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Productive Method and System to  
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# Productive Method and System to Control Dimensional Uncertainties at Final Assembling Stages in Ship Production

VIIIB-2

Markku Manninen, Visitor, Prometrics Ltd., Finland and Jarl Jaatinen, Visitor, Optec-International, Ltd., Finland

## ABSTRACT

Strict dimensional control of interim products through the different assembly stages is vitally important profitable ship production (1). Studies made in Finland show that a 30% reduction in labour costs is possible in hull construction (2). This reduction can be gained by eliminating unnecessary fitting and reworking using tight accuracy control methods.

Although accuracy control of the prefabrication stages is important because it forms the basis for the hull production, the dimensional control of the block assembling stages is essential if major improvements in productivity are to be achieved.

Fig.1 explains the situation. The figures for the diagram were collected from measurement experiments carried out at major Western shipyards during the years 1989-91. Usually the accuracy level of the production is reasonable at the first stages, but the inaccuracies increase rapidly and most nonlinearly as a function of the complexity of the interim products. This means that the assembling methods have a strong influence on the dimensional uncertainties of the interim products (blocks) at the final assembly stages. At the same time the labour costs in these final stages are very high. Thus notable productivity improvements can be gained by implementing progressive assembling methods and dimensional control systems at these final assembly stages.

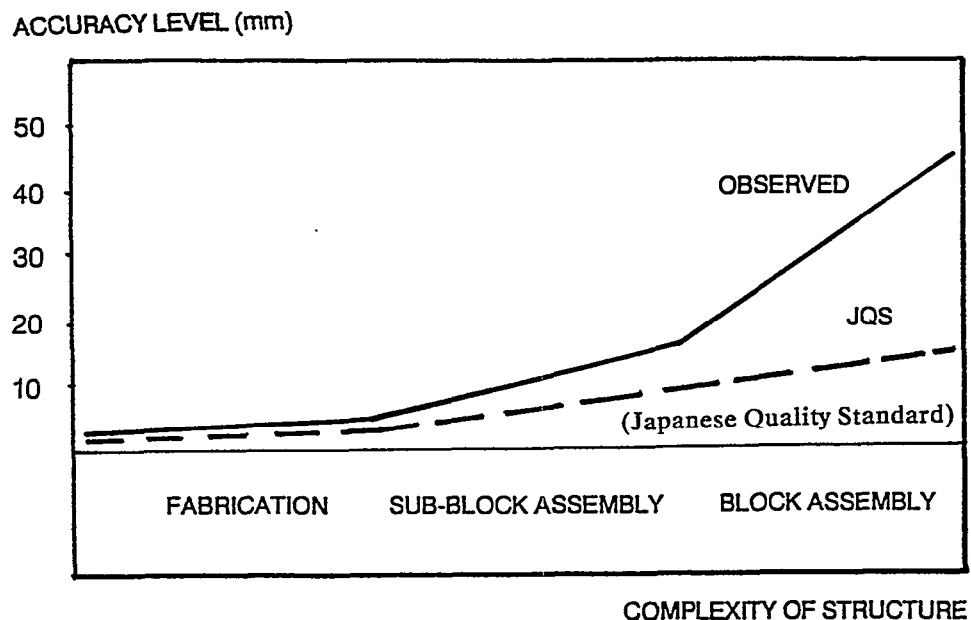


FIGURE 1

One key problem is how to effectively organize the dimensional control of the production of large shipblocks. A modern approach is to use three dimensional (3D) coordinate measurement systems (3). Although these new systems provide excellent means of taking measurements, there remains a problem of applying the systems in a way that allows a straightforward interpretation of the results. The resulting interpretation should be applicable to different purposes. One objective is to meet the need of fast real time measurements on site; another is the monitoring of dimensional accuracies of different assembly stages as well as the use of the collected measurement data to improve the design and production methods.

This paper presents a method for dimensional control of block assemblies. The dimensional control is thereby separated from the positional control of the block. The method is a 3D-coordinate based approach relative to a positional reference system. Also described is a real dimensional control case and an evaluation of different measurement technologies in performing the proposed task. The evaluation is made comparable to a system study performed at the National Steel and Shipbuilding Co. (NASSCO) Shipyard, San Diego, USA during

## METHOD

### Problem Statement

A major problem related to profitable ship production is manufacturing of shipblocks of optimal accuracy. A key factor therefore, at major yards with proper control of the part production process, is to minimize rework at the hull erection stage.

The hull is normally assembled relative to a reference system. The reference system is based on a defined lane and on a line on this plane. The line is called center line (C.L.) and the plane is the bottom plane, on which the frame lines (F.L.) usually are named bottom lines (B.L.). This reference system is sketched in Fig.2. The basic plane and the line define a Cartesian coordinate system as shown in the figure. The axes of this coordinate system are: x-axis along the C.L., y-axis parallel to the frame lines, and z-axis defining the height from the bottom plane. We call this reference system a positional reference system. The same coordinate system is used when designing a ship. Because Computer Aided Design (CAD) systems are adapted to modern ship design in a continuously growing number, the use of coordinates play a vital role in controlling the manufacturing processes.

Two critical manufacturing problems can be distinguished at the final hull assembly stage. The first is a dimensional problem: the dimensions of the blocks will deviate from their nominal measures making the erection work tedious. The second is a positional problem: due to the dimensional uncertainties, the correct positions of the blocks are hard to define. Thus a block might have accurate dimensions, but be incorrectly positioned, or alternatively a block might be in correct position but have accurate dimensions. Often these problems are overlapping in the sense that a block might have both dimensional errors and be incorrectly positioned.

In practice the joining of blocks is done relative to the bottom plane and C.L. as mentioned above. However, when large dimensional deviations are encountered and the constrictions of the ship boundaries are considered, some compromise must be made regarding the positioning of the block.

### Basic Definitions

When manufacturing blocks for the erection stage (these definitions can also be used for other assembly stages), two control tasks can be defined:

- 1) Dimensional control, meaning to control the dimensions and the shape of the block relative to the positional reference system defined (Fig.2) and
- 2) Positional control, meaning to control the position and the orientation of a block relative to the reference system defined.

### Objectives

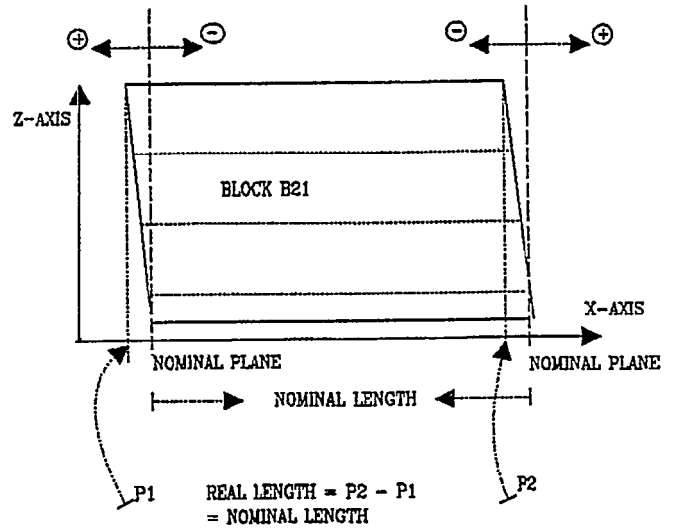
The method described herein focuses on producing ship blocks with optimal accuracy and minimizing rework in the erection stages. Thus three basic goals are considered:

- 1) The method should provide dimensional data relative to the block (not to the position of the block) making possible later analysis development manufacturing processes;
- 2) The erection and joining of the blocks should be done strictly to the positional reference (hull design coordinate) system;
- 3) All marked (vital) points on the block should be dimensional reference points of the block, or directly related to specific assembling methods or equipment of the prefabricating stages.

Description of the Method

The control method concentrates on the final assembly stages, but is also applied to earlier stages of production.

Dimensional Control. The dimensional reference system, shown in Fig.2, is used to express the exact position of a point on a block. When a position of a block is defined, then correspondingly the position of each point on that block is defined relative to the same reference system.



P1: POSITION ON X-AXIS (-SIGN COMPARED TO NOMINAL POSITION)

P2: POSITION ON X-AXIS (-SIGN COMPARED TO NOMINAL POSITION)

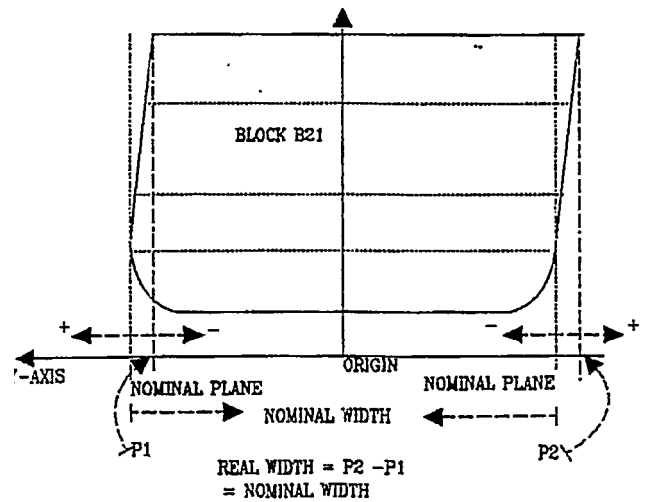
**FIGURE 3**

When dealing with the width of a ship the situation is similar as shown in Fig.4, where the same block is sketched on the y,z-plane. Once again the projection of point P1 shows a negative value, indicating shortage of material, and P2 a positive value? indicating excess material of the top deck, while the actual y-dimension of the deck is correct. Also in this case, when controlling the y-dimension, a “+” sign is defined to mean deviation outwards from the block and a “-” sign inward to the block.

**FIGURE 2**

When dealing with coordinate systems however, the above method might cause some confusion. For example, a block is sketched on the z,x-plane in Fig.3. If the shape of the block is distorted as shown in the figure, then the projections of points P1 and P2 (top deck) on the x-axis, are negative compared to their nominal values on the x-axis. This gives an impression of having shortage of material while the actual x-dimension (length) of the deck is correct.

This confusion can be circumvented by separating the x-dimension of the block from the position of the point defining the dimension. Thus in dimensional control the deviation from the nominal value is useful to define. Therefore a “+” sign is used when the deviation is outwards from the block and a “-” sign when the deviation is inward to the block, according to Fig.3.



P1: POSITION ON Y-AXIS (-SIGN COMPARED TO NOMINAL POSITION)

**FIGURE 4**

Correspondingly, the control of the z-dimension (the height) of the block is defined in the same way as the control of the x- and y-dimensions (length and width). Thus in dimensional control the signs of the block deviations from the nominal values are chosen as follows:

- " + " sign means that the deviation is outwards from the block
- " - " sign means that the deviation is inwards to the block

Positional control. In positional control the signs of the deviations are absolutely defined by the reference system and thus the position of each specific point in the construction space is uniquely defined by its 3D-coordinate value.

### Establishing a Permanent Vital Point System

From a practical point of view, a reference point system is needed to implement the dimensional and the positional control method. This means that in each work piece there are defined points, called vital points which are used for taking control measurements. The points should be defined and marked so that they can be used for continuous dimensional and positional control. This means repetitive measurements are taken using the same points throughout the different assembly stages. These vital points should be marked permanently on each work piece at sub-assembly stages.

The vital points are defined and the nominal coordinate values of these points extracted from the design (CAD) system at the detailed design phase. Thus each steel structure has vital points preassigned at each assembly stage. It is essential to select the points in the way that the location of the point describes the dimensional performance of the particular assembly stage. Vital points can be grouped into three main categories:

- 1) Points which define the geometry of the block through all assembling and block transport stages (stiff points);
- 2) Points that assist in the later analysis of parts and sub-assembly accuracies and directly relate to production equipment and methods;
- 3) Points attached at specific assembly stages to assist the production team in block erection work and in dimensional measurement tasks.

### The Importance of Collection of Dimensional Data

The collecting of dimensional data in a way defined above is vitally important when monitoring and developing manufacturing processes. Monitoring of accuracy levels of different assembly stages is based on the statistical analysis of dimensional variations of work pieces. To accomplish this, production standards for each type of assembly must be devised, sub-assemblies and blocks classified, and relevant production equipment and methods related to these classifications used. The monitoring is then done relative to well established accuracy limit values.

Of major importance in collecting the dimensional data is the development of assembly methods based on the trends in an accuracy data base. In the long run, this will lead to essential improvements in productivity (1).

### Requirements for Control Systems

This dimensional control method is meant to be implemented using modern measurement and computer facilities. Several requirements for these kind of systems and their operation can be made:

- 1) The measurement technology should provide instant and efficient (on-line) coordinate measurement execution;
- 2) The control system should have a direct link to the yard's design system, enabling transfer of data between the control and the design systems;
- 3) The collection of the real measurement data should be organized so that future reference to the data bank is straightforward, making dimensional monitoring and analysis easy to perform.

The goal of such a system should be on-line "measuring to marks" by the production team which then uses the dimensional information for instant corrective decisions. The team can also perform post-analysis of the accuracy situation for fast feedback to the planning department for devising production improvements.

## DIMENSIONAL CONTROL OF A BLOCK ENTERING ERECTION

### Description of the Case

As pointed out, the dimensional control of blocks relative to the reference system (Fig:2) is vitally important in to eliminate unnecessary reworking when positioning the block correctly and joining two locks together, especially at the final assembly stages.

To illustrate the selection of vital points on a large structure, a drawing used for accuracy control purposes is shown in Fig.5 below. The structure is part of a twin hull 350 passenger luxury cruiser being built at the Rauma Yard, Finland.

Typical dimensions of blocks for larger vessles are height 10 (30), width 20 (60) and length 22 m (67 ft). The number of vital points on one end of block is ca 25 and the total for a symmetrical block is thus 50 points.

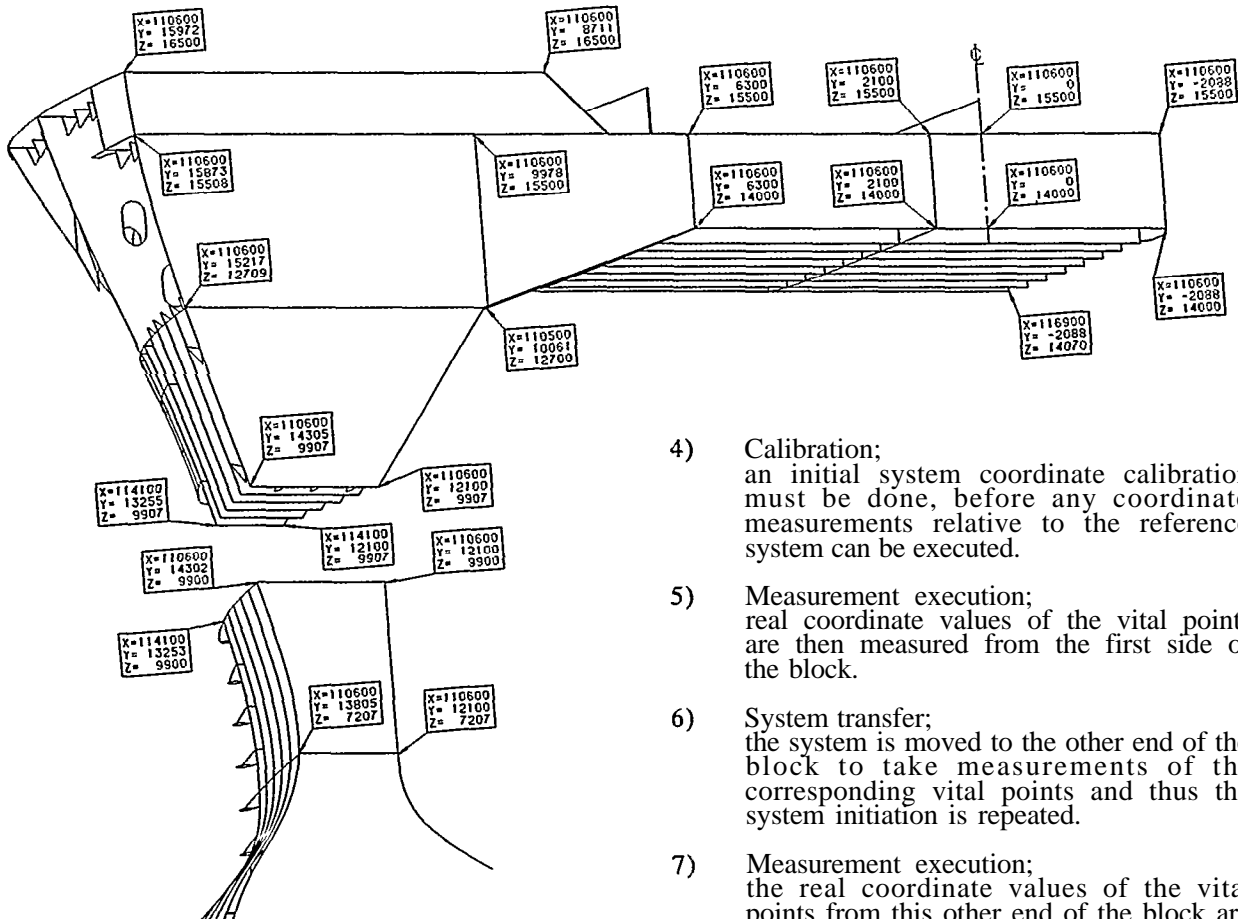


FIGURE 5

### Measurement Tasks

The dimensional control of a block described above includes several tasks.

- 1) Planning the measurement; defining points to be measured, extracting the nominal coordinate values of the points, making a measurement sketch of the block, showing the locations of the measurement points, transferring the nominal and design data to the measurement and control system.
- 2) Setting up the measurement system; bringing the system on site and performing the system initiation.
- 3) Marking of the target (vital points); it is supposed that most of the vital points are permanently marked. Normally some additional points must be marked just before measurement execution.
- 4) Calibration; an initial system coordinate calibration must be done, before any coordinate measurements relative to the reference system can be executed.
- 5) Measurement execution; real coordinate values of the vital points are then measured from the first side of the block.
- 6) System transfer; the system is moved to the other end of the block to take measurements of the corresponding vital points and thus the system initiation is repeated.
- 7) Measurement execution; the real coordinate values of the vital points from this other end of the block are measured.
- 8) Recording the measurement results; the measurement results (the dimensional data) are transferred to a database installed in a PC-computer.

## Control and Measurement System Evaluation

The suitability of different types of measuring systems related to control software systems to perform the dimensional control task described above can be evaluated on the basis of tests carried out at NASSCO (4).

Table I shows the total costs of performing dimensional control tasks with different type of measuring systems. The figures in the table are extracted from the original report of the field tests at NASSCO. The comparable costs figures of total station type surveying instruments have been added to the table and are based on work done in a major Finnish yard (5).

The results in the summary table show that of different kind of systems, the single man operated Acmeter MC-type optical coordinate meter, which allows direct measurement of the vital points of the block, is most effective in the measurement execution to form a basis for productive dimensional control systems for the final and critical assembly phases in ship production.

The Acmeter MC is the measuring tool of the Acman system, originally developed in close collaboration with major Finnish shipyards to enable building of integrated management systems. The Acmeter has thereby to meet stringent design goals required by the industry:

- 1) Accuracy within one millimetre (0.4");
- 2) Measuring direct to the surface or alternatively to fixed tapes;
- 3) System operated by one single man with real-time coordinate display;
- 4) Software attachments to the CAD and production processes.

The Acman system integration is facilitated by the Accad graphical interface and Abase relational data base programs. Descriptions of different coordinate measuring systems and of their measuring properties are included in references (3) and (4)

### **SUMMARY TABLE**

#### **BLOCK MEASUREMENT- EVALUATION; TASK EXECUTION TIME AND OPERATING COSTS OF FOUR DIFFERENT SYSTEMS**

TASK	ACM/MC	TOT.ST*)	DIG.THEO*)	PH.GRAM
1. SYSTEM SET-UP	8	12	25	15
2. MARRING TARGET POINTS	30		30	30
3. CALIBRATION	6	10	10	
4. MEASUREMENT EXECUTION	25	85	110	30
5. TRANSFER	6	8	15	15
6. CALIBRATION	6	10	10	
7. RECORDING OF RESULTS	5	5		
8. OTHER WORK				130
TOTAL EXECUTION TIME (MIN)	86	2x130 260	2x200 400	255
<hr/>				
TOTAL COST(505/60MIN)	72	217	333	213
COST PER POINT(S)	1.4	3.6	5.6	3.6
CAPACITY (POINTS/60MIN)	35	23	15	24

ACM/MC - ACMETER MC,

TOT.ST = TOTAL STATION-type surveying instrument (e.g. Nikon DTM-A5/A10/A20, Wild TACHYMAT TC1000-TC1600),

DIG. THEO = DIGITAL THEODOLITES (e.g. ECDS, Wild Leica),

PH.GRAM - PHOTOGRAMMETRY.

\*) THESE SYSTEMS NEED TWO MEN TO TAKE MEASUREMENTS.

**TABLE I**

## CONCLUSION

In this report the importance of dimensional control of large block assemblies is emphasized based on discussions, consulting and measurement experiments carried out at more than 20 Western shipyards. The dimensional control is separated from the positional control of the blocks. These two control Problems are, however, overlapping in practical-measurement cases. It is therefore essential to use control methods able to distinguish logically these two different problems.

A dimensional control method relative to a positional reference system is proposed. The method points out the need of real time dimensional control as well as the collecting of measured dimensional data for monitoring and analysing the performance of manufacturing stages. A vital point system, where the target points are marked permanently on the work pieces, is essential when implementing the described control method.

A real dimensional control case of a cruise vessel is shown and measurement tasks listed. The effectiveness of different measurement systems representing various technological approaches are then evaluated in executing the proposed dimensional control problem. The evaluation is based on field experiments done at a number of major West European yards and at NASSCO in USA (4).

Based on the references given and on the requirements of the accuracy control method proposed here, the measurement technology represented by ACMETER MC-type equipment is the most cost effective method of performing the dimensional control task and as an on-site building and inspection tool during all phases of hull block construction. Thus the equipment combined with the methods described here form a good basis for implementation of productive integrated dimensional control systems to meet the accuracy management needs of profitable shipbuilding practices today.

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## FIGURES

- 1 The observed accuracy level of the interim product as a function of product complexity. The accuracy level proposed by J.Q.S can be regarded as a reference.
- 2 The positional reference system typically used in ship production when assembling and designing the hull.
- 3 A sketch of a distorted block on the x,z plane. The location of the top deck is negative compared to the nominal position while the x-dimension (length) of the deck is correct.
- 4 A sketch of a distorted block on y,z-plane. The location of the top deck negative compared to the nominal location while the y-dimension (width) of the block is correct.
- 5 Drawing of a cruise vessel block indicating the vital points permanently located on the work piece.

## TABLE

- 1 Summary table. Block measurement evaluation, task execution time and operating costs of four different systems.

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