A method for the accurate manufacturing of large welded steel constructions in shipbuilding

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A considerable increase in the quality level and, at the same time, less costs in production and assembly in shipbuilding can only be expected if systematic solutions are put on a scientific basis and realised consequently. The main components of this method of approach are quality management, system of tolerances, system of values of expected shrinkage and system of accurate fit-up marking. A method for sections of the parallel midship area will be introduced, the practicability of which has been proved in practice.

1 Introduction

The elements of the ship’s body (individual parts, subassemblies, plane and curved flat sections, volume and block sections) are bar- or plate-shaped parts or stiffened constructions with extremely large length-thickness or breadth-thickness relations. Under the influence of technological infringements with local heat input (cutting, joining, straightening) and considerable mechanical energy (bending, assembling), that often occur in combination, significant undesirable and, unluckily, unavoidable geometry deviations of the subassemblies and sections are caused, which make assembly more complicated or even impossible without adjusting works. Japanese studies show that assembly and welding works in steel ship building make up a very big share of the total fitting man-hours /1/, while a significant time for adjusting works has to be accepted /2/. These relations, shown in figure 1, make clear the lack of research in this field on one hand, on the other hand a reserve of productivity that has not been tapped yet. The very complex and normally stochastic effect of quite a number of technological factors makes a scientific approach to this problem extremely difficult and was the reason for the still practised philosophy of assembly with excess and non-welded stiffeners at the ends. The excess for assembly, that can be interpreted as "deficit reserve", is an overdimensioning on the assembly edges that allows an easy fitting to the assembly
partner even in the case of major deviations in shape and measurement. Another reason for this procedure was the underdeveloped technology for length measuring, because an immediate short-term registration of relevant geometric data without disturbing the production and assembly process but with sufficient accuracy for practical purposes was impossible.

"... Substantial fitting work accounts for only 20% of total fitting man-hours, and most of the rest is wasted on adjusting procedures due mainly to the inaccuracy of the hull blocks."

Figure 1: Account of adjusting works of total fitting man-hours in shipbuilding

The worldwide dramatically increasing competition turned out to be a conclusive driving force for process innovation in shipbuilding which, especially in Europe but increasingly also in Japan, is used as compensation for disadvantages in production costs. The great changes in production processes one could see during the past decade led to a thorough process optimising, reengineering and restructuring. A quality of production and assembly that at the beginning of this development still seemed to be sufficient and tolerable will become more and more a first-rate hindering factor.

2 Approaches to the introduction of accurate manufacturing in shipbuilding

With establishing modern production methods (CNC-marking, cutting and welding robot technology), the development of production measurement instrumentation and consistent introduction of CAD systems, decisive precondi-
tions for a vigorous improvement of production accuracy were created. Deeper knowledge of the deformation behaviour of stiffened constructions under heat influence widened this basis later on.

The first approach started from the tolerance supported quality control, practised successfully in machine building. This inductive procedure is called BOTTOM-UP METHOD. It culminates in the determination of production tolerances on the basis of an elaborate analysis of the given production situation and determined evaluation of appropriate experience.

The sum of all single geometry deviations gives the difference between actual and intended shape of the product which, under the aspect of assembly, has to be within the tolerance defined in advance. Else manual fitting-up has to be done.

Experiences with automated production systems like the Japanese ROTAS system showed that - even with an algorithmised and sensor-supported production control - measurement deviations of the bloc sections are in the range of ± 5 mm, in which the mean variation - starting from ± 2 mm with subassemblies (unstiffened plate fields and stiffening elements) - experience a mean increase of ± 1 mm per further technological operation /3/.

The success of this approach in practice demands a consistent production-accompanying quality control and - facing the strict "no-trash rule" in shipbuilding - if need be, choice of suitable assembly partners or even rework. Expenditures like this can seldom be accepted from an economic point of view and could lead into a dead end, which even could end in the traditional method of excess and non-welded stiffeners. On the other hand, it could smooth the way for the introduction of the alternative variant if coupled with vigorous evaluation and condensing of the incurring measurement data.

This alternative is offered by the second approach, known as TOP - DOWN METHOD (deductive procedure). Independent on the actual measures of the product, a state in which it can be assembled has to be defined. The above mentioned mean variations can be used as a first reference point. Using the measure-chain theory and statistics, the tolerance of the final product will be projected by recomputing to its elements and the individual part. Thus production tolerances are derived, and, if they are obeyed, complete or at least probable exchangeability will be reached.

Due to this, tolerance system and production accompanying quality management get a new dimension - they are no longer evidence of tolerance excess with trash as a consequence but promote the continuous improvement of product quality. The high measurement requirements needed in the beginning can be reduced noticeably the better the approach is handled, and in the end narrowed to samples.

Both approaches are shown in figure 2.

3 Features of accurate manufacturing

The first as well as the second approach assume certain conditions and premises, that have much in common. Both have three main features:
- quantification of the required quality by a tolerance system
- definition of a system of values of expected shrinkage
- determination of a system of accurate fit-up marking for positioning and geometry controlling based on reconstructable intern marks of the element

Figure 2: Approaches to the definition of production tolerances.

The features of accurate manufacturing are represented in figure 3 and will hereunder shortly be discussed. Accurate manufacturing is to be understood as the strict elimination of excess and non-welded stiffeners at the mounting edges of the subassemblies and sections.

The following considerations mainly refer to sections of the midship area and are partly restricted to the double bottom. This restriction results from the effort to show more general principles and, at the same time, to point out more concrete findings and results that, as a whole, represent a new method.
The experiences made in German shipbuilding have shown several times that the introduction of accurate manufacturing according to the TOP-DOWN approach is a long-lasting iteration process. First this process must cover the plane sections followed by the volume sections with mainly one-axial slightly bent outside surfaces, and finally the fore and after body.

3.1 The tolerance system

The settlement of the production tolerances according to the TOP-DOWN approach can be done on the basis of functional, geometric and technological characteristics of the hull sections to be built. More detailed examination showed that this process can be expressed in an algorithm. In figure 4 this is shown with a double bottom as an example.
Figure 4: Algorithm for the definition of production tolerances.

Figure 5: Basic structure of the system of values of expected shrinkages for double bottom sections.
3.2 The system of values of expected shrinkages

The geometric information that can be extracted from the CAD system contains the intended values of the structure to be built. Geometry deviations from thermal deformation, temperature and transport influences are not included; their compensation means the correction of the theoretic measures with consideration of systematic production influences. However, the stochastic share of these influences can be intercepted by production tolerances only. The splitting of the production influences into one part that can be determined and thus compensated, and a stochastic one is an essential step towards the realization of the deductive approach.

A decisive part of this is represented by weld-induced shrinkage. The basic structure of the system of values of expected shrinkages for this major factor is schematically shown in figure 5.

From a sensibly laid out technological database you can either get empirical values with high statistic accuracy or even, after condensing the measure values, derive defining equations for a class of geometric elements. Figure 6 shows the definition of the values of expected shrinkage for butt welding in the panel production.

As a basic rule for the distribution of the values of expected shrinkage applies that the place of the expected shrinkage has to be taken into account, while at the same time the order of assembly has a great influence, too.

![Figure 6: Values of expected shrinkage for butt weld plane to plane (UP-weld).](image-url)

3.3 The system of accurate fit-up marking

The system of accurate fit-up marking is used to guarantee an unequivocal measurement derivation with reference to the geometrically ideal elements (plane, line, point) in the process of production and assembly. The geometric
elements chosen as reference marks must be embodied by reference points in
the real component and checkable by instruments. These reference points have
to be made visible as system of accurate fit-up marking by internal marks of
high accuracy on the material surface.

Thus, a high concentration on the geometric features takes place, which is
of essential influence on the fitting geometry and positioning processes. By this
orientation on the exclusive description of the fitting geometry, the necessary
amount of data (which possibly has to be checked as well) is substantially
reduced. Research in the double bottom area of conventional medium-sized
vessels have shown that about 1/10 of the complete geometric information is
sufficient /4/.

The useful grouping of the assembly objects into basic fit up elements
(e.g. plane to plane, part onto plane, plane onto plane and section to section -
see figure 7) as well as the point and line marks on the parts make the fitting
according to given measures possible without permanently having to measure
great lengths. In addition to a significant saving of expenditures for expensive
3-D equipment, there is also the influence of the use of handy, uncomplicated
instruments with only little inaccuracy, which must not be underestimated.

Figure 7: Basic fit-up element part on plane.
The part internal marks are classified into:
- base-line mark (waterline, frame line, base line)
- part mark (basic fit-up element part on plane)
- plane mark (basic fit-up element plane on plane).

4 Production accompanying quality management

By production accompanying quality management, the activities for the realisation of the features, shown in figure 3, are interconnected and governed. Measuring planning and implementation, data handling, measurement evaluation (operative and statistical evaluation), compacting of the measurement results and, finally, feedback to the production are tasks of quality management. A vital aspect of their realisation is the instrumentation to be used, which will be illustrated in the following.

The introduction of accurate manufacturing requires a considerable expansion of measuring activities in order to
- measure the fitting geometries of sections
- fit up on the basis of the system of accurate fit-up marking
- record shrinkage dimensions.

According to this, 5 main groups in production measuring must be distinguished:
- measure and shape survey
- shape and position survey
- plane measurement
- 3-D measurement
- machine control.

Figure 8: Reproducibility MONMOS 2000 (section width 32 000 mm).
The main emphasis is in the three-dimensional surveillance of volume sections. The instruments for 3-D measuring offered in the market have reached a level in their development that can be judged as sufficient for shipbuilding and steel construction. In German shipbuilding the systems ACMAN 1000 and MONMOS 2000 have proved successful. An important factor is the measurement inaccuracy of these devices under consideration of the tolerance to be measured. In figure 8, the result of tests about reproducibility of the MONMOS system under practice conditions is depicted.

The accuracy of volume section measurement can be increased by using special test-point adapters for pointing at the real test points. In the use of 3-D coordinate measuring techniques, the latter play an especially important role if test points in real construction element geometries have to be registered (moulding edge relation, welding cuts). In German shipbuilding special test-point adapters have been tested with success.

For the measure and shape survey "small lengths" in elemental fit-up processes one can fall back upon high-precision instruments. In figure 9, an example for this with the use of a visual sensor (CCD-camera) is given.

![Figure 9: Fit-up measuring technics.](image)

**5 Summary**

The above described method of accurate manufacturing and resulting conclusions are successfully being put into action in German shipbuilding. The major features of this method are

- system of tolerances
- system of values of expected shrinkage
- system of accurate fit-up marking
- quality management
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These features are to be looked at as a unit and make clear the emphasis when using this method. Only when accurate manufacturing of double bottom sections and similar subassemblies is securely operated, its expansion to other, more complicated parts of the hull should be effected.

References

1. Fujita, M. Computer Application to Accuracy Control in Hull Construction ICCAS 1985, Trieste

