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COMPUTER CONTROL OF A SUPERAUTOMATED SHIP, THE "OTSUKAWA MARU" FOR KAWASAKI KISEN K.K. VIA KAWASAKI HEAVY INDUSTRIES, LTD.

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I. INTRODUCTION

The remote manoeuvering, monitoring and other operations of the engine had leading parts in the ship automation. However, there were limits in the expansion of economic and safe operation. The tiend to high level centralized control of all of a ship's functions by computer can be considered as a natural development along with the remarkable expansion of the use of computers in all fields of industry. While Japan, as the world's major shipbuilder, had taken the lead, the foreign technique for a automated ship had remarkably improved. Under these circumstances, the research and development of highly centralized control systems in ships (superautomation) using computers was undertaken in 1967 as one of the important political theme of the Ship Bureau of the Ministry of Transportation. To promote this research and development, the Shipbuilding Research Association of Japan formed the SR 106 committee. The participants in this committee included persons from universities, research institutes, shipowners, shipbuilders and related industries. Trial designs were drawn up for various systems including navigation, the hull, turbine plant, diesel plant and computers. As a result, several experimental ships including the Seiko Maru, Mitsuminesan Maru, Kinko Maru, Otsukawa Maru and Tottori Maru have been completed and placed in service.

In 1968, the Kawasaki Kisen K.K., Kawasaki Heavy Industries, Ltd., Fuji Electric and Fujitsu established the Kawasaki Superautomation Committee (hereafter referred to as the KSA committee) for the construction of experimental ships. This Committee promoted research concerning superautomation systems but the committee has now completed the above-mentioned Otsukawa Maru, a 150,000 ton ore/oil carrier in the Kobe shipyard of Kawasaki Heavy Industries, Ltd. The main systems in this ship are the cargo oil/ballast control and the navigation system. High density centralized control has been achieved through the use of the highly stable FACOM 270-20 which has been widely used in control applications.

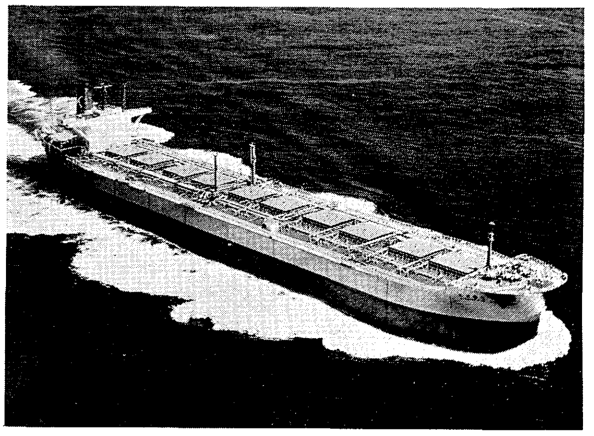


Fig. 1 General view of the M/S "Otsukawa Maru"

From the standpoint of performance/cost, an economical and rational control method was adopted whereby all systems are controlled by a single computer. After its maiden voyage, the ship has already completed her voyages several times. It has been confirmed that the computer control operates as expected. As more voyages are repeated in the future, the efficiency and reliability of the system will be appraised. This article gives an outline of this control system.

II. OUTLINE OF THE OTSUKAWA MARU

This ship is an ore/oil carrier with a bulbous bow. It was designed to have greater safety and good operation performance than ordinary ships and employs an inert gas system, a strippingless system and MO regulation of the NK.

For the strippingless system, the "Hudson Primavac" system is used in the three cargo oil pumps and by means of self-priming, the main cargo oil pumping can be performed up to stripping. One of the main features of this ship is the improved loading/unloading efficiency by the use of the Primavac system. In addition, there is a wide range of automation in the engine room including the main engines and the generators. It is also designed to make possible unattended machinery space in accordance with the NK rules for MO ships.

Ship class NK (MO)

Length (o.a.)	289 m
Breadth (molded)	44 m
Depth (molded)	24.2 m
Gross tonnage	87,120.92 t
Dead weight	157,618 t
Max. sea trial	16.18 kt
Main engine	Kawasaki MAN K 8 SZ 105/180 type 2 cycle diesel engine × 1
Max. continuous output	32,000 ps × 106 rpm
Normal output	27,000 ps × ca 100 rpm
Crew	30
Passenger	6
Ore hold volume	85,960.7 m^3
Cargo tank volume	194,012.7 m^3
Fuel oil tank	9,537.4 m^3
Diesel oil tank	767.4 m^3
Fresh water tank	372 m^3
Ballast tank only	17,687.5 m^3

III. HARDWARE SYSTEM

1. Composition and Specifications of Equipment

The configuration of the computer system of the Otsukawa Maru is shown in *Fig. 2*. The devices which are not required for ordinary operations such as the CPU and the input/output equipment are located in an air conditioned computer room. The cargo oil/ballast handling control device and equipments related to medical consultation are located in the ballast control room. The optimum course guidance device for narrow area is in the computer office and the equipment for navigation such as the Omega receiver is located on the bridge. The specifications of the main devices are as follows:

1) Central processor (FACOM 270-20) one
   - Word length: 16 bit core +1 memory protection +1 parity
   - Core memory capacity: 16 k-words (1 k-word = 1.024 words)
   - Computing system: Binary parallel with floating arithmetic option
   - Address system: 1 1/2 (direct, indirect and relative)
   - Index registers: 3
   - Interrupt priority sequence: 12 levels
   - Cycle time: 2.4 μs
2) Data channel device (FACOM 7232) one
3) Magnetic drum unit
   - One internal, one external
   - No. of characters (per unit): 128 k-words
   - Access time: average 20 ms
4) Input/output equipment
   - FACOM writer (FACOM 801 D) one
     15 characters/sec (with paper tape reader and puncher)
   - High speed paper tape reader (FACOM 749 A) one
     200 characters/sec
   - High speed paper tape puncher(FACOM 767 A) one
     100 characters/sec

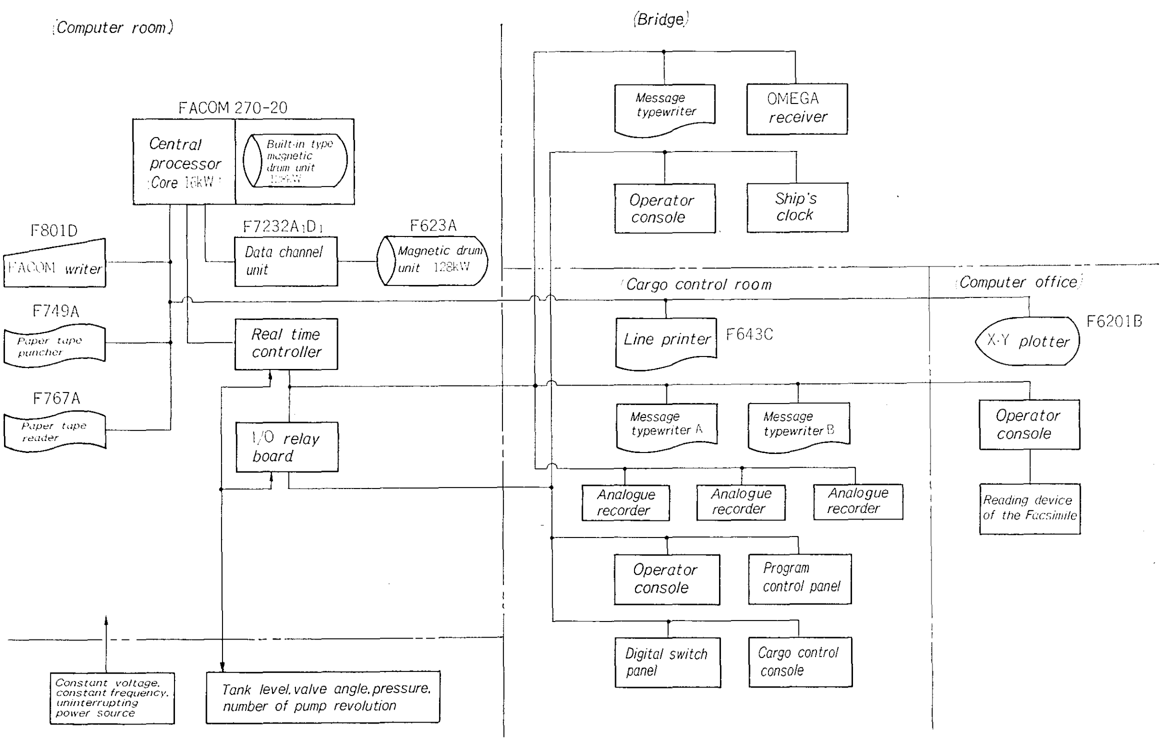


Fig. 2 System construction of hardware

Line printer (FACOM 643 C) one
120 lines/min. 136 characters/line
X-Y plotter (FACOM 6201 B) one
400 steps/sec

5) Real time control device one
Digital input 492 points
Digital output 314 points
Analog input 108 points
Analog output 7 points
Interrupting input 43 points
6) Input relay panel one
7) Message typewriter three
IBM 735, selectric type
8) Operators console two
9) Program control panel, digi-switch panel
one each
10) Facsimile read-out device, control stand
one each
11) 12-point self-balancing recorder three
12) Others (cargo oil/ballast control panel, pump, liquid level meter,pressure transmitter)
one system

2. Marine Countermeasures

It is necessary to take countermeasures in ship systems against adverse conditions such as vibrations, pitching and rolling, temperature, humidity, salinity and oil vapor. However, the general standards have not yet been established for computers. Therefore the four KSA companies undertook serious investigations and studies and established their own standards. On the basis of these studies, the measures taken included reinforced construction of the computer room and complete air conditioning by means of two special unit coolers on the ship side. For especially important equipment, thorough tests were performed on land and then measures for adapting to the ship were taken as follows:

1) Reinforcement of frame, box, etc.
2) Means to prevent looseness or falling out of parts, screws, etc.
3) Means to prevent breaks in electric wires
4) Improvement and strengthening of attachment and tightening systems
5) Marine design for magnetic drums.

In this case, a line printer was installed on a ship for the first time. Large amounts of important data not obtained so far are typed out at all times and it is of great convenience to the crew. There were no problems in the various voyages.

In respect to radio noise, complete grounding was performed by ground wires at the time of installation and the wiring plan was carefully studied so that absolutely no troubles occurred.

3. Power Supply System

A motor generator set with output of 10 kVA was installed to supply the computer with stable power at constant voltage and frequency. The system was

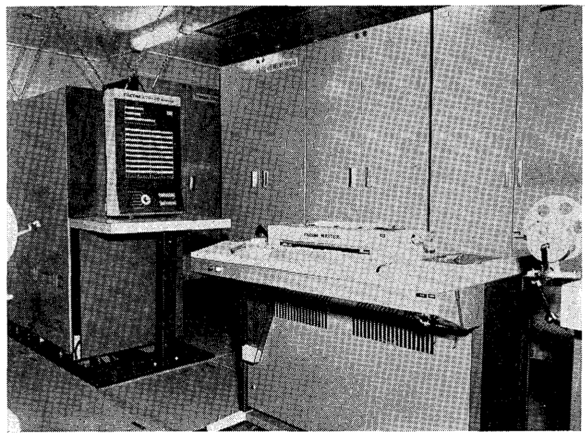


Fig. 3 Central processing unit on board

designed to function continuously even in the case of short power interruptions by means of the floating battery operation. In the case of longer interruption exceeding a set period, a device is provided to protect the memory contents on the computer side.

IV. SYSTEM PLAN

Fig. 4 shows the complete composition of this software system. The items marked by an asterisk (*) in the figure are for off-line use and the rest are for on-line use.

The monitor III_3 which has high reliability and wide successful application is employed. Both the FASP assembler and the FORTRAN compiler are employed as a language programs. FASP is mainly used for the cargo oil/ballast control program which requires rapid processing, and FORTRAN is employed

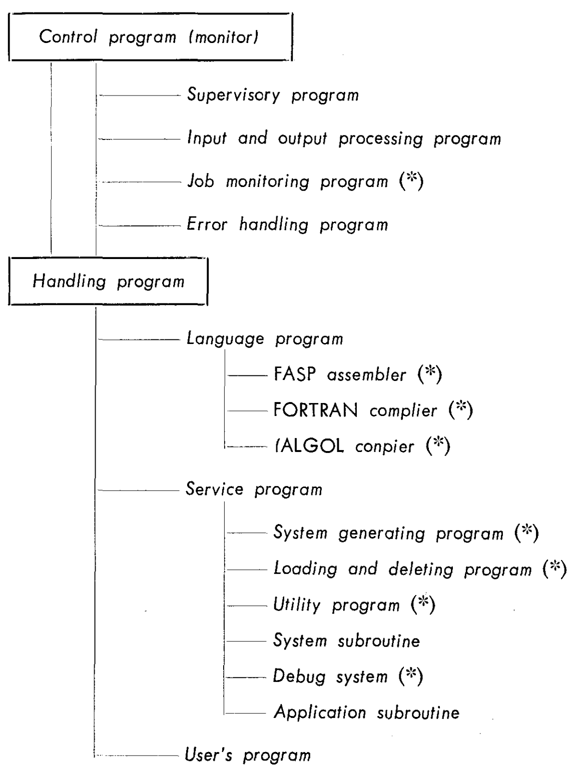


Fig. 4 Constitution of monitor III_3 system

for the navigation programs which includes complex calculations. For the medical consultation FASP is used because there are many repetitions of logical judgements.

The applications subroutines were selected from among the large number which have so far been developed and used accordingly but there were also some newly developed for this system. The subroutines normally stored in the core whenever possible in order to speed-up program processing. The main parts of the system are the cargo oil/ ballast control system, the navigation system and the medical consultation system. These are described in detail below.

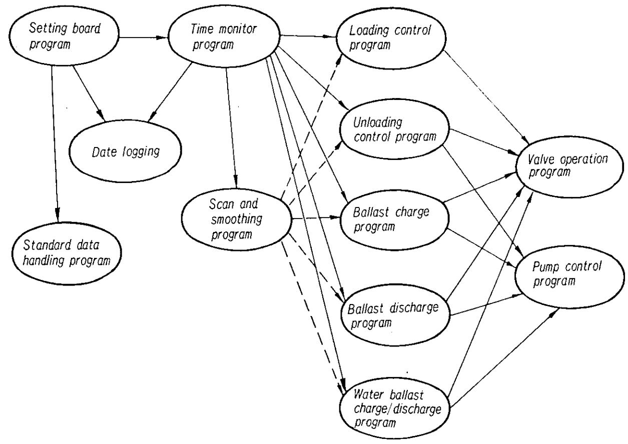


Fig. 5 Programs of cargo oil/ballast control system

V. CARGO OIL/BALLAST CONTROL SYSTEM

1. Basic Concepts

Fig. 6 shows the tank layout and piping of this system, *Fig. 8* the outer view and *Fig. 5* the connection between the various programs making up the cargo oil/ballast control system. As can be seen in *Fig. 6*, the piping layout consists of three systems of cargo oil/ballast lines, one water ballast line system, three oil pumps and one water ballast pump, and 22 tanks.

Operation of cargo oil/ballast line is so complex that each line is used for a different type of cargo, or one line is charged or discharged by two pumps or more. Therefore, each line (and pump) has its own independent software and the design is such that they can be optionally combined. In other words, each program can be designed so that it can process a line at will and the data which can process all four lines processes the necessary line in accordance with the parameters transferred from the control program.

Fig. 7 shows the data flow in the ballast control system. The programs are explained below in accordance with the data flow.

2. Input Systems

1) Control panel progrom

Figs. 9 and *10* show the control panel and the program control panel respectively. Data concerning the limit values of manifold pressure, oil and water properties, temperature, trim limit values, the applied pipe lines, pumps, tanks, final ullage and so on are fed in from the control panel before loading/unloading. The instructions for program starting, stopping and momentary stopping and replies to the operator from the computer are fed in from the program control panel.

2) Standard data shift control program

A large number of cases concerning standard loading/unloading are stored on the drum beforehand, and one set of standard data can be used by instructing the case number. The standard data can also be used with a partial change. The data used are printed by the line printer so that they can be confirmed by the operator.

3) Cargo oil/ballast calculation system

The calculation programs for the cargo oil/ballast controll are as follows.

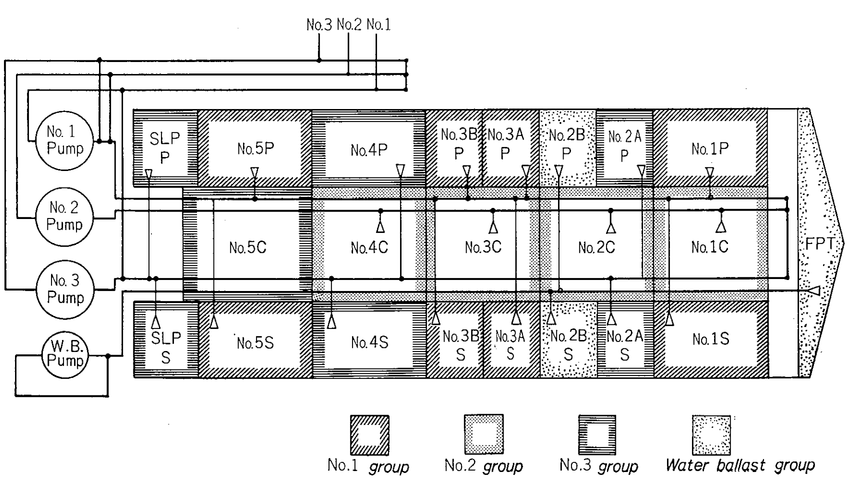


Fig. 6 Tank layout and piping

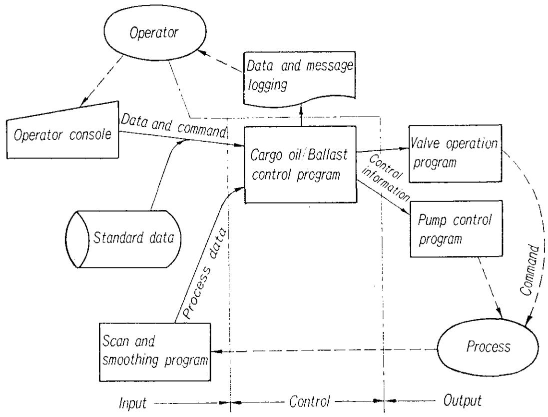


Fig. 7 **Flow of information in the system**

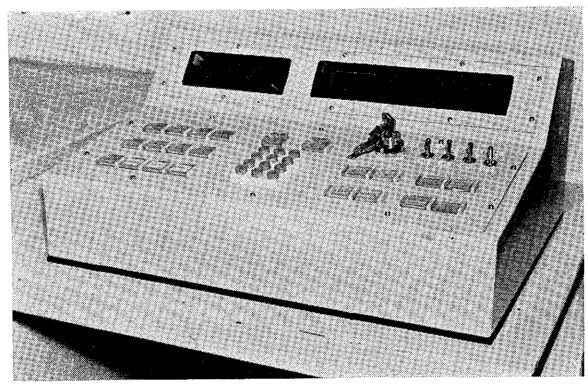


Fig. 9 **Operator console for input**

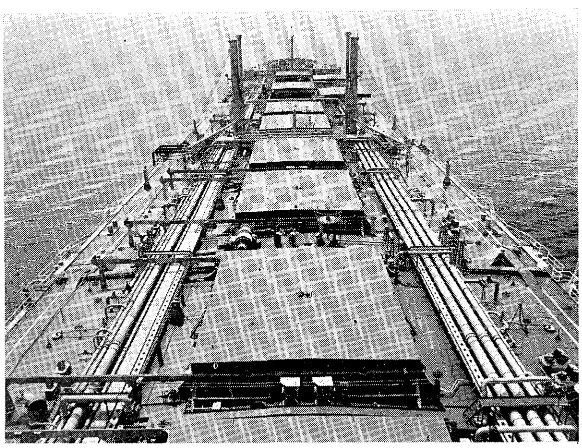


Fig. 8 **Outerview of piping**

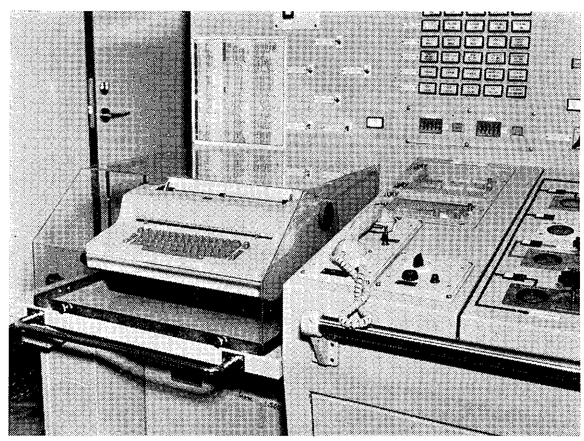


Fig. 10 **Operator console for input**

(1) Calculation program of optimum loading condition
(2) Hull longitudinal strength calculation program
(3) Storage report compilation program
4) Scan and data smoothing program

This program serves to read in various types of process data and transfer to the cargo oil/ballast control program. For the level and draft gauges, rough and fine read out values are formed, instantaneous values are calculated and data smoothing is performed to eliminate the influence of waves. The data smoothing employs methods which differ when the ship is stopped and when it is underway. In both cases, suitable filtering is performed.

Since double level and draft gauges are provided, data are compared mutually and if there is any abnormality, an alarm is given. The gauge to be used can be decided by the operator.

For the pressure gauges, speedometers and heel gauges, the read-out values are smoothed appropriately and transfer is made to the various control programs. Back-up operations are also performed for the fault sensors.

3. Control Systems

1) Loading program

In the case of loading, the oil is transported via a pump (or pressure head) on land. For the transfer rate of the oil from the land, a loading rate (full/half/slow) in accordance with the requirements at the time is given out from the computer. The main purpose of this program is continuous monitoring of the liquid levels and level increase rates in each tank. Therefore, the various tank values are controlled so that the final ullage can be performed in accordance with reqirements and the ship's trim, heel and draft can be kept normal. Continuous monitoring of the manifold pressure with suitable alarms and control is also performed.

The complex manual valve switching operations and automatic valve checks prior to loading/unloading can also be performed correctly by indications from the computer.

The indications to the operator are made by simultaneous display with lamps and buzzers and printing out on the typewriter for important matter and printing out on the line printer for reference data. For important steps in the loading/unloading sequence, the operator confirms the computer indications and proceeds to the next sequence step in accordance with his decision. Except for this case, all control is automatic.

2) Unloading program

Since unloading is performed by the pumps on the ship, the program controls the pumps and valves simultaneously.

The unloading progrom is divided into initial, middle and final stages. The initial operations are intended to eliminate oil overflow due to the influence of excess trim, etc. in the initial stage of unloading. The middle stage operations include the majority of the oil pumping work and control the pumps in accordance with instructions from the operator at suitable times during the unloading. The various tank valves are controlled in accordance with the ship's condition which is detected from the trim limit values given at the start of unloading and scan data.

When the set level is reached in the tanks for the each pipe lines, the final stage operations (stripping using Primavac equipment) begin for the pipe line concerned. Transfer to stripping is performed automatically by the computer.

3) Ballast charge program

Since this program is used to control the trim, heel and draft of the ship, the basic concepts are the same as those for the loading and unloading programs. Only the following points differ. Because this program is also used when the ship is underway, proportional distribution control of the level is employed instead of a trim and heel control program with feedback control. This distribution control uses feed forward control in respect to the trim and heel. In this way, control variations due to the influence of waves are eliminated.

Since the number of tanks connected to one pump are fewer in the case of ballast unlike in the case of oil, level and final ullage control are more difficult because the level increases rapidly and waves have a strong influence.

4) Ballast discharge program

The main part of this program can be used in common with the unloading program. However, it has been designed so that highly accurate discharge can be performed until the level determined for each of the tanks is reached. The level control is performed by a proportional distribution control program.

5) Water ballast charging/discharging program

Since this is a water ballast chargihg/discharing program, the control is the same as when the ballast is inside the cargo oil tank. However, since both line and pump are used only for this purpose, the software is also employed exclusively. Another point of difference is that charging/discharging control by gravity is used effectively in addition to pump control.

4. Output Systems

1) Valve operation program

From the various loading/unloading programs and the various ballast charging/discharging programs, various control requirements (opening instructions) are given for the different valves. In this program, however, overall judgements are made at set periods for these requirements in respect to priority, mutual relations, safety, etc., and the actual valve opening outputs are determined. After a set time, the output value (instructed value) and the actual opening value (read-out value) are compared and alarms are given in case of abnormalities.

2) Pump control program

By continuous monitoring of the loading/unloading conditions, the main pumps are controlled in such a way that the most efficient and safe operation is performed under the given conditions.

The pump operating conditions are divided into ten patterns such as complete stopping, momentary stopping, rate increase, normal operation and parallel speed adjustment etc., so that operation can be performed in accordance with these patterns. The program is also designed for smooth and safe mode switching among parallel/independent and computer/manual operation.

On the basis of the flow rates set by the operator, overall evaluation is made by means of instructions from limit pressure, maximum flow rate, minimum flow rate and cavitation elimination programs. In this way, the rotary speed of the pumps and the degree of opening of the delivery valves is controlled.

During rate increases or stopping, rapid changes in the load of the boiler of the drive turbine occur in accordance with rapid changes in pump loads. However, this control system provides with boiler follow-up control.

3) Data logging

The printing contents are the same for set time and optional logging. The line printer prints out such information as trim, heel amount of deflection, levels of various tanks, liquid volumes, tank valve opening degrees and control reasons, pump speeds and control reasons, loading/unloading amounts under final loading/unloading conditions, flow rates, delivery and suction pressures, manifold pressures, results of calculations of ship hull strength and expected loading/unloading times.

4) Message print-out

At every stage of loading/unloading, the equipment can provide a wide variety of message print-outs so that the operator can take suitable measures. These messages include confirmation messages for data input from the operator, and messages that the operator's control instructions and confirmation operations have been received. They are printed out on an exclusive typewriter.

A comment type message indicating the loading/unloading conditions is printed out on the line printer.

VI. NAVIGATION SYSTEM

1. Celestial navigation and geodetic navigation

This system is performed by manual input of the necessary data calculated previously by hand from an operator console located in the chart space on the bridge (wheel house). Calculations are made by the computer and the results are printed out on a typewriter.

1) Celestial navigation program

The input data are as follows: latitude and longitude of assumed position, eye level, air pressure, air temperature, water temparature, number of spheres observed, identifying numbers of spheres, observation altitude, d, E, U, altitude correction values based on visual radius and altitude correction values based on visual differences in the horizon. For the data from the identifying numbers of the spheres, calculations are possible up to a maximum of five groups of data. The outputs are assumed position, sphere identification unmbers, azimuth and intercept.

2) Geodetic navigation program

This includes the following fiive programs:

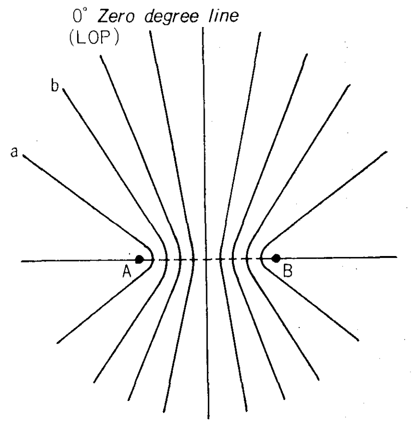
(1) Program for calculation of sailing distance in a log line
(2) Program for calculation of destination position in a log line
(4) Program for calculation of great circle route plan
(5) Program for calculation of ship's speed

2. Omega Position Measurement System

The Omega position measurement system is a type of electronic navigation and measures the position of the ship by hyperbolic curves obtained by receiving radio waves from land stations.

There are eight Omega stations throughout the world located in Norway, Trinidad, Hawaii, North Dakota, La Reunion, Argentina, Australia and Japan. The waves generated from the stations are sent out on a time sharing basis as shown in *Fig. 11* so that the utilizer can distinguish from what station the waves come.

The fundamental frequency of the Omega system has been selected as 10.2 kHz minimum. As shown in *Fig. 12*, the basic line for determining the ships position is the line with a phase difference of 8° every 8 nautical miles on the line connecting stations A and B. The value attached to this line is known as the LOP value. A space wave correction is necessary for a highly accurate position since the influence of the ionospheric height on the wave transmission speed is great with Omega waves (VLF).



A, B: sending station
Distance between A and B: ca 8 nautical miles
(Fundamental frequency of OMEGA system is 10.2 kHz)

Fig. 12 Line of position for OMEGA system

When a computer is not used, the operator calculates the ship's present position by using the Omega chart and table prepared beforehand on the basis of LOP value data received by the receiver.

In this system, processing and tracing of the data received and even the space wave correction using a trace model are processed automatically the computer. The measurement results are typed out on a typewriter.

The accuracy of this system is expected to be about one nautical mile in the day time and about two nautical miles at night. *Fig. 13* shows an outerview of the Omega receiver and interface located in the chart space of the wheel house.

3. System for Setting Optimum Route in Narrow Area

When determining the ship's route, the weather and nautical conditions are very important in the evaluation but their importance has increased recently with the large scale and higher speeds of ships. In this system, anticipated values for ship operation in respect assumed speed and route in a required area

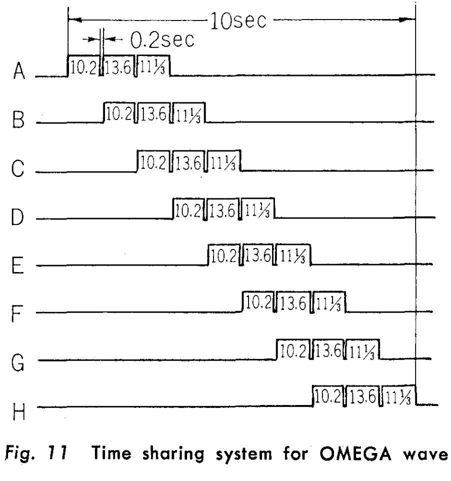


Fig. 11 Time sharing system for OMEGA wave

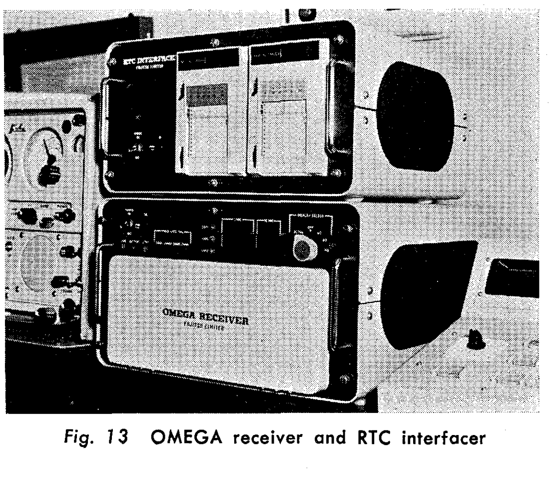


Fig. 13 OMEGA receiver and RTC interfacer

are displayed on a X-Y plottter on the basis of an assumed weather chart received in the ship in respect to complex weather and sea conditions. *Fig. 14* shows an output example of this system. The result data are used by the navigator when setting the ship's course.

VII. MEDICAL CONSULTATION SYSTEM

This system has been manufactured to provide the person in charge of health and sanitation with direct information when an illness occurs at sea on ships which have no doctor on board. It consists of internal medicine and surgery (limited to external wounds) programs.

The consulatation process employs a conversation system via the operator's console for loading/unloading and the typwriter for messages located in the cargo control room. The results of the consultation are typed out with the disease's name and a code which is decided beforehand in relation to the degree of severity and the method of treatment, in order to provide rapid display if required.

With this system, the patient has in principle a discussion, a simple palpation and examination with the person in charge of hygiene. If the result of this indicates a large external wound, the wound question table is inserted and for other cases, the the question table for internal diseases is inserted. These question tables are divided into many questions and replies, mainly with the answers " yes ", " no " and " unclear ". When the replies are given from the computer, the next input is performed. It is also possible to check the logic of the reply and when it is judged unsuitable, it is possible to correct the reply since the question number is given out for the reply.

VIII. CONCLUSION

This systm performs centralized control with only one computer, but in the future a change to a hierarchical localized computer system with exclusive minicomputers for the navigation, loading/unloading, machinery and mooring systems, as well as the single generalized computer if neecsary for back-up of the whole system is expected. In this system, the advantages will be efficiency, reliability and standardization during the tests in accordance with the remarkable recent advances in minicomputers and this system is very expected in future. However, the group of test ships including this ship is the result of cooperation between owners, shipbuilders and related manufacturers with the backing of the Ministry of Transportation. In order to complete the total system of the ship, it will be necessary to maintain this cooperation in the future.

It will also be necessary to strictly take into consideration the technical aspects upto now liable to be neglected precise human judgement, operation, handling and reliability from the specialist's standpoint. We believe these measures will be of help in labor saving on ships and improvement of safety and economy.

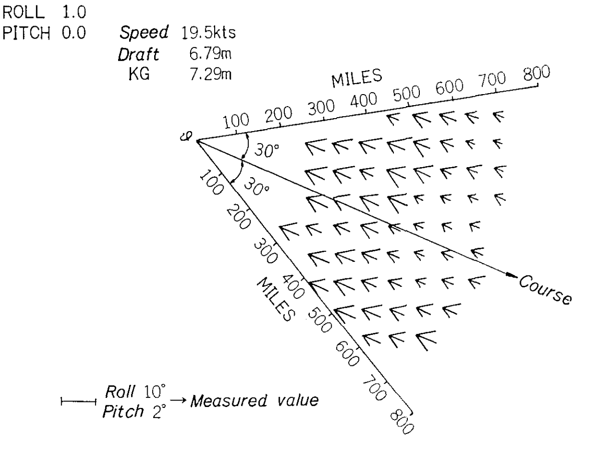


Fig. 14 **Output example**