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FORWARD

This publication is one of six volumes of the final report on Mathematical Ship Lofting and Numerical Control of Shipyard Fabricating Equipment. The work reported on herein was performed under Bureau of Ships Contract No. NObs-4427, Code 70, during the period from April 1961 to March 1963.

The volumes of this final report have the following titles:

- Vol. 1. Project Summary Report (Technical Report 9.0.0)
- Vol. 2. Mathematical Ship Lofting -
 - Part 1. - Theory (Technical Report 1.0.0-1)
 - Part 2. - Operating Manual (Technical Report 1.0.0-2)
- Vol. 3. Mathematical Ship Lofting - Summary Report (Technical Report 1.5.0)
- Vol. 4. Programming System for Numerically Controlled Flame Cutting of Ships Parts - Operating Manual (Technical Report 5.0.0)
- Vol. 5. Development and Testing of Programming System for Numerically Controlled Flame Cutting of Ships Parts - Summary Report (Technical Report 5.5.0)
- Vol. 6. Numerically Controlled Shipyard Fabricating Equipment - Summary Report (Technical Report 3.0.0)

The work was accomplished by the Research and Development Group of the Los Angeles Division of Todd Shipyards Corporation, San Pedro, California. Mr. Thomas G. Smith was Project Manager for the work, and Dr. Henry A. Schade of the University of California, Berkeley, was Principal Consultant.

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ABSTRACT

This report briefly describes the conventional methods of lofting and fabricating ships parts and presents concepts for replacing these methods with mathematical lofting and numerically controlled or automatic processes.

Presented are:

Specifications for numerically controlled flame and plasma-arc cutting machines

Design concepts and specifications for stretch forming machines

Design concepts and specifications for a machine for cutting shell plate after forming

Procedure for making a cost analysis of the proposed process

Recommendations are made for continuing development of the new concepts presented toward the goal of reducing ship construction costs.

SUMMARY

Contract NObs-4427 has as part of its initial goal the "... determination of the most desirable control media and/or the economical attainment of numerical control for automatic burning/marketing machines, frame bending machines, rolls, presses, etc., for operations that are now performed manually, or for machines that now require templates in their non-automatic operations."

The Contract further required the "The machine control media selected should be compatible with computer fairing methods ..." as developed in another phase of the contract work and "... be capable of development directly from information developed by these methods...".

We have reviewed conventional lofting and fabrication processes which require templates in their operation to determine the requirements for a full mathematical lofting/numerically controlled fabrication process.

Numerically controlled flame cutting machines are presently available, and preliminary specifications for such machines have been presented.

Conventional forming processes were not found to be directly adaptable to numerical control. However, the stretch forming process as used in aerospace industries appeared to offer a practical method of forming by numerical control. Shell plate and frame forming machines were conceived, and the conceptual designs and preliminary specifications have been presented.

The mechanics of forming shell plate by the stretch forming process required that the plates be cut to size after forming. A new method for

defining the geometry of these plates was developed, and a machine for cutting after forming was conceived. The method and conceptual design of the machine for cutting after forming has been presented.

Numerically controlled marking and layout methods have been described and methods have been given for preparing reduced-scale graphical lines or full-scale templates by numerical control.

The economies of numerical control were discussed only briefly, as the work had not been carried to the extent where any cost determinations and production rates could be established. A procedure was presented for making an analysis of economies when the cost and production data is determined.

It has been concluded that a total mathematical lofting/numerical control fabrication process appears feasible.

Recommendations are made that mechanical and economic feasibilities of processes and concepts such as those presented be investigated further.

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*These are complete reports having their own numbering system

Section I

INTRODUCTION

The purpose of this report is to present preliminary specifications and conceptual designs for numerically controlled or automated equipment to replace those which now require templates in their operation. In addition a cost analysis procedure is presented for determining the economies of numerically controlled fabricating equipment.

To provide a better understanding of the processes and equipment considered for replacement, conventional methods are first reviewed in Section II. The numerically controlled or automated counterparts to this conventional system are then presented in Section III. The economics of the numerically controlled process is discussed briefly in Section IV.

Though the work was not carried to completion* (that is, feasibility and costs were not determined), certain conclusions are drawn from the work accomplished. These conclusions together with the recommendations are presented in Section V.

*Contract NObs-4427 had as part of its initial goal the "determination of the most desirable control media and/or the economical attainment of numerical control for burning/marking machines, frame bending machines, rolls, presses, etc., for operations that are now performed manually or for machines that now require templates in their non-automatic operation."

The contract further required that "The machine control media selected should be compatible with computer fairing method..." as developed in another phase of the contract work and "be capable of development directly from information developed by these methods..."

Work proceeded on this aspect of the contract from March 1, 1961, until July 1962. During this time, cutting and forming machines were conceived and preliminary specifications were written for various numerically controlled shipyard fabricating equipment. In June, the Bureau of Ships determined that this work had been completed to the extent desired, and the work was discontinued.

Section II

REVIEW OF CONVENTIONAL LOFTING AND FABRICATING PROCESSES

GRAPHICAL HULL FORM

In the conventional lofting process the loftsmen, starting with the preliminary lines drawing and station offsets as furnished by the Naval Architect, lays down and fairs graphically a full- or reduced-scale body plan. To be able to define the structural parts of the ship, he must also lay out on this body plan the frame lines, stringer location, innerbottom contours, shell sight edges, deck intersection, shaft center lines, etc. A typical body plan as laid down is shown in Fig. II-1. The work of obtaining all the hull contours shown requires a great many approximations, cross checks, and adjustments. Only when this extensive procedure is completed is the loftsmen ready to start defining the ship's parts for cutting, forming and marking.

CUTTING PARTS

The loftsmen prepares graphical templates of the parts, either full scale or reduced scale, by merging the dimensional information given on the structural working drawings with the lofted lines. These templates, depending upon the type produced, can then be used to:

Layout and cut the parts manually

Layout and cut the parts semi-automatically, or

Guide automatic cutting machines with tracer controls.

These methods usually involve a sequence of duplicated operations, each with contributing error possibilities. The final result is often less than desired.

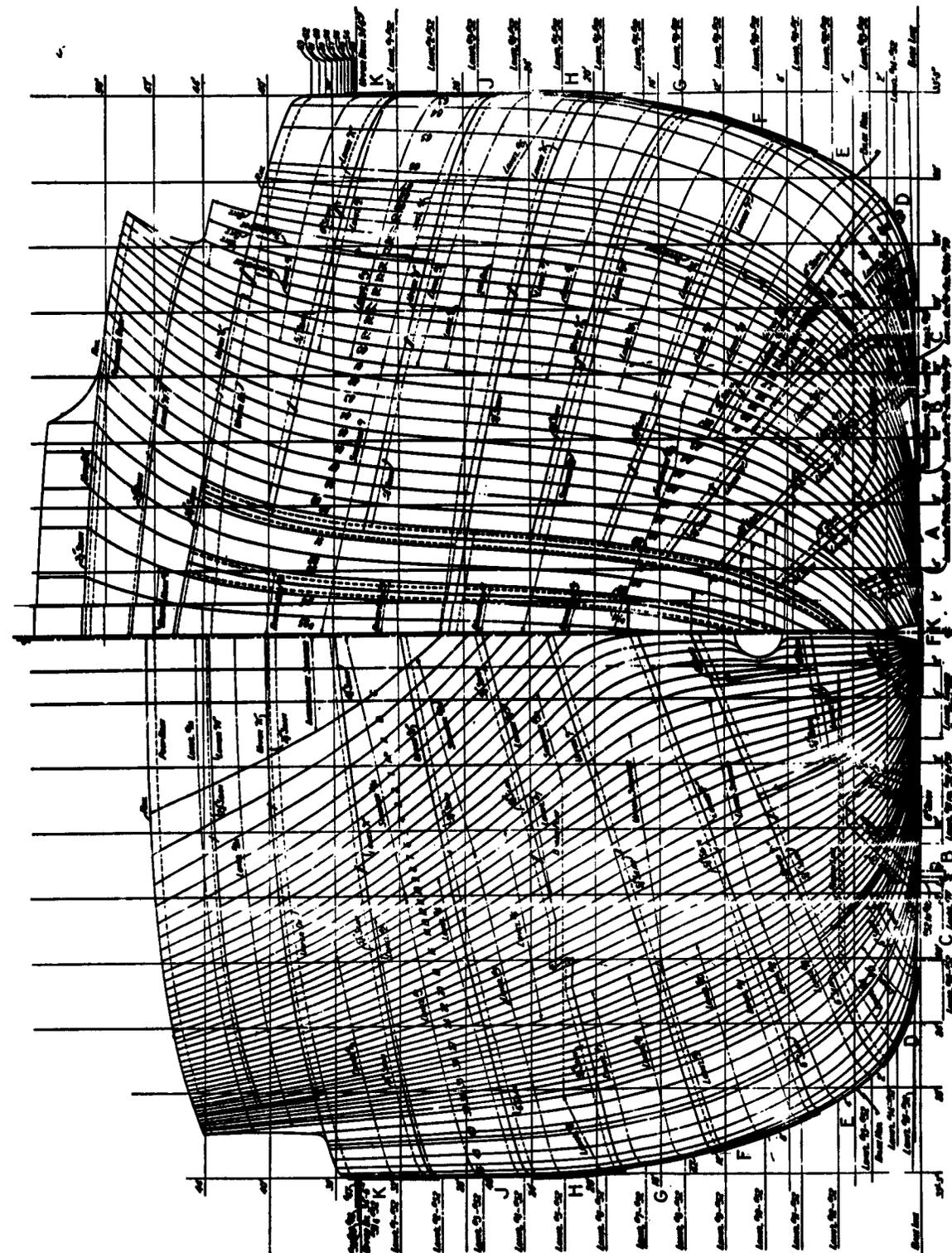


Fig. II-1 Typical Body Plan as Laid Down in the Mold Loft

FORMING PARTS

The conventional loftsmen also prepares either reduced- or full scale templates for use as patterns in bending and forming plates and structural shapes to suit the hull contours.

With these templates, plates and structural shapes are formed on pyramid rolls, hydraulic or mechanical presses, special bending machines, or they are hot formed to templates or jigs. Forming parts in this manner is relatively slow and as a result is costly. Errors in contour, which often occur, increase erection costs.

DEVELOPMENT WORK

Templates are required for cutting shell plates, bilge keels, and built-up longitudinal stringers. Because these parts are usually trimmed prior to contouring the loft must determine the "Flat Plate" pattern. This is usually done by a procedure known as triangulation or center squaring. Under the best of conditions this is only an approximation of the actual size and shape and is largely dependent on the skill of the loftsmen.

MARKING A LAYOUT

The loft is further called upon to provide information for marking and identifying the location of the parts, and for locating sections for erection. All of this information is taken from the loft lines and/or working drawings, and is provided to the production forces as markings on the templates, as wooden battens scribed to indicate distances, or in the form of tabulated dimensions.

Though this system works with reasonable success, there is a desire throughout the industry for more automatic and foolproof methods.

Section III

MATHEMATICAL LOFTING AND NUMERICALLY CONTROLLED FABRICATION PROCESSES

MATHEMATICAL LOFTING

To determine the hull contour information required in the numerically controlled fabrication processes, a method has been developed for mathematically lofting the ship.*

This method produces surface equations describing the hull form from which the loftsmen can obtain mathematical descriptions for frame lines, stringer locations, shell plate sight edge, deck intersection, and most of those items which the loftsmen locate on his body plan. In effect, the graphical representation of the body plan has now been replaced with an analytic one. In practice, however, a body plan is considered desirable, and therefore procedures have been developed whereby the lines can be drawn or scribed by an automatic plotting machine.**

The speed and accuracy with which this can be accomplished has been demonstrated in the aerospace industry.

CUTTING PARTS BY NUMERICAL CONTROL

To replace the graphical templates used in conventional cutting processes, a system for programming a numerically controlled flame cutting machine has been developed.***

*This method is reported on in complete detail in Ref. 1.

**Ref. 1 gives the procedure and computer program to accomplish this by a plotter on-line with a computer. The procedure and computer programs to plot by numerical control on an on-line plotter is included in Ref. 2.

***This system is presented in complete detail in Ref. 2.

Several tape controlled flame cutting machines have been built: one in the United States and three known to be in production in Europe.*

Preliminary specifications for numerically controlled flame or plasma-arc cutting machines (Appendix A) were developed with the cooperation of Air Reduction Co. and Linde Co. These specifications were written to include plazama-arc cutting because this new process holds such great promise for reducing cutting time and costs. Numerical control appears to be the most logical means to direct a plazma-arc torch for contour cutting.

FORMING PARTS BY NUMERICAL CONTROL

Conventional forming machines (brakes, rolls and benders) are more difficult to convert to numerical control because:

Most forming is basically sectional: the machine forms one section of the part and then moves to another section, and so on until the complete part is formed.

The formed plate or shape "springs back" from the die or forming tool, requiring the part to be initially bent to a curvature greater than the template so that it will fit the template when it springs back.

One hydraulic press brake manufacturer (Pacific Industrial Manufacturing Company) was given specifications for a numerically controlled press brake. They reported that they felt such a machine could be built, but the design work would have to be sponsored. We understand that other press and frame bender manufacturers are or have been developing such equipment, but to date we are not aware of any successes in this regard.

Because work is being done by others in an effort to numerically control existing types of equipment, and because of the above-cited problems inherent in the forming methods, the Project investigated other forming methods which might prove more suitable (Ref. 4).

*These machines have been described in Ref. 3.

The stretch forming process being used extensively in the aerospace industry was selected as having the best potential for forming ships' parts by numerical control. Using this process, a conceptual design for a stretch press for forming ships' frames was developed (Appendix B).

The major problem to be overcome in applying this stretch forming process to frame bending was to develop a die which could be adjusted by numeric inputs to conform to the shape of the frame or plate desired. A position control mechanism, employing a spline to obtain a fair curve or several splines to obtain fair surfaces was conceived. This "Position Control for Multiple Tools" is described in the invention disclosure in Appendix B.

From these investigations and design work, preliminary specifications were written for digitally controlled frame and plate forming stretch presses (Appendix B).

The control data for the stretch forming process can readily be obtained from the mathematical loft in the form of punched tape or cards, or as tabulated data for manual input*.

These coordinates, directly applied to the contouring mechanism, offer a very accurate means for forming control.

CUTTING AFTER FORMING

In the stretch press method of forming, excess material must be left on the ends of parts for the gripping devices. It will probably also be necessary to leave excess on the edges of plates to be formed. As a consequence, plates formed by the stretch press method will have to be cut to size after forming (versus cutting prior to forming as in conventional process).

*The method for obtaining this information is described in Ref. 1

A burning machine was therefore needed which could cut the edges of shell plate neat while in a formed condition, since manual cutting of these edges would probably render the entire process uneconomical. Further, it did not appear economical to design an expensive, special-purpose, numerically controlled burning machine to cut only these plate edges.

A new method of defining shell plates has been developed in which the edges must be seen, in projection, as a straight line. This permitted the development of an economical, special-purpose cutting machine for cutting shell plate after forming*.

LAYOUT AND MARKING

The mathematical loft can readily furnish all the information required for either manual or automatic marking.

There are several marking processes under development for numerically controlled flame cutting machines, such as automatic center punching. The information for actuating such devices can readily be obtained and programmed into the numerically controlled operating tape.

A full-scale, numerically controlled, X-Y plotter has been developed by the Burmeister Wain Company of Copenhagen, Denmark, for laying out and marking large subassemblies. This plotter, which looks like a bridge crane, projects a beam of light through crosshairs to locate marking points - these points are then centerpunched and ringed with paint.

*Appendix C describes in detail this new method and the cutting machine. Also included are the specifications for the machine and invention disclosures covering the method and the control device required for the cutting machine.

The project was verbally advised that the design is available for purchase, or Burmeister Wain will construct a machine on order. (The unit was described in greater detail in Ref. 3.)

The control tapes for operating this type of marking machine can be readily prepared using a programming system such as presented in Ref. 2.

ADJUSTABLE JIGS

Adjustable positioning jigs are required in the use of the above-referenced, full-scale X-Y plotter, in order to support contoured sections in an approximately horizontal position. Adjustable jigs can also be used to position sections for welding. The heights, for setting such jigs, are also readily obtainable from the mathematical loft.

PREPARATION OF GRAPHICAL TEMPLATES FROM MATHEMATICAL LOFT

Pending development and general use of numerically controlled forming machines, it will be necessary to use conventional forming equipment. Templates for the present forming process can be produced by the mathematical loft in several ways.

Offsets can be generated from which full-scale lines can be laid down and full-scale graphical templates made

Curves can be plotted (or scribed) in reduced scale for direct use with optical marking or burning equipment.

A numerically controlled burning machine can be used as a full-scale plotter to draw or scribe templates by replacing the torch with a pen or scribing tool.

Section IV

ECONOMIES OF NUMERICAL CONTROL

The economies of a full mathematical loft/numerically controlled fabricating process are yet to be determined.

Numerically controlled flame cutting, through production testing, appears economically competitive now and has a potential for being improved, whereas conventional methods have about reached their maximum capabilities.

The economies of the stretch forming and flame cutting equipment conceived under this Project can be determined after:

Machine design work is completed
Feasibility is established
Acquisition costs are determined
Production rates are known

When this information is known, each potential user can then evaluate each process in relation to his own projected work load, facility costs, amortization rates, etc.* Based upon such individual circumstances, each user may then elect to use all or any part of the process.

*"A Procedure to Establish a Cost Analysis and Comparison Between Different Production Methods" (Technical Report 7.1.0) is included as Appendix D.

Section V

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

The mechanical feasibility of numerically controlled flame cutting has been adequately demonstrated. Economic feasibility remains to be determined.

From the limited investigation and development work accomplished, it appears mechanically feasible to replace other mechanical fabrication processes, now requiring graphical templates in their operation, with numerically or automatically controlled equipment. Manual processes requiring loft information and not subject to automating can obtain that same information from a mathematical loft as is presently derived from the graphical loft.

Combining numerically controlled processes with those requiring templates is feasible and practical. For any combination where cutting is by numerical control, it would be advantageous to loft the ship mathematically. Where stretch press forming is used, it is almost mandatory to mathematically loft the ship.

RECOMMENDATIONS

No further effort need be expended on determining the mechanical feasibility of numerically controlled flame cutting. However, the economies of a full production system, though appearing favorable, are as yet unknown. A pilot installation in a shipyard could provide this necessary information.

The mechanical and economical feasibility of other numerically controlled fabrication processes should be determined to the extent necessary to demonstrate the advantages or disadvantages of such processes.

Section VI

REFERENCES

1. Todd Shipyards Corporation, Mathematical Ship Lofting, Part 1, Theory; Part 2, Operating Manual, Technical Report 1.0.0, Mar 1963 (Vol 2 of Final Report, Contract NObs-4427)
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3. Todd Shipyards Corporation, Summary of Progress to June 1, 1961, (Progress Report No. 1, Contract NObs-4427 - Computer Fairing and Numerical Control of Machinery)
4. Todd Shipyards Corporation, State-of-the-Art Studies on Processes Considered for the Fabrication of Ship Parts Under Digital Control, Technical Report 3.1.0, by Bruce L. Baird, 8 Jun 1962 (Contract NObs-4427)

APPENDIX A

**PRELIMINARY SPECIFICATIONS
NUMERICALLY CONTROLLED FLAME OR PLASMA-ARC CUTTING MACHINES**

I. SCOPE

A. Purpose

To provide tentative description and performance specifications for plate cutting machines to meet the requirements of the ship-building industry.

B. Classification

Plate cutting machines shall be of the following types and sizes. Types and sizes are at the option of the customer.

1. Type

- a. Type F - flame cutting machine, employing two simultaneous moving torchheads (oxygen - fuel gas) enabling cutting of two mirror-image workpieces.
- b. Type P - plasma arc cutting machine, employing two simultaneous moving torchheads (electrical arc in gas stream) enabling the cutting of two mirror-image workpieces.

2. Size

- a. Size 10 - working width = 10 feet
- b. Size- working width = ... feet

C. Intended Use

1. Basically

To cut under any mode of operation simultaneously with two torches:

- a. By flame cutting process -
Flat plates made from carbon and low-alloy steels.
- b. By plasma-arc cutting process -
Flat plates made from carbon and low-alloy steels, stainless steels, and aluminum.

2. Flexibility

- a. While not a requirement, it would be highly desirable to use four (4) instead of two torchheads in order to simultaneously cut four plates of six feet maximum width each.
- b. Besides cutting contoured parts under tape control, machine must be able to cut rectilinear plates using manual controls only.
- c. It is also desirable to build the machine in such a way that optical tracer control may be adapted at any later time. This feature is at the option of the machine builder.
- d. While it is a requirement to have two torchheads cutting simultaneously but in opposite directions to cut mirror-images of two plates of maximum (12 ft) width, it is also desirable to make both torchheads move simultaneously and in the same direction to cut two alike plates of maximum width. This feature preferably should also apply

to the four torchheads cutting plates of half-width.

e. Units of Measurement -

All length measurements (for X and Y axes) are to be commanded in inches and decimals thereof, with a resolution of .01 inch. It may also be required to have all length measurements in feet and decimals thereof, in which case the resolution is .001 feet (= .012 inch). Disregarding the decimal point, this requirement can be easily met by increasing the number of teeth on the proper ratio-giving gear of the position transducer by a factor of 1.2.

The alternate employed is at the option of the customer.

II. APPLICABLE SPECIFICATIONS

- A. NMTBA Electrical Standards
- B. EIA Electrical Standards
- C. JIC Hydraulic Standards
- D. NAS Machine Axis Nomenclature

III. REQUIREMENTS

Manufacturers' contractual obligations for design and function of machine.

A. Design

The dimensions and capacities are applicable to all types and sizes of machines. The machine shall be of the moving tool (torchhead), stationary table type.

The machine builder has the choice of configuration, such as bridge type or cantilevered type crossrail.

B. Capacity

1. Type

- a. Type F - Torches shall employ the flame cutting process, using oxygen and fuel gas.
- b. Type P - Torches shall employ the plasma-arc cutting process using electrical arc in gas stream.

2. Size

Dimensions and capacities as shown in Table 1 are applicable to all types of machines.

3. Feed

Feedrates as shown in Table 2 are applicable to all sizes of machines.

4. System Accuracy

Accuracies as shown in Table 3 are applicable to all types and sizes of machines.

TABLE 1
DIMENSIONS AND CAPACITIES
 (Minimum Requirements)

<u>Item</u>	<u>Size 10</u>	<u>Size</u>
Working width [*]	2 @ 10 feet	... @ ... feet
Working length ^{**}	Customer's option
Material thickness ^{***}	2 inch inch
Torch rise and fall	5 inch inch
Rotation of torch about vertical axis (360° turns)	unlimited	unlimited
Rotation of torch about horizontal axis	± 45° from vertical	± 45° from vertical

Notes:

^{*} Two (2) working areas of specified width arranged side by side.

^{**} Min. length 36 feet. Components to allow assembly to any greater length in increments not larger than four (4) feet. Machine builder to specify basic length and length of increments.

^{***} Maximum thickness of any specified material to be cut with two (2) torchheads at optimum speed. Allow a reduction to half the thickness when cutting with four (4) torchheads.

TABLE 2

FEED RATES

(Minimum requirements, unless otherwise stated)

<u>Item</u>	<u>Type F (Flame)</u>	<u>Type P (Plasma-arc)</u>
Cutting feed	5 - 35 IPM	10 - 300 IPM
Rapid traverse	150 IPM	300 IPM
Jogging feed	5 IPM max. or .01" per smallest manual command	5 IPM max. or .01" per smallest manual command
Torch rise and fall speed	20 IPM	20 IPM
Speed of rotation of torchhead about vertical axis	40 RPM	80 RPM
Cornering speed, programmed	20 IPM	40 IPM

TABLE 3
SYSTEM ACCURACIES

Minimum inside corner radius (depending on kerf)	$R_{\min} = \frac{\text{kerf dia.}}{2} + \frac{1}{32}$ (inch)
Minimum outside corner radius (for corners programmed as sharp)	$R_{\min} = \frac{1}{32}$ (inch)
Linear accuracy in X-Y plane:	
Any point within any 12 x 12 ft area, deviation from true location*	± .020"
Accumulation for every additional 12 foot length*	± .015"
Torch tip to workpiece distance (required for bevel cuts)**	± 15%
Cut edges perpendicular to X-Y plane	± 2-1/2°
Angular position of torch about vertical axis */**	± 5°
Linear velocity of torch in any horizontal direction**	± 5%

Notes:

*With indicator mounted on torch

**In reference to commanded data

C. Construction of Machine

1. Machine shall be constructed to comply with the requirements of Section III, and with the inspection and acceptance tests of Section IV.
2. Crossrail shall be of sufficient size to permit storing of any inactive torchheads without reducing the cutting width below the specified minimum.
3. Machine shall provide clearance for loading and unloading of maximum size workpieces, both vertically from overhead and horizontally from both ends.
4. Machine shall be furnished with supports enabling the alignment of the X-axis tracks and with supports carrying the power supply hoses and cables over the full travel range. The purchaser will be required to supply the foundation for these supports or for any other detached components.
5. Machine shall be supplied with an operator control station, having a minimum of control functions, which will move with the carriage along the X-axis. These functions shall be:
 - Start - Stop
 - Torch on - off
 - Torch rise and fall
 - Gas pressure
 - Arc energy controls
6. Machine shall also be supplied with stationary emergency button at a convenient location of the machine. This button to stop all feed movements and shut off oxygen or electric arc supply.

7. Machine shall be furnished complete with all control cables, power cables, junction boxes, control panels, frequency converters, starters, hoses, piping, tubing, reels, operator's stand, and any other items required to complete the installation.

The purchaser will be required to supply services to the machine or control panel as the case may be, and make the connections at this place only. All other inter-connections to be furnished by the machine builder.

8. The purchaser will be required to supply the work table and its foundation (optional).
9. Machine shall be supplied with reference position readouts for the full capacity of the X- and Y-axes. Readouts must give the position of the torchheads in reference to an adjustable system-zero to the resolution and accuracy of the system, and must be engaged at all times (optional).

D. Control

1. Manual Adjustments

Machine shall provide manually adjustable devices for the following functions:

- a. Adjust torch to compensate for variations in kerf width.
- b. Adjust torch vertically to obtain the torch-tip to table surface distance, as specified in Table 1.
- c. Disengage any torch head from the mechanism driving it in the Y-axis.
- d. Reverse the direction of the torchhead movement along the Y-axis (optional).

2. Automatic Adjustments

Machine shall provide automatic control of the following functions:

- a. Maintain the manually-set torch-tip to plate distance over the entire cutting cycle. Raise torches whenever oxygen or electrical arc supply is shut off.
- b. Automatic machine stop when cutting flame fails to pierce plate.
- c. Synchronize electric power and gas flow with the torch feed rate to obtain the best ratio between these variables. Feature needed to maintain an accurate cut at reduced speed, such as is required for sharp turns. (Plasma-arc torch only.)

3. Numerical Control System

a. Controlled Axes

- i. Machine shall be equipped with a continuous path numerical control system for controlling the X (longitudinal), Y (transverse), and c (torch rotation) axes.
- ii. The system shall be capable of controlling the functions individually, or any combination of them simultaneously.

b. Design

- i. The control system shall be complete with tape transport mechanism and necessary control circuitry installed within the control cabinet.
- ii. The system shall be such that control of auxiliary functions such as outlined in Section III.D.3.d can be programmed as desired.
- iii. Tape synchronization adjustment controls for the programmed start position of the various controlled motions shall be located convenient to the operator.
- iv. The machine shall be controlled by binary-coded decimal, 1" 8-channel perforated tape, per EIA Standard.
- v. A feed rate override shall be provided at the operator's panel which will permit variation of the programmed feed rate to at least plus or minus 50%, within the specified absolute limits per Table 2.
- vi. A dwell time override shall be provided at the operators panel (no limits).

c. Manual Mode of Operation

Controls shall permit the execution of the following operations simultaneously or sequentially where desirable:

- i. Adjust kerf compensating device
- ii. Adjust torch tip to plate distance
- iii. Retract and lower torch
- iv. Adjust all gas pressure, flow regulating, and electrical power regulating devices for cutting torches
- v. Move torches under rapid traverse, cutting feed rate, or by jogging to any point within the travel limits
- vi. Adjust setting of preheat flame
- vii. Start and stop flow of oxygen and fuel gas for the flame torch or electrical power and gas for the plasma-arc torch
- viii. Ignite flame torch
- ix. Actuate plate marking mechanism
- x. Switch over to tape control

d. Tape Control Mode of Operation

Controls shall permit the execution of the following operations:

- i. Govern path of travel during cutting cycle
- ii. Govern feed rate during cutting cycle (subject to manual override).

- iii. Govern path of travel when in rapid traverse
- iv. Start and stop flow of oxygen and fuel gas for the flame torch, or electrical power and gas for the plasma-arc torch.
- v. Ignite flame torch
- vi. Actuate plate marking mechanism without interrupting cutting cycle

e. Safety Devices

Each machine shall be furnished with suitable safety devices of the latest type. Parts which are hazardous to the operator shall be suitably guarded where practical. Ample protection against electrical shock shall be provided. Safety stops limiting extreme travel of carriage (gantry) and torchheads are to be installed.

f. Interchangeability

All replaceable parts shall be constructed to definite standards, tolerances, and clearances in order that any such part may be replaced or adjusted without requiring modification. Where practicable, such parts shall be permanently and legibly marked with the manufacturer's part number.

IV. INSPECTION AND ACCEPTANCE

A. Classification of Tests

1. Verification of requirements of Section III.
2. Tolerance Tests, Section IV.C.2.
3. Performance Tests, Section IV.C.3.

B. Test Conditions

Each machine shall be tested under the following conditions as specified under Ordering Data (Section VI):

1. At manufacturer's plant by manufacturer, with verified test results furnished customer.
2. At manufacturer's plant witnessed by customer
3. At customer's plant

C. Test Details

1. Check required items specified in Section III. not covered in Section IV.
2. Tolerance Tests per later submitted detailed instructions.
3. Performance Tests - These tests are (1) for testing the function accuracy of the machine under actual cutting conditions, and (2) to prove the performance of the tape transport, the machine control unit, the machine drive and feedback units, and cutting torches.

V. OPERATING AND INSTALLATION DATA

The manufacturer shall furnish a copy of the following data for each purchased machine. Additional copies shall be furnished at purchaser's option.

- A. Scaled plan view, front elevation and end elevation with major dimensions, consisting of all work space clearance dimensions, overall height, width, and length dimensions, and dimensions of peripheral equipment, such as control cabinets.
- B. Certified foundation and/or installation drawings, showing location and sizes of all required services where applicable. Drawings to be furnished sixty days prior to shipment.
- C. Maintenance Manual
- D. Operator's Manual
- E. Parts List, including recommended spare parts list
- F. Electrical wiring and schematic diagram to EIA electrical standards
- G. Hydraulic and pneumatic circuit schematic to JIC standards (if applicable).

VI. ORDERING DATA

- A. Customer's option, per classification (Section I.B.)
- B. Customer's option of unit of measurement (Section I.C.2.d)
- C. Customer's option on Acceptance Tests (Section IV.B)
- D. Preservation and Packing
- E. Shipping instructions

Appendix B

STRETCH PRESSES - DESIGN CONCEPTS AND SPECIFICATIONS

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FEATURES OF THE PROPOSED STRETCH PRESS

- I. All machine parts located above floor level, to avoid entrance of sea water at low elevations.
- II. Flush floor without pit, to avoid accumulation of dirt or fluids.
- III. Easy access to all moving parts of the machine.
- IV. Novel control system (see Disclosure of Invention) allows economical use of digital control.
- V. System equally well suited for manual or tape control.
- VI. Frame with controls independent of load-carrying structure, maintaining accuracy without using excess material.
- VII. Extension rods allow the forming of any specified length material.
- VIII. Wide use of concrete as a low-cost material for the structure.
- IX. All major parts of the machine under tension or compression, for best use of material properties.
- X. Use of modular components, enabling lower cost in their fabrication.
- XI. Reduced shipping costs by pouring concrete into steel shells on the installation site.
- XII. Existing Shipyard equipment is sufficient to handle the machine components for installation.

STRETCH
FORCE

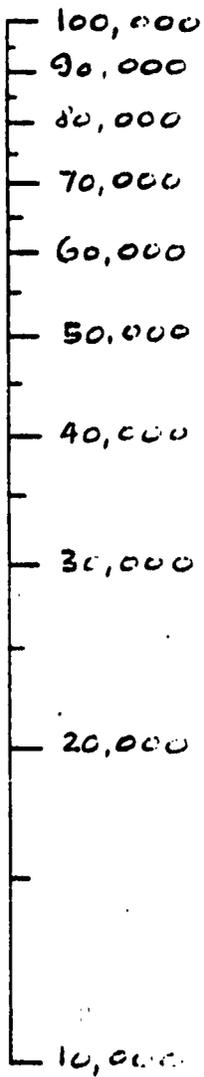
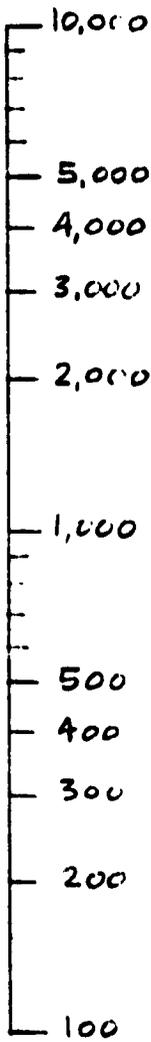
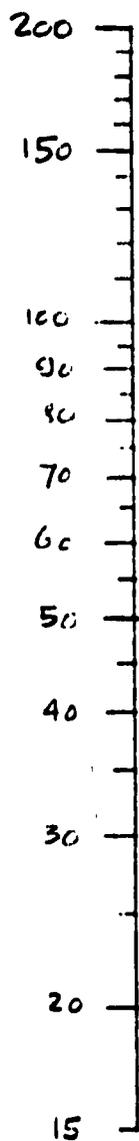
TONS



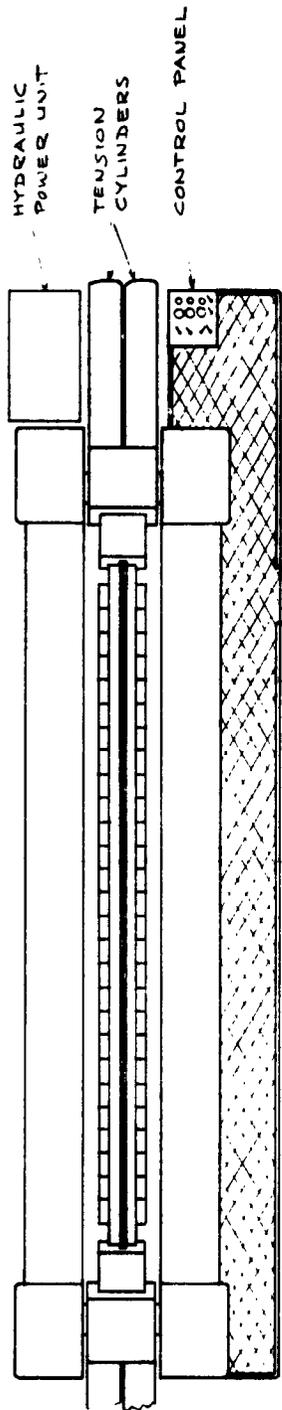
YIELD STRENGTH

LBS. / SQ. IN.

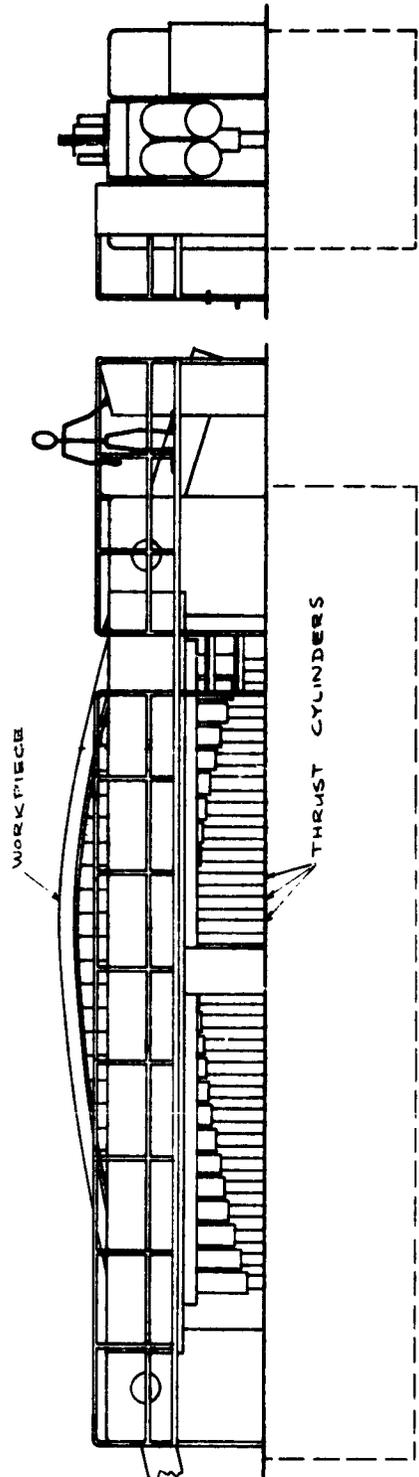
AREA
SQ. IN.



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B-3

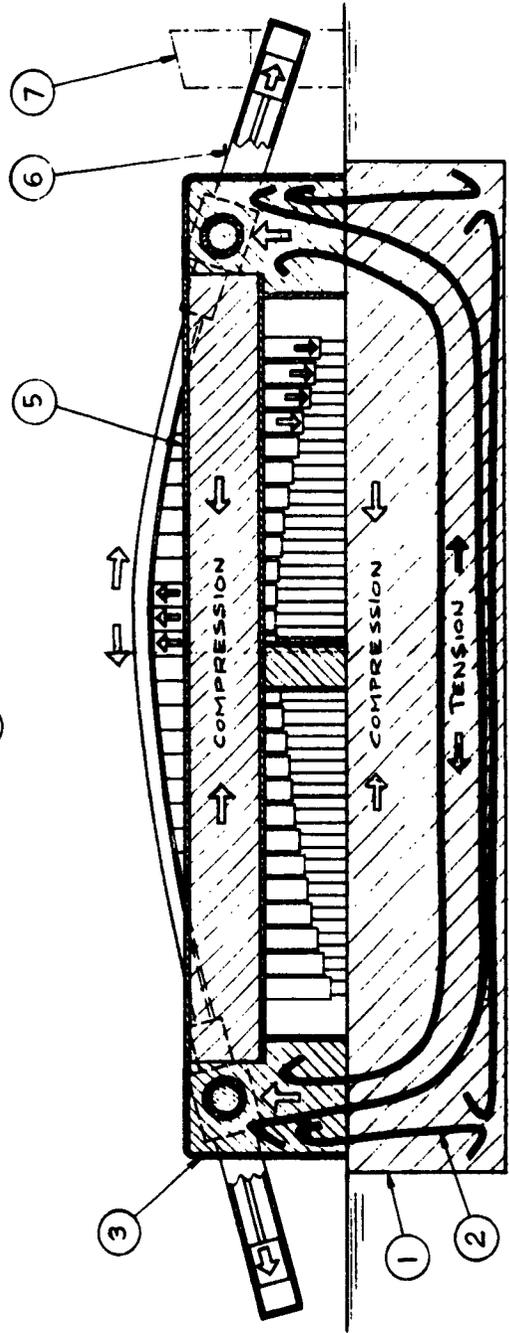
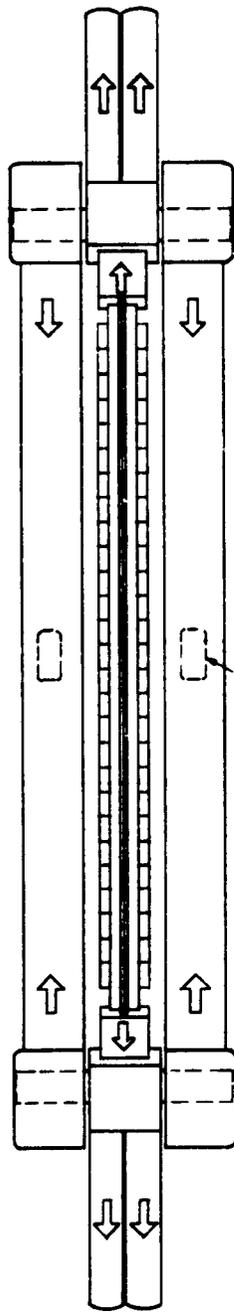


STRETCH PRESS
FOR BENDING FRAMES

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STEPS FOR THE ERECTION OF THE PROPOSED STRETCH PRESS

- I. Pour concrete foundation (1) to floor level with tension rods (2) in place.
- II. Dry for two weeks.
- III. Erect steel shells for anchors (3) and beam supports (4).
- IV. Erect steel shells for compression beams (5).
- V. Fill all shells (3), (4), and (5) with concrete.
- VI. Dry for two weeks.
- VII. Erect machine proper (6) and installations (7).
- VIII. One month after last pouring of concrete, machine is ready to operate under full load.



STRETCH PRESS
MACHINE STRUCTURE

3-7-62 102

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DISCLOSURE OF INVENTION

Page 1 of 8

TITLE: POSITION CONTROL FOR MULTIPLE TOOLS

3.4.1

Report 3.4.2

SUMMARY

Description of a device, consisting of the required minimum number of adjustable controls, connected with a spline to obtain a faired curve; and any desirable number of followers, arranged to align themselves automatically to the spline at intermediate locations.

Servo-controlled power drives, suitable for adjusting and holding tool segments under load, conforming to the desired curve.

I. PROBLEM

The problem, as existing on machines with multiple adjustable tool segments which are arranged in a faired curve, is treated. It is assumed that the fairing was done previously by either graphical or mathematical methods. The tool segments in the machine may be arranged to allow forming of two- or three-dimensional workpieces.

The great number of adjustable segments required to obtain workpieces of sufficient smoothness causes the following difficulties:

- A. Manual adjustments require considerable time and prevent the machine from being used efficiently.
- B. Automatic adjustments require a transducer drive system for each segment, resulting in high equipment cost.

II. EXISTING METHODS

Forming machines with adjustable die segments to eliminate the need for one-purpose dies are already proposed. Some of them use a template and servo-valves to control the die adjustment. A template is usable for only one particular shape, and many templates have to be made and stored if this technique is applied to shipbuilding.

Others are proposed with manual control of the individual tool segments which is extremely time consuming. Also, in such a system, access to the adjusting devices may be problematic.

Still other machines are proposed with control by stored numeric data, in which case the format of such storage may be too great to be practically handled.

Shown and Described to us
this 20th day of February 1962

Janice H. Thompson
Thomas J. Smith
Witnesses

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this 20th day of February 1962

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3.4.1

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II. EXISTING METHODS (Cont.)

Conventional machines using one-purpose dies are not discussed here, since the involved tool costs are too high for shipbuilding.

III. DESCRIPTION OF A NEW METHOD

If the desired form follows a faired line, only a fraction of the required tool segments need to be controlled. A flexible beam of constant cross section, such as used in lofting (in the following referred to as "spline") is adjusted laterally on known tactical points, much the same way as faired lines are produced graphically.

Servo-devices pick up the lateral position of spline sections between control points to position hydraulic cylinders automatically.

IV. AN APPLICATION OF THIS METHOD

Fig. 1 shows the arrangement of the discussed elements as applied to a stretch press.

A machine frame (1) holds control units (2) which are spaced along the length of the spline (3). Between control units, one or more follower units (4) are placed, separated by the desired spacing. Tools (5) are attached to all of the units.

In the example, a workpiece (6) is held in tensioning devices (7), to be shaped to a curve as directed by the bent spline.

Fig. 2 shows one each of the control and follower units.

On the control unit a dial or automatic drive (8) rotates a screw (9) to position a nut (10) to a commanded height. Guide rollers (11) hold the spline (3) at this height, while the latter is free to move lengthwise.

A servo-valve spool (12) is also connected to the nut and moves along its axis within the valve body (13). A pressure port (14) is covered by the upper land, and an exhaust port (15) by the lower land of the spool, with the latter in its neutral position. The valve body is fixed to a moving cylinder (16), which is guided by a stationary piston (17). Hole or pipe (18) connects cylinder and central port of valve.

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DISCLOSURE OF INVENTION

TITLE: POSITION CONTROL FOR MULTIPLE TOOLS

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3.4.1

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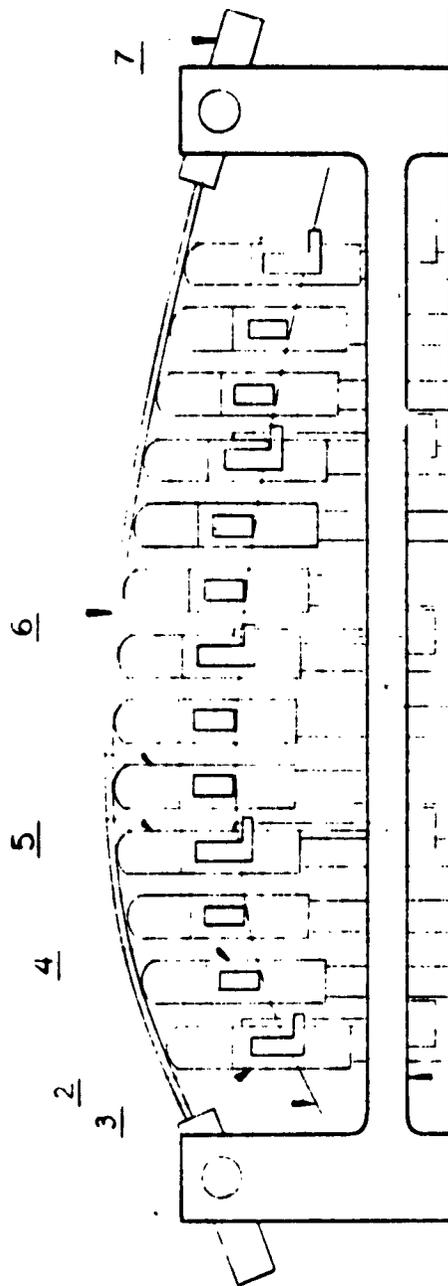


FIGURE 1.

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3.4.1

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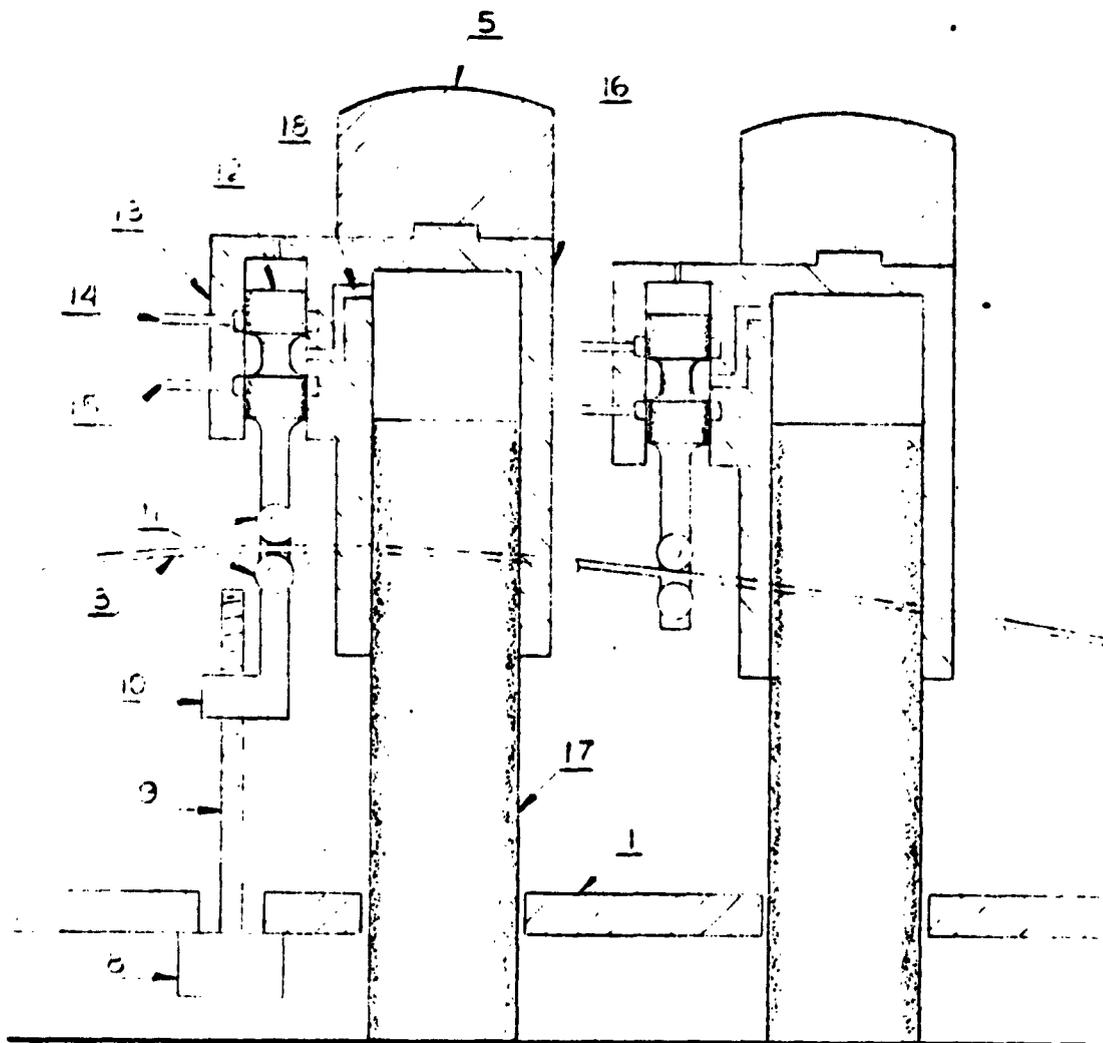


FIGURE 2

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Page 5 of 8

TITLE: POSITION CONTROL FOR MULTIPLE TOOLS

3.4.1
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IV. AN APPLICATION OF THIS METHOD (Cont.)

With the spool in its neutral position, no hydraulic fluid can pass to or from the cylinder, which is held in its position. Lowering the spool will keep the pressure port closed and open the exhaust port, draining sufficient fluid from the cylinder to drop the latter and the valve body until equilibrium is established. Lifting the spool will uncover the pressure port while keeping the exhaust port closed, allowing more fluid to enter the cylinder and lift the same together with the valve body, until again equilibrium is established.

Forces exerted on each tool (5) are transmitted through the fluid and piston directly to the floor, not deflecting the machine frame (1).

The follower unit consists mainly of the same parts as the control unit, except for the input device. The spline locates the spool of the servo-valve, initiating movements as described beforehand.

V. DESIGN VARIATIONS

In contrast to the shown application, the spool in the servo-valve may be spring-loaded against one side of the spline. This would allow the retraction of all tool segments with the spline in its pre-set position simply by bypassing the valves and draining the fluid from the cylinders.

Instead of using a direct circuit as shown, low-pressure pilot valves may actuate high-pressure valves on the cylinders.

Also, in contrast to the shown two-dimensional application, splines can be arranged in a network, allowing three-dimensional parts to be formed.

Fig. 3 is a plan view and Fig. 4 a front view of such an installation.

Splines (19) and (20) are two out of all main splines along the one axis. They are adjusted on convenient points, such as (21), (22), (23), and (24). These are the only adjusting points for the area within. Splines (25) and (26) are two of the main splines arranged perpendicular to (19) and (20). Servo-splines such as (27), (28), and (29) are arranged between main splines.

Swivel joints (30) are placed on crossing points between splines to keep them at a constant distance and prevent twisting. Guides (31) help to

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3.4.1

TITLE: POSITION CONTROL FOR MULTIPLE TOOLS

Report 3.4.2

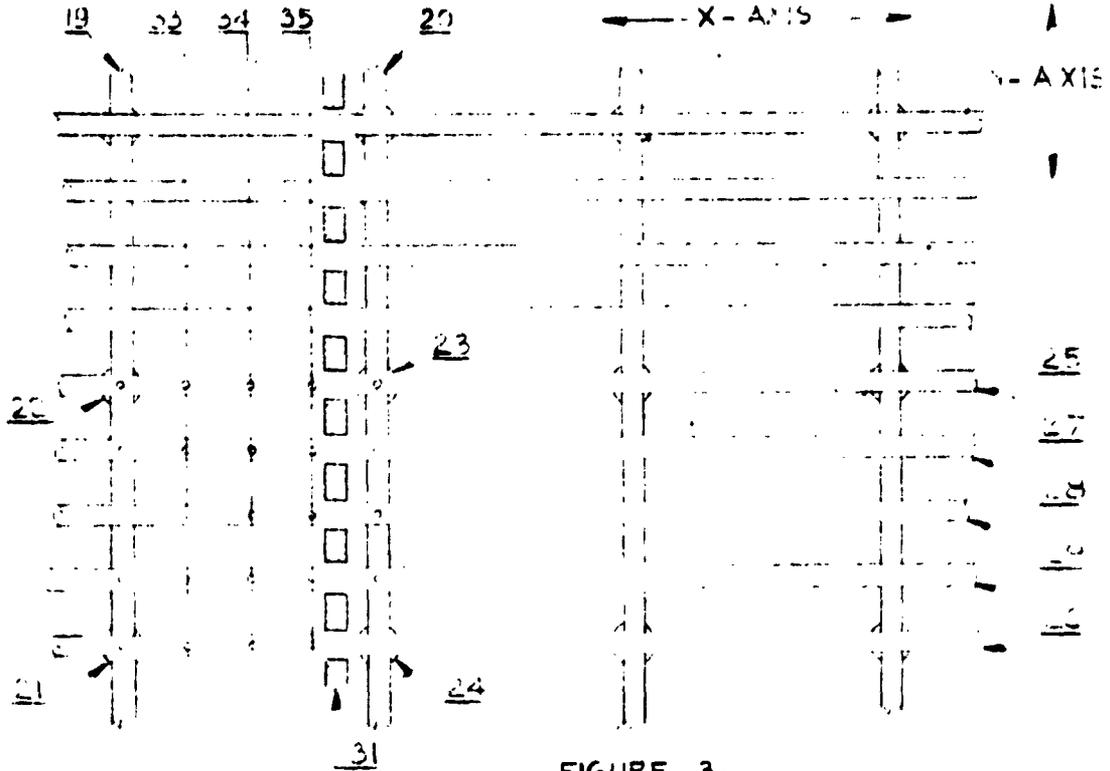


FIGURE 3.

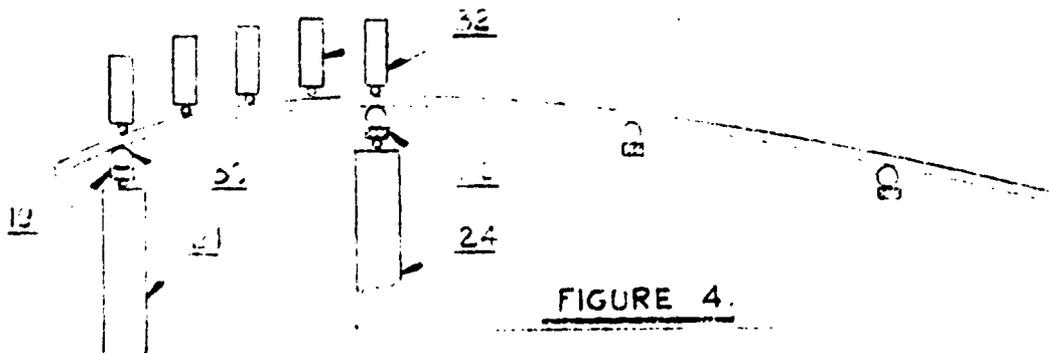


FIGURE 4.

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TITLE: POSITION CONTROL FOR MULTIPLE TOOLS

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V. DESIGN VARIATIONS (Cont.)

keep the splines separated horizontally. All splines are free to move longitudinally.

Servo-devices (32) are placed on intersections of splines and centerlines such as (33), (34), and (35). It can be seen in the example that for the area between points (21), (22), (23), and (24) a total of twenty-five servodevices are governed by the spline network, while only few position adjustments have to be made.

If:

N_x = number of main splines in the X-axis

N_y = number of main splines in the Y-axis

n_x = number of servo-points in line between two main Y-splines

n_y = number of servosplines between two main X-splines

then:

Number of adjusting points: $N_{total} = N_x \times N_y$

and:

Number of adjustable tool segments:

$$n_{total} = [N_x + n_x (N_x - 1)] \times [N_y + n_y (N_y - 1)]$$

VI. ADVANTAGES OF THIS INVENTION

- A. With the machine manually controlled, much time can be saved, since only a fraction of the tool segments have to be positioned, while the remainder follows automatically.
- B. With the machine automatically controlled, considerable cost savings result, since a substantial part of it is in the position transducers and their number is reduced.

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VI. ADVANTAGES OF THIS INVENTION (Cont.)

- C. Reduced format of data to be stored enables smaller memory devices in the control system, with further savings possible.
- D. The arrangement eliminates the need for one-purpose templates as required by other template-controlled machines. This should result in considerable time and material savings and also eliminates a storage problem.

In the foregoing, comparison was made only with other controls using individually adjustable tool segments.

VII. NOVELTY

Machines with template-controlled tool segments were already proposed. The use of a spline for graphically establishing faired curves is a known practice.

However, the combination of both elements brings new advantages beyond the capabilities of the existing methods. Such a combination was, to our knowledge, never proposed before.

Therefore, it is claimed that a control, which incorporates a spline, several adjusting devices, and servo-devices as described in this disclosure, is a new invention.

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PRELIMINARY SPECIFICATIONS

DIGITALLY CONTROLLED STRETCH PRESS FOR SHIPS' FRAMES

I. SCOPE

A. Purpose

To provide description and performance specifications for frame forming machines employing the stretch press principle to meet the requirements of the shipbuilding industry.

B. Classification

Stretch presses shall be of the following types, sizes, and classes. Types, sizes, and classes are at the option of the customer.

1. Type

- a. Type "A" - Stretch press, employing adjustable die sections in the Y axis
- b. Type "B" - Stretch press, employing numerically controlled adjustable die sections in the Y axis.

2. Size

- a. Size 20 - Frame length = 8 to 20 ft.
- b. Size 35 - Frame length = 8 to 35 ft.

3. Class

- a. Class 1 - Stretch press with manually controlled sequencing of the forming operation
- b. Class 2 - Stretch press with semi- or full automatically controlled sequencing of the forming operation

C. Intended Use

To form under any mode of operation to mathematically defined and digitally controlled contours frames made from mild steels, Classes A, B, and C (per American Bureau of Ships).

The machine shall enable the gripping of any listed size frame on both ends and pre-stretch it to the yield point, whereafter the ram is advanced while a pre-determined tension is maintained.

D. Units of Measurement

All height measurements (for Y axis) are to be commanded in inches and decimals thereof, with a resolution of .01 inch. It may also be required to have all height measurements in feet and decimals thereof, in which case the resolution is .001 feet (= .012 inch).

The alternate employed is at the option of the customer.

II APPLICABLE SPECIFICATIONS

- A. NMTBA Electrical Standards
- B. EIA Electrical Standards
- C. JIC Hydraulic Standards
- D. NAS Machine Axis Nomenclature

TABLE 1

DIMENSIONS AND CAPACITIES

(Minimum Requirements)

<u>Item</u>	<u>Size 20</u>	<u>Size 35</u>
Workpiece length *	8 - 20 feet	8 - 35 feet
Maximum height of formed workpiece over X Axis baseline	4 feet	6 feet
Minimum readings of curvature, inside	6 feet	6 feet

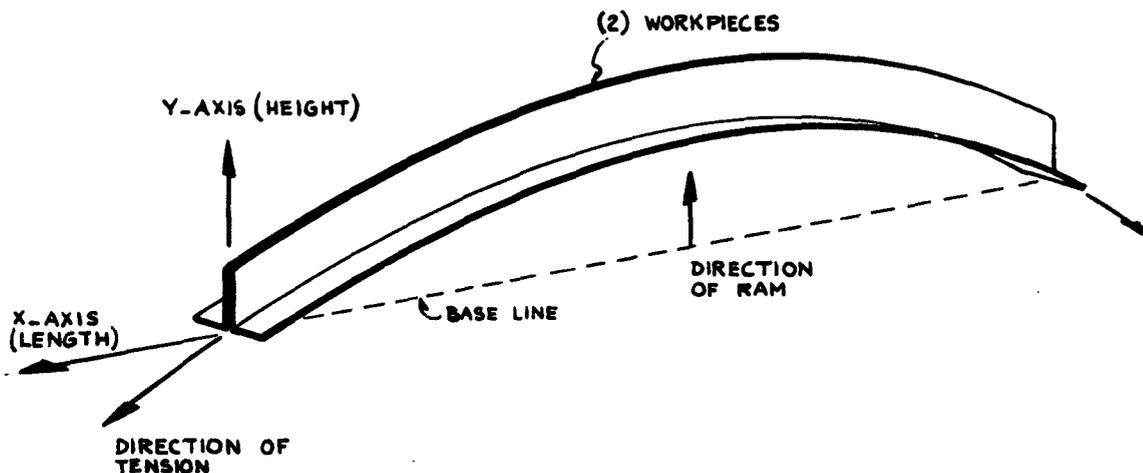


TABLE 2

FRAME CROSS SECTIONS

	<u>Flange Thickness</u>	<u>Flange</u>	<u>Web</u>	<u>Web Thickness</u>	<u>Web (Sq. in.) Area</u>
Unequal Leg Angles					
Maximum	8	1-1/8	6	1-1/8	14.5
Minimum	3	1/4	4	1/4	1.7
Equal Leg Angles					
Maximum	8	1-1/8	8	1-1/8	16.7
Minimum	5	3/8	5	3/8	3.6
Cut Channels					
Maximum	4-1/2	11/16	18	5/8	14.7
Minimum	2-3/8	7/16	9	1/4	2.8

*Dimensions before forming

TABLE 3
FEED RATES

(Minimum requirements, unless otherwise stated)

<u>Item</u>	<u>Type "A"</u>	<u>Type "B"</u>
Pre-tensioning speed	50 IPM	50 IPM
Ram Speed	25 IPM	25 IPM
Time to adjust all die segments *	10 minutes	3 minutes
Time to return all die segments to zero position	2 minutes	1/2 minute

*For maximum travel

TABLE 4

SYSTEM ACCURACIES

Linear accuracy in X axis:

Any die section within any 12 ft length, deviation from true location *	+ -	.12 inch
Accumulation for every additional 12 foot length*	+ -	.06 inch

Vertical accuracy over X axis baseline:

Any die section top surface, deviation from true location**	+ -	.015 inch
--	--------	-----------

Resolution of die movement		.010 inch
----------------------------	--	-----------

*Location of center of cylindrical surface

**In reference to commanded data

III. REQUIREMENTS

Manufacturers' contractual obligations for design and function of machine

A. Design

The dimensions and capacities are applicable to all types of machines.

The machine builder has the choice of configuration, such as position of the workplace in reference to the floor.

B. Capacity

1. Size

Dimensions and capacities as shown in Tables 1 and 2 are applicable to all types and classes of machines.

2. Feed

Feedrates as shown in Table 3 are applicable to all sizes and classes of machines.

3. System Accuracy

Accuracies as shown in Table 4 are applicable to all types, sizes, and classes of machines.

C. Construction of Machine

- 1. Machine shall be constructed to comply with the requirements of Section III, and with the inspection and acceptance tests of Section IV.**

2. Machine shall provide clearance for loading and unloading of maximum size workpieces vertically from overhead.

3. If the concrete foundation is part of the structure, same is responsibility of and must be cast under supervision of machine builder.

Purchaser to provide the additional foundation as may be required by local soil conditions.

4. Machine shall be furnished with supports carrying the power supply hoses and cables over the full travel range. The purchaser will be required to supply the foundation for these supports or for any other detached components.

5. Machine shall be supplied with an operator control station having the minimum of necessary control functions within easy reach of the operator.

6. Machine shall be supplied with indicating pressure gages for ram, tensioning, and gripping circuit.

7. Machine shall also be supplied with stationary emergency button at a convenient location of the machine, to stop all feed movements.

8. Machine shall be furnished complete with all control cables, power cables, junction boxes, control panels, hoses, piping, tubing, operator's stand, and any other items required to complete the installation.

The purchaser will be required to supply services to the machine of control panel as the case may be, and make the connections at this place only. All other inter-connections to be furnished by the machine builder.

9. Machine shall be furnished with gripping mechanisms which allow to hold two back-to-back "L" sections of any specified size (see Table 2), and allow to change frame sizes within capacity without major setup.
10. Tension cylinders to have sufficient stroke and power to allow the forming of the maximum size workpieces as listed in Table 1.
11. Devices which allow the forming of all intermediate lengths within the capacity as listed in Table 1 must be provided.
12. Forming die to consist of a system of individually adjustable die sections, the spacing of which is not to exceed 6-1/2 inches.
- 13 Formed material between the location of these dies may follow straight lines instead of the overall curvature.
14. Radius of cylindrical die section surface to be approximately 10 inches, with its axis perpendicular to both X and Y axes.
15. Machine shall be furnished with two marking devices which apply non-destructive marks in known dimensional relationship to the die sections. Marks to appear on the top of the workpiece near each grip.

D. Controls

1. Manually adjusted die sections (Type "A" control only)
 - a. Machine shall be equipped with a manually adjustable and conveniently readable dial system.

- b. The system shall be capable of controlling the die sections individually in any sequence.
- c. The system must allow the disengagement of any die section and keep same in the retracted position.

2. Numerically controlled die sections (Type "B" control only)

- a. Machine shall be equipped with a point-to-point positioning numerical control system for controlling all die sections in the Y axis.
- b. The system shall be capable of controlling the die sections individually, any number of them simultaneously or sequentially.
- c. The control system shall be complete with tape or card reader and transport mechanism, and control circuitry installed within the control cabinet.
- d. The system must allow the disengagement of any die section and keep same in the retracted position.

3. Manually controlled forming sequence (Class 1 control only)

- a. Manual controls must permit the origination of all individual operations during the forming cycle in the proper sequence.
- b. These operations shall be:
 - Pre-tension material after gripping
 - Advance ram sections, while backing off on tensioning devices
 - Apply final tension after ram sections are in position
 - Return all members to starting position to unload workpiece
- c. System shall allow the actuation of the frame marking mechanisms

4. Automatically controlled forming sequence (Class 2 control only)

a. Automatic controls must initiate all individual operations during the forming cycle in the proper sequence to previously adjusted limits after starting the cycle manually.

b. These operations shall be:

Pre-tension material after gripping

Advance ram sections while backing off on tensioning devices

Apply final tension after ram sections are in position

Actuate frame marking devices

Return all members to starting position to unload workpiece

E. Safety Devices

Each machine shall be furnished with suitable safety devices of the latest type. Parts which are hazardous to the operator shall be suitably guarded where practical. Ample protection against electrical shock shall be provided. Safety stops limiting extreme travel of jaws and tool sections are to be installed.

F. Interchangeability

All replaceable parts shall be constructed to definite standards, tolerances, and clearances in order that any such part may be replaced or adjusted without requiring modification. Where practicable, such parts shall be permanently and legibly marked with the manufacturer's part number

IV. INSPECTION AND ACCEPTANCE

A. Classification of Tests

1. Verification of requirements of Section III.
2. Tolerance Tests, Section IV.C.2.
3. Performance Tests, Section IV.C.3.

B. Test Conditions

Each machine shall be tested under the following conditions as specified under Ordering Data (Section VI):

1. At manufacturer's plant by manufacturer, with verified test results furnished customer.
2. At manufacturer's plant witnessed by customer
3. At customer's plant

C. Test Details

1. Check required items specified in Section III., not covered in Section IV.
2. Tolerance Tests per later submitted detailed instructions
3. Performance tests - Tases tests are (1) for testing the function accuracy of the machine under actual forming conditions, and (2) to prove the performance of the machine control unit, the frame gripping mechanism, and the adjustable die sections.

V. OPERATING AND INSTALLATION DATA

The manufacturer shall furnish a copy of the following data for each purchased machine. Additional copies shall be furnished at purchaser's option.

- A. Scaled plan view, front elevation and end elevation with major dimensions, consisting of all work space clearance dimensions, overall height, width, and length dimensions, and dimensions of peripheral equipment, such as control cabinets.**
- B. Certified foundation and/or installation drawings, showing location and sizes of all required services where applicable. Drawings to be furnished sixty days prior to shipment.**
- C. Maintenance Manual**
- D. Operator's Manual**
- E. Parts List, including recommended spare parts list**
- F. Electrical wiring and schematic diagram to EIA electrical standards**
- G. Hydraulic and pneumatic circuit schematic to JIC standards**

VI. ORDERING DATA

- A. Customer's option, per classification (Section I.B.)**
- B. Customer's option of unit of measurement (Section I.D.)**
- C. Customer's option on Acceptance Tests (Section IV.B.)**
- D. Preservation and Packing**
- E. Shipping instructions**

**PRELIMINARY SPECIFICATIONS
DIGITALLY CONTROLLED STRETCH PRESS FOR SHELL PLATES**

I. SCOPE

A. Purpose

To provide description and performance specifications for plate forming machines employing the stretch press principle to meet the requirements of the shipbuilding industry.

B. Classification

Stretch presses shall be of the following types and classes. Types and classes are at the option of the customer.

1. Type

- a. Type "A" - Stretch press, employing manually adjustable die sections in the Z axis
- b. Type "B" - Stretch press, employing numerically controlled adjustable die sections in the Z axis

2. Class

- a. Class 1 - Stretch press with manually controlled sequencing of the forming operation
- b. Class 2 - Stretch press with semi- or full-automatically controlled sequencing of the forming operation

C. Intended Use

To form under any mode of operation to mathematically defined and digitally controlled contours:

- a. Flat plates made from mild steels, Classes A, B, and C,
(per American Bureau of Ships)
- b. Flat plates made from HY-80 alloy-steels

The machine shall enable the gripping of a maximum size plate along both short edges and pre-stretch it to the yield point, whereafter the ram is advanced while a pre-determined tension is maintained.

D. Units of Measurement

All height measurements (for X axis) are to be commanded in inches and decimals thereof, with a resolution of .01 inch. It may also be required to have all height measurements in feet and decimals thereof, in which case the resolution is .001 feet (= .012 inch).

The alternate employed is at the option of the customer.

II. APPLICABLE SPECIFICATIONS

- A. NETBA Electrical Standards
- B. EIA Electrical Standards
- C. JIC Hydraulic Standards
- D. NAS Machine Axis Nomenclature

TABLE 1
DIMENSIONS AND CAPACITIES
 (Minimum Requirements)

Item	Workpiece Material	
	Mild Steel	HY-80
Workpiece width*	12 ft	10 ft
Workpiece length*	15 - 35 ft	15 - 35 ft
Workpiece thickness*	1/4 - 1-3/8 in.	1/4 - 3/4 in.
Maximum height of formed workpiece over X-Y plane	2 ft	2 ft

*Dimensions before forming

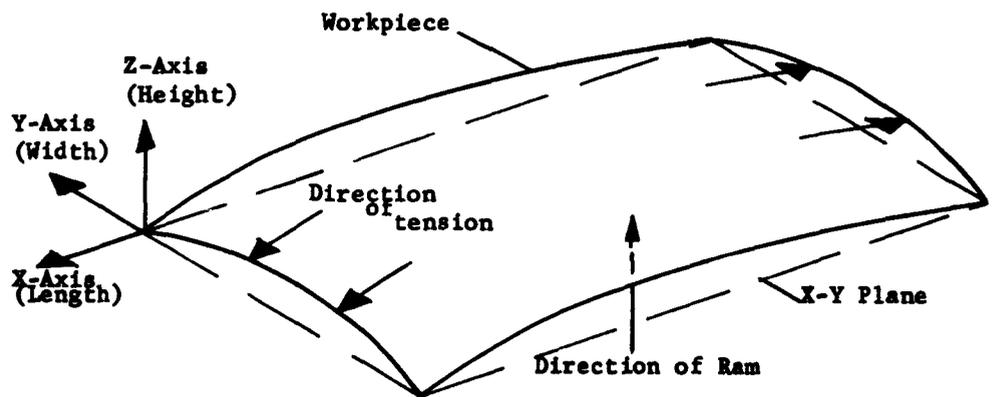


TABLE 2

FEED RATES

(Minimum requirements, unless otherwise stated)

<u>Item</u>	<u>Type "A"</u>	<u>Type "B"</u>
Pre-tensioning speed	50 IPM	50 IPM
Ram speed	25 IPM	25 IPM
Time to adjust all die segments *	30 min	10 min
Time to return all die segments to zero position*	5 min	1 min

*For maximum travel

TABLE 3
SYSTEM ACCURACIES

Linear accuracy in X-Y plane:

Any die section within any 12 x 12 ft
area, deviation from true location* \pm .12 in.

Accumulation for every additional
12 ft length* \pm .06 in.

Vertical accuracy over X-Y plane:

Any die section top surface, deviation
from true location** \pm .03 in.

Resolution of die movement .010 in.

* Location of center of spherical surface

** In reference to commanded data

III. REQUIREMENTS

Manufacturers' contractual obligations for design and function of machine

A. Design

The dimensions and capacities are applicable to all types of machines.

The machine builder has the choice of configuration, such as position of the workpiece in reference to the floor.

B. Capacity

1. Size

Dimensions and capacities as shown in Table 1 are applicable to all types and classes of machines.

2. Feed

Feedrates as shown in Table 2 are applicable to all classes of machines.

3. System Accuracy

Accuracies as shown in Table 3 are applicable to all types and classes of machines.

C. Construction of Machine

1. Machine shall be constructed to comply with the requirements of Section III, and with the inspection and acceptance tests of Section IV.

2. Machine shall provide clearance for loading and unloading of maximum size workpieces vertically from overhead.

3. If the concrete foundation is part of the structure, same is responsibility of and must be cast under supervision of machine builder.

Purchaser to provide the additional foundation as may be required by local soil conditions.

4. Machine shall be furnished with supports carrying the power supply hoses and cables over the full travel range. The purchaser will be required to supply the foundation for these supports or for any other detached components.

5. Machine shall be supplied with an operator control station having the minimum of necessary control functions within easy reach of the operator.

6. Machine shall be supplied with indicating pressure gages for ram, tensioning, and gripping circuit.

7. Machine shall also be supplied with stationary emergency button at a convenient location of the machine, to stop all feed movements.

8. Machine shall be furnished complete with all control cables, power cables, junction boxes, control panels, hoses, piping, tubing, operator's stand, and any other items required to complete the installation.

The purchaser will be required to supply services to the machine or control panel as the case may be, and make the connections at this place only. All other inter-connections to be furnished by the machine builder.

9. Machine shall be furnished with gripping mechanisms which allow change of plate thickness within capacity without major setup change.
10. Tension cylinders to have sufficient stroke and power to allow the forming of the maximum size workpieces as listed in Table 1.
11. Devices which allow the forming of all intermediate lengths within the capacity as listed in Table 1 must be provided.
12. Forming die to consist of a system of individually adjustable die sections, the spacing of which is not to exceed 6-1/2 inches in the Y-axis, and not to exceed 17 inches in the X-axis.
13. Formed material between the location of these dies may follow straight lines instead of the overall curvature.
14. Radius of spherical die section surface to be approximately 10 inches.
15. Machine shall be furnished with two marking devices which apply non-destructive marks in known dimensional relationship to the die sections. Marks to appear on the top of the workpiece near each grip.

D. Controls

1. Manually adjusted die sections (Type "A" control only)
 - a. Machine shall be equipped with a manually adjustable and conveniently readable dial system.

- b. The system shall be capable of controlling the die sections individually in any sequence.
- c. The system must allow the disengagement of any die section and keep same in the retracted position.

2. Numerically controlled die sections (Type "B" control only)

- a. Machine shall be equipped with a point-to-point positioning numerical control system for controlling all die sections in the Z-axis.
- b. The system shall be capable of controlling the die sections individually, any number of them simultaneously or sequentially.
- c. The control system shall be complete with tape or card reader and transport mechanism, and control circuitry installed within the control cabinet.
- d. The system must allow the disengagement of any die section and keep same in the retracted position.

3. Manually controlled forming sequence (Class 1 control only)

- a. Manual controls must permit the origination of all individual operations during the forming cycle in the proper sequence.

- b. These operations shall be:

Pre-tension material after gripping

Advance ram sections, while backing off on tensioning devices

Apply final tension after ram sections are in position

Return all members to starting position to unload workpiece

c. System shall allow the actuation of the plate marking mechanisms

4. Automatically controlled forming sequence (Class 2 control only)

a. Automatic controls must initiate all individual operations during the forming cycle in the proper sequence to previously adjusted limits after starting the cycle manually.

b. These operations shall be:

Pre-tension material after gripping

Advance ram sections while backing off on tensioning devices

Apply final tension after ram sections are in position

Actuate plate marking devices

Return all members to starting position to unload workpiece

E. Safety Devices

Each machine shall be furnished with suitable safety devices of the latest type. Parts which are hazardous to the operator shall be suitably guarded where practical. Ample protection against electrical shock shall be provided. Safety stops limiting extreme travel of jaws and tool sections are to be installed.

F. Interchangeability

All replaceable parts shall be constructed to definite standards, tolerances, and clearances in order that any such

part may be replaced or adjusted without requiring modification. Where practicable, such parts shall be permanently and legibly marked with the manufacturer's part number.

IV. INSPECTION AND ACCEPTANCE

A. Classification of Tests

1. Verification of requirements of Section III.
2. Tolerance Tests, Section IV.C.2.
3. Performance Tests, Section IV.C.3.

B. Test Conditions

Each machine shall be tested under the following conditions as specified under Ordering Data (Section VI):

1. At manufacturer's plant by manufacturer, with verified test results furnished customer.
2. At manufacturer's plant witnessed by customer
3. At customer's plant

C. Test Details

1. Check required items specified in Section III., not covered in Section IV.
2. Tolerance Tests per later submitted detailed instructions
3. Performance tests - These tests are (1) for testing the function accuracy of the machine under actual forming conditions, and (2) to prove the performance of the machine control unit, the plate gripping mechanism, and the adjustable die sections.

V. OPERATING AND INSTALLATION DATA

The manufacturer shall furnish a copy of the following data for each purchased machine. Additional copies shall be furnished at purchaser's option.

- A. Scaled plan view, front elevation and end elevation with major dimensions, consisting of all work space clearance dimensions, overall height, width, and length dimensions, and dimensions of peripheral equipment, such as control cabinets.
- B. Certified foundation and/or installation drawings, showing location and sizes of all required services where applicable. Drawings to be furnished sixty days prior to shipment.
- C. Maintenance Manual
- D. Operator's Manual
- E. Parts List, including recommended spare parts list
- F. Electrical wiring and schematic diagram to EIA electrical standards
- G. Hydraulic and pneumatic circuit schematic to JIC standards

VI. ORDERING DATA

- A. Customer's option, per classification (Section I.B.)
- B. Customer's option of unit of measurement (Section I.D.)
- C. Customer's option on Acceptance Tests (Section IV.B.)
- D. Preservation and Packing
- E. Shipping instructions

Appendix C

**TOMB SHIPYARDS CORPORATION
Los Angeles Division
San Pedro, California**

**Contract N6bs-4427
COMPUTER FAIRING
AND NUMERICAL CONTROL OF MACHINERY**

**TECHNICAL REPORT NO. 3.4.3
METHOD AND MACHINE FOR CUTTING SHELLPLATES AFTER FORMING**

By Warner R. Lauper

December 10, 1962

ABSTRACT

A new method is proposed wherein three-dimensionally formed shellplates for welded ships can be described and cut to the required outline using straight lines only for establishing the shape.

Specifications are presented and a recommended design of a torch cutting machine is described which permits the application of this method to cut the outline of shellplates after the forming operation.

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SECTION I
INTRODUCTION

A. THE PROBLEM

The shells of welded steel ships consist of sizeable plates which are individually formed before assembling to conform to the desired hull shape. Unlike the plates or strakes of ships built by some other methods, these shell plates must join without gaps or overlap.

Gaps which are too wide make welding difficult (blow-by) and costly (more time and electrodes consumed), and are for reasons of quality and esthetics unacceptable. Local interference cannot exist, since it would prevent the plates from meeting properly, causing gaps on other places along the seam.*

The cut must also be made with sufficient quality to permit the subsequent welding without further machining. This requires that the tolerances of the cut outline must be as good as economically possible. If for some reason the shell plates cannot be cut to acceptable tolerances, allowance has to be given and trimmed off in the fitting operation.

Shellplates are preferably made to an optimum size, which is governed by the welding cost, the equipment capacity, and by the cost of commercially available plate stock. To take full advantage of this, all plates should be close to a rectangular shape of the same optimum size. (A limitation to this is imposed by the practice of never laying a seam on a deckline, a transverse frame on a butt, nor crossing them at small angles.)

* Both longitudinal seams and transverse "butts" are here called seams.

In areas where the hull is three-dimensionally molded, the plate periphery deviates from the ideal rectangular shape. It follows that, with the exception of the flat bottom keel and the parallel side body, the outlines of shellplates cannot be simple, geometric figures, and are therefore conventionally established by developing methods. In other words, the outline is established for the flat condition of the plate by giving the actual girth dimensions from a coordinate system. Figure 1 is an illustration of this principle. Using a sufficient number of such girth dimensions, the outline can be produced on any tracer- or tape-controlled burning machine prior to forming by any suitable method.

A plate formed with little camber, which does not need to be pre-crimped, should not present difficulties in maintaining the previously-cut outline. In the formed plate, any error in curvature, as existing on the feed-in and feed-out ends due to rolling or crimping, will result in a displacement at the pre-cut edge. Such anticipated errors are sometimes avoided by allowing excess material to be trimmed off at the sub-assembly on the platen and also at final assembly on the ways. Such trimming is done after a check at location of assembly with a hand-held torch, leaving, of course, much to be desired on tolerances.

Hot forming on jigs does not permit pre-cutting to size of the plate in the flat condition, since the manual work performed on the hot plate will distort the outline in an uncontrollable way. Therefore, cutting after forming is a must on parts produced in this manner.

The forming of shellplates on a stretch press with adjustable die segments* has distinct advantages over other methods. First, it

*See Todd Shipyards Corporation Technical Report, "Preliminary Specifications - Digitally Controlled Stretch Press for Shell Plates," Report 3.0.0, Appendix B.

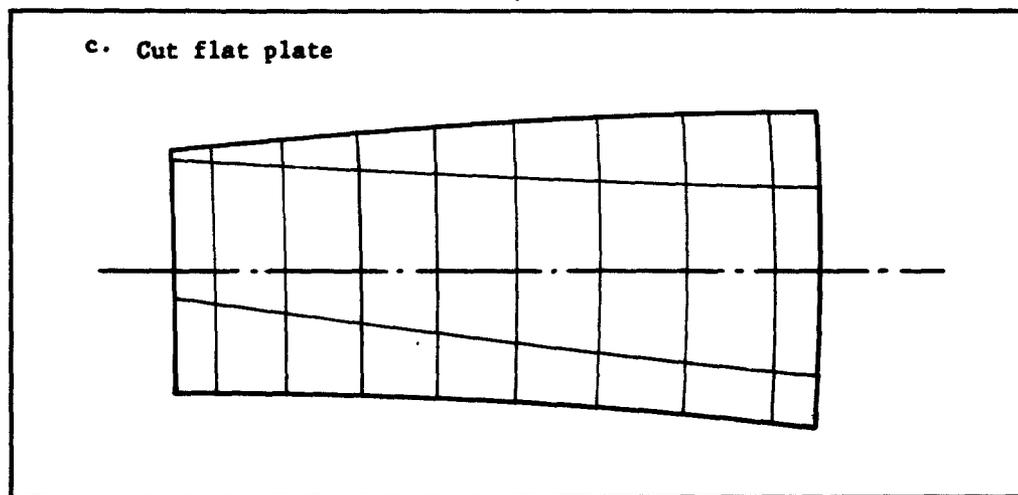
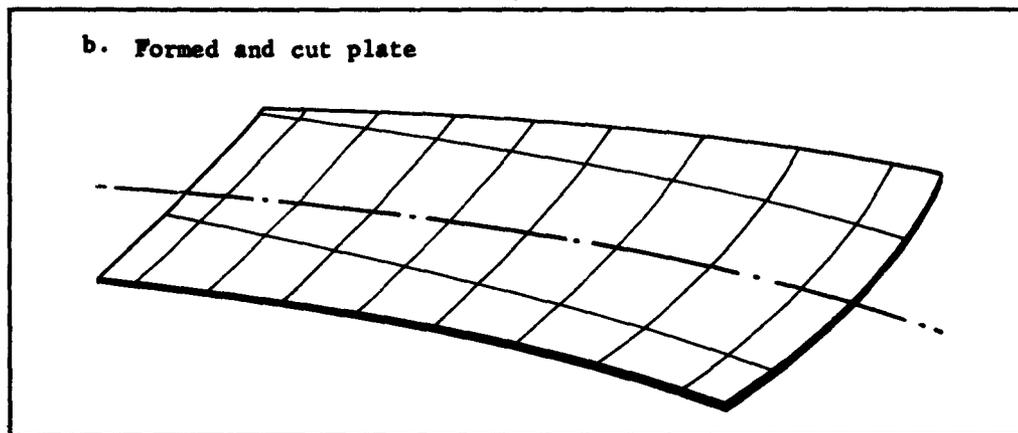
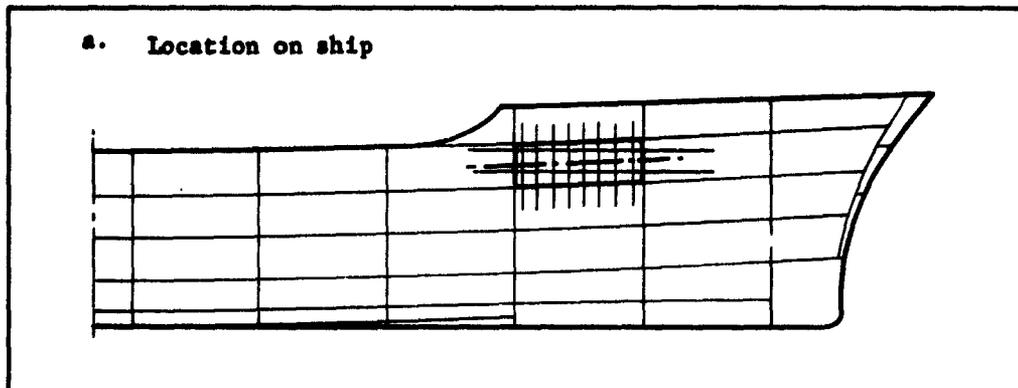


Fig. 1 Developing a Shellplate

enables the direct setting of mathematically established data as tool offsets into the machine, and secondly, the process will yield a workpiece which is not subject to springback. To maintain a uniform elongation over the full area of the workpiece during the pre-tensioning cycle, the raw material must be of constant width. Another requirement is that material has to be added for gripping in the tensioning jaws along both narrow edges. These jaws mutilate the surface of this material; furthermore, it is not possible to form the workpiece close to, or within the jaws. These areas are therefore lost to the usable length of the shellplate and must be cut off after forming. It is appropriate to say that all four side of a shellplate must be cut after forming on a stretch press.

B. PRESENT METHODS OF DEVELOPING AND CUTTING SHELLPLATE

Fabrication methods which allow the cutting of the plate edges in the flat (expanded) condition depend on the proper development of these plates by any of several accepted methods.

By full and one-tenth scale lofting, the girth dimensions are scaled off the floor or off the drawing in reference to waterlines and stations. Such dimensions must be taken in sufficient quantity to insure a non-ambiguous and accurate curve. The time required to develop one plate is approximately three hours in the one-tenth loft, and approximately twelve hours in the full-scale loft. The output can be used to make either templates or a reduced-scale drawing for use in any optically controlled burning machine.

A German company introduced a shellplate development jig* for the

* Shipbuilding and Shipping Record, Sept. 21, 1961, p. 376

purpose of speeding up the process. It is suitable only for the one-tenth lofting method, since the input is from one-tenth scale drawings and the output is in the form of markings on an unfinished drawing of this same size. It is not directly usable for either full-scale or mathematical lofting methods, since it lacks suitable input and output. A box-like frame holds individually adjustable, flexible spline, the form of which is transposed from the one-tenth scale lines drawings. All splines together simulate the shape of this hull section, and a blank drawing laid snug onto the splines will represent the uncut shellplate. The drawing, still in the bent state, is now marked at strategic points with the offsets, then removed to be finish-drawn in the flattened state. The builder of this jig claims an average time of approximately forty minutes to develop one plate.

A mathematical method is proposed^{*} which uses offsets of frames directly from the mold loft or mathematical loft, without requiring any drafting or duplicating work. This method is an approximation, replacing the actual geodesic line along a frame between two end points (strakes) with a circular line, the radius of which is located by three points.

The actual cutting operation is performed in the flat condition along the expanded contour of the plate on mechanically or optically tracer-controlled, or recently on tape-controlled burning machines. This seems at first look satisfactory; however, it is limited to subsequent forming methods which do not favor automation or a direct application of the faster mathematical lofting method.

^{*} See Todd Shipyards Corporation Technical Report No. 1.2.4ga, "System for Mathematically Developing Shell Plate for Ships' Hulls," by Donald A. Atkins and T. A. Dunaway, Rev. August 24, 1962

Because of inherent inaccuracy in any methods other than mathematical developing method, some plates are made with a trim allowance which is removed at the sub- or final-assembly. All plates now hot formed on specially made jigs require cutting after forming with a hand-held torch. This method, of course, is cause for greatest inaccuracies, since there are no pre-established and absolute reference lines obtainable, and the cut must be performed after locating and marking the plate at the assembly.

C. THE NEED FOR A SIMPLIFIED METHOD

For the following reasons it is desirable to machine-cut the outline of a shellplate after forming:

Shellplates which cannot be properly developed due to hot-forming are already cut in this order, but by a manual, and therefore inconsistent method.

New forming methods* make it imperative to drop the present sequence, which cannot provide a usable plate edge.

In all cases, the accuracy can be improved, due to the mechanical feed and the use of a measuring device which is mounted on the machine

A plate supporting system must be devised which allows the locating of a properly marked and formed shellplate in reference to the axes of the machine. It may be advisable to double the capacity of the machine by cutting two plates (starboard and port) simultaneously, by placing them side-by-side and increasing the number of torch-heads.

The method and the machine must function with either conventional oxygen-fuel gas torches or the new plasma-arc torches. It is anticipated that the newer process, since it is much faster and more economical, will be employed. A control system must be provided

*Forming shellplates with Stretch Presses, See Report 3.0.0, Appendix B
3.0.0

which will hold the torch at the constant distance above the plate surface, and the range of its travel must be sufficient to follow a shellplate formed to the specified curvature.

Since mechanized plate burning is done in the expanded and flat condition, no commercially available burning machine is capable of this now-needed additional travel. Standard machines, now available, do not provide for the support of a formed plate, but are equipped with welded tables or conveyors conforming to a horizontal plane.

An attempt to equip a burning machine, which uses the conventional method of contour cutting along the outline, with the two named features would mean going to a four- or possibly five-axis control system. This would bring the price of such equipment to a level considerably above all existing burning machines.

It was therefore considered not feasible or desirable to maintain the present geometry of shellplates, since a more promising method was devised, which is described in Section II of this Report.*

A comparison of expected performance against the other methods is made in Fig. 2, while Fig. 3 shows how the new method fits in to the overall program.

*Refer also to Appendix A.

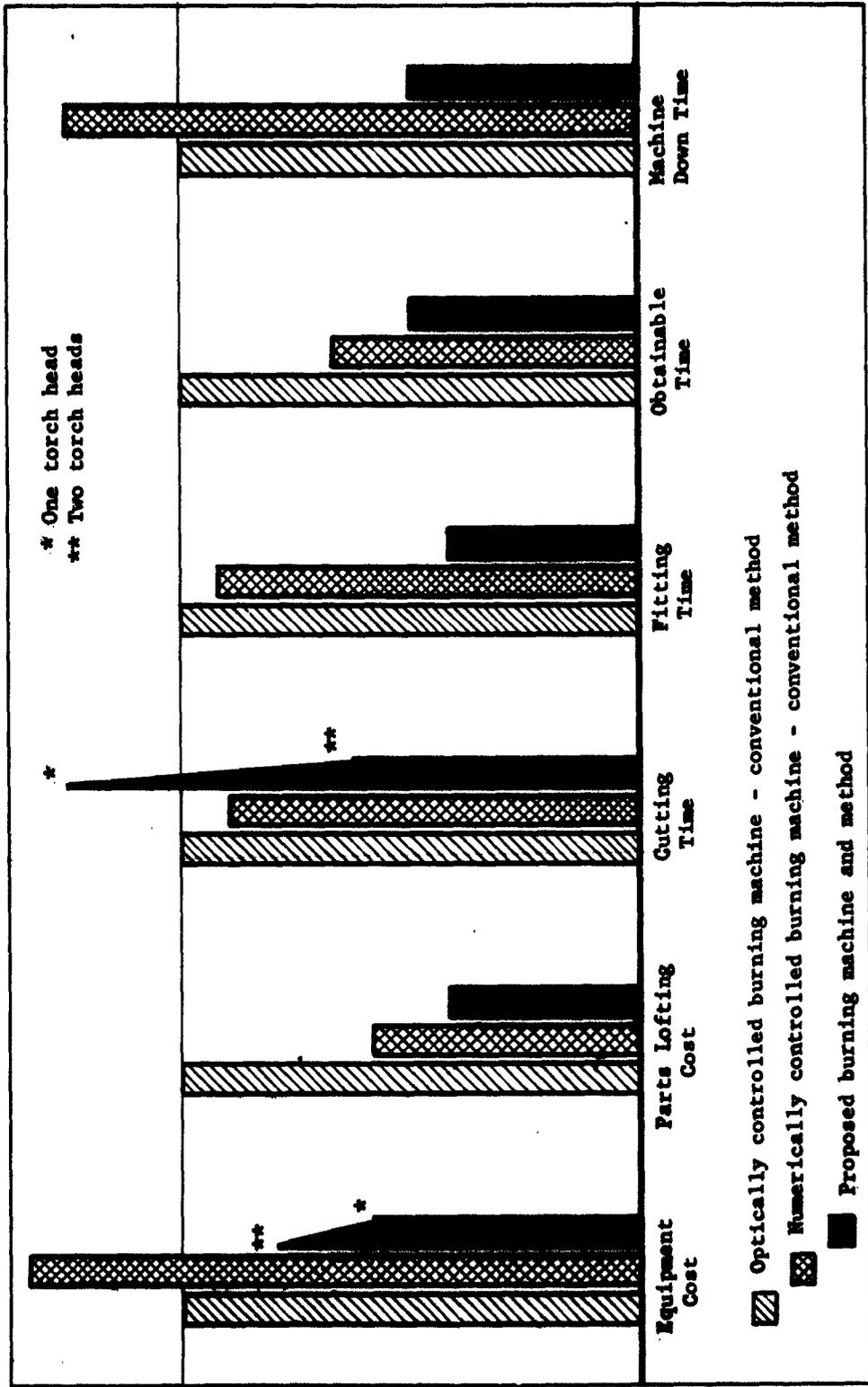


Fig. 2 Comparison Between Conventional and New Methods, Based on Same Fuel

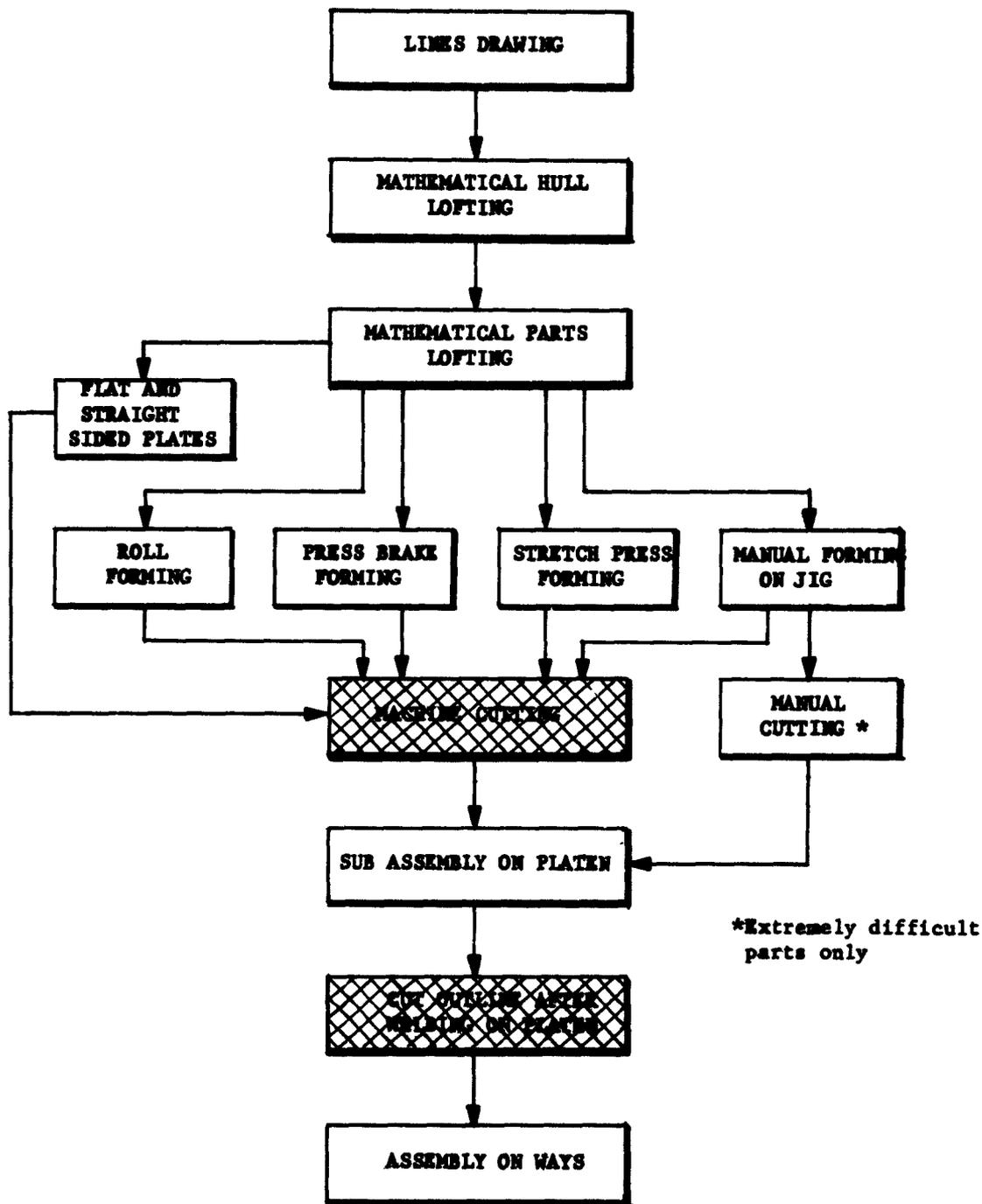


Fig 3 Cutting Shellplates After Forming

Section II

CONCEPT

A. EXPLANATION OF THE PROPOSED METHOD

The joining edges of all formed shellplates can be made to lie in the cutting plane. In making the plate layout, the corner points of all plates are established by mathematical or graphical methods in the same manner and location as presently used. These corner points are used to establish the straight cutting planes for all adjoining plates. The connecting lines between such cornerpoints are common to two adjoining plates.

Fig. 4 shows an area of several shellplates and is an illustration for the method. Points A, B, C, and D, are the corners of a selected shellplate. They are joined by geodesic lines* A-B, B-C, C-D, and D-A, respectively. These geodesic lines represent the welding seams of the respective adjoining plates. In most cases, the four points will not lie in one plane, and a diagonal line such as B-D must be imagined to divide the four-sided figure into two triangles. In the illustration, the plane going through the points B, C, and D, is extended to point E, which is a projection

*All shortest or near shortest surface lines between two points of a curved surface are here assumed to be true geodesic lines, although this is not true in all cases. This generalization does not affect the theory of the proposed method but is merely a simplification of nomenclature.

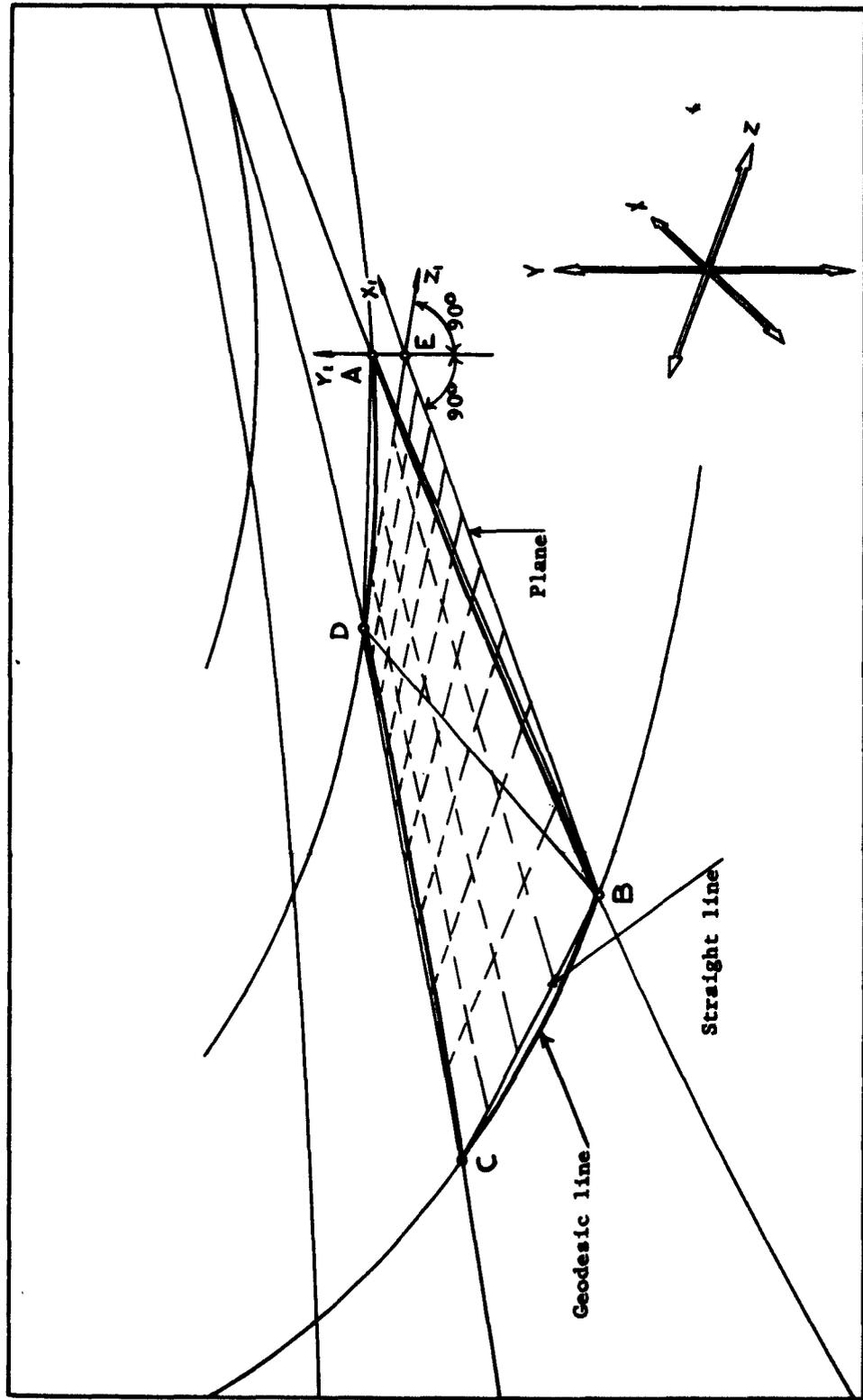


Fig. 4 Basic Plane of a Shellplate

of point A perpendicular to said plane. The known offsets for the points A, B, C, and D, in reference to the X-Y-Z-axes of the ship must be mathematically converted into offsets in reference to the X-Y-Z-axes of the plane E-B-C-D. In three-dimensionally formed shellplates, the geodesic line between two corner points does not coincide with the straight line going through the same corner points.

If all plate planes would be parallel to each other, it would be sufficient to cut the outline simply by holding the torch perpendicular to the reference plane and thus insure proper matching of all plates. Since most planes are arranged under angles to each other, the angle between the torch axis and the plane has to be controlled in reference to the angle under which these planes meet. Figure 5 shows how this angle is determined. For reason of clarity, all corner points of the plates are laid on their respective planes.

B. SELECTED SIZE AND FEATURES

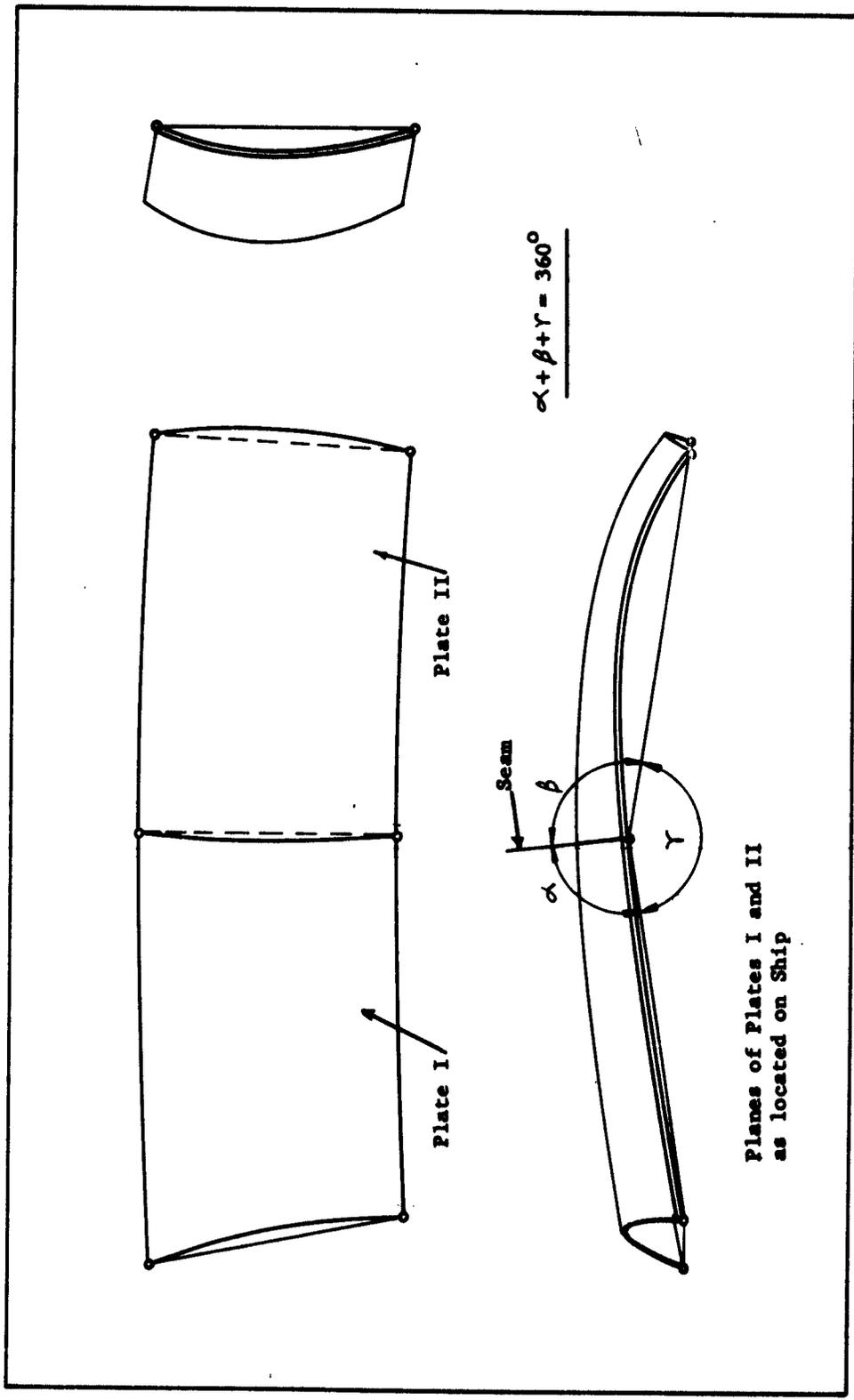
An immediate use of a machine which cuts plates as described, exists only in the shipbuilding industry. For such a limited application, it cannot be justified to invest largely in sophisticated controls or machinery.

The criteria for size and features are established for each main component, which are:

- The torch-carrying structure
- The torches and power supply
- The plate support
- The control and drive system

1. Torch-Carrying Structure

The shellplates which have to be produced are now in the size range of 10 - 12 ft wide, approximately 32 ft long, and maximum



Planes of Plates I and II
as located on Ship

Fig. 5 Angle Between Shellplates

1-1/2 in. thick. The thickness has practically no bearing on the machine structure and is not discussed here. The width is of higher significance, since it requires a longer crossrail, the deflection of which is to be considered.

Forming equipment, commercially available stock sizes, and handling, make it feasible to limit the plate width to 12 ft maximum.

Although we have an automatic torch tip to plate control, excessive sag or droop of the crossrail is not permissible because vertical control must also be maintained in reference to an inclining baseline. It is therefore proposed to support the crossrail at both ends of each twelve-foot span as an effective means of the desired weight control, thus also enabling a reduction of structural vibrations.

Gantry-type machines with double drive need synchronization of the driving gear and mean also a duplication of some components, such as gearbox, rack, and covering device for the latter.

For the tolerances needed in our application, a single drive on a properly guided carriage is sufficient, thus enabling a cost saving. The measuring device (rack) should be near the powerdrive and the guiding ways of the carriage. The support of the crossrail at the end opposite the drive should be through a level rail and an anti-friction roller. All requirements are met by this simple design and outrigger type carriage. The same basic components are used for either single plate or double plate type, enabling flexibility in the choice of the capacity.

The time required for loading, adjusting and unloading a workpiece is the same per plate, whether it be on a single- or double-sided

Machine. The proposed method allows for simultaneous cutting of the two long edges of a plate, as shown in Fig. 6. Choosing the plasma-arc process with an assumed cutting speed of 60 IPM and a plate size of 10 x 30 ft, a true cutting time of ten minutes results. For setting dials and other manual operations, add three minutes, making it thirteen minutes if plate is made singly, or six and one-half minutes if plates are made in pairs. Assume ten minutes for loading and unloading each plate, and seven minutes to align each plate, which will make a handling time of seventeen minutes per plate by either process. Total time is now thirty minutes per plate if made singly, or 23-1/2 minutes per plate if made in pairs.

These production rates are not decisively different, and the higher cost of a twin machine may not be justified. The higher rate is therefore used with both types for a cost estimate.

Increasing the length of the machine creates no new design problems, since the longitudinal track as well as the drive- and measuring-rack are built up of sections. The length should be at the option of the purchaser; however, a useable length of thirty-two feet is considered the minimum for present conditions.

An overtravel must be provided for any capacity, for the transport of the crossrail to one end and subsequent vertical loading or removal of a formed shellplate of maximum size, clearing said crossrail.

2. Torches and Power Supply

Two cutting processes are suitable for this machine: by fuel gas (oxygen flame) and by the recently introduced plasma-arc.*

*Todd Shipyards Corporation, Tec. Report 3.1.0, "State-of-the-Art Studies on Processes Considered for the Fabrication of Ship Parts" by Bruce L. Baird, dtd Jun 8, 1962

An approximately threefold increase in cutting speed of the plasma-arc process over the flame process is obtainable, as shown in Fig. 7. Considering the increasing number of plates for superstructures made of aluminum alloys, would give the plasma-arc a decisive edge. The power supply for either process must be of a size permitting simultaneous cutting of 1-1/2 in. thick carbon steel, with two torches at the recommended speed on the single side machine or with four torches on the double side machine.

It is planned to use standard torches and power supplies from any of the suppliers and merely apply them to the proposed machine. These components are for both flame- and arc-process available.

3. Plate Supports

To support the formed plates at the correct height and level, a system of individually adjustable vertical pins must be provided. The number of these pins must be sufficient to support the plate without undue local deflections which would introduce errors in the following cutting operation. A few master supports, the X-Y location of which is known and which is vertically adjustable to a known dimension, are hydraulically connected to a network of slave supports which help to distribute the load of the plate.

On the double-sided machine, this support system has to be duplicated, while the (vertical) control of them may be combined. The control by manual setting should be to an accuracy of approximately .05 in., with a resolution on the measuring element of .1 inch.

4. Control and Drive System

At this time it does not seem advisable to engage tape control for any of the control functions. Aligning of the workpiece requires considerable time and cannot be reduced by such means. The plasma-arc

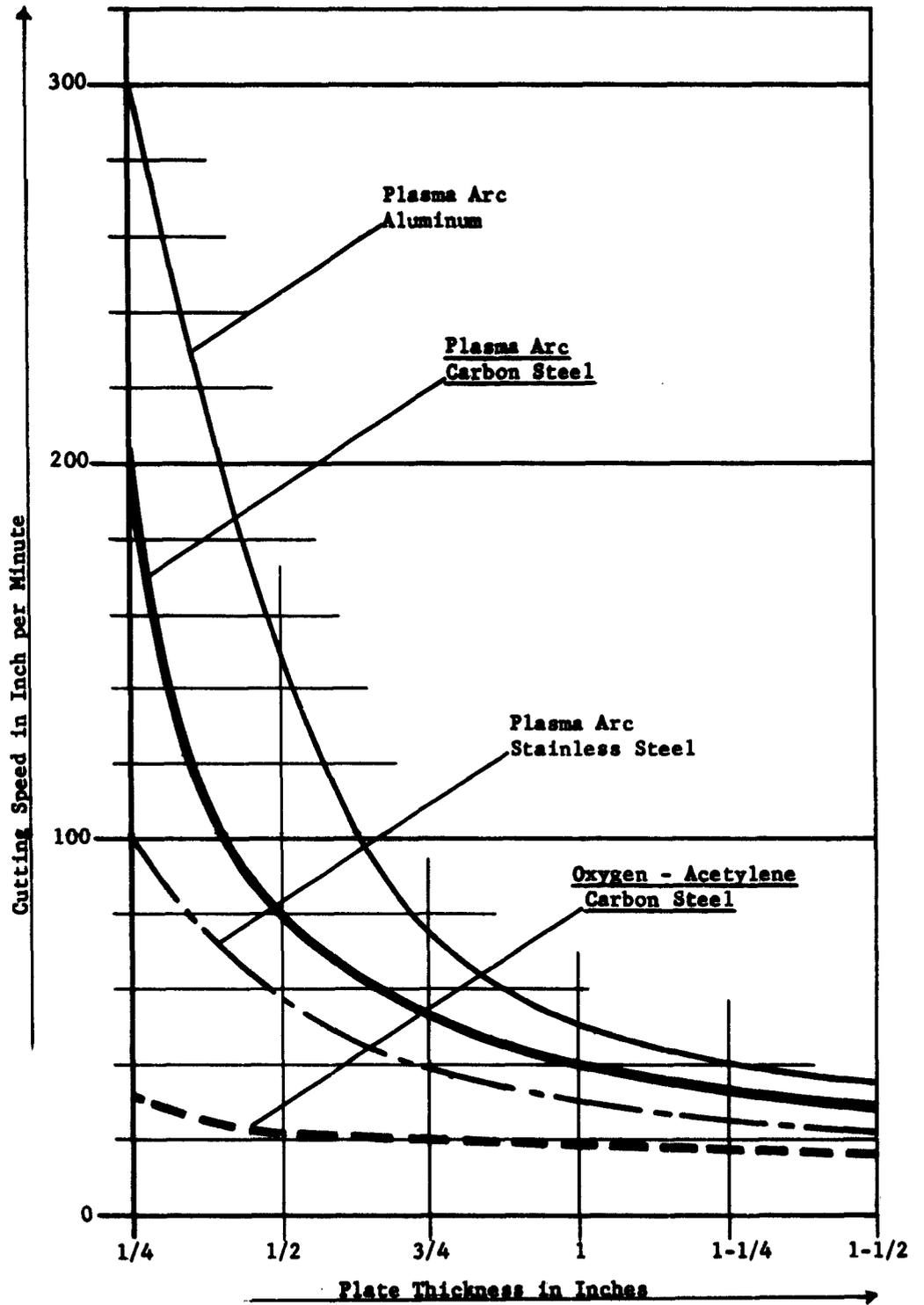


Fig. 7 Comparative Cutting Speeds

process proves much more efficient in reducing the floor-to-floor time of a workpiece.

It is therefore proposed to use a manually controlled device, such as described in Appendix B, to govern the torch movements along the X-Y plane. After each straight line cut, the next direction must be dialed in. A synchronization between the angle of cut in reference to the X-Y axes and the torch rotation about a vertical axis can be easily established. This torch rotation is required to insure correct location of the cut edges. It can be proved geometrically that a torch with a vertical rotary axis, with the nozzle directed perpendicular to the base line of the seam, makes a cut compatible with the cut of the adjoining plate, if the angle about the horizontal axis, which is parallel to said base line is in correct relation to the other plate. This condition applies to the full length of the seam.

The tilt angle of the torch nozzle about a horizontal axis, which is parallel to the base line of the cut edge, is adjusted manually and may be different for each edge of the plate.

The existing methods for the torch-tip to plate-distance control, measuring the capacitance between the workpiece (made of conductive material) and a shoe fixed to the torch, are sufficient and can be maintained. The desired distance can be set and is automatically maintained within certain limits.

The torch must be able to make a vertical movement, while moving along either X or Y axis; and the combination of these vertical and horizontal movements must give a resultant motion on an inclined straight line. The control for this motion is similar to the one which governs the cutting path in the X-Y plane.

A drive motor must provide, within limits, variable feed for either X or Y axis, from which other motions are governed. A self-contained servo-drive must be provided for the automatic torch to workpiece distance control.

SECTION III

SPECIFICATIONS - MACHINE TO CUT SHELLPLATES AFTER FORMING

I. SCOPE

A. Purpose

To provide description and performance specifications for cutting machines for formed shell plates to meet the requirements of the shipbuilding industry.

B. Classification

Plate cutting machines shall be of the following types and sizes. Types and sizes are at the option of the customer.

1. Type

- a. Type F - flame cutting machine, employing one or two (simultaneous) moving torchheads (oxygen - fuel gas) enabling cutting of shellplates
- b. Type P - plasma arc cutting machine, employing one or two (simultaneous) moving torchheads (electrical arc in gas stream) enabling the cutting of shellplates

2. Size

- a. Size 1 - capacity = 1 shellplate @ 12 ft width
- b. Size 2 - capacity = 2 shellplates @ 12 ft width

C. Intended Use

1. Basically

To cut by either flame or plasma-arc process simultaneously with two torches formed shellplates made from carbon and low-alloy steels

2. Flexibility

Machine must also be able to cut flat plates within stated capacity to any straight-sided (angular or rectangular) outline

D. Units of Measurement

All length measurements (for X and Y axes) are to be commanded in inches and decimals thereof, with a resolution of .01 inch. It may also be required to have all length measurements in feet and decimals thereof, in which case the resolution is .001 feet (= .012 in.). Disregarding the decimal point, this requirement can be easily met by increasing the number of teeth on the proper ratio-giving gear of the position transducer by a factor of 1.2.

The alternate employed is at the option of the customer.

II. APPLICABLE SPECIFICATIONS

A. NETBA Electrical Standards

B. JIC Hydraulic Standards

C. NAS Machine Axis Nomenclature

III. REQUIREMENTS

Manufacturers' contractual obligations for design and function of machine.

A. Design

The dimensions and capacities are applicable to all types and sizes of machines. The machine shall be of the moving tool (torchhead), stationary table type.

The machine builder has the choice of configuration, such as bridge type or cantilevered type crossrail.

B. Capacity

1. Type

- a. Type F - Torches shall employ the flame cutting process, using oxygen and fuel gas
- b. Type P - Torches shall employ the plasma-arc cutting process, using electrical arc in gas stream

2. Size

Dimensions and capacities as shown in Table 1 are applicable to all types of machines

3. Feed

Feedrates as shown in Table 2 are applicable to all sizes of machines

4. System Accuracy

Accuracies as shown in Table 3 are applicable to all types and sizes of machines.

TABLE 1
DIMENSIONS AND CAPACITIES
(Minimum Requirements)

Item	Size 1	Size 2
Working width	12 ft	2* @ 12 ft
Working length**	Customer's option	Customer's option
Material thickness***	1-1/2 in.	1-1/2 in.
Torch rise and fall vertically	1 ft	1 ft
Torch rise and fall axially	2 ft	2 ft
Rotation of torch about vertical axis (360° turns)	unlimited	unlimited
Rotation of torch about horizontal axis	± 45° from vertical	± 45° from vertical

Notes:

- *Two (2) working areas of specified width arranged side by side
- **Min. length 32 ft. Components to allow assembly to any greater length in increments not larger than four (4) ft. Machine builder to specify basic length and length of increments.
- ***Minimum thickness of any specified material to be cut with two (2) torchheads per plate at optimum speed.

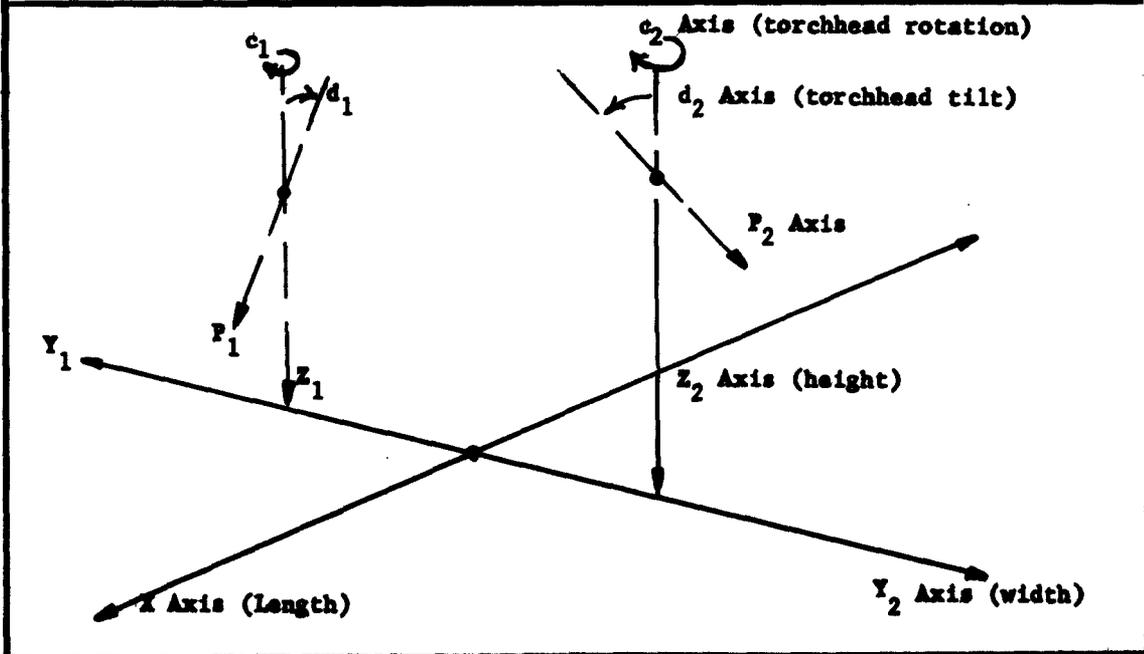


TABLE 2

FEED RATES

(Minimum requirements, unless otherwise stated)

Item	Type F (Flame)	Type P (Plasma-arc)
Cutting feed*	5 - 35 IPM	10 - 300 IPM
Rapid traverse*	150 IPM	300 IPM
Jogging feed *	5 IPM max. or .01" per smallest manual command	5 IPM max or .01" per smallest manual command
Torch rise and fall speed:		
Automatically following straight line**	4 IPM	18 IPM
Automatically following contour***	8 IPM	35 IPM
Nozzle retract***	20 IPM	35 IPM
Notes:		
*Along any direction in the X - Y plane		
**Along Z axis (vertically)		
***Along P axis (main nozzle axis)		

TABLE 3
SYSTEM ACCURACIES

Linear accuracy in X-Y plane:	
Any point within any 12 x 12 ft area, deviation from true location*	$\pm .020''$
Accumulation for every additional 12 ft length*	$\pm .015''$
Torchhead to table distance across useable length of crossrail	$\pm .060''$
Torch tip to workpiece distance along P axis (required for bevel cuts)**	$\pm 15\%$
Cut edges perpendicular to X-Y plane	$\pm 2-1/2^\circ$
Angular position of torch about vertical axis**	$\pm 5^\circ$
Linear velocity of torch in any horizontal direction**	$\pm 5\%$
Notes:	
*With indicator mounted on torch	
**In reference to commanded data	

C. Construction of Machine

1. Machine shall be constructed to comply with the requirements of Section III, and with the inspection and acceptance tests of Section IV.
2. Crossrail shall be of sufficient size to permit storing of any inactive torchheads without reducing the cutting width below the specified minimum.
3. Machine shall provide clearance for loading and unloading of maximum size workpieces vertically from overhead.
4. Machine shall be furnished with supports enabling the alignment of the X-axis tracks and with supports carrying the power supply hoses and cables over the full travel range. The purchaser will be required to supply the foundation for these supports or for any other detached components.
5. Machine shall be supplied with an operator control station, having a minimum of control functions, which will move with the carriage along the X-axis. These functions shall be:
 - Start - Stop
 - Torch on - off
 - Torch rise and fall
 - Gas pressure
 - Arc energy controls
6. Machine shall also be supplied with stationary emergency button at a convenient location of the machine. This button to stop all feed movements and shut off oxygen or electric arc supply.

7. Machine shall be furnished complete with all control cables, power cables, junction boxes, control panels, frequency converters, starters, hoses, piping, tubing, reels, operator's stand, and any other items required to complete the installation.

The purchaser will be required to supply services to the machine or control panel as the case may be, and make the connections at this point only. All other inter-connections to be furnished by the machine builder.

8. Machine shall be supplied with reference position readouts for the full capacity of the X- and Y-axes. Readouts must give the position of the torchheads in reference to an adjustable system-zero to the resolution and accuracy of the system, and must be engaged at all times.

D. Control

1. Manual Adjustments

Machine shall provide manually adjustable devices for the following functions:

- a. Adjust torch radially to compensate for variations in kerf width as material thicknesses are changed.
- b. Adjust torch vertically to obtain the torch-tip to table surface distance, as specified in Table 1.
- c. Disengage any torch head from the mechanism driving it in the Y-axis.

2. Automatic Adjustments

Machine shall provide automatic control of the following functions:

- a. Maintain the manually-set torch-tip to plate distance over the entire cutting cycle.
- b. Raise torches whenever oxygen or electrical arc supply is shut off.

3. Manual Mode of Operation

Controls shall permit the execution of the following operations simultaneously or sequentially where desirable:

- a. Adjust kerf compensating device
- b. Adjust torch tip to plate distance
- c. Retract and lower torch
- d. Adjust all gas pressure, flow regulating, and electrical power regulating devices for cutting torches
- e. Move torches under rapid traverse, cutting feed rate, or by jogging to any point within the travel limits
- f. Adjust setting of preheat flame
- g. Start and stop flow of oxygen and fuel gas for the flame torch or electrical power and gas for the plasma-arc torch
- h. Ignite flame torch
- i. Actuate plate marking mechanism

E. Safety Devices

Each machine shall be furnished with suitable safety devices of the latest type. Parts which are hazardous to the operator shall be suitably guarded where practical. Ample protection against electrical shock shall be provided. Safety stops limiting extreme travel of carriage (gantry) and torchheads are to be installed.

F. Interchangeability

All replaceable parts shall be constructed to definite standards, tolerances, and clearances in order that any such part may be replaced or adjusted without requiring modification. Where practicable, such parts shall be permanently and legibly marked with the manufacturer's part number.

G. Power Supply

Machine shall be able to operate properly when supply voltage is off ± 10% from nameplate values.

IV. INSPECTION AND ACCEPTANCE

A. Classification of Tests

1. Verification of requirements of Section III
2. Tolerance Tests, Section IV.C.2.
3. Performance Tests, Section IV.C.3.

B. Test Conditions

Each machine shall be tested under the following conditions as specified under Ordering Data (Section VI):

1. At manufacturer's plant by manufacturer, with verified test results furnished customer
2. At manufacturer's plant witnessed by customer
3. At customer's plant

C. Test Details

1. Check required items specified in Section III., not covered in Section IV.
2. Tolerance Tests per later submitted detailed instructions
3. Performance Tests - These tests are (1) for testing the function accuracy of the machine under actual cutting conditions, and (2) to prove the performance of the machine control unit, the machine drive, and cutting torches.

V. OPERATING AND INSTALLATION DATA

The manufacturer shall furnish a copy of the following data for each purchased machine. Additional copies shall be furnished at purchaser's option.

- A. Scaled plan view, front elevation and end elevation with major dimensions, consisting of all work space clearance dimensions, overall height, width, and length dimensions, and dimensions of peripheral equipment, such as control cabinets.
- B. Certified foundation and/or installation drawings, showing location and sizes of all required services where applicable. Drawings to be furnished sixty days prior to shipment.
- C. Maintenance Manual
- D. Operator's Manual
- E. Parts List, including recommended spare parts list
- F. Electrical wiring and schematic diagram
- G. Hydraulic and pneumatic circuit schematic

VI. ORDERING DATA

- A. Customer's option, per classification (Section I.B.)
- B. Customer's option of unit of measurement (Section I.D.)
- C. Customer's option on Acceptance Tests (Section IV.B.)
- D. Preservation and Packing
- E. Shipping instructions

SECTION IV
INFLUENCES ON SHIP DESIGN

To take fullest advantage of the new method and the used raw material, a few rules should be followed:

Preferred plate dimensions are of a rectangular size which can be handled by available forming equipment and which is commercially available at economical cost. The cut plate should follow the raw outline as much as is possible to avoid waste of material.

For easy programming, staggered weld seams (or butts) should be avoided by using common corner points on adjoining plates. Today's welding techniques allow crossover of seams at small angles, thus making steps in shell seams to cross deck plates at right angles unnecessary.

Seams are made without regard to being fair over the full ship. The proposed method will create a fair line along each side of a plate. Although the next plate will again have a faired edge, the entire edge of two plates may be unfair, due to a slight break at the common corner point. Such breaks may be visually detectable only by looking along the seam with the eye close to one end of it. The seams do not affect the three-dimensional shape of the plates, which may be produced to follow the ideal hull form. Therefore, seams thus produced do not interfere with the hydrodynamic properties of the ship.

APPENDIX A

TODD SHIPYARDS CORPORATION
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Page 1 of 7

DISCLOSURE OF INVENTION

Report 3.4.3

TITLE: SIMPLIFIED METHOD OF CUTTING CORNERS OF SHELL PLATES AFTER FORMING

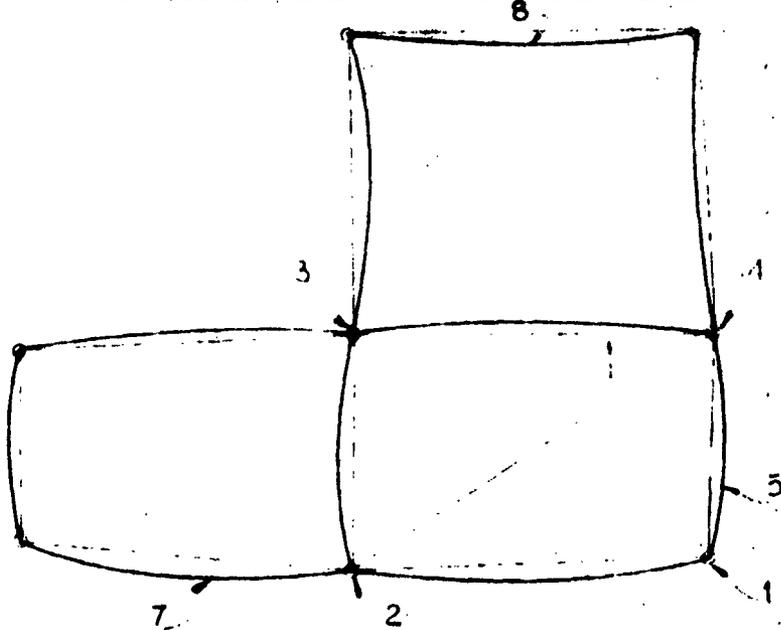


FIGURE 1

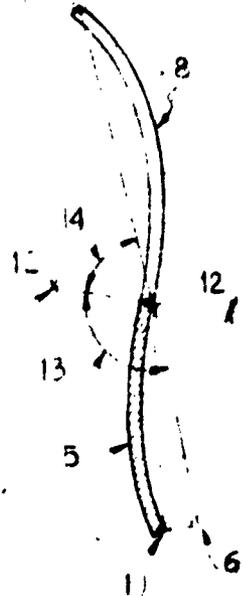


FIGURE 2

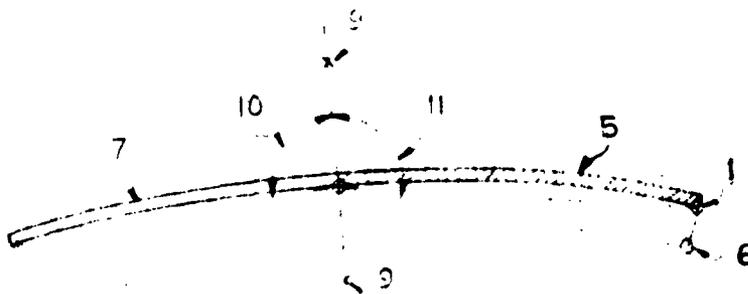


FIGURE 3

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DISCLOSURE OF INVENTION

Report 3.4.3

TITLE: SIMPLIFIED METHOD OF CUTTING CONTOURS OF SHELL PLATES AFTER FORMING

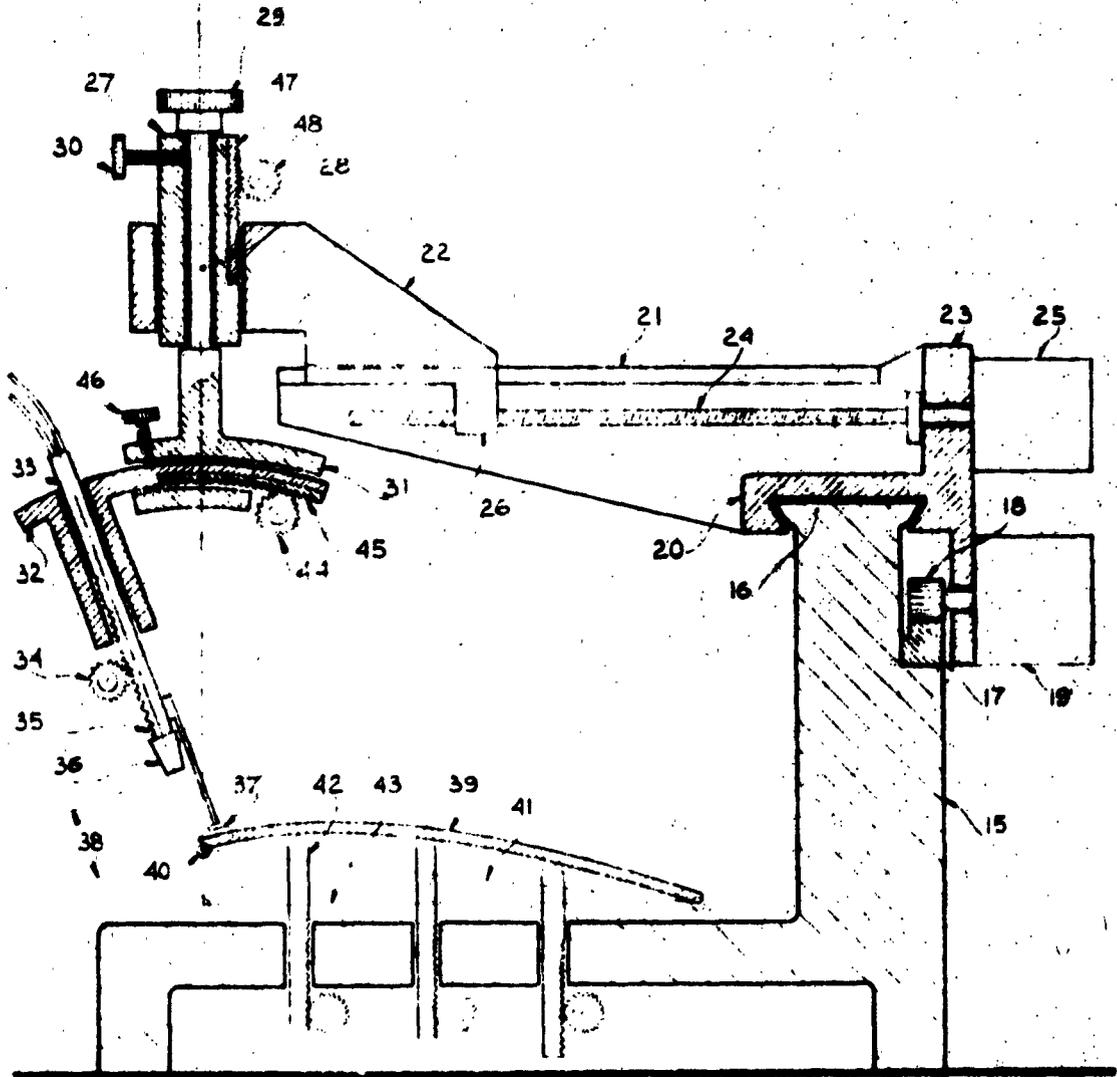


FIGURE 4

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DISCLOSURE OF INVENTION

Report 3.4.3

TITLE: SIMPLIFIED METHOD OF CUTTING CONTOURS OF SHELL PLATES AFTER FORMING

ABSTRACT

A method is described, wherein three-dimensionally formed plates can be cut to the required outline with a minimum of information, i.e., one straight line for each side of the basic shape.

Further, a torch cutting machine is described which enables the application of this method using the same information to control the slide movements along the established straight sides.

I. PROBLEM

Shell plates for ship hulls are cold-formed on rolls or presses, or hot-formed manually on jigs. While simple forms may be cut along the outline in advance, more complicated forms will distort the outline considerably. Some fabrication methods require excess stock for feed-in or gripping purposes on two sides.

These reasons, together with the requirement that the parts be made with little or no fitting on the sub-assembly or aboard, make it desirable that such shell plates be torch-cut along the sides after forming.

II. EXISTING METHODS

Some of this work is presently done by cutting before forming, resulting in inaccuracies. Parts are also being cut part way manually at installation, resulting in high labor cost and inaccuracies. Other proposed automatic cutting machines need 2 or 3 axes of continuous control. Considerable effort has to go into mathematically defining and programming the contour.

III. DESCRIPTION OF A NEW METHOD

The contours required for joining shell plates by welding can be established with a simple method.

A network of lines, the location of which is governed by the individual shell plates, is laid throughout the entire ship's hull. Corner points are established for straight-sided triangles or four-sided figures, such that adjoining areas have common sides. These areas follow closely the particular shell plate.

If such an area is not a plane, it must be divided into two triangles (surface

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DISCLOSURE OF INVENTION

Report 3.4.3

TITLE: SIMPLIFIED METHOD OF CUTTING CONTOURS OF SHELL PLATES AFTER FORMING

III. DESCRIPTION OF A NEW METHOD (Cont.)

planes) for computing and control purposes only. A projection of the four-sided area, its plane preferably enclosing one of the triangular planes, is to be established. The location of the corner point, which is outside the four-sided plane, must be established in reference to the latter.

The projected planes are of rectangular shape in the midship section and become trapezoids, quadrilateral figures, or triangles, toward both ends of the ship.

The fact that the sides of the projected planes are straight may be gainfully utilized in building a burning machine which is able to produce a three-dimensional contour on a formed plate by following straight lines. Continuous path contouring by tape is no longer necessary and can be reduced to point-to-point positioning with constant speed control by means of punch cards, tape, or pre-set dials.

Drawings are attached to illustrate the relationship between the shell plates and the described planes of a limited hull area. Fig. 1 is a plan view of this area, Fig. 2 is the cross-section approximately perpendicular to the plan view, and Fig. 3 is a section approximately perpendicular to both Figs. 1 and 2. To simplify the problem, the corners of all surface planes are laid to the inside surface of the shell.

Points (1), (2), (3), and (4) are the corners of a straight-sided area which is not a plane. A diagonal (2) - (4) divides this area in two triangular planes, with all corners on the shell (5). Plane (2) - (3) - (4) is extended to enclose the projection of triangle (1) - (2) - (4). The projected four-sided plane is now (6) - (2) - (3) - (4).

The planes of the shell plates (7) and (8) have common base lines with the plane of shell plate (5), namely (2) - (3) and (3) - (4) respectively. All shell plates have the same corner points as their planes, but may have curved sides.

A cutting plane (9) is laid through the two adjoining planes approximately perpendicular to the shell plate and ending at the points (2) and (3). The angles (10) and (11) are to be noted for later use in fabricating the shell plates. Said cutting plane describes a seam or butt between two plates of a hull. Plane (12) is another cut through adjoining plates and forms, together with their planes, the angles (13) and (14). These angles may be different for all four sides of a plate and can be chosen to suit fabrication best, i.e., a cut approximately perpendicular to the shell surface.

The feature of this method is: any chosen cutting angle will produce a matching

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DISCLOSURE OF INVENTION

Report 3.4.3

TITLE: SIMPLIFIED METHOD OF CUTTING CONTOURS OF SHELL PLATES AFTER FORMING

III. DESCRIPTION OF A NEW METHOD (Cont.)

set of seams on the two adjoining plates, the coordinates of which seams need never be known. The system is applicable to both convex and concave shapes as well as to a combination of both.

IV. AN APPLICATION OF THIS METHOD

As was pointed out earlier, shell plates are to be torch-cut along their outline after forming. In the following, a machine is proposed to do this job with a minimum of controls. Fig. 4 shows an end view of the machine looking in the direction of the longitudinal axis.

The base (15) has fixed to it the longitudinal ways (16) and the rack (17), which is in mesh with the gear (18), driven by motor (19). Carriage (20) is support to said motor and moves longitudinally. Integral with the carriage is a cross beam (21), guiding the crossslide (22). The carriage contains also the thrust bearing (23) for the screw (24), which is powered by motor (25). Screw-nut (26) converts the rotation of the screw into a linear motion.

A quill (27), is mounted vertically in the crossslide, containing a shaft (28). The rotation of this shaft is controlled by a dial or drive (29). Locking device (30) permits holding the shaft in a given angular position. The shaft carries circular ways (31), guiding a rocking segment (32) which in turn allows a toolholder (33) to be moved by drive-gear (34) and rack (35). Said toolholder carries the single or multiple torch (36).

A device (37), such as is already in use on flame cutting machines, governs the drive (34), to hold the torch at a constant distance (38), from the work-piece (39). The axes of both shaft (28) and toolholder (33) converge at any setting at a point (40) which lies in the earlier discussed straight side of the surface plane (41).

Adjustable supports (42) hold the work-piece at the height which places the earlier discussed projected plane (43) at a constant level. The angle between shaft (28) and toolholder (33) is adjustable by gear (44), and gear segment (45), and can be locked with device (46). Conditions may require this angle to be set differently for all sides of a work-piece.

The machine is now able to make movements in the longitudinal and cross axis, to cut shell plates with a rectangular base plane. However, straight line angular movements in a horizontal plane can be executed by using a compensating device, which advances the tool in one axis an amount equal to the tangent of the desired angle, multiplied by the length traveled along the other horizontal axis. This procedure can be repeated for each side of any triangle or four-sided figure.

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DISCLOSURE OF INVENTION

Report 3.4.3

TITLE: SIMPLIFIED METHOD OF CUTTING CONTOURS OF SHELL PLATES AFTER FORMING

IV. AN APPLICATION OF THIS METHOD (Cont.)

If the projected plane (43) is not identical with the surface plane (41), a vertical adjustment of the tool has to be made. For this purpose, the quill (27) contains a rack (47), which is driven by a gear (48). Another compensating device makes a vertical adjustment which is equal to the tangent of the angle between the side lines of planes (41) and (43), multiplied by the length traveled along the respective horizontal axis.

The taper attachment of a lathe is one such known compensating device. A more convenient and, for this purpose, adaptable device is described in a Patent Disclosure by W. Lauper dated June 13, 1961. Such a device is suitable for either manual or tape input.

V. OTHER POSSIBLE APPLICATIONS OF THIS METHOD

In this disclosure, an application is described and terms are used pertaining to shipbuilding. The method can be applied to other industries using three-dimensionally shaped skins, shells, or vessels. The machine can be designed with multiple torch heads and controls to make two or more cuts simultaneously, as for the opposite sides of the same plate, or for alike or symmetrical multiple plates.

While an application for torch cutting is described, other suitable cutting tools may be employed. The method and machine is also adaptable for joining plates by welding - gaining similar advantages.

The terms "shellplate" and "projected plane," as described, pertain to the single one-piece plate. However, they may also be applied to the total of any number of assembled plates, especially in the size of a pre-fabricated sub-assembly as used in shipbuilding.

A variation of the machine design can be such that a rail structure, carrying the cutting or welding heads, is portable and adjustable to align to the seam.

VI. ADVANTAGES OF THIS INVENTION

Mathematically defining a ship's hull is simplified, since in establishing the contour of each individual shell plate, all but the corner points can be eliminated. The actual three-dimensional outline of a shell plate need never be established, since these dimensions are not needed for cutting the part. Time is saved in both defining the shape and programming for following fabrication.

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DISCLOSURE OF INVENTION

Report 3.4.3

TITLE: SIMPLIFIED METHOD OF CUTTING CONTOURS OF SHELL PLATES AFTER FORMING

VI. ADVANTAGES OF THIS INVENTION (Cont.)

A machine as described has a control mechanism far less complex than as required for conventional contouring by continuous control. Considerable savings should be possible.

By employing mechanical control elements, it is possible to build a low cost, semi-automatic machine in which commands can be pre-set with dials.

By using numerical control, the limited amount of information needed would permit the use of a single punch card per shell plate, instead of a longer tape, as required for continuous control.

VII. NOVELTY

Working to the basic plane of a formed part instead of its physical contour for producing the latter, was - to our knowledge - never attempted before.

While this method is claimed to be new, only a machine as described can fully utilize the advantages of this method. Since no machine with these features is known to be existing, novelty is also claimed for the design of a machine which uses the straight-sided outlines of surface planes to control the movement of a tool holder in such a way that three-dimensional contours can be produced.

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DISCLOSURE OF INVENTION

Report ID-3

TITLE: CONTROL DEVICE FOR ANGULAR MOVEMENT OF X-Y SLIDES

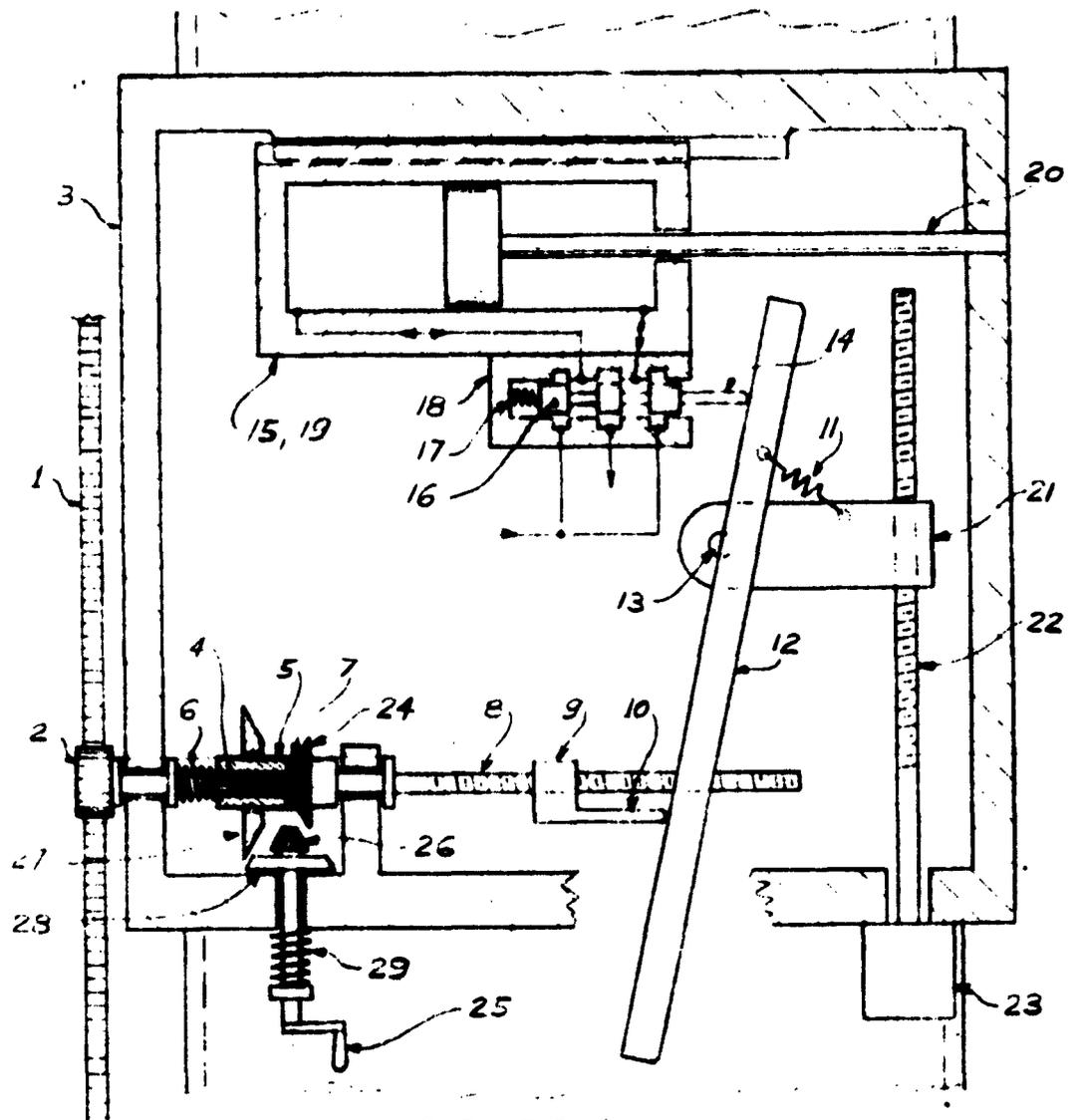


FIGURE 1

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Page 3 of 6

DISCLOSURE OF INVENTION

Report ID-3

TITLE: CONTROL DEVICE FOR ANGULAR MOVEMENT OF X-Y SLIDES

ABSTRACT

A device is described which governs the lateral movement of a machine slide in a selected proportion to a longitudinal movement of a second slide to obtain a resultant angular movement.

The angle and direction of this resultant movement is adjustable by means of a positioning mechanism, enabling direct setting of any desired cut.

I. PROBLEM

A machine as described in Disclosure Report 3.4.3 of March 26, 1962, (Simplified Method of Cutting Contours of Shell Plates After Forming) relies on the execution of straight-line parallel or angular movements.

Other burning machines require simultaneous parallel or angular movements of multiple torch heads for the production of stripes out of plate stock, as used in steel constructions.

Conical shapes on lathe work, especially when of considerable length, pose other control problems.

II. EXISTING METHODS

Parallel and perpendicular cuts can of course be made without additional controls by simply clamping one slide while moving the other along its axis. Angular cuts can be made by placing the workpiece at the desired angle and making, in reference to the machine ways, a parallel cut. This requires considerable set-up time, especially when all sides are of different angles.

It is also possible to use tape control for such movements, which is a rather expensive method for operations of such simplicity.

The so-called "Taper Attachment" of lathes does this job with some efficiency; however, it requires a full-length adjustable template.

A Patent Disclosure by W. Lauper dated June 13, 1961, (Norden Division of U.A.C.) describes a device capable of doing the same control function in a different manner.

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Page 4 of 6

Report ID-3

DISCLOSURE OF INVENTION

TITLE: CONTROL DEVICE FOR ANGULAR MOVEMENT OF X-Y SLIDERS

III. DESCRIPTION OF A NEW METHOD

Figure 1 shows the basic principle of this control device. Along the longitudinal axis of a machine is a rack (1), in mesh with pinion (2), which is carried by the longitudinal slide (3). When this slide is moved, the pinion is caused to rotate and will transmit its rotation over a spline shaft (4) to the coupling half (5). A spring (6) keeps this part engaged with coupling half (7), causing a screw (8) to rotate.

Rotation of this screw in turn moves the nut (9) and input stylus (10) in a straight line. A spring (11) keeps the straight-sided rocker arm (12), which is suspended on pivot point (13), in intimate contact with the input stylus. A Follower-stylus (14), moving in a straight line along the transverse slide (15), is connected to the spool (16) of a servovalve. A return spring (17) keeps the follower-stylus in contact with the rocker arm. The body (18) of the servovalve is fastened to the cylinder (19), the forces of which are reacted through the piston (20) on the longitudinal slide (3). The transverse slide (15), carrying the tools, is mounted to the cylinder. The function of the servovalve is assumed to be known and is not explained here.

The position of the pivot point (13) and the nut (21) depend on the rotation of the screw (22), governed by an angle drive and transducer (23). The ratio of distances of each stylus to the pivot point is a measure for the angle to be cut. By bringing the pivot point in line with the follower-stylus, no output movement will result. Moving the pivot point beyond the centerline of the follower-stylus will reverse the direction of the transverse travel.

A zero shift device is incorporated, permitting the screw (8) to rotate while the pinion (2) is in stillstand. A bevel gear (24) is mounted on the screw (8), in such a way that if a handwheel (25) is axially depressed, a bevel-gear (26) is brought in mesh with the first bevel-gear. In this position, the coupling half (5) is disengaged from the coupling half (7) by means of the interference of cone (27), axially locked to coupling half (5) and cone (28), fastened to bevel-gear (26). Rotating the handwheel in the depressed position will allow lateral movement of the nut and input stylus without movement of the longitudinal slide.

Thus, after setting the angle drive, the possibly mis-positioned machine slide may be brought into correct position while observing the position readout for this axis. A spring (29) will disengage the bevel-gears and allow engagement of the coupling upon release of pressure on the handwheel.

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DISCLOSURE OF INVENTION

TITLE: CONTROL DEVICE FOR ANGULAR MOVEMENT OF X-Y SLIDES

III. DESCRIPTION OF A NEW METHOD (Cont.)

Figure 2 shows a variation of the angle transducer and drive. In this, the screw (22) is rotated by a drive (30), while the angle transducer (31) receives its rotation over a linear-to-rotary mechanism (32), which is being displaced by a logarithmic template (33). This template now allows the use of a conventional position transducer with a linear characteristic.

Another (not shown) variation is possible by introducing a reversing gear in the input for the transverse movement, thus eliminating the need for going with the center of the pivot point beyond the centerline of the follower-stylus.

IV. AN APPLICATION OF THIS INVENTION

The device is directly applicable to a machine as described in Disclosure Report 3.4.3, which executes straight line angular or parallel movements. On such a machine it may be required to control either one or more out of two or more axes. The lateral movement of any axis is always dependent on the movement along any other selected axis.

The angle adjustment may consist of a simple handcrank with dial, a manually operated drive with position readout, or a fully numerically controlled servomotor with position transducer.

Engagement and rotation of the zero shift device may also be designed for remote control, if this seems desirable.

V. OTHER APPLICATIONS OF THIS INVENTION

A multiple torch-head burning machine, similar to existing ones, but able to make angular cuts, can be controlled with the described device. Such parallel cutting machines are widely used in the steel construction field for simultaneous cutting of long strips out of plate stock. Introducing angular movements to such machinery would widen their application considerably.

Another possible application of this device is the control of the cross-slide on lathes for the production of conical shapes. After setting the angle and the diameter on the starting end of the cone to be turned, engagement of the longitudinal feed will cause the cross-slide to move along the selected angle. The same principle may be employed for face-turning on lathes, whereby the crossfeed causes the carriage to move the desired amount along the longitudinal axis, thus producing a steep taper on the workpiece.

Shown and Described to us
this 10th day of May, 1962

Glenn M. Jones
Thomas G. Smith Witnesses

Signed
this 10th day of May, 1962

Warner R. Lauper
Warner R. Lauper Inventor

DISCLOSURE OF INVENTION

TITLE: CONTROL DEVICE FOR ANGULAR MOVEMENT OF X-Y SLIDES

VI. ADVANTAGES OF THIS INVENTION

A control as described eliminates the need of rotating a workpiece on the machine to keep the desired contour parallel to the machine ways. Functions which before needed continuous-path numerical control can now be governed simply by manual dial settings.

Full-capacity taper attachments for large lathes would become unreasonably big and awkward to handle, whereas the described device is but a small package taking advantage of the already existing longitudinal rack. Especially for long travels, this device enables cost savings and easy handling.

Besides manually, this device may also be adjusted by any numerical control positioning system, if required.

VII. NOVELTY

It is claimed that the method of using the movement along one axis to control the movement of a second axis perpendicular to said first axis, by means of a mechanical transmission as described, is unique and new.

Further, it is claimed that the method of an angle adjustment, which enables the production of any angle cut within feasible limits, was never used before and is novel.

Further, it is claimed that the alternate design of this angle adjustment, using a logarithmic template to enable the use of standard transducers with linear characteristics is unique to the invention and is novel.

Shown and Described to us
this 10th day of May, 1962

Signed
this 10th day of May, 1962

Klemme M. Jones
Thomas J. Smith
Witnesses

Warner R. Lauper
Warner R. Lauper Inventor

Appendix D

**TODD SHIPYARDS CORPORATION
Los Angeles Division**

San Pedro, California

Contract NObs-4427

**COMPUTER FAIRING
AND NUMERICAL CONTROL OF MACHINERY**

TECHNICAL REPORT NO. 7.1.0

**PROCEDURE TO ESTABLISH A COST ANALYSIS AND COMPARISON
BETWEEN DIFFERENT PRODUCTION METHODS**

By Warner R. Lauper

June 11, 1962

ABSTRACT

A procedure is described by which the economy of conventional and newly proposed fabrication methods in shipbuilding can be compared.

The purpose of such a comparison is to enable any user to select the best equipment for their yard, based on an anticipated workload. To develop such an evaluation, typical ships are divided into typical parts and data is compiled for the final evaluation. Equipment cost, labor cost, and all factors contributing to the price of a produced part are entered.

Special care is given to the fact that data must be available in a form to allow great flexibility and expandability in the evaluation.

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ILLUSTRATIONS

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SECTION I

INTRODUCTION

The ultimate goal of Contract NObs-4427 is to lower the cost of building ships. The conventional methods now used in this industry require relatively low-cost equipment. However, because of insufficient accuracy obtained, these same methods demand a great amount of manual labor - first in the actual production of the parts, and second in the fitting of these parts for the sub-assembly on the platen and for final assembly on the ways.

Methods and machines with promising features are proposed under a different task of this Contract. Such machines of higher complexity (requiring less labor, enabling fabricating of more accurate parts, and raising production rate) can be obtained only at a higher cost, and must therefore be justified if used in place of simpler and cheaper equipment. Knowledge of the desired production in a given yard for a selected time is necessary in order to recommend a particular type of equipment for that yard. A statement that the best solution be found for producing - say 10 ships, is not sufficient, since we have to be concerned with different workloads of many yards at different times. Some methods may bring more advantages to a particular ship's type due to the number or shape of parts employed. It would therefore also be false not to distinguish between different types of ships. It is sufficient to have the required

data presented as a comparison of costs, eliminating all factors which apply as an equal amount to all methods. As an example, the material of a finished shellplate is omitted, since its size is certainly the same after employing any method; however, excess material required in the production of the part and eventually wasted is included, since it is expected to vary for some methods. The material used for making jigs and the energy used for the actual fabrication of parts have to be compared with the labor and equipment cost, which require that all data must be presented in dollars.

Basically, all ships are built up of a number of components which look much alike, although different in the actual dimensions. It is proposed to find and describe classes of typical workpieces and establish the cost for only one of each kind. A count of such typical parts will then be made for any class ship, since the type of ship to be built has a bearing on this comparison, e.g., a ship employing a great number of flat shellplates will not require as much emphasis placed on plate forming equipment as will a ship of the same size using all formed plates.

Utilizing this theory, a cost comparison can be conveniently established in a short time for any selected workload of any yard. This important flexibility is obtainable without additional cost simply by having the sub-totals available in the most useful form. It is possible to select the best equipment to build any one ship, any number of such ships, or any combination of any number of ships.

Typical workpieces as occurring on Merchant and Navy Ships will be considered. Fabrication methods representative of the average for the entire shipbuilding industry will be used to establish most of the fabrication costs. Data of these methods will be obtained from the appropriate sources. Production costs for methods using equipment not yet existing will be established by estimating, again considering average conditions in line with most yards.

This report covers the cutting and/or forming of shellplates, deckplates, floors, bulkheads, and frames. The comparison starts with the lofting already done and available as offsets, and ends with the fit-up on the ways, but does not include welding. The cost comparison between mathematical and graphical lofting is the subject of another report and is not treated herein. The procedure, showing how the problem of comparing costs was attacked, is a method for obtaining the data only. Final conclusions and recommendations cannot be drawn yet, since the true estimated figures are not available as of this writing.

In Section II, the method of selecting typical workpieces and their application on typical ships is explained. Direct production costs consisting of labor, material, and energy used for the manufacturing operation of such typical workpieces, as well as for needed tooling, are treated in Section III. The equipment cost for standard or special-built units is the subject of Section IV. The application of these compiled data for any yard, together with a procedure for the evaluation of different fabrication methods, are treated in Sections V and VI of this report.

SECTION II

METHOD FOR SELECTING TYPICAL WORKPIECES RELATING TO ANY SHIP CLASS

The workpieces of a ship which we are considering in this evaluation are the frames, as well as the plates for the shell, floors, bulkheads and decks. In any group of these workpieces, several can be found with sizes of sufficient similarity to allow them to be considered typical.

Forms 7/8-1 A through C* give the description of such typical workpieces. Plates will be grouped by their perimeter because this length is a direct measure for the cutting time. Sub-grouping is made for formed shellplates according to their maximum curvature, which is a direct criterion for the difficulty in forming. Bulkheads, floors, and deckplates are also grouped according to the complexity of their outline. An average thickness of 3/4" for shellplates and of 1/2" for bulkheads, floors and deckplates is assumed for estimation purposes. This approximation is permissible and greatly simplifies estimating. Frames will be classified by their cross section and curvature, for both single and reversed bends.

Sufficient typical workpieces must be established for the utilization of this method on any type of existing surface ship - both military and commercial.

Since all types of ships can be considered built of typical workpieces,

* See Appendix A for sample forms.

a cost comparison can be easily established if the number of typical workpieces is known.

Form 7/8-2 serves the purpose of making the count of such workpieces for each type of ship. This data must be based mainly on available ship plans and on the experience of the Naval Architect. It can be established in advance for all known ship types, while newly-developed ships can be estimated at any future date.

SECTION III
ESTIMATING PRODUCTION COSTS

All practical fabrication methods for each workpiece group are listed on Form 7/8-4. Some of these methods are characteristic of and identified by certain makes of machines, such as the "Hugh Smith" Cold bender. Besides the conventional method of cutting the developed shellplate before forming, a method of cutting after forming is proposed and also listed.

On Form 7/8-3 data is entered for each typical workpiece and method, detailed as indicated. The breakdown is to be as complete as possible, including production jigs, inspection templates, but without including the cost of the basic machine. Parts lofting, either graphically or mathematically (the latter divided into operator and computer time), is listed, as well as drafting, programming for tape control, or other preparatory functions, to establish sufficient fabrication data. The production of the actual workpiece requires labor and energy, both of which are to be listed separately. Excess material required in forming or cutting of parts but eventually wasted is included; it does not include the material for the finished part. Labor is required for handling the workpieces as a single part as well as on the sub-assembly and on the final assembly on the ways, while fitting of the parts requires labor on both sub-assembly and aboard. Costs for individual operations may be omitted only if they apply in equal amounts to all considered methods.

All above entries are then added in the following sub-totals for each fabrication method:

- A. Non-recurring costs, consisting of production- and inspection-tooling, and work preparation.
- B. Recurring costs, under which are listed all actual fabrication and which cannot be avoided by multiple fabrication.
- C. Learning costs, consisting of the additional time required to make the first one of each ship class. These costs comprise a certain percentage of the production operation, the fitting on the platen and on the ways.

While estimated data for some of the workpieces are entered on these forms, more data can be established by interpolation and all together are collected in Form 7/8-6.

SECTION IV

ESTIMATING EQUIPMENT COSTS

Form 7/8-5 is prepared for the cost compilation of equipment used in the fabrication of frames and plates.

The actual cost of both standard and specially-made equipment must be considered. Prices of standard machines are based upon actual quotations as far as they are available. The cost of non-standard and specially-made equipment will be estimated after making preliminary design studies. Consideration is given to the fact that under high or multiple-yard production, several machines would have to be purchased or built permitting a distribution of the design and tooling costs for the specially-built machines over a greater number of units, thereby lowering the per-unit price.

Because amortization of design and tooling does not always coincide with the number of machines initially built, the price based on any desired pro-rating must be established. The cost for building is divided between setup and actual production cost of one machine, to enable the establishment of the machine price for any number of machines built at the same time.

Since we are comparing simple machines and methods against more sophisticated equipment, the costs for maintenance, overhaul, storage, and amortization of equipment will differ greatly. Maintenance costs, excluding major overhauls, are estimated for one year, e.g., for a simple jig, this cost

will be nil, while for a roll it will consist of lubrication of the transmission. On a numerically controlled and hydraulically powered machine, maintenance will consist of replacement of electronic parts in the control system, lubrication, and refilling of hydraulic fluid. The many components will require more frequent maintenance and must therefore be considered. If a building is required for the proper functioning of the equipment or for storage while not in use, such cost must also be entered for purpose of this comparison.

Anticipated breakdowns of the equipment because of wear or aging must be prevented by a major overhaul at the most economical time prior to such breakdown. This overhaul may consist of replacing bearings, ways, motors, seals, hoses, or entire sub-modules in any part of the system. Disassembling of the equipment for cleaning and inspection purposes and re-alignment may also be part of such an overhaul. The number of years between overhauls varies for the different types of equipment and is therefore also entered. An amortization period - not for taxing purposes, but based on the actual life expectancy and usefulness - is estimated and entered to conclude the basic information of Form 7/8-5.

This data is now used to calculate more and directly applicable costs such as needed for a later evaluation.

SECTION V

SELECTING WORKLOAD OF YARDS

The last preparation for the cost evaluation is to select the workload of all considered shipyards for a given period. Past performance and existing contracts will furnish the data for establishing the best possible workload forecast if the method of bidding and granting of contracts is to be maintained as practiced.

The number of different ship types and all yards under consideration are entered on Form 7/8-10. The number of ships which must be built in any given yard will be decisive in the selection of the needed equipment for said yard.

SECTION VI

EVALUATING COST DATA

By multiplication, the production cost of all plates and frames for any class ship can be established from information developed on Form 7/8-6 (Workpiece Cost, Interpolated), and Form 7/8-2 (Workpieces of a Typical Ship).

Some of the employed fabrication methods may not be capable of producing all of the needed parts in one group, and certain methods may be employed economically only for part of a workpiece group, while the remaining parts are best produced by a different method. Thus, a combination of several methods may best serve our purpose. In such a combination, as many parts as possible should be made by a preferred method, leaving the balance to second and third choice methods, if required.

In filling out Form 7/8-7, the costs are entered only in the places where they are selected to apply, and care must be exercised to prevent duplication or the omission of any part among the different choices of fabrication methods. It must be remembered that the method indicating the lowest figures on Form 7/8-6 is not always the most favorable. As an example, a particular method may be best for a few parts only, while most remaining parts require different equipment for their production. Instead of buying the equipment for both methods, the few parts may also (but at a higher cost) be made on the equipment which is definitely needed to make

all the remaining parts, thus reducing the overall cost.

Such maneuvering of data has to be left to the judgment of the person making the evaluation. It is also recommended to follow several combinations and using their results for further evaluation of still other combinations and ratios.

Filling out Form 7/8-7 may be considered the most important step in the procedure, making it possible to adapt to existing conditions.

An evaluation of the previously established data may be made in two different ways, as shown in the following flow charts:

- A. Figure 1 gives the inter-connection of the function and associated forms for a single-type ship production, in which all fabrication methods are compared, based on a varying number of a particular ship type to be built. These data will show which ships have similar cost characteristics. The resultant information is directly applicable to a yard specializing in a given type ship only. Sufficient orders available, such a yard is anticipated to work most efficiently. Form 7/8-8 is a table for the comparison of these results, using data from Forms 7/8-5 and 7/8-7 while Form 7/8-9 presents the same information graphically.
- B. Figure 2 shows the functions and forms for a multiple-type ship production, in which the fabrication methods are compared, based on any selected workload for any yard. Such information is taken

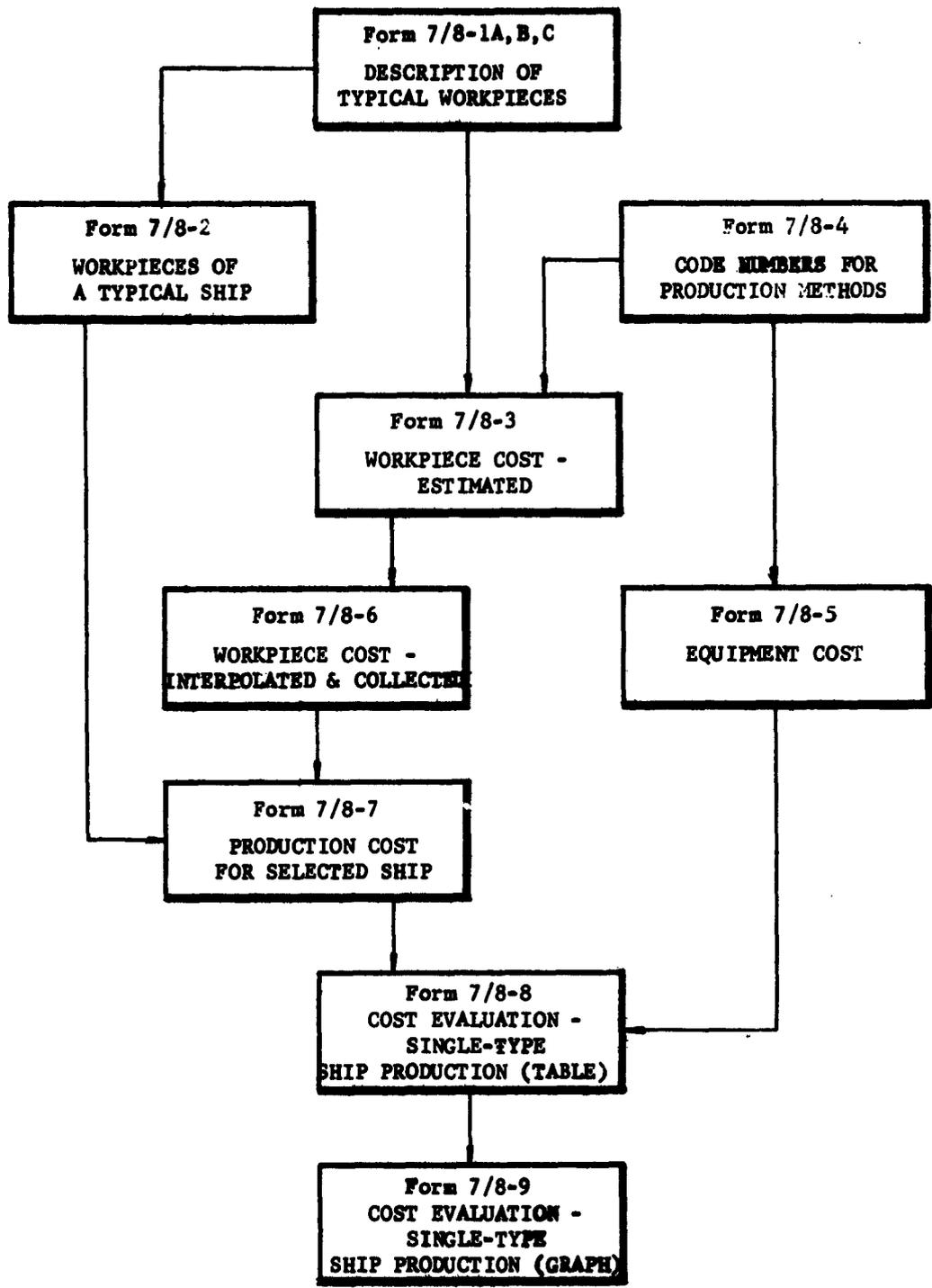


Fig. 1 Forms Used for the Cost Analysis for Single-Type Ship Production

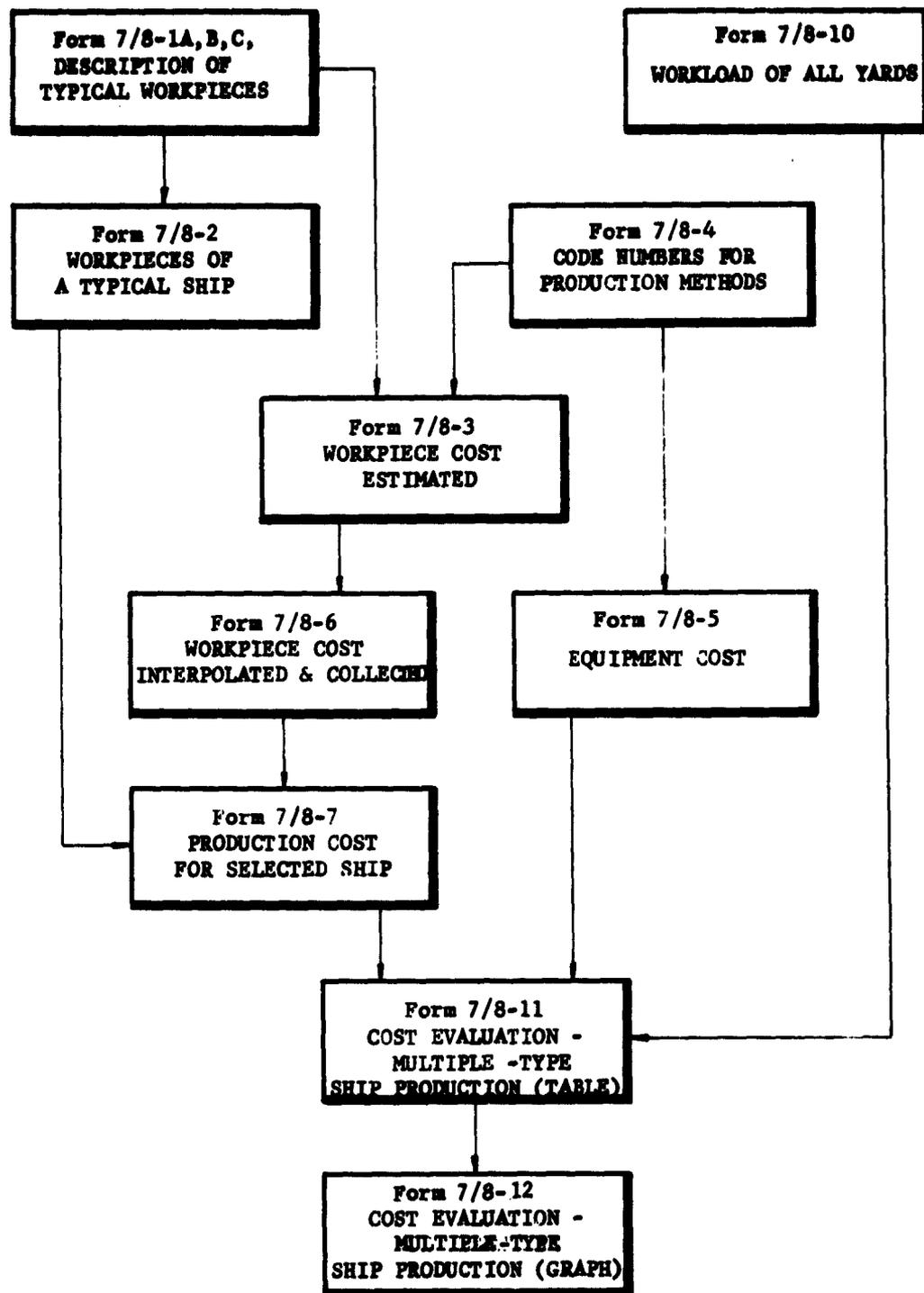


Fig. 2 Forms Used for the Cost Analysis for Multiple-Type Ship Production

from Forms 7/8-5, 7/8-7, and 7/8-10 and entered on Form 7/8-11.

Here again, the results are in the form of a table, while Form 7/8-12 presents the same information graphically.

Using the production rate from Form 7/8-7, the number of units of equipment needed for each method, working one, two, or three shifts, can be easily established.

Conclusions and recommendations for equipment will be made after all data are compiled and will be the subject of a separate report.

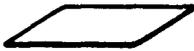
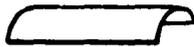
CONTENTS OF APPENDIX A

FORM	
7/8-1A	DESCRIPTION OF TYPICAL WORKPIECES - CODE NUMBERS FOR SHELLPLATES
7/8-1B	DESCRIPTION OF TYPICAL WORKPIECES - CODE NUMBERS FOR BULKHEADS, FLOORS, DECKPLATES
7/8-1C	DESCRIPTION OF TYPICAL WORKPIECES - CODE NUMBERS FOR FRAMES
7/8-2	WORKPIECES OF A TYPICAL SHIP
7/8-3	WORKPIECE COST, ESTIMATED
7/8-4	CODE NUMBERS FOR PRODUCTION METHODS
7/8-5	EQUIPMENT COST
7/8-6	WORKPIECE COST, INTERPOLATED AND COLLECTED
7/8-7	PRODUCTION COST FOR SELECTED SHIP TYPE
7/8-8	COST EVALUATION - SINGLE-TYPE SHIP PRODUCTION (TABLE)
7/8-9*	COST EVALUATION - SINGLE TYPE SHIP PRODUCTION (GRAPH)
7/8-10	WORKLOAD OF ALL YARDS
7/8-11	COST EVALUATION - MULTIPLE-TYPE SHIP PRODUCTION (TABLE)
7/8-12*	COST EVALUATION - MULTIPLE-TYPE SHIP PRODUCTION (GRAPH)

*Not included herein. These forms are prepared after all information is collected as outlined by this report.

DESCRIPTION OF TYPICAL WORKPIECES

CODE NUMBERS FOR SHELLPLATES

Description		Perimeter (in Feet)			
		Over 30 to 45	Over 45 to 60	Over 60 to 75	Over 75 to 90
Flat	Rectangular 	/	/	S 1	(S 2)
	Contoured 	/	/	S 3	(S 4)
Single Curvature, Contoured	Curve only 	(S 5)	S 6	S 7	(S 8)
	Curve & Knuckle 	/	S 9	(S 10)	/
3-Dimensional Curvature, Contoured	Height up to 6" 	(S 11)	S 12	S 13	(S 14)
	Height 6 to 12" 	(S 15)	S 16	S 17	(S 18)
	Height over 12" 	(S 19)	S 20	/	(S 21)

Establish time, material, and required energy to produce above-circled parts on Form 7/8-3, and enter data for each method on Form 7/8-6.

Interpolate non-circled but listed parts, using data from Form 7/8-3, and enter directly on Form 7/8-6.

Material: Mild Steel, 3/4" thick

DESCRIPTION OF TYPICAL WORKPIECESCODE NUMBERS FOR BULKHEADS, FLOORS, DECKPLATES

Perimeters of Outline and Cut-outs (in feet)	Description	
	Straight Line Outlines Without Cut-outs	Contoured Outlines With or Without Cut-outs
Up to 30	/	(B 5)
Over 30 to 45	(B 1)	(B 6)
Over 45 to 60	B 2	B 7
Over 60 to 75	B 3	B 8
Over 75 to 90	(B 4)	(B 9)
Over 90	/	B 10

Establish time, material, and required energy to produce above-circled parts on Form 7/8-3, and enter data for each method on Form 7/8-6.

Interpolate non-circled but listed parts, using data from Form 7/8-3, and enter directly on Form 7/8-6.

All plates are flat.

Material: Mild Steel, 1/2" thick

DESCRIPTION OF TYPICAL WORKPIECES

CODE NUMBERS FOR FRAMES

Description		Radius-to-Web Ratio	
		$\frac{R}{T} = 13$ or More	$\frac{R}{T} =$ Less than 13
Single Curved	Up to 5	(F 1)	(F 2)
	Over 5 to 10	F-3	F 4
	Over 10 to 15	(F 5)	F 6
Reverse Curved	Up to 5	(F 7)	(F 8)
	Over 5 to 10	F 9	F 10
	Over 10 to 15	(F 11)	F 12



Establish time, material, and required energy to produce above-circled parts on Form 7/8-3, and enter data for each method on Form 7/8-6.

Interpolate non-circled parts, using data from Form 7/8-3 and enter directly on Form 7/8-6.

Material: Mild Steel

3.0.0

WORKPIECES OF A TYPICAL SHIP

CLASS OF SHIP:

Compiled by _____ Date _____

Index of Code No.	Quantity of Parts per Ship		
	Shellplates S 1 through S 21	Bulkheads, Floors, Deckplates B 1 through B 10	Frames F 1 through F 12
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
16			
17			
18			
19			
20			
21			

WORKPIECE COST, ESTIMATED

WORKPIECE:

METHOD:

Compiled by _____

Date _____

Line No.	Operation Description: L = Labor M = Material E = Energy R = Equipment Rent	Quantity, Units, and Price	Dollars
a	Production Tooling L	hr. @	
b	Production Tooling M	lb. @	
c	Parts Lofting or Programming L	hr. @	
d	Parts Lofting, Templates M	lb. @	
e	Parts Lofting, Negatives M	pc. @	
f	Computer Rental R	hr. @	
g	TOTAL NON-RECURRING COSTS	-	
h	Workpiece Production L	hr. @	
i	Fit-up on Platen L	hr. @	
j	Fit-up on Ways L	hr. @	
k	SUB-TOTAL, Lines h through j	-	
m	Enter Sub-Total from Line k	-	
n	Work Preparation L	hr. @	
p	Excess Material M	lb. @	
q	Production Energy E	... @	
r	Handling at Production L	hr. @	
s	Handling on Platen L	hr. @	
t	Handling on Ways L	hr. @	
u	TOTAL RECURRING COSTS	-	

w	Production Rate in Hours per Piece	
	Check here, if parts are made in pairs	

CODE NUMBERS FOR PRODUCTION METHODS

Description of Parts Production Method	Shellplates, Bulkheads, Floors, Deckplates				Frames			
	Mathematical Hull Loft	1/10 Scale Hull Loft	Full Scale Hull Loft	17-P (Travograph)	Mathematical Hull Loft	1/10 Scale Hull Loft	Full Scale Hull Loft	Full Scale Hull Loft
Contour Cutting before Forming	Tracer-controlled, Full Size Template, Single Head							
	Optically-controlled, Reduced Size Drawing, Twin Head		11-P (Tele/Mono)					
	M/C, Twin Head	1-P						
	Oxygen-Acetylene							
	M/C, Twin Head	2-P						
	Plasma-Arc							
	Manual Hot Forming	3-P (Some)	12-P (Some)	18-P (Some)	1-P	7-F	10-F	
	Manually Controlled Rolls	4-P	13-P	19-P				
	Manually Controlled Press Brake	5-P	14-P	20-P				
	M/C Press Brake	6-P						
Forming	Manually Controlled Cold Bender				2-F	8-F (Hugh Smith)	11-F	
	M/C Cold Bender				3-F			
	Manually Controlled Stretch Press	7-P			4-F			
	M/C Stretch Press	8-P			5-F			
	Semi-Automatically Controlled Oxygen-Acetylene	9-P	15-P	21-P				
	Semi-Automatically Controlled Plasma-Arc	10-P						
	Manually Controlled Cut-Off					6-F	9-F	12-F

EQUIPMENT COST

METHOD:

- PURCHASED STANDARD EQUIPMENT
- PURCHASED NON-STANDARD EQUIPMENT
- IN-HOUSE DESIGNED SPECIAL EQUIPMENT

Compiled by _____

Date _____

Line	Description	Unit	Amount
A	Design Cost	\$	
B	Number of Machines, Among which "A" is Amortized	No.	
C	Tooling Cost	\$	
D	Number of Machines, Among which "C" is Amortized	No.	
E	Setup Cost to Build (1) Machine	\$	
F	Production Cost to Build (1) Machine	\$	
G	Installation Cost	\$	
H	Number of Machines Built in One Lot	No.	
J	Maintenance Cost per Year	\$	
K	Major Overhaul Cost	\$	
L	Number of Years Between Major Overhauls	yrs.	
M	Amortization Period, Multiple of "L"	yrs.	
P	Storage Cost (Building) per Year	\$	
Q	Purchase Price of Machine	\$	
R			
S			
T	Maintenance and Overhaul Cost per Year	\$	
U	Cost to Build and Install (1) Machine, without Design, if Built in Lots of "H"	\$	
W	Cost to Design, Build, and Install (1) Machine, if Built in Lots of "H"	\$	
Z	Equipment Cost for (1) Machine, Amortized and Maintained for "M" Years	\$	

$$Z = \frac{A}{B} + \frac{C}{D} + \frac{E}{H} + F + G + M\left(J + \frac{K}{L} + P\right) \quad T = J + \frac{K}{L}$$

$$W = \frac{A + C + E}{H} + F + G \quad U = \frac{C + E}{H} + F + G$$

If equipment is purchased: $W = G + Q \quad Z = G + Q + M\left(T + \frac{K}{L} + P\right)$

PRODUCTION COST FOR SELECTED SHIP TYPE

SHELLPLATES

BULKHEADS, ETC.

FRAMES

Compiled by _____

Date _____

Index of Code No.	Total Cost of Parts by Code by Fabrication Methods *											
	1st Choice:				2nd Choice:				3rd Choice:			
	g	k	u	v	g	k	u	v	g	k	u	v
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												
11												
12												
13												
14												
15												
16												
17												
18												
19												
20												
21												
TOTAL												

*Judgment must be exercised in the selection of preferred choice of method based on previously determined cost per part, the number of parts fabricated, and the cost of equipment required.

SHIP EVALUATION - SINGLE-TYPE SHIP PRODUCTIONSHIP TYPE:

Compiled by _____

Date _____

Work-pieces	Totals from Form 7/8-7 for Following Methods											
	g	k	u	v	g	k	u	v	g	k	u	v
Shell-plates												
Bulk-heads												
Total Plates	g_1	k_1	u_1	v_1	g_2	k_2	u_2	v_2	g_3	k_3	u_3	v_3
Total Frames	$g = g_4$	$k = k_4$	$u = u_4$	$v = v_4$	$g = g_5$	$k = k_5$	$u = u_5$	$v = v_5$	$g = g_6$	$k = k_6$	$u = u_6$	$v = v_6$

Z = Equipment cost for one unit for the period of 12 years, (a) fully maintained, and (b) amortized in the ratio of $\frac{12}{N}$ (See Form 7/8-5).

N = Number of ships to be built during the period of 12 years.

n = Number of equipment needed, based on 21,000 working hours per shift (adjust in accordance with actual practice) and 12 years. (Rounded off)

Single Shift:

Two Shifts:

Three Shifts:

$$n = \frac{V}{21,000}$$

$$n_a = \frac{V}{42,000}$$

$$n_b = \frac{V}{63,000}$$

Note: Substitute n_a or n_b for n where applicable.

Y_1 = Cost to build parts of N ships, employing one method.

Y_2 + through Y_6 = Costs for remaining methods.

$$Y_1 = \frac{g_1 + (.125 \times k_1) + (Z_1 \times n_1)}{N} + u_1$$

Y = Sum of Y_1 through Y_6 for desired combination of methods.

WORKLOAD OF ALL YARDS

FOR PERIOD OF YEARS

Compiled by _____ Date _____

Yard Code No.	Quantity of Ships per Yard per Class of Ship						
	C-3	C-4	DEG	DDG	DLG
I							
II							
III							
IV							
V							
VI							
VII							
VIII							
IX							
X							
XI							
XII							
XIII							
XIV							
XV							
XVI							
XVII							
XVIII							
XIX							
XX							
TOTAL							

COST EVALUATION - MULTIPLE-TYPE SHIP PRODUCTION

YARD CODE NO.

SHIP TYPE:

Compiled by _____

Date _____

Work-pieces	Totals from Form 7/8-7 for Following Methods:											
	g	k	u	v	g	k	u	v	g	k	u	v
Shell-plates												
Bulk-heads												
Total Plates	G_1	K_1	U_1	V_1	G_2	K_2	U_2	V_2	G_3	K_3	U_3	V_3
Total Frames	$g = G_4$	$k = K_4$	$u = U_4$	$v = V_4$	$g = G_5$	$k = K_5$	$u = U_5$	$v = V_5$	$g = G_6$	$k = K_6$	$u = U_6$	$v = V_6$

(See also Form 7/8-8)

Establish for each fabrication method:

$$Y_1 = \frac{G_1 + (.125 \times k_1)}{N} + U_1 \quad \text{Also: } Y_1 \text{ through } Y_6$$

Y = Sum of Y_1 through Y_6

Y_N = Cost to build all ships of one type with same method

Y_{Nt} = Sum of Y_N for all ships of all types made with same method

w_t = Sum of v for all ship types made with same method

$$n = \frac{w_t}{N \times 1,750} \text{ (rounded off)}$$

Equipment cost for each method and all ships $Z_t = Z \times n$

Total cost of all ships including equipment for each method

$$= Y_{Nt} + Z_t$$