Suppose that (X, Y) plane is selected and defined. Therefore, select and define the direction of X or Y axis (figure 8). Measuring at least two reference points on the axis in sensor coordinate system does the axis definition. The positive direction is from the first to second point.

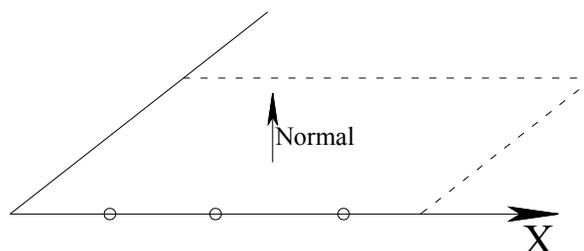


Fig. 8. Defining a reference line

3. *Defining a specific point of the object* - After the direction of the axis of the OCS has been established, we can select and define the specific point with an offset or not. The values of the specific point are given in the object coordinate system for x, y, z and it is measured in sensor coordinate system respectively. The value in object coordinate system may equal (0,0,0) or whatever is necessary (figure 9).

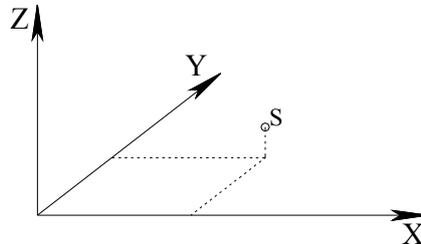


Fig. 9. Defining a specific point of the object

5. Case study

As a case study, there were realized measurement for one of the subassembly of a marine barge which was under construction at Damen Shipyard in Galati using Leica TDRA 6000 Laser Station and DCP100 office software in order to perform data processing and report over the studied subassembly.

Before performing measurements, the design values of the coordinates of desired points P1,....P14 (Table 1) were uploaded in the instrument.

Table 1. Design values of the coordinates of the point of interest

Point no.	Design coordinates in object coordinate system		
	X (mm)	Y (mm)	Z (mm)
P1	-1128.0	7745.0	9905.0
P2	-1128.0	-7745.0	9905.0
P3	-828.0	-7980.0	7305.0
P4	-828.0	7980.0	7305.0
P5	-1128.0	0.0	9905.0
P6	9300.0	7745.0	9905.0
P7	9300.0	-7745.0	9905.0
P8	9300.0	-7995.0	7305.0
P9	9300.0	7995.0	7305.0
P10	9300.0	0.0	9905.0
P11	9300.0	-3342.0	9905.0
P12	9300.0	3342.0	9905.0
P13	9000.0	-3342.0	7305.0
P14	9000.0	3342.0	7305.0

After the measurements were performed we obtained the actual values of the coordinates of points of interest (Table 2) to these points in order to obtain.

The deviations of the points were obtained by comparing the actual values of the coordinates with the measured values of the points, after which an report with all data was created and also the a CAD drawing (figure 10) in order to highlight the deviations betwin actual/design values of the points.

Table 2. Actual values of the coordinates of the point of interest

Point no.	Actual coordinates in object coordinate system		
	X (mm)	Y (mm)	Z (mm)
P1	-1136.0	7701.2	9882.1
P2	-1149.3	-7694.7	9895.2
P3	-808.5	-7964.0	7317.3
P4	-741.9	7975.4	7286.8
P5	-1132.5	-1.3	9887.2
P6	9334.4	7725.3	9890.0
P7	9330.5	-7761.4	9846.9
P8	9310.4	-8008.6	7287.5
P9	9348.8	7992.2	7324.8
P10	9303.4	-40.9	9828.7
P11	9334.5	-3344.8	9860.4
P12	9352.5	3331.9	9879.1
P13	8997.4	-3352.7	7240.7
P14	8998.0	3348.6	7234.0

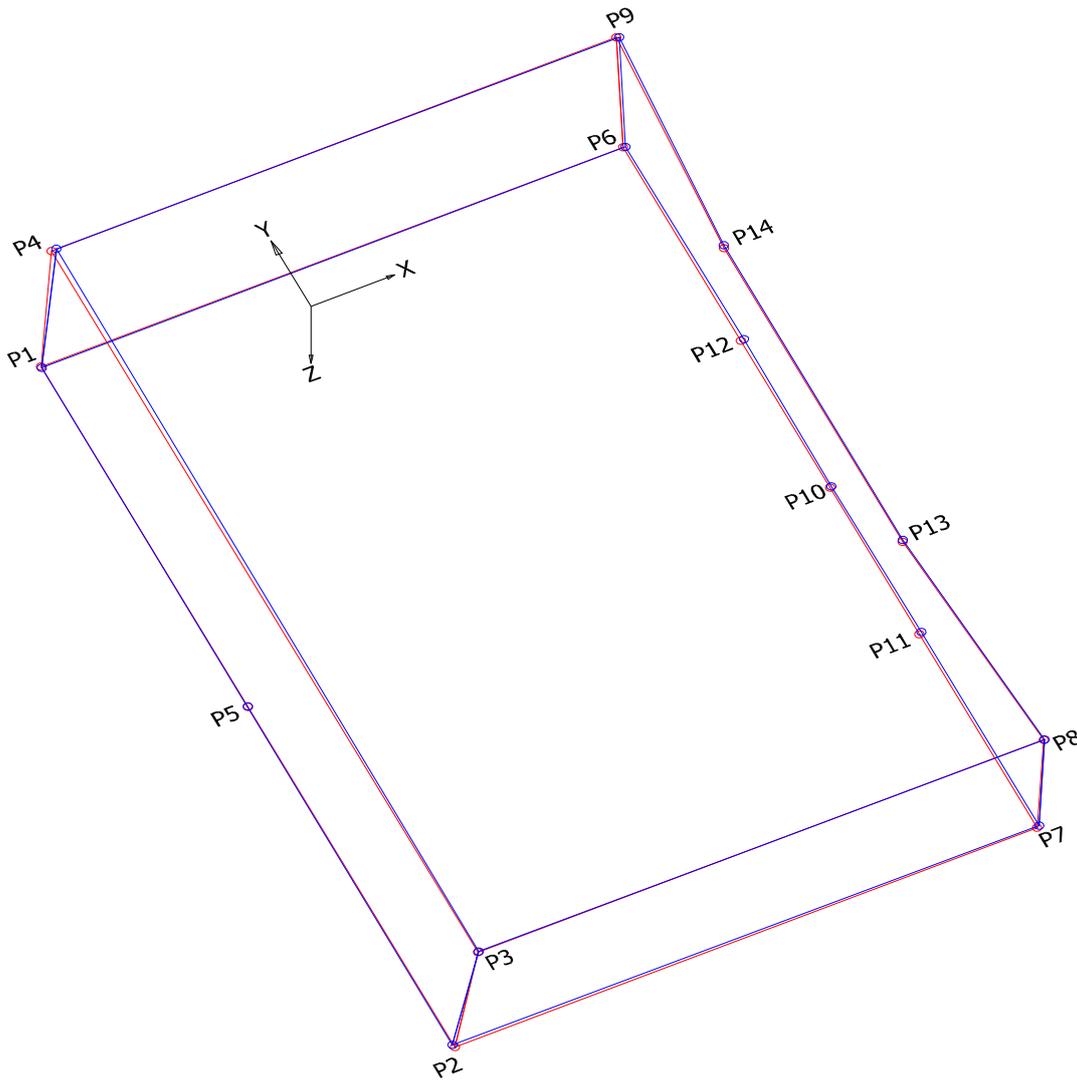


Fig. 10. Drawing report for measured section

The differences between actual/design coordinate were calculated using DCP 100 software, owned by Accuracy Measurement Systems LTD and in table 3 it was intended to emphasize the points deviations by comparing the measured values with those from the project, as well to be used within the quality control of the subassembly manufacturing process, as well for the purpose of precise integration within the entire ensemble of the vessel.

Based on the dX, dY and dZ deviation can be calculated the root mean square errors (RMSE) for each point (Table 3) which is defined as the distance between design values and the actual values of the coordinates:

$$RMSE_n = \sqrt{dX_n^2 + dY_n^2 + dZ_n^2}$$

After the calculation of each RMSE error, it will be calculated the total RMS error (Table 3) using the following formula:

$$RMS_T = \sqrt{\sum_1^n \frac{RMSE}{n}}$$

Table 3 The deviation between actual/design coordinates

No.	P ID	Actual – Design			RMSE
		dX	dY	dZ	

1	P1	-8.0	-43.8	-22.9	50.07
2	P2	-21.3	50.3	-9.8	55.50
3	P3	19.5	16.0	12.3	28.06
4	P4	86.1	-4.6	-18.2	88.12
5	P5	-4.5	-1.3	-17.8	18.41
6	P6	34.4	-19.7	-15.0	42.38
7	P7	30.5	-16.4	-58.1	67.64
8	P8	10.4	-13.6	-17.5	24.48
9	P9	48.8	-2.8	19.8	52.74
10	P10	3.4	-40.9	-76.3	86.64
11	P11	34.5	-2.8	-44.6	56.46
12	P12	52.5	-10.1	-25.9	59.41
13	P13	-2.6	-10.7	-64.3	65.24
14	P14	-2.0	6.6	-71.0	71.33
RMS _T		7.39 mm			

6. Conclusions

This paper aimed to describe work methodology and the possibilities offered by used technology, evidenced by a case study whose object was a subassembly of an industrial construction - unit of a vessel. Regarding the advantages of using a TDRA6000-DCP100 type system can be mentioned:

- The accuracy offered by the instrument is one of the best and is suitable for the control work performed in shipbuilding industry if taking into account the quality control requirements imposed for this domain;
- RMSE errors, calculated by using Euclidean distances between actual and designed values of the coordinates obtained in this study, fits within the range that has as a minimum of 18.41 mm and 88.12 mm as a maximum. Total RMS error is equal with 7.39 mm and express the value of the precision of construction works performed for the ship unit;
- The degree of automation of the system allows the user to perform in a significantly reduced time (compared to other methods and technologies) the inspection and verification measurements in a "one-man show" process. Furthermore, some benefits of using the system that can be mention is real-time visualization of results, automatic storage of data along with performing measurement operation, etc.
- The DCP100 program provides methods to prepare a large variety of dimensional control reports. On one hand brief reports are available for internal use and on the other hand complete reports can be prepared to meet the requirements of the customers and quality audits.

The author proposes in a future study to highlight the mathematical algorithm of transformation of the sensor coordinate system to the object coordinate system, used by the laser station field software and a comparative study of methods and precision provided by TDRA600 laser station and Scanstation2 laser scanner

7. References

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