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SOME REPORTS ON THE STATE-OF-THE-ART IN AUTOMATION OF MODERN MERCHANT SHIPPING. VOLUME I. T/T SEA SERPENT

Donald H. Kern, et al

Purdue University

Prepared for:

Naval Ship Systems Command

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VOLUME I — T/T SEA SERPENT

First Quarterly Report
May 16, 1973 — August 15, 1973
Contract No. N00024-73-C-5483
Naval Ship Systems Command

Sponsored by
Advanced Research Projects Agency
ARPA Order No. 2425

REPORT NUMBER 55
Purdue Laboratory for Applied Industrial Control

Prepared by

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PREFACE

This report constitutes the First Quarterly Report under Contract N00024-73-C-5483 with the Naval Ship Systems Command, United States Navy, under Advanced Research Projects Agency (ARPA) Order 2425. The work reported here was carried out by personnel of the Purdue Laboratory for Applied Industrial Control, Schools of Engineering, Purdue University, with the assistance of personnel of Specialized Systems, Incorporated, Mystic, Connecticut.

Under the Statement of Work of the above contract the first task was to:

> "Conduct a thorough review of the present state-of-the-art, including contacts with personnel and companies actually engaged in building and operating automated surface ships, and Navy personnel of its Navy Ship Research and Development Center."

This has been carried out through three media: first, through a voyage on the automated VLCC, T/T SEA SERPENT, of Salen Lines of Stockholm, Sweden on May 18 - June 7, 1973; second, through attendance at the IFAC/IFIP Symposium on Ship Operation Automation in Oslo, Norway, on July 3 - 5, 1973; and third, through visits to firms involved in developing and manufacturing equipment for ship automation during the interim period to the above dates. This document reports the results of these investigations.

The trip aboard T/T SEA SERPENT was arranged through the help and courtesy of Mr. Leif Sten, Electrical Engineer, of Kockums Mekaniska Verkstads AB, Malmo, Sweden, who serves as project manager for ship computer systems, and Mr. Nils Friberg, Chief Inspector, Salen Shipping Companies, Stockholm, Sweden. All personnel concerned, Kockums, Salen Shipping, the two Port Agents, and especially the officers and crew of the T/T SEA SERPENT were most courteous, and helpful to us in arranging the trip and during the voyage itself. Captain Bengt Svensson and Chief Engineer Evald Sjölund receive the particular thanks of the authors for imparting their extensive knowledge of the automation system of the T/T SEA SERPENT.

This research was supported by the Advanced Research Projects Agency of the Department of Defense and was monitored by the Naval Ship Systems Command under Contract No. N00024-73-C-5483.

Donald H. Kern

Theodore J. Williams

CHAPTER 1

INTRODUCTION

The field of the automation of the operation of sea-going vessels has been one of the last of the major industries of this nation and of the world to undergo significant automation. However, perhaps because of this late start, progress in this area has been rapid and significant over the past few years. It is, therefore, important that the present project on the Automation of Naval Surface Ships should begin with a thorough review of the state-of-the-art of this field as it exists at the moment. Accordingly, the first quarter of the project period has been devoted to this factor through a voyage taken on the steam turbine powered tanker SEA SERPENT of Salen Lines of Stockholm, Sweden; through attendance at two international Conferences with a significant bearing on this field; and through visits to several manufacturing and research companies active in the ship operation automation field.

This First Quarterly Report on the Project reports the findings of our visits. Especially significant here is the report on the SEA SERPENT with its detailed description and discussion of a very successful class of automated tankers, the Kockums 530 Series, of which the SEA SERPENT was the first member.

The remainder of this first chapter is a short discussion of the current state-of-the-art of ship automation as derived from several articles appearing in recent special issues of the journal, MOTOR SHIP (March 1971, 1972, 1973).

A SHORT DISCUSSION OF THE PRESENT STATE-OF-THE-ART

In the relatively short span of 10 years we have seen the unmanned engine room concept develop from an interesting talking point to a standard marine engineering practice.

Throughout this period the economic justification for automation has been a principal debating point, and the majority of papers on the subject have sought to justify, limit or deny the cost advantage of various degrees of automation.

In reviewing the situation today, it can be fairly said that the unattended machinery space is recognized as an operational requirement for many ocean-going vessels. It is estimated that well over 50 percent of new major ships on order are being extensively automated, to a degree consistent with immediate or future operation with unattended machinery spaces. Traditionally, the attempt has been made to justify the cost of marine automation by considering the opinions and operating experience of progressive shipowners, shipyards and equipment manufacturers. It must be admitted that while no clear economic case has emerged from these deliberations, history has overtaken debate. This is no doubt due to the fact that whether or not automation offers a firm cost advantage, the number and quality of marine engineers opting for sea-going service is continuing to decline despite very substantial improvements in remuneration and social conditions. Now that the unmanned engine room is here to stay, it is important to consider the environment in which this new branch of marine engineering has to develop, and in this respect there is cause for concern. At present, there would appear to be a conflict of interest between the parties concerned which, if protracted, may well cause the teething troubles of marine automation to develop into a permanent disability, and a severe handicap to the entire marine industry. To examine today's environment more closely, we pose two questions.

What Expenditure is Justified?

Generally, the marine engineer's approach to this question is the quite rational one of trying to measure the savings in such areas as manning, fuel bills, and repairs. However, a study of some of the papers set out on these lines will show that a good marine engineer does not necessarily make a good accountant. For example, one such paper completely ignores wage escalation in calculating the capital expenditure justified by the reduction in the number of men carried over the 15 years' life of a ship. In these days of high wage awards this is a serious miscalculation, leading to an error of up to 280 percent, based on a 10 percent p. a. increase in wages.

Loss of Earnings Factors

Another factor which is often neglected is the rapidly increasing rate at which loss of earnings for a ship must be calculated. Although it may have been reasonable in the past for the less enthusiastic superintendent to assume that marine automation would bring no reduction in out of service time due to machinery repairs, having decided to fit automation equipment, (perhaps resulting from a *force majeur*), it is now essential to look at the other side of the coin. Poor quality equipment is certain to decrease ship availability. For example, an engineer may be required to choose between two alarm monitoring systems for a 250,000 ton d.w. tanker with unattended machinery spaces. One may be the cheapest system offered by the shipyard, at say $15,000. The other system, developed specially for marine service, may cost $50,000. The price difference may be seen to be something over 200 percent, or alternatively as equivalent to 24 hours machinery out of service time at any period in the 15 year life of the ship. The more expensive system can therefore pay for itself on the grounds of ship-availability alone, by assisting in the avoidance of one minor engine room incident during the life of the ship, which event may well occur as early as the sea trials or delivery voyage of the vessel. The same can be said of many control systems, safety devices, and fire alarms. It is also widely recognized that loss of engine power in confined water such as the English Channel can be an extreme hazard.

It is therefore essential that marine control equipment must be of very high reliability. This is accepted by most shipowners and some equipment manufacturers. However, equipment with the requisite reliability has not been developed for the relatively small marine industry since the industry has not in all cases been prepared to pay an economic price for the product. It is one thing for a manufacturer to sell equipment to the marine market as a fringe interest, but quite another to develop equipment specially for marine service. While some have claimed that there should not be a difference between industrial and marine equipments, the principal areas of difference are (a) the more severe environmental conditions, (b) the extremely difficult after-sales service problem, and (c) the necessity to cater to an international market with many differing regulations, philosophies and prejudices. All of these factors have in many cases led to a demand for specially designed marine equipments.

Currently, the cost of instrumentation and control equipment for a large diesel engine-driven tanker is in the region of $100,000 including bridge control of the main engine, temperature and pressure controls for main and auxiliary services, automatic continuity of electrical supply, engine room monitoring and fire alarm systems. This price is not particularly influenced by the size of the ship, be it 80,000 tons d.w. or 320,000 tons d.w. The amount at risk, from the veiwpoint of loss of earnings in the event of machinery casualties is, however, in the ratio 4:1. Assuming that the larger vessel costs $310 million, the present cost of controls and instrumentation represents about 0.03 percent of the total. This does not compare very well with installations in refineries, power stations or freighter aircraft, where the percentage expenditure on automation is at least 10 times as much.

Influence of Shipyards

After price, the shipyard will often choose equipment for the sake of its familiarity, which leads to a problem of standards. Naturally, a shipyard has preferred suppliers for particular items of equipment. Shipyard staff are familiar with this equipment, installation drawings are on hand, and discounts for repeat orders may be available. However, as a result of this, the owner who builds a series of, say 12 ships at six different shipyards, will be faced with a very difficult logistic problem with respect to the provision of spares and the transfer of personnel between the ships of the fleet.

Marine control and instrumentation equipment represents a very small fraction of total ship cost, less than one percent in many cases, and remains a casualty in the highly competitive shipbuilding business. Only a few have recognized that its potential effect, for better or worse, on ship profitability is far in excess of its small contribution to total ship cost.

Is the Time Scale Right?

It is an unfortunate fact that the controls and instrumentation section of the ship specification is the last part to be finalized; but conversely, as it is tailored to suit a particular outfit of main and auxiliary machinery components, it requires a fairly lengthy time scale for procurement, manufacture, and commissioning. Consequently, a one-year delivery time for the ship may have been defrayed to less than six months before orders are placed with automation subcontractors. This state of affairs exists because the finalization of all details of the control engineering specification is dependent on decisions regarding practically all aspects of the main and auxiliary machinery.

The quality of an installed instrumentation and controls complex is highly dependent on the attention that was devoted to detail at the design stage, and the care used in the evaluation of plant requirements to provide an integrated system which could fulfill its functions as the nervous system of the engine room. This process cannot be carried out properly in the very short time of a few months, for the best that can be hoped for under these circumstances is that the system looks and behaves like an afterthought. The result is that the shipowner does not receive good value for the capital expenditure; the shipyard may have been faced with a penalty for late delivery, and high guarantee costs; and the equipment supplier has placed his reputation at risk.

Progress in Automation

The foregoing remarks may be most forcefully summarized by stating that marine automation, as currently practiced, is being carried out on too lean a budget, with the wrong people making the decisions, in an inadequate time scale. This is, of course, too great a generalization to be totally accurate, yet we believe that each of the two questions posed needs very careful consideration by shipowners, builders and equipment manufacturers. The environment in which marine automation is expected to flourish is not a healthy one at present.

The most progressive shipowners, and the most economical equipment salesmen, foresee the completely "hands off" ship as a viable proposition for the near future. Already, the unattended bridge is being spoken of in exactly the same way as was the unattended engine room 10 years ago.

Maintenance and Troubleshooting

The maintenance of electronic control systems on board ship is a lengthy topic. In the present day situation where there are continually increasing commercial pressures to reduce the running costs, and hence the manning of ships, it is unreasonable to expect an operator to carry an electronics specialist on a crew; and the most practical approach has been one which permits routine maintenance and basic fault finding by unskilled personnel. This, together with problems arising during operation and maintenance of the equipment in a marine environment, have made it desireable that equipment manufacturers consider the problems of protection, servicing and fault finding at the design conception stage, and where followed through in design, development and production, a simple maintenance routine has been possible. Inadequate attention to maintenance in the design of automated systems can produce a shipboard installation such that the rack of transistor circuits tends to induce one of two extreme reactions, either, (a) "it is complicated and I cannot understand it," leading to a mental block in which normal electrical routine checks are completely ignored, or, (b) "it is not too much trouble to replace a small component like that," in which the unwary, armed with an oversized soldering iron, produce a generation of faults which totally obscure the original failure.

Operational Methods for Unmanned Engine Rooms

As a general rule, duty engineers are required to check alarms, control circuits and machinery in detail before leaving the engine room, and it has been found that the incidence of alarms - false or otherwise - during unattended periods, depends to a marked extent on the enthusiasm and diligence of the individual officers.

Where a fixed routine for inspecting controls and machinery, night and morning, has been formulated for each installation, and records of alarms are kept and carefully studied by senior engineers and superintendents, taking action to eliminate causes of spurious alarms where necessary, the safety and reliability of the system has been greatly enhanced.

Correct installation of fire detecting equipment is most important and there is no doubt that inexperience resulted in some early installations being inadequate, until the correct location and setting of detector heads were determined. Air flow patterns within the machinery spaces and the sensitivity of individual detectors has been found to be critical.

Experience to date on unmanned vessels has been reassuring insofar as remarkably few faults have arisen which might be said to have constituted serious hazards, had they remained undetected. Fuel leakage is probably the most potentially dangerous, followed by flooding due to pipe fracture.

Staffing of automated vessels has not presented any difficulty. Whenever possible, staff are given training in basic instrumentation and control engineering. This, it is found, is amply justified by virtue of the encouragement it gives engineers to investigate and correct faults themselves; which is infinitely preferable to summoning service engineers to attend to what are often relatively minor defects.

SECTION I

AN EXAMPLE OF A PRESENT DAY

AUTOMATED VESSEL

REPORT OF A VISIT ABOARD

T/T SEA SERPENT

CHAPTER 2

BACKGROUND

During the period of May 18 - June 7, 1973, Messrs Donald H. Kern and Theodore J. Williams visited on-board the steam turbine powered tanker SEA SERPENT of Salen Lines AB, Stockholm, Sweden. The SEA SERPENT off-loaded its cargo of crude oil at Point-a-Pierre, Trinidad, from May 15 - May 24 and then sailed to Cape Town, South Africa, on her way to the Persian Gulf oil fields to reload. The present authors left the ship at Cape Town having completed their investigative period. The following subsection is a slight abbreviation of the descriptive material on the T/T SEA SERPENT as released by Kockums Mekaniska Verkstads AB, her builders.

DETAILS OF THE SEA SERPENT

General Features

Kockums Mekaniska Verkstad of Malmo, Sweden, delivered the 255,350-ton d.w. turbine tanker SEA SERPENT to Rederi AB Strim, Gothenburg, an affiliate of Salenrederierna AB, Stockholm on November 18, 1971. She is first in a group of six sister ships ordered by the Salen group. Another three of these were scheduled for delivery during the first half of 1972, and the remaining two by late 1973 and early 1974.

SEA SERPENT has been built to the highest class of the Lloyd's register for classification + 100 A1, Oil Tanker, + UMS. The latter symbol stands for periodically unmanned engine room. Outfit and accommodation is in accordance with Swedish Marine Board regulations.

Main particulars are:

Length (Over All)	340.51m	(1,117 ft 2 in)
Length (Between Perpendiculars)	329.18m	(1,080 ft 0 in)
Breadth (Moulded)	51.82m	(170 ft 0 in)
Depth (Moulded)	25.60m	(84 ft 0 in)
Draught (Summer Load Line)	20.08m	(65 ft 10.25 in)

Cargo capacity	338,595 m^3	(11,957,346 ft^3)
Ballast cap (clean only)	7,714 m^3	(272,417 ft^3)
Bunker capacity	16,037 m^3	(566,346 ft^3)
Pump capacity	4 X 4,500 m^3/h	
Gross tonnage	125,414	reg ton

Significant features of this class of vessel are cylindrical bow, raised forecastle deck, six-level deckhouse aft, separate engine room casing with one tall funnel and cruiser stern slightly shortened by a small triangular transom.

Hull structure shows certain minor alterations in comparison with its forerunners. Thus, all fifteen cargo tanks have been made easier to clean by reduced width of the lower transverse bulkhead stringer. Bulkhead webs have been strengthened to compensate for this change. The center tank swash plates have been eliminated by using a deep deck-web and higher bottom web without perforations.

The forward piping system for fuel oil and ballast water has been sectionalized by concentrating all piping from maindeck into three pump towers which were pre-assembled and fitted with submersible hydraulic fuel pumps, piping for drive water and oil heating water, extension spindles for ballast valves, etc., and were put aboard as one unit. This arrangement is reckoned to have reduced the ship's outfitting period by two work days.

The cargo compartment is sub-divided into five groups of centerline and port and starboard wing tanks, all of them intended for paying cargo. Nos 5 wing tanks are fitted with slop tanks with a capacity of 7,232 m^3. Clean ballast spaces are arranged only in forward and aft peaks and as wing tanks along the sides of the engine room. Ballast is normally loaded in all cargo tanks to achieve optimum draft when transiting without cargo oil aboard.

In the pumproom, adjacent to the engine room, there are four turbine-driven Stal-Eureka cargo oil pumps each capable of discharging 4,000 m^3/h against a head of 13 kp/cm^2 and two 900 m^3/h eductors chiefly intended for feeding contaminated water into the slop-receiving No. 5 center tank. Further, there is a 200 m^3/hr reciprocating steam pump for transferring of water between the two wing slop tanks and finally overboard. All tank washing machines are of the Gunclean make.

Cargo pumps are fitted with automatic priming systems (Prima Vac) which prevent the pumps from running dry at reduced discharge-flow by recirculation of oil. Conventional stripping pumps are not installed since main pumps can be used virtually to the last drop of cargo oil. Center tanks Nos 2, 3, and 4, which can be used as ballast tanks, have free flow through bulkhead valves at bottom level. Filling and emptying is from center tank No. 4.

Out of 123 butterfly valves fitted in the cargo oil system 49 are remotely operated from a control room in the deckhouse on a Kracht type hydraulic control system. Thirty-one valves are hydraulically operated from local control boxes, and the remaining 43 are manually operated. A mimic diagram in the cargo control room indicates continuously the hydraulic valves' position. Also end position of manual valves can be indicated but require a pressbutton signal from the operating location. Tank levels are automatically indicated by ullage meters of the Neil Varec type.

Machinery

Propulsion is by a regular set of Kockum Stal-Laval cross-compound triple-reduction geared steam turbines rated at 32,000 metric shp at 85 propeller revs/min. Contract speed is 15.9 knots (equal to service speed) but during sea trials a mean speed of 16.2 knots was attained at full draught and full engine output. The engine moves a five-bladed propeller weighing 52 tons and measuring 8.900 m in diameter and 6.154 m in mean pitch.

Steam is taken from two Combustion Engineering type V2M-8 water-tube boilers, each delivering a maximum of 71 t/h steam at 60.8 kp/cm^2 and 510 deg.C. Electricity is normally supplied by a Stal-Laval/ASEA turbo alternator of 1,250 KVA, 3 phase, 450 V, 60 Hz. A Hedemora-Pielstreck-ASEA diesel alternator of similar power serves as a standby and starts automatically should the main supply fail.

The usual range of ancillary units, such as condensers, pumps of many descriptions, evaporators, steam-to-steam generators, compressors, separators, etc, is, of course, also to be found, all of them monitored from the engine control room where all vital data are recorded.

Machinery Instrumentation

The engine control room is fitted with a complete set up of Kockums electronic control and monitor devices which permit unmanned operation.

The ship's process computer system is mainly designed for Navigation and Steering but the computer also handles the Bridge Remote Control of the propulsion turbines, (Item 6 below). Otherwise, the engine functions are controlled and monitored by the following electronic units:

1. Kockums Combustion Control MK 3TF for regulation of steam production and feed water supply within narrow tolerances over the entire speed range.

2. Kockums Burner Control, for performing of boiler purge, burner light on and burner shut off in logical sequences.

3. Kockums Flame Guard, for direct observation of flame quality in the furnace.

4. Kockums Controller System, for fingertip regulation of numerous boiler functions other than those regulated by Combustion Control.

5. Kockums Boiler Safety System, for automatic boiler shut off at abnormal conditions such as irregular water levels in steam drum, fan failure, gas/air heater failure, etc.

6. Kockums Propulsion Control, for regulation of steam flow to main turbines on signals from the Kockum Bridge 530 type process computer.

Items Nos 1 to 4 have been available separately for some years but Nos 5 and 6 are now appearing for the first time. No 6 is a link between the computer and the turbine valves and is also used for local control from the engine room control station quite independent of the computer.

Bridge Process Computer

The Kockum Bridge 530 computer system is intended for two main purposes, navigation (inclusive of precision steering) and main turbine control. The computer is placed in a room immediately below the bridge and is equipped with a 24 K memory, two instrument cabinets, and one typewriter placed in the wheelhouse.

The heart of the system is a general purpose digital computer manufactured by Kongsberg Vapenfabrikk, Norway. It is a robust structure with military specified components and integrated circuits.

The combined wheelhouse and chartroom is fitted with modern navigation devices connected to the computer. These are mainly comprised of:

1. Doppler Log, type Ametek Straza, with two transmitter units forward and one aft in the ship's bottom and

three indicators, one of which is located on each bridge wing. Having both bottom-track and water-track this apparatus measures speed and drift with an accuracy of 0.02 knots. Readings are continuously fed into the computer and used for dead reckoning and steering.

The Doppler Log is of special value when navigating in current water, and at anchoring and mooring occasions when the momentum of a loaded ship must be taken into consideration even at very low speed.

2. Satellite receiver, type Magnavox MX 902-2, for automatic position finding anywhere. Signals from the U.S. Navy Satellite System are decoded by the computer. Current ship position is displayed as Latitude and Longitude on a digital position indicator at the chart table. Satellite fixes with an accuracy of abt 0.2 nautical miles are received approximately every 90 minutes. During the intervals, position indication is continued by dead reckoning relying mainly on information from gyro-pilot, Doppler Log and SAL Log via a special position filter that weighs the results from the different navigation methods in an optimal way by comparison with earlier measurements and variances.

3. In addition to a modern Sperry Autopilot there is also a computer autopilot. The core of the computer pilot is a separate rate gyro. Originally it was developed by the Swedish Military Research Organization for the purpose of steering guided missiles. Made available also for commercial applications it is now manufactured by AB ATEW, Sweden. Reacting on the first indication of course deviation, the gyro allows the computer autopilot to steer the ship with great precision and exceedingly small rudder angles. Speed reductions through course deviations are therefore minimized. Input data are course, angular speed and rudder servomechanism position.

4. Kockums Steermaster, a small panel to communicate with the computer for steering. Hence, the computer is operated by means of a keyboard, and both set course and actual course can be digitally displayed. The panel also has press-buttons for requesting printouts of great circle and satellite navigation data.

Automatic great circle navigation is incorporated in the Kockum Bridge 530 computer routine. Place of destination is entered by means of the typewriter. Up to 9 destinations can be entered at the same time. The computer automatically compensates the course for drift due to wind and current.

The drift is calculated from the result of satellite-navigation and Doppler log.

5. Kockums Propulsion Control comprises one panel on the bridge for remote computer control, and one panel in the engine room for local control. On initiation from anyone of three bridge engine telegraphs the computer controls steam flow to the ahead or astern main turbines. When main engine is manually operated the same control is effected direct by the Propulsion Control from engine control room. Valve operation is in accordance with a time program until the shaft speed coincides with the speed set on the engine telegraph.

Efficiency Calculations

The Kockum Bridge 530 also scans fuel oil flow and temperature, shaft speed and shaft torque. From these data, shaft power and fuel rate are computed and logged by means of the typewriter.

Bridge Instrumentation

The bridge instrumentation is divided into four groups located, as follows: The maneuvering console and the communication console are oriented athwartships on the forward starboard side of the bridge immediately adjacent to the wind screen; a multipurpose alarm console is located on the starboard side; and a chart table panel is centrally located in the bridge compartment.

Two interswitchable radar PPIs (Raytheon TM 1660/12 S and Rm 1645/12 X) are placed on line with the chart table at starboard, and the Sperry steering stand is on the centerline forward of same.

The maneuvering console carries a Kockums Propulsion Control (similar to that in the engine control room) and all other control and alarm devices required for remote control of main engine and emergency operation of steering gear. The Jungner type engine telegraph can be operated also from the bridge wings.

The communication console is fitted with dial telephone and two soundpowered emergency telephones, crew calling system, wireless paging system, control unit for docking loud hailer system, and Doppler Log main indicator.

The starboard side console contains the control for lanterns, mast lights and deck lighting, Tyfon automatic sound and light signals, as well as alarm panels for computer system and the ship's general emergency alarm inclusive of ventilation fan shut off.

The chart table is, from left, fitted with central clock (Burk), radio direction finder (Plath), Decca Navigator, digital position indicator (Kockum's), SAL-log, echo-sounder (Simrad), gyro compass and course recorder (Sperry) and VHF communication control panel.

Separately installed in the wheelhouse are the automatic fire alarm control unit (Salwico) watching both accommodation and engine room, a weather facsimile printer and the computer typerwriter.

The ship's radio station manufactured mainly by Standard Telephone and Radio AB is on lease from the Swedish Board of Telecommunication. It embraces a Telex set for direct communication with similar shore installations.

Miscellaneous Outfit

Deck machinery is steam driven and of the Helsingborg make. It consists mainly of two vertical 70-ton windlasses for 114 mm chain cables, ten 30-ton automatic mooring winches, four of which are placed on maindeck, and two 6.5-ton cargo winches. These serve a samson post and a single 15-ton boom placed between cargo cross-over lines on the port and starboard side of the main deck. Aft of main superstructure there is a 2.5-ton telfer crane travelling on a gantry reaching well out over the ship's side.

The personnel accomodations are of high standard and support a complement of 44 officers and crew. Normally the complement does not exceed 32. By means of incombustible bulkheads in the living accommodations the space is divided into fire proof sections of 50 m^3 as a maximum. Partition bulkheads have been doubled in thickness in order to improve sound insulation. As to furniture, plastic upholstering has been avoided as much as possible and all cabin decks are completely carpeted.

DEVELOPMENT

The Salen Shipping Companies have a long history of interest in the automation of ship functions. All of their ships, of all types, built since 1966 have been equipped with the unmanned engine room concept. The SEA SPIRIT and SEA SPRAY, both completed in 1966 experimented with automatic valving systems for cargo handling.

The T/T SEA SOVEREIGN project, a joint development of Kockums; ASEA, a Swedish systems house; the Swedish Ship Research Institute; and Salen Shipping Companies, which was launched in November 1969 is one of the best known of the early experiments with computers on board merchant ships.

When the SEA SERPENT group of ships was contracted for, it was decided to develop an in-house capability at Kockums to carry out all of the work involved in designing, programming and installing a ship's automation system. As a result the Kongsberg computer system for navigation and bridge control was produced and married to the previously developed specialized analog systems. The result is the present system.

PLANS FOR NEW SHIPS

At this writing plans being considered between Salen and Kockums for their next series of ships, the 350,000 DWT tankers, calls for very complete automation including the following:

1. Automatic navigation with satellite and Decca system.
2. Computerized anticollision radar system.
3. Fully automated engine room with duplicate presentation on the bridge.
4. Computerized, automated cargo handling from a bridge position.
5. Anchor operation from the bridge with television inspection.
6. Docking radar as well as docking sonar systems.
7. Electromagnetic log in place of present pitot tube type.
8. Deck winch operation from the bridge with TV monitoring from 2 cameras.
9. 5 - 6 cameras for TV monitoring of engine room.
10. X-Y recorder for automatic plotting of positions.
11. Facsimile system for receiving weather maps.

AN OVERVIEW

As will be seen from a review of the following material, Kockums and Salen have achieved a remarkable success with what is really a quite simple system compared with what would probably be demanded of a corresponding American system. As it has shown during this trip the computer system and its associated engine room automation are quite capable of taking the T/T SEA SERPENT across thousands of miles of open ocean unattended. Human intervention is necessary to establish new courses at turning points in the selected track, to maintain an anticollision watch, and to take care of normal maintenance and any equipment emergencies which might occur.

Dependence is placed upon one method of position determination, the TRANSIT satellite, but with completely satisfactory results except for close in shore sailing. Only rudimentary and absolutely necessary logging is carried out - none for record purposes. Again, the ships officers are quite happy at present with this.

As others hear of this success, it should have a very positive effect upon the rate of introduction of automation in merchant vessels.

CHAPTER 3

DESCRIPTION OF THE COMPUTER SYSTEM ON BOARD T/T SEA SERPENT

GENERAL

The characteristics of the computer system installed by Kockums Mekaniska Verkstads AB on board the T/T SEA SERPENT of Salen Lines AB are as described in Table I. The block diagram of the system is illustrated in Figure 1. The computer is connected to the ship's machinery through a specially designed I/O interface developed by Kockums and installed with the computer in the Electrical Equipment Room on E deck, one deck below the bridge. The computer interfaces with the ship's personnel through the Teletype, the Kockums Steermaster panel (Figure 2) at the wheel location, the Kockums Position Indicator (Figure 3) at the chart table, and the Kockums Propulsion Control (Figure 4) on one of the bridge engine room panels. All are on the bridge.

Table II presents a list of the analog input points to the computer. Table III presents the corresponding digital inputs while Table IV gives the digital outputs used. Note that there are no analog outputs as such.

The computer system has four main tasks: First, dead reckoning navigation modified by fixes obtained from the transit satellite; second, transmission of bridge commands to the engine room modified by the capabilities of the engine room machinery to respond at that particular moment; third, steering of a straight course by rate gyro sensing; and fourth, communication with the bridge officer. The computer has no control over the engine room operation other than transmission of properly modified bridge command signals which position throttle valves controlling steam to the main turbines.

Reliable operation of the computer system is monitored by a Watch Dog Timer timed to trip at 0.5 seconds if no updated signal is received to reset it. Tripping of the Watch Dog Timer causes a computer printout of COMPUTER FAILURE and horn alarms on the bridge and in the engine control room. A check is also made of a special computer generated I/O test signal, Point 35. This must always be within two percent of its established value otherwise a computer failure is indicated.

Each of the functions will be reported on in turn. The reverse order will be used for convenience.

TABLE I

CHARACTERISTICS OF THE KOCKUMS COMPUTER

(KONGSBERG VAPENFABRIK A/S SM-3)

16 bit word length

Integrated circuit construction

24 K core memory, no mass memory

CPU operates asychronously to memory

8 general registers

97 instructions

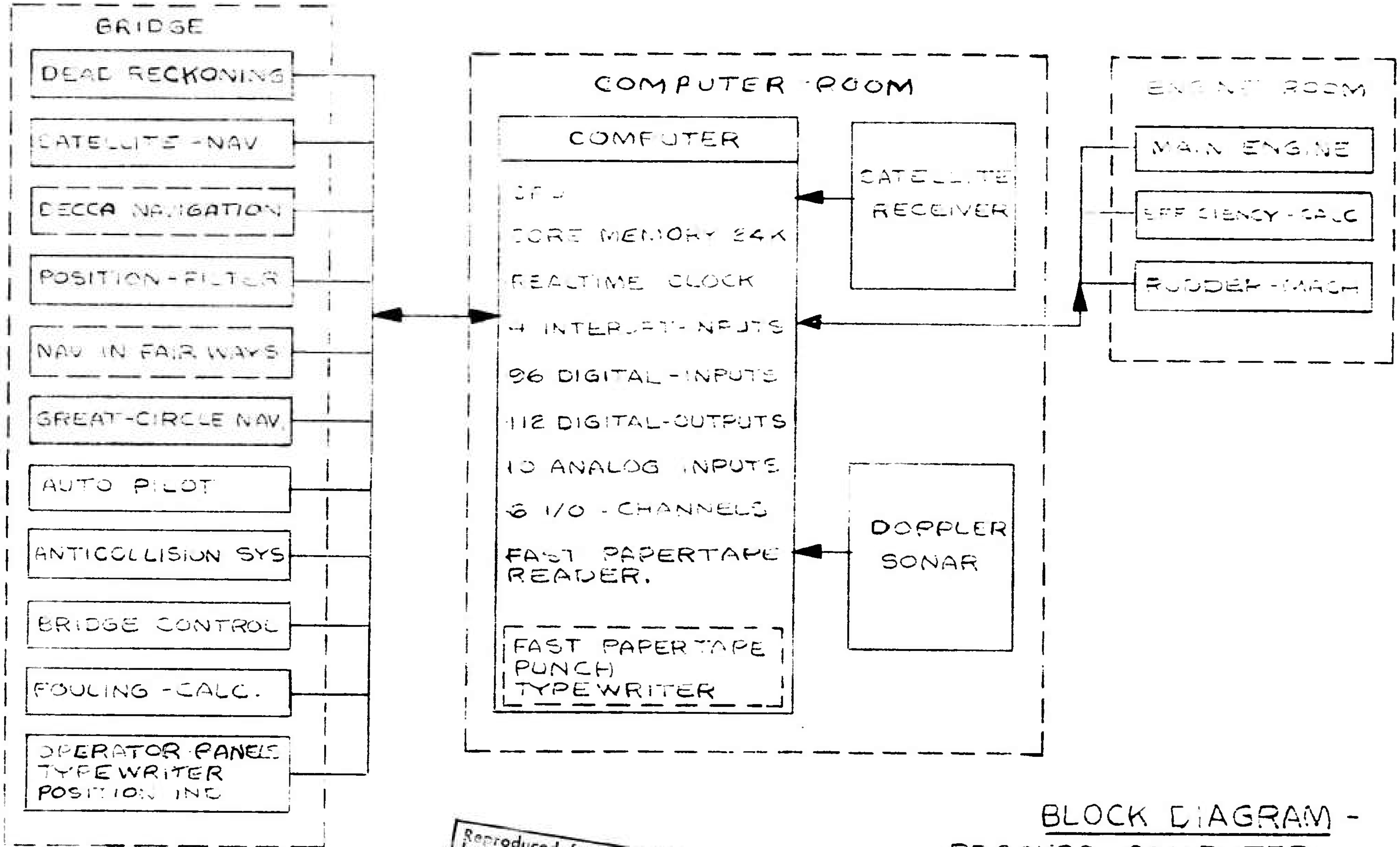
Peripherals

KSR 33 Teletype, no punch or tape readers (located on the bridge)

Digitronics High Speed Paper Tape Reader, Model 2540 EP (located with the computer on E Deck).

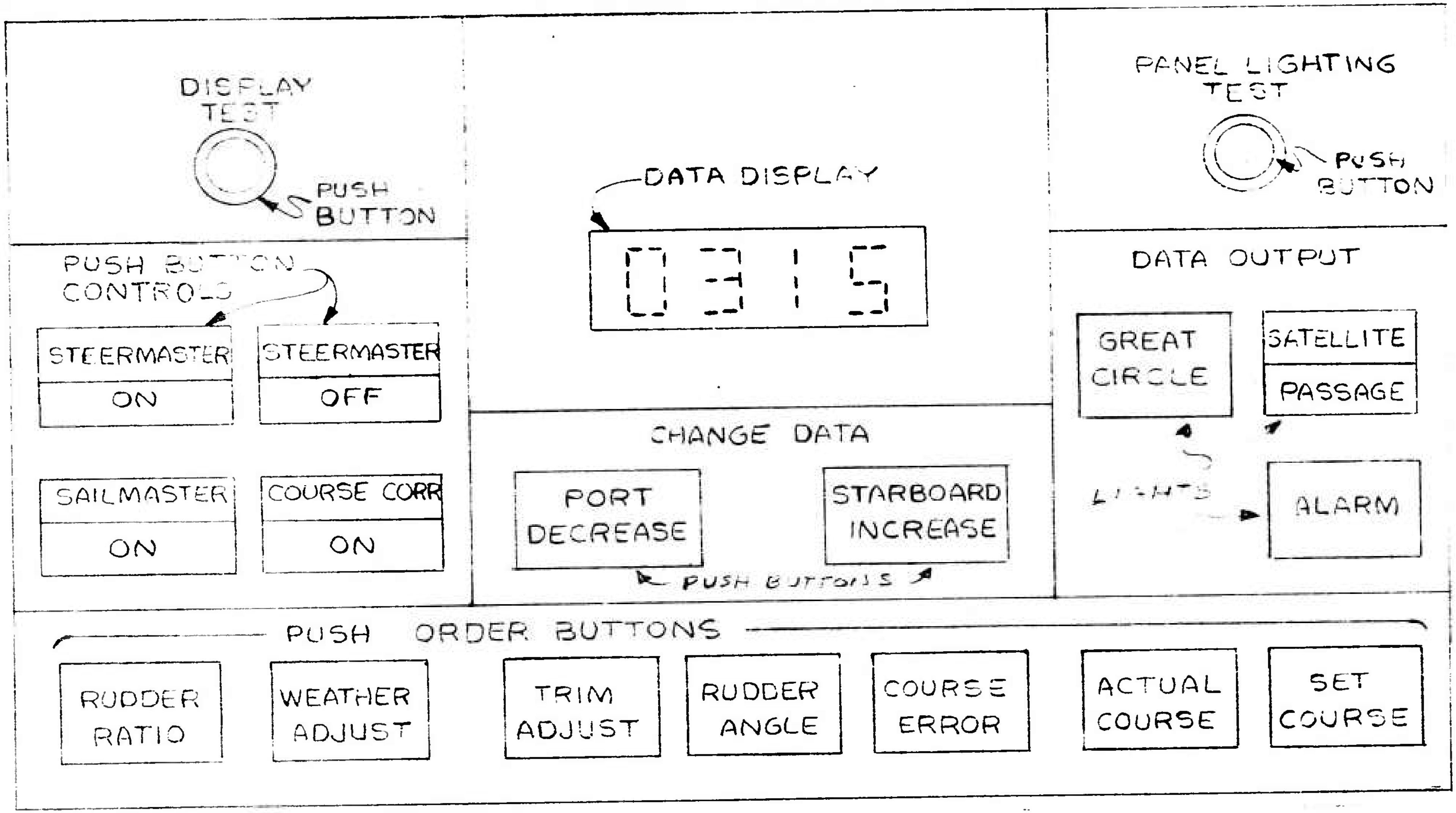
Note:

The design of the SM-3 is a modification of a computer developed by the Norwegian Defense Research Laboratory, Kjeller, Norway, for military applications. This latter machine is based on the Xerox Data Systems Sigma 2 design.



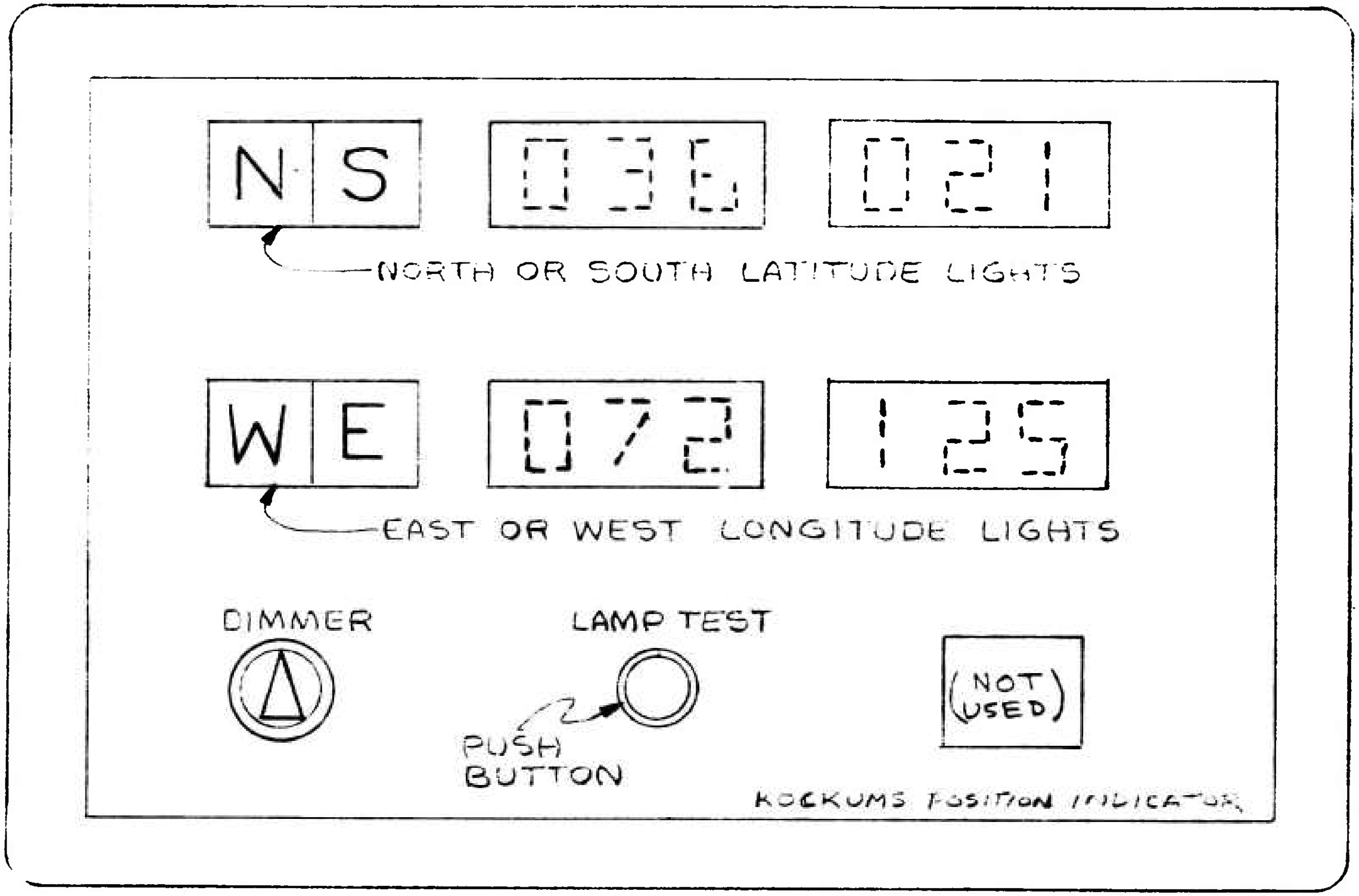
BLOCK DIAGRAM -
PROCESS COMPUTER
SYSTEM ON BOARD
T/T SEA SERPENT

FIGURE 1



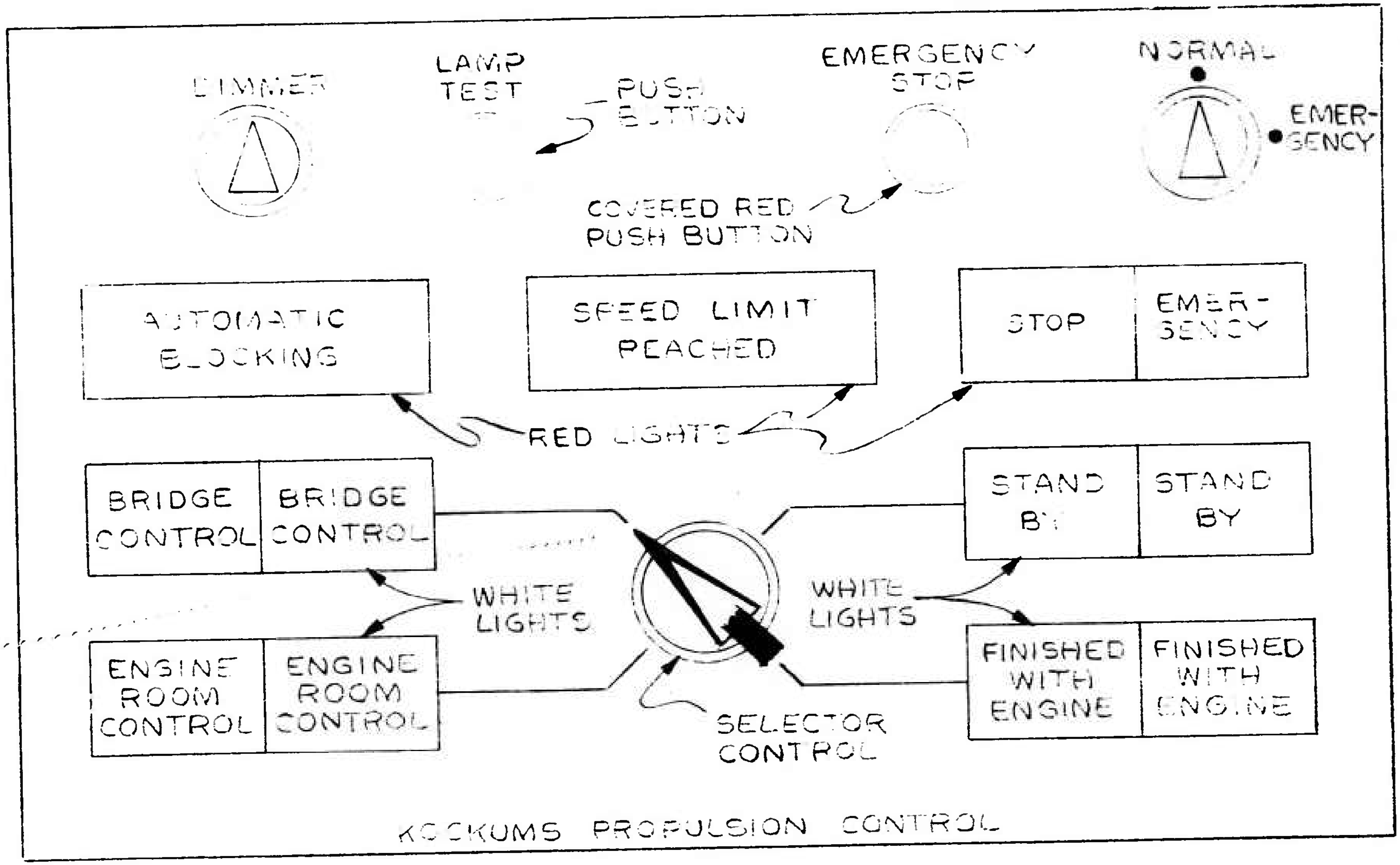
KOCKUMS
STEERMASTER PANEL

FIGURE 2



KOCKUMS POSITION INDICATOR

FIGURE 3



KOCKUMS
PROPULSION CONTROL

FIGURE 4

TABLE II

LIST OF ANALOG INPUT POINTS TO COMPUTER SYSTEM

Point Number	Description	Units
1/3 Second Scan Cycle		
1	Course	Degrees
1 Second Scan Cycle		
2	Rudder Position	Degrees
3	Course Change Rate	Degrees/Sec
4	Engine Telegraph Position (Bridge)	RPM
5	Propeller Speed (Input)	RPM
6	Steam Pressure STPT (HP Turbine)	ATM
7	Steam Pressure (Back Turbine)	ATM
8	Propeller Speed	RPM
9	Propeller Speed - 5 minute average	RPM
10	Propeller Speed - 4 hour average	RPM
3 Second Scan Cycle		
11	Speed - Doppler Log	KTS
12	Speed - Doppler Log - 5 minute ave.	KTS
13	Speed - Doppler Log - 4 hour ave.	KTS
14	Speed - SAL Log	KTS

TABLE II cont.

Point Number	Description	Units
15	Speed - SAL Log - 5 min. ave.	KTS
16	Speed - SAL Log - 4 hour ave.	KTS
17	Transverse Speed - Forward	KTS
18	Transverse Speed - Aft	KTS
37	Wind and Current Drift	Degrees
38	Wind and Current Drift - 5 min. ave.	Degrees
19	Spare	
10 Second Scan Cycle		
20	Stress - Propeller Shaft	KNm
21	Stress - 5 minute ave.	KNm
22	Stress - 4 hour ave.	KNm
23	Temperature - Fuel Oil	°C
24	Temperature - Fuel Oil - 5 min. ave.	°C
25	Spare	
26	Fuel Flow	kg/sec
27	Fuel Flow - 5 min. ave.	kg/sec
28	Fuel Flow - 4 hour ave.	kg/sec
29	Spare	
30	Power Output - 5 min. ave.	KW
31	Power Output - 4 hour ave.	KW
32	Spare	

TABLE II cont.

Point Number	Description	Units
33	Specific Fuel Consumption - 5 min. ave.	g/KWH
34	Specific Fuel Consumption - 4 hour ave.	g/KWH
35	Test Voltage	Volts
36	Test Voltage - 5 min. ave.	Volts
39-44	Spares	
45	Rudder Servo Rate	

TABLE III

LIST OF DIGITAL INPUTS TO COMPUTER SYSTEM

Channel	Bit	Input	Description
0	0-13	1-14	Value of Reading of Docking Log
	14	15	Direction of Motion
	15	16	Water Track
1	0-11	17-28	Value of Reading of Transverse Log - Aft
	12	29	Direction of Motion
	13-15	30-32	Value of Reading of Transverse Log - Forward
2	0-8	33-41	
	9	42	Direction of Motion
	10	43	Blocked when Tested
	11	44	Temperature Control, I/O Unit
	12	45	Test Point to Digital I/O
	13	46	Teletype Service
	14	47	Spares
	15	48	
3	0	49	Alarm for Rate Gyro
	1	50	Spare Position Indicator
	2	51	Order Button - Rudder Ratio
	3	52	Order Button - Weather Adjust
	4	53	Order Button - Trim Adjust
	5	54	Order Button - Actual Course

TABLE III cont.

Channel	Bit	Input	Description
	6	55	Order Button - Set Course
	7	56	Order Button - Course Error Limit
	8	57	Order Button - Rudder Angle Limit
	9	58	Order Button - Port/Decrease
	10	59	Order Button - Starboard/Increase
	11	60	Great Circle Data
	12	61	Satellite Data
	13	62	Course Correction
	14	63	Sailmaster On
	15	64	Steermaster On
4	0-10	65-75	Compass Inputs
	11-13	76-78	Gyro Interface
	14-15	79-80	Spares
5	0	81	Spare
	1	82	Computer Connected to Bridge Steering
	2	83	Engine Telegraph Ahead
	3	84	Engine Telegraph Astern
	4	85	Ahead Valve Closed
	5	86	Ahead Valve Open
	6	87	Astern Valve Closed
	7	88	Astern Valve Open
	8	89	Blocking Water Level 1, Low Alarm

TABLE III cont.

Channel	Bit	Input	Description
	9	90	Blocking Water Level 2, Low Trip Alarm
	10	91	Blocking Pressure 1
	11	92	Blocking Pressure 2
	12	93	Main Engine Tripped
	13	94	RPM Ahead/Astern
	14	95	Emergency Stop
	15	96	Circulation pumps running
6	0-15		Spares
7	0-15		Spares

TABLE IV

LIST OF DIGITAL OUTPUTS FROM COMPUTER SYSTEM

Channel	Bit	Output	Description
0	0-15	1-16	Latitude Reading
1	0-4	17-20	
	5	21	North or South
	6-8	22-25	Spares
	9-15	26-32	Longitude Reading
2	0-13	33-46	
	14	47	East or West
	15	48	Spare
3	0-1	49-50	Spare
	2	51	Watch Dog Timer - Computer Failure
	3	52	Alarm - Computer High Temperature
	4	53	Alarm - High Fuel Rate
	5	54	Alarm - Course Error
	6	55	Alarm - Steermaster Failure
	7	56	Destination Reached
	8	57	Alarm - Computer I/O Failure
	9	58	Test of Digital I/O
	10	59	Alarm - TTY Failure
	11-15	60-64	Spares

TABLE IV cont.

Channel	Bit	Output	Description	
4	0	65	Open Valve Ahead - Main Turbine	
	1	66	Close Valve Ahead - Main Turbine	
	2	67	Open Valve Astern - Main Turbine	
	3	68	Close Valve Astern - Main Turbine	
	4	69	Lamp - Computer Clear	
	5	70	Lamp - Automatic Blocking	
	6	71	Lamp - Maneuver Underway	
	7	72	Idling in Force	
	8	73	D/A Converter for KCC	
	9	74	D/A Converter for KCC	
	10	75	D/A Converter for KCC	ENGINE SPEED COMMAND
	11	76	D/A Converter for KCC	
	12	77	D/A Converter for KCC	
	13	78	D/A Converter for KCC	
	14	79	Alarm - Transmitter Failure	
	15	80	Spare	
5	0-15	81-96	Indicator on Steering Panel	
6	0	97	Spare	
	1	98	Spare	
	2	99	Steermaster On	
	3	100	Lamp - Course Correction	
	4	101	Lamp - Satellite Passage	

TABLE IV cont.

Channel	Bit	Output	Description
	5	102	Sailmaster On
	6	103	Order for Port Steering Correction
	7	104	
	8	105	Order for Starboard Steering Correction
	9	106	
	10-15	107-112	Spares
7	0-12	113-125	Spares

COMMUNICATION WITH BRIDGE OFFICERS

Table V lists those items which the computer system operator, almost always the Watch Officer, can enter into the computer or those commands which he can request of it. Indicated by capitals underlined are the respective command words used. Table VI presents an example in each case of the type of printout obtained from the computer system. Table VII lists those analog inputs which can be calibrated and which have high and low alarm limits. The valves given are the original set for this ship. They are not necessarily correct at this time. No complete record of these latter are readily available as mentioned elsewhere in this report.

Logging

As is shown by Items 6, 7, and 8 of Table VI, the computer system acts as a simple one variable logger. It automatically logs watch positions (highest priority in printing) and satellite fixes (second priority). All other logging is by specific request. No multiple variable logs or time repeated logs other than watch position can be obtained. Repeat logs can be had for any interval of time up to 60 seconds.

TABLE V

ITEMS WHICH CAN BE ENTERED THROUGH THE OPERATOR'S CONSOLE (TELETYPE)

1.	Calendar	-	Year, Month, and Day, <u>DATE</u>
2.	Present Position	-	Latitude and Longitude in degrees, minutes, and tenths of minutes, to update the dead reckoning calculations, <u>FIX</u>
3.	Course	-	Degrees and tenths, used to calibrate the gyro compass,<u>COMP</u>
4.	Speed and Direction of Current	-	In knots and tenths of knots and in degrees, <u>STREAM</u>
5.	Order to Proceed to Next Destination in the Stored list	-	<u>NEXT</u>
6.	Print Position of Next Destination	-	Latitude and Longitude in degrees and tenths, <u>PRDEST</u>
7.	Acceptable Accuracy of Dead Reckoning Position at Destination	-	Tenths of nautical miles from 0.1 - 9.9, <u>POSAC</u>
8.	Determination of Latitudes on the Chosen Great Circle Course Equivalent to a Given Longitude	-	Longitude entered as degrees, minutes and tenths <u>LATP</u>

TABLE V cont.

9.	Up to Ten Separate Turning Points Between Initial and Final Destination	-	Entered in direct series in degrees, minutes and tenths of minutes, DEST
10.	Determination of Longitude on the Chosen Great Circle Course Equivalent to a Given Latitude	-	Latitude entered as degrees, minutes, and tenths, LONGP
11.	Equivalent Antenna Height for Satellite Navigation. Correction for Geoidal and Ship Heights	-	Meters., ANT
12.	Satellite Alert	-	A list of times of passage and local elevations of the transit satellite for the period of time requested (up to 24 hours ahead). ALERT
13.	Request for Print out of Next Satellite Position Determination	-	SATFIX
14.	Request for Print out of Satellite Characteristics	-	Items requestable are: a) Orbital parameters b) Doppler count c) Doppler spread d) Results (i.e., position) PRSAT

TABLE V cont.

15.	Request for Calendar Data	-	Year, Month, and Date DATE
16.	Request for Time	-	Hours and minutes in GMT TIME
17.	Request for Time Zone Correction	-	Hours and tenths BRASS
18.	Request for Determination of Admiralty Constant (i.e., Speed Loss Due to Marine Growth)	-	Tenths of knots calculated by an exponential relationship with time, water temperature, etc. ADM
19.	Request for Time Check	-	Second, Minute, Hour, Day, Month, Year, DATCL
20.	Request for Fuel Density	-	Density to four decimal places versus ambient temperature, FUEL
21.	Request for Print out of a Point Value (Single Time)	-	LOG
22.	Request for Repeat of Printout of Point Value	-	LOGINT sets number of points and interval in seconds, RLOG starts repetitive log.
23.	Change of Input Handling Conditions	-	Changes involved. a) Point on and off scan b) Point on and off alarm c) Value of soft alarm limit - low d) Value of soft alarm limit - high e) Value of hard alarm limit - low f) Value of hard alarm limit - high g) Calibration constant, MIPS

TABLE V cont.

24.	Request for Print out of a Memory Location Value in Octal Form	-	DUMP
25.	Request for Print out of Memory Location Value Decimal Form	-	FDUMP
26.	Change of the Value of a Memory Location in Octal	-	CHANGE
27.	Request to Change to Alternate Method of Reading the Course From the Gyro-Compass (Two Methods Available)	-	COURSE followed by ENCODER YES or NO

TABLE VI

EXAMPLES OF COMPUTER TTY PRINT OUTS

1. SATELLITE POSITION

TIME 8.12

OLD POSITION

LAT	N	10	20.2
LONG	W	61	32.6

SATELLITE FIX

LAT	N	10	19.7
LONG	W	61	39.3

ITER 6 EL 86.3 RES 0.05 SAT 7441 ANT 30

2. SATELLITE ORBIT PARAMETERS

ORBIT PARAMETERS

118.7085000
3.3660808
43.4211000
0.0019804
0.0027060
7463.5600032
348.3835002
-0.0000234
0.0062760
270.2233000
0.9999800

TABLE VI cont.

2.

26	293	0
36	305	0
46	309	-3
56	304	0
66	291	-7
74	271	0
80	244	-10
84	212	0
86	177	0
-1	-1	-1
-1	-1	-1
-1	-1	-1
-1	-1	-1

3. SATELLITE DOPPLER SPREAD

0111111111111111111000000000000000000000

4. SATELLITE DOPPLER COUNT

1	80	539897
2	80	529783
3	80	519043
4	80	507737
5	87	601614
6	80	481145
7	80	468730
8	80	456251
9	80	443860
10	87	523477

TABLE VI cont.

4.	11	80	417402
	12	80	406188
	13	80	395555
	14	80	385567
	15	87	436456
	16	80	365863
	17	80	358084
	18	80	350979
	19	80	344517
	20	87	411177
	21	80	332300
	22	80	327651
	23	80	323478
	24	80	319740
	25	87	384421
	26	80	312829
	27	80	310243
	28	80	0
	29	80	0
	30	87	0
	31	80	0
	32	80	0
	33	80	0
	34	80	0
	35	87	0
	36	80	0
	37	80	0
	38	80	0
	39	80	0
	40	87	0

TABLE VI cont.

5. SATELLITE ALERT

14.33 ALERT

TIME HOURS 24

SATELLITE ALERTS

TIME	ELEV
16.22	6
21.18	20
23.04	40
23.36	44
0.34	2
1.24	18
2.14	63
4.02	12
9.00	11
10.44	58
11.08	24
12.54	33
13.44	30

6. WATCH LOG

04.00 DEAD RECKONING

LAT	N	10	20.3
LONG	W	61	32.6

SAILED DIST. LAST WATCH PERIOD 0.1 NM

NUMBER SATELLITE FIXES 2

TABLE VI cont.

7. DAILY LOG

00.00	DEAD RECKONING		
LAT	N	10	20.1
LONG	W	61	32.5

SAILED DIST. LAST WATCH PERIOD 0.1 NM

NUMBER SAT FIXES 3

SAILED DIST.LAST DAY 0 NM

MEAN VELOCITY 0.0 KTS

8. EXAMPLES OF LOGGING

09.35 PNT 1 LOG 100.6 DEGR @

09.35 LOG INT

NUMBER 20

TIME S 5

09.35 RLOG

PNT NR 1

09.35	PNT	1	LOG	100.2	DEGR
09.36	PNT	1	LOG	100.2	DEGR
09.36	PNT	1	LOG	100.2	DEGR
09.36	PNT	1	LOG	100.2	DEGR
09.36	PNT	1	LOG	100.2	DEGR
09.36	PNT	1	LOG	100.2	DEGR
09.36	PNT	1	LOG	100.1	DEGR
09.36	PNT	1	LOG	100.1	DEGR
09.36	PNT	1	LOG	99.9	DEGR

TABLE VI cont.

8.	09.36	PNT	1	LOG	99.9	DEGR
	09.36	PNT	1	LOG	99,9	DEGR
	09.36	PNT	1	LOG	99.9	DEGR
	09.36	PNT	1	LOG	99.9	DEGR
	09.37	PNT	1	LOG	99.9	DEGR
	09.37	PNT	1	LOG	99.9	DEGR
	09.37	PNT	1	LOG	99.9	DEGR
	09.37	PNT	1	LOG	99.9	DEGR
	09.37	PNT	1	LOG	99.9	DEGR
	09.37	PNT	1	LOG	99.9	DEGR
	09.37	PNT	1	LOG	99.9	DEGR

ETC.

9. EXAMPLES OF ALARM LOGGING

	12.34	PNT	11	LOG	NO SCAN		
***	12.34	PNT	35	INPUT ERR.	NO SCAN		
***	12.34	PNT	35	LOW ALARM	10.2	LI	10.5V
RTN	12.34	PNT	35	LOW ALARM	10.7	LI	10.5V
***	12.34	ADC	ERR				
***	12.34	BUFF	FUL				

10. PRINT OUT OF COURSE PARAMETERS
(PNT 45)

12.34		COURSE DEGR	RUDDER DEGR	RATE DEGR/S
12.34	40	344.1	-2.1	-0.005

TABLE VI cont.

11. PRINT OUT OF DESTINATION DATA AND TURNING POINT FOR TRACK:

11.47 PRDEST

11.48 GREAT CIRCLE DESTINATIONS

ACTUAL POSITION

0 DESTINATIONS STORED

TOTAL DISTANCE 0 NM

11.48 DEST

NUMBER 2

LAT	N	10	47
LONG	W	61	43.6

NUMBER 3

LAT	N	11	35
LONG	W	60	23

NUMBER 4

LAT	S	01	40
LONG	W	10	30

TABLE VI cont.

NUMBER 5

LAT	S	33	49
LONG	E	18	17

11.50 GREAT CIRCLE DESTINATIONS

ACTUAL POSITION

COURSE OUT 338 DEGR

DISTANCE 29 NM

NUMBER 1

COURSE IN 338 DEGR

LAT N 10 47.0

LONG W 16 43.6

COURSE OUT 59 DEGR

DISTANCE 92 NM

NUMBER 2

COURSE IN 59 DEGR

LAT N 11 35.0

LONG W 60 23.0

COURSE OUT 112 DEGR

DISTANCE 1951 NM

TABLE VI cont.

NUMBER 3

COURSE IN 115 DEGR

LAT S 1 40.0

LONG W 30 30.0

COURSE OUT 131 DEGR

DISTANCE 3343 NM

NUMBER 4

COURSE IN 114 DEGR

LAT S 33 49.0

LONG E 18 17.0

4 DESTINATIONS STORED

TOTAL DISTANCE 5415 NM

12. EXAMPLES OF USE OF SYSTEMS PARAMETER CHANGE METHODS

12.57 MIPS

PNT NR 20

CODE SCANN (To Place Point on and off Scan)

OLD NO

NEW YES

TABLE VI cont.

CODE ALARM	
OLD YES	(To Place Point on and off Alarm)
NEW NO	
CODE ERLOW OR ERHIG	
OLD 30.00 DEGR	(To Set Limits of Soft Alarm)
NEW 28.5	
CODE ALLOW OR ALHIG	
OLD 31.20 DEGR	(To Set Limits of Hard Alarm)
NEW 32.50	
CODE KALIB	
+10V 32.67	(To Calibrate a Variable for the Computer)
-10V 30.05	
CODE ?	(To indicate MIPS Operation Complete)

The computer will indicate an incorrect combination of inputs to the operator by printing our the words INVALID COMBINATION.

TABLE VII

POINT INPUTS WITH CALIBRATION AND LIMITS

Point No.	Reading Versus Calibration Voltage + 10 V	Reading Versus Calibration Voltage - 10 V	Recommended Limits High	Recommended Limits Low
2	+ 43.00	- 43.00	+ 40.00	- 40.00
3	+ 1.10	- 1.10	+ 1.00	- 1.00
4	+ 104.50	- 104.50	+ 100.00	- 75.00
5	+ 115.40	- 115.40	+ 100.00	- 75.00
6	+ 70.90	- 7.90	+ 65.00	- 3.00
7	+ 70.90	- 7.90	+ 65.00	- 3.00
8	+ 500.00	- 500.00	+ 95.00	- 95.00
14	+ 29.15	- 0.00	+ 20.00	-0-
20	+3236.00	-3236.00	+3000.00	-3000.00
23	+ 156.25	- 43.75	+ 156.25	- 43.75
26	+ 500.00	- 500.00	+ 500.00	-0-
33	+ 500.00	- 500.00	+ 500.00	-0-
35	+ 15.00	- 0.00	+ 10.20	- 9.80
37	+ 5.00	- 5.00	+ 5.10	- 5.10

Alarm Logging

The computer system prints time, point number, type of violation if any, actual value, and value violated for each point which violates soft or hard alarm limits or returns to acceptable values after having violated these limits. A printout is given if a variable is not read by the scanner. In this case a NO SCAN printout is given but no last good value as in many other systems.

In addition errors in the ADC and a condition of full program buffer are printed out.

Alarm logging occurs only on points whose analog values are read into the computer. There is no automatic logging of alarms from the Kockums Propulsion Control. Likewise no actions taken on the Kockums Propulsion Control are recorded. The computer does print out actions taken with the Kockums Steermaster (computerized steering) and the Kockums Sailmaster (computerized dead reckoning navigation).

When a point goes NO SCAN for any reason it must be returned to SCAN by action of the Operator using the MIPS command. There is no automatic check of this condition.

PNT2 - Rudder Servo will give NO SCAN failure if > 20° requested.

PNT11 - Doppler Log will give NO SCAN failure if it is switched off or if > 20 KTS speed indicated.

PNT 14 - SAL Log will give NO SCAN failure if switched off or pulled.

All must be reinstated by MIPS before use again.

Kockums Steermaster

Adjustment of Course and changes of Automatic Pilot settings are conducted by means of buttons on the Kockums Steermaster Panel (Figure 2). Change is accomplished by simultaneously pressing the Order Button for the function desired and one of the Change Data buttons. All except "Actual Course" change by values of 1.0. Actual Course changes by 0.1.

Kockums Position Indicator

The Kockums Position Indicator continuously reads out Latitude and Longitude at the Navigators Chart Table to the nearest tenths of minutes. The button at the lower right hand corner previously allowed current and wind effects to be read out alternatively to actual position. This function has been recently discontinued in the continual revision of the computer program by Kockums.

AUTOMATED STEERING

The ship is equipped with a Sperry Twin Rate Gyro Pilot. However, under computer control the ship is steered by computer commands based on the computation outlined in Figure 5 where the computers senses the rate gyro output and corrects rudder movement to compensate. The actual control algorithm is a digital three-mode equation as follows:

Course Error (E) = Ordered Course - Actual Course + Drift Correction

Rudder Command = -Rudder Servo Position - Integrated Yaw Rate Factor + Controller Modified Course Error.

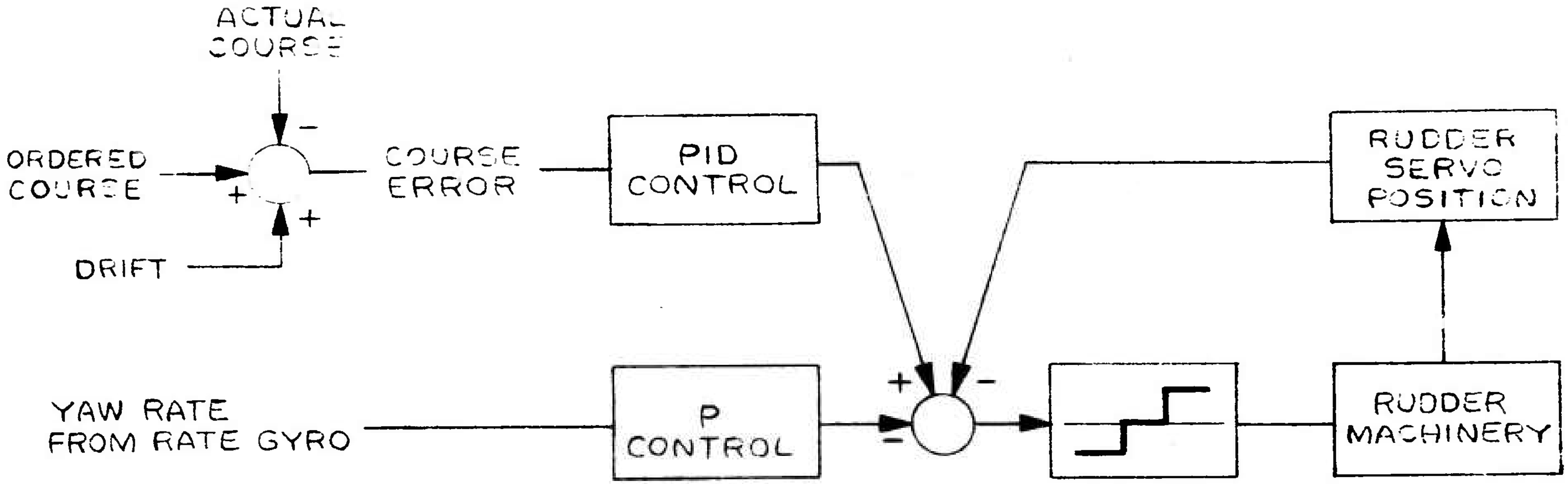
Controller Output = (Rudder Ratio) E + (Weather adjust) $\frac{dE}{dt}$ + (Trim Adjust) $\int E\,dt$

Rudder Ratio = P - Constant

Weather Adjust = D - Constant

Trim Adjust = I - Constant

Changing weather conditions and changing cargo conditions give different parameter combinations for Rudder Ratio, Weather Adjust, and Trim Adjust. It is recommended that every ship conduct a lengthy series of experiments to find the best combination of values.



BLOCK DIAGRAM -
AUTO PILOT -
COMPUTER BASED

FIGURE 5

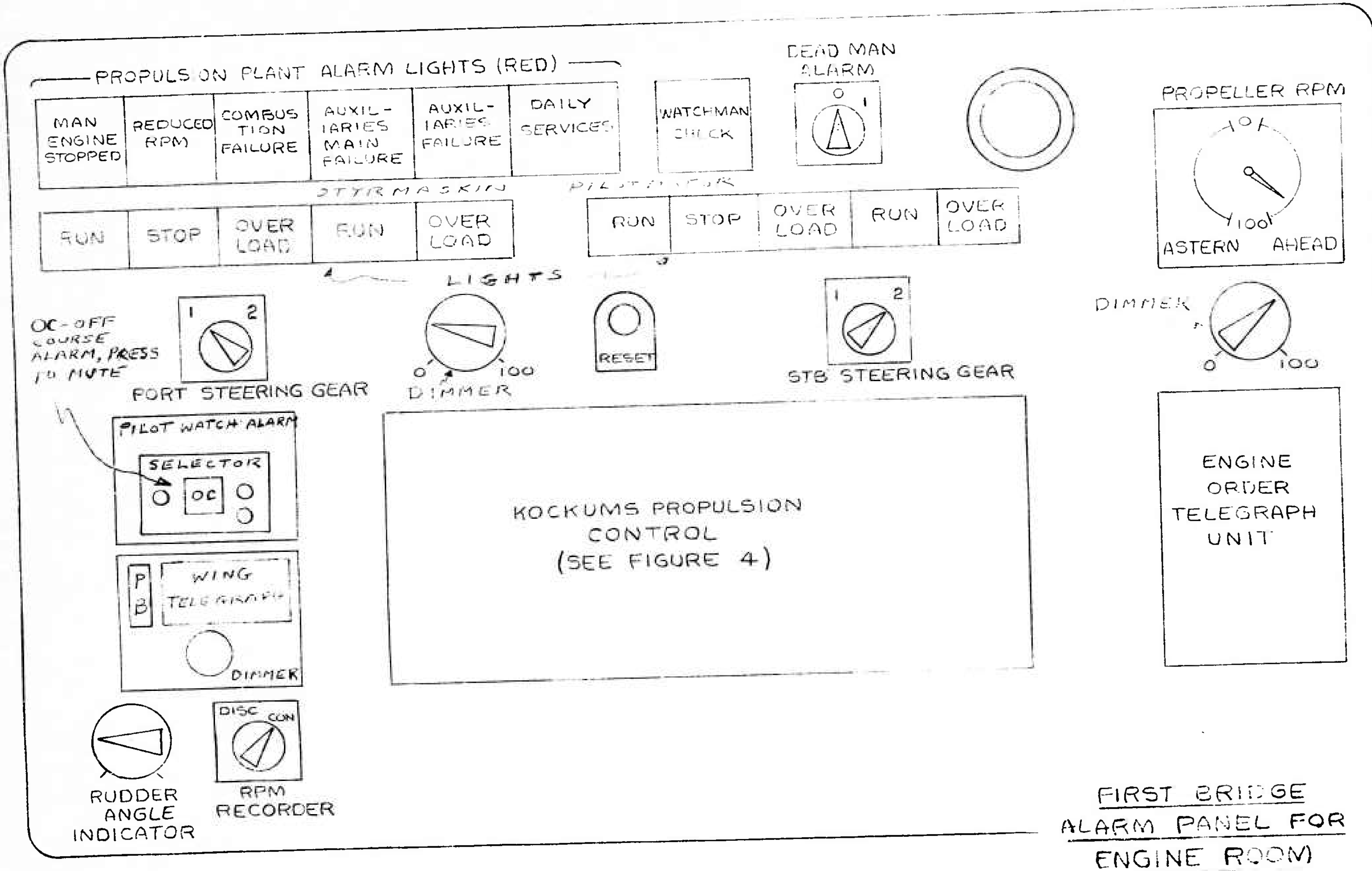
BRIDGE CONTROL OF ENGINE

A major use of the computer is in connection with the unmanned engine room system to permit bridge command of engine function without human intervention in the engine room. In this role the main function of the computer is to modify bridge commands according to a timed cycle of engine parameter change capabilities and to impose constraints on bridge operation when the engine is disabled in any way.

Operation is through the Kockums Propulsion Control Panel (Figure 4) mounted on the First Bridge Alarm Panel for Engine Room (Figure 6). Additional alarms are mounted on the Second Bridge Alarm Panel (Figure 7). Table VIII defines some of the alarms and other functions of these panels.

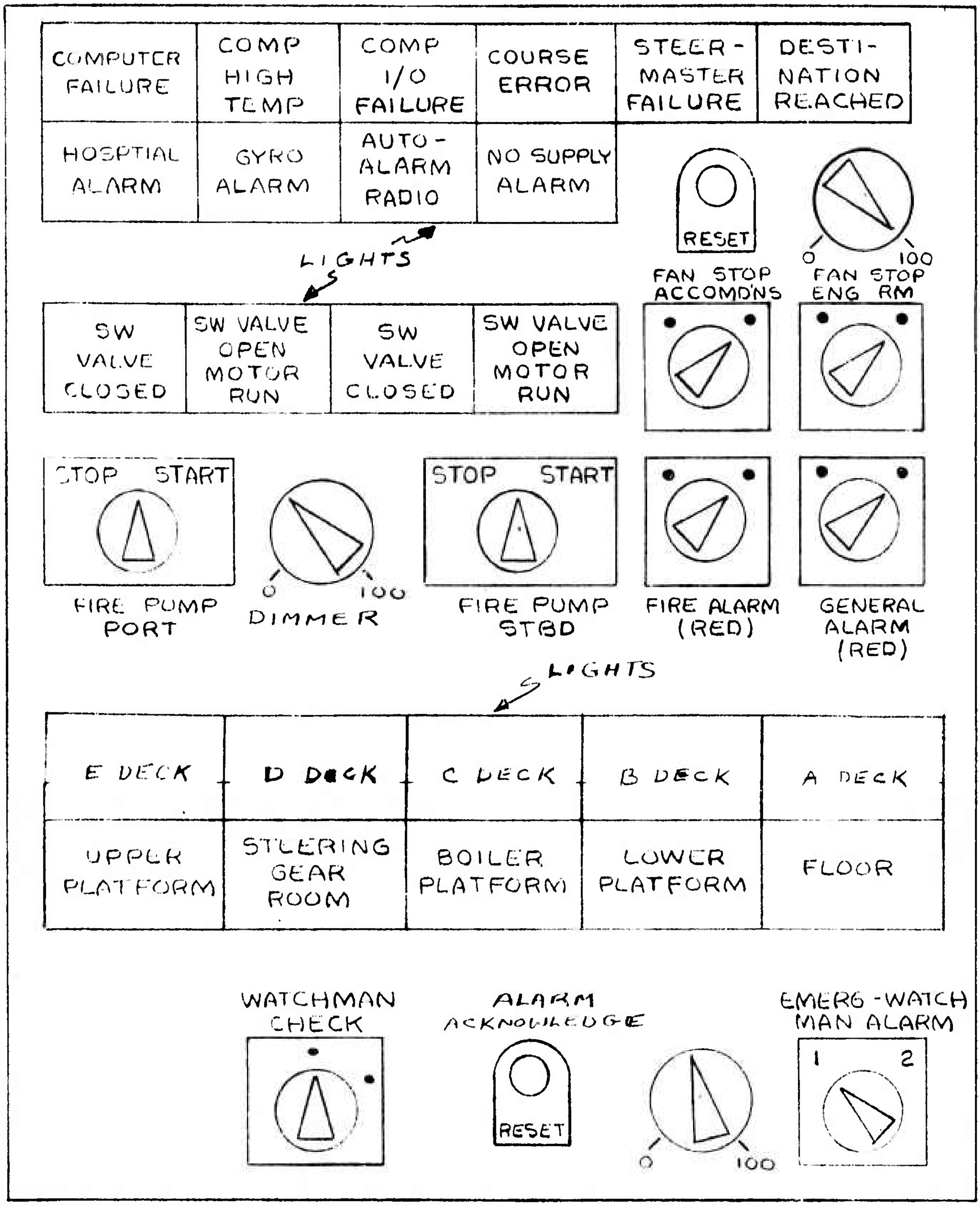
Engine Speed Control

Figure 8 presents the mechanical system diagram and Figure 9 the computer block diagram for the method of transmission of bridge commands to the engine through the computer. Figure 10 presents the actual time program imposed by the computer between the Watch Officer's command and actual execution of the command by the engine. Modification of computer commands when the engine is disabled is carried out by the Automatic Blocking Function. For example, if the boiler level or the boiler pressure should be too low, or if an input-failure related to engine functions should occur the time program will be blocked and the given engine telegrapic value will be modified. The alarm light "Auto Blocking" will be lighted on the Engineering Control Center Panel and Bridge Panel. The blocking action and modifications imposed are described in detail in Chapter IV.



FIRST BRIDGE ALARM PANEL FOR ENGINE ROOM

FIGURE 6



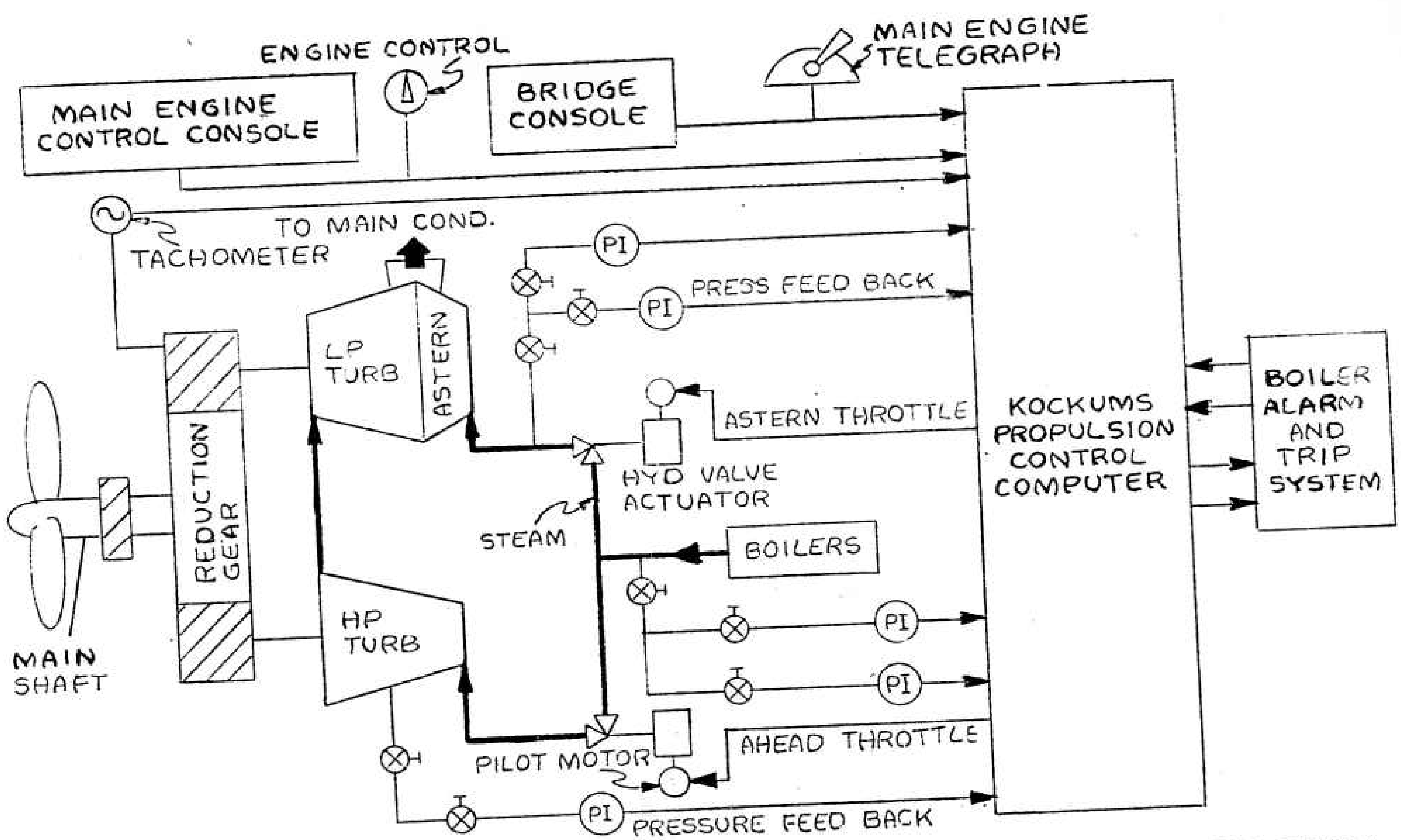
SECOND BRIDGE ALARM PANEL

FIGURE 7

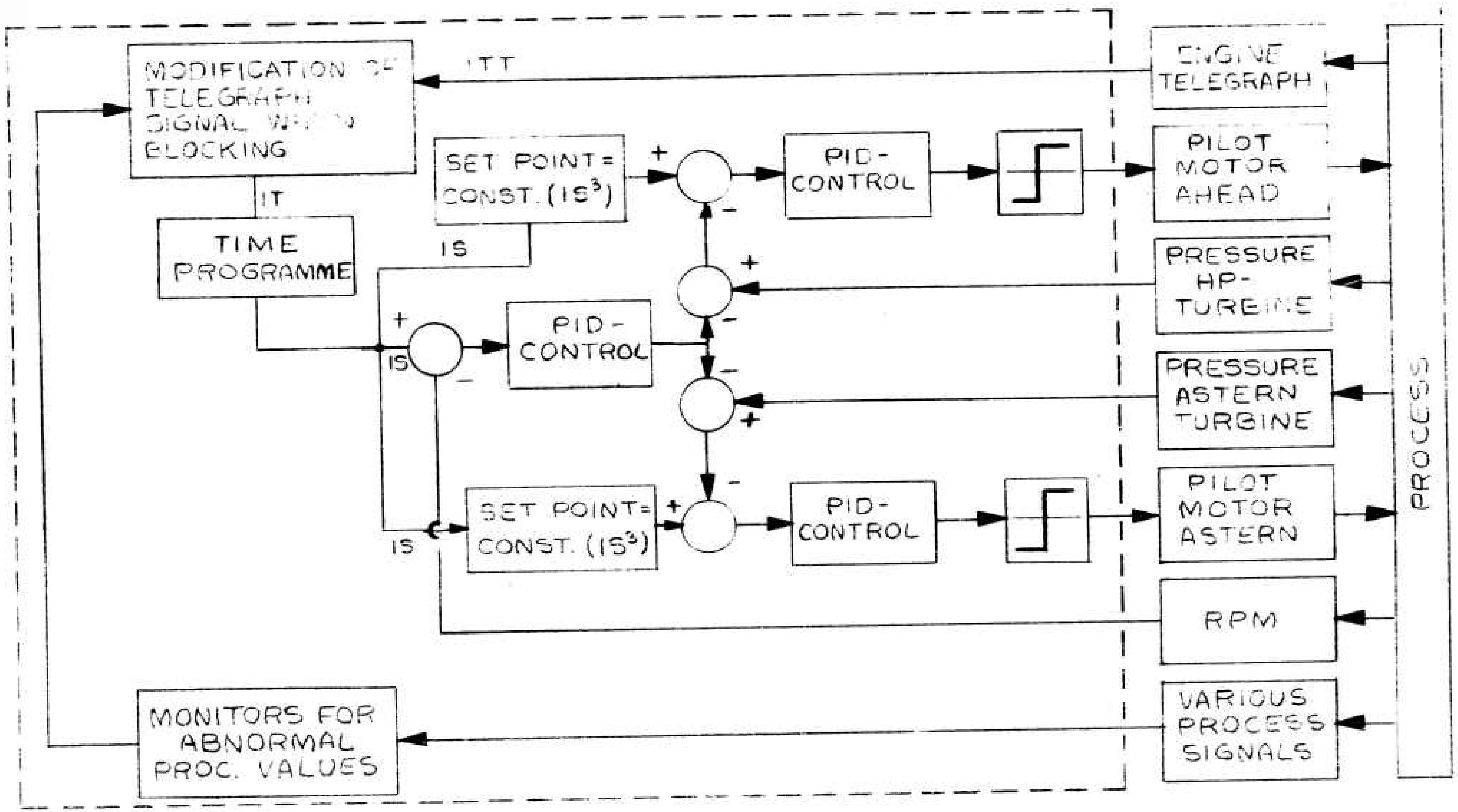
TABLE VIII

SOME FUNCTIONS OF THE ENGINE ROOM ALARM PANELS

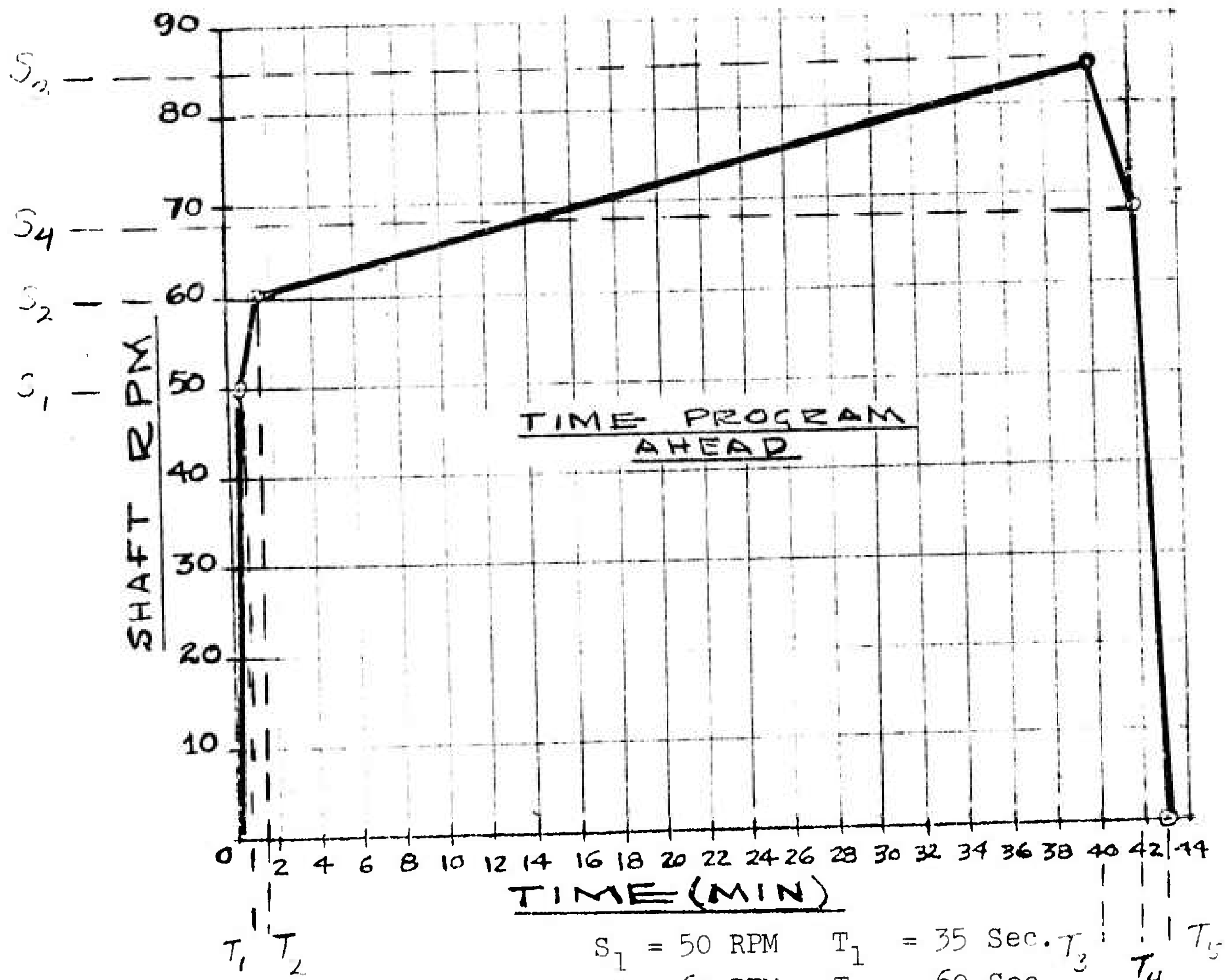
Daily Services	-	Filling of day tanks, soot blowing, etc.
Dead Man Alarm	-	30 minute requirement for answering by engine room watch
Pilot Watch	-	Check of deviation of steering gear greater than preset limit



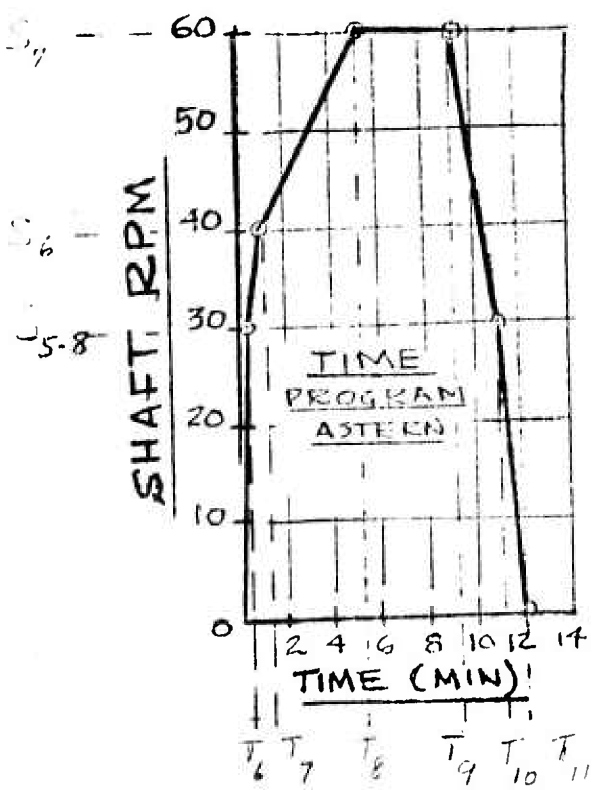
SYSTEM DIAGRAM-
BRIDGE CONTROL
OF MAIN ENGINE
FIGURE 8



BLOCK DIAGRAM-
BRIDGE CONTROL
OF MAIN ENGINE
FIGURE 9



S_1 = 50 RPM		T_1 = 35 Sec.	
S_2 = 60 RPM		T_2 = 60 Sec.	
S_3 = 85 RPM		T_3 = 40 Min.	
S_4 = 68 RPM		T_4 = 25 Sec.	
		T_5 = 55 Sec.	
S_5 = 30 RPM		T_6 = 3 Sec.	
S_6 = 42 RPM		T_7 = 17 Sec.	
S_7 = 60 RPM		T_8 = 4 Min.	
S_8 = 30 RPM		T_9 = 9 Min.	
		T_{10} = 25 Sec.	
		T_{11} = 55 Sec.	



TIME PROGRAM
ENGINE SPEED
CHANGE COMPUTER
CONTROL

FIGURE 10

NAVIGATION

The most important use made of the computer is its conduct of a continuous dead reckoning navigation of the ship in position and steering along a great circle track between its present position and the designated destination or intermediate turning point. This dead reckoning is based upon a continuous Doppler or mechanical log reading. Dead reckoning positions are modified by fixes taken from the TRANSIT navigation satellite. Current and wind induced drift is also determined from satellite fix data. Fixes from Pilotage or Decca Receiver or other sources can be entered by hand by the Watch Officer through the teletype. Dead reckoning then continues from this new fix position.

Satellite Navigation

Item 2 of Table VI presents an example of the data presented by the computer from its pickup of TRANSIT navigation satellite data. Table IX and Figure 11 show the interpretation of this data as given to the Watch officer. The receiver used is a Magnavox Model MX 902. Figure 12 shows the average time between satellite fixes, a function of latitude. Actual fix availability varies between 2 and 5 per four hour watch.

Figure 13 and 14 diagram the way in which satellite fixes are incorporated into the dead reckoning procedure. The actual algorithm used and the values of the coefficients employed are not available to the ship's personnel. The computer uses the course made good between satellite fixes to determine and modify the determination of the effect of current and wind known as STREAM. A function called COURSE CORRECTION could then be initiated on the STEERMASTER to compensate for these effects.

As stated earlier, a Decca Receiver is available but its position determinations are not automatically entered into the computer. They can be entered by hand through the teletype. No Omega system is carried. An RDF receiver is available. Again such fixes must be entered into the computer by hand.

Some Notes on Operation of Navigation Function

Whenever the computer judges itself to be within the established position error limit, POSAC, of the destination or turning point a horn is blown on the bridge and the STEERMASTER and SAILMASTER are shut off. The Watch officer must make the corresponding turn and line up the ship on the new course, and re-engage the STEERMASTER and SAILMASTER for steering and navigation to be reinstituted.

It is usual practice to deactivate STEERMASTER when meeting another ship to avoid the possibility of a computer directed course correction turning one into the other ship.

The computer clock must be set within fourteen minutes of the correct GMT time for a satellite fix to be received and computed by the system.

Whenever an error occurs in the course signal, PNT 1, to give NO SCAN, the course must be recalibrated and re-entered into the computer system. Otherwise the computer system will attempt to steer a course which is incorrect by the calibration error. Likewise PNT 3 must be reset whenever there is a current interruption on the ship. It should also be noted that the gyro repeater used for course change rate determination is located on the ship's port side at C deck. Thus, it is much more susceptible to ship's roll than if placed deep in the engine room.

TABLE IX

INFORMATION PRESENTED CONCERNING THE SATELLITE NAVIGATION SYSTEM

Monitoring the Satellite-Navigation System

For monitoring the receiver and the program a transcription of the received data can be requested.

Description of how different types of data can be monitored.

1. Doppler counts.

   Written in a table with 3 columns.

   Column 1 states the number of 23-seconds interval from the beginning of the passage. To be counted from 1 to a maximum 40.

   Column 2 states the number of interruptions pulses from the satellite receiver to the computer during the respective interval. Every fifth should be equal to 87, the others 80.

   Column 3 states the number of counted doppler-periods during each respective interval. These should be decreasing from about 600000 to about 200 000. Every fifth period should be greater than the adjacent. A naught indicates a useless interval. Naughts in the middle of the passage indicates unstable receiving conditions.

TABLE IX cont.

2. Orbit parameters.

These data have been received from the satellite in digital numbers and have been decoded by the computer. They consist of the fixed orbit-parameters which describes the orbit of the satellite, and the variable orbit-corrections. The fixed orbit parameters are adjusted insignificantly every day. That is the reason why they can be compared with some "typical data". This however, doesn't concern parameter number 1, which fluctuate violently. The variable corrections consists of a 3-figure number, that fluctuates continually within the respective columns. Not received data are indicated by a naught of a "-1".

3. Doppler spread.

1 states a usable interval above 7.5 degrees elevation. ? states a usable interval below 7.5 degrees elevation. 0 states a unusable interval.

The arrow points at the highest elevation in the passage.

TABLE IX cont.

Error conditions, no fix determined from passage.

E-SH = Too short passage

E-MV = Decoding impossible

E-NS = No solution

E-TK = Wrong decoding of the time

No information is presented in the information on board the ship as to how the computer actually uses the above data or what are the symptoms of how erroneous performance other than complete failure may appear.

DOPPLER SPREAD

```
O O ? ? ? O ? ? ? ? ? ? ? ? ? O ? ? O ? O O O O O O O O O O O
BAD                 ↑

O O O O O O O ? ? | | | | | | | | | | | | O | ? O O O O O O O O O O O O
GOOD                    ↑

O | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | O O
EXCELLENT                 ↑
```

↑ INDICATES MAX ELEVATION ANGLE

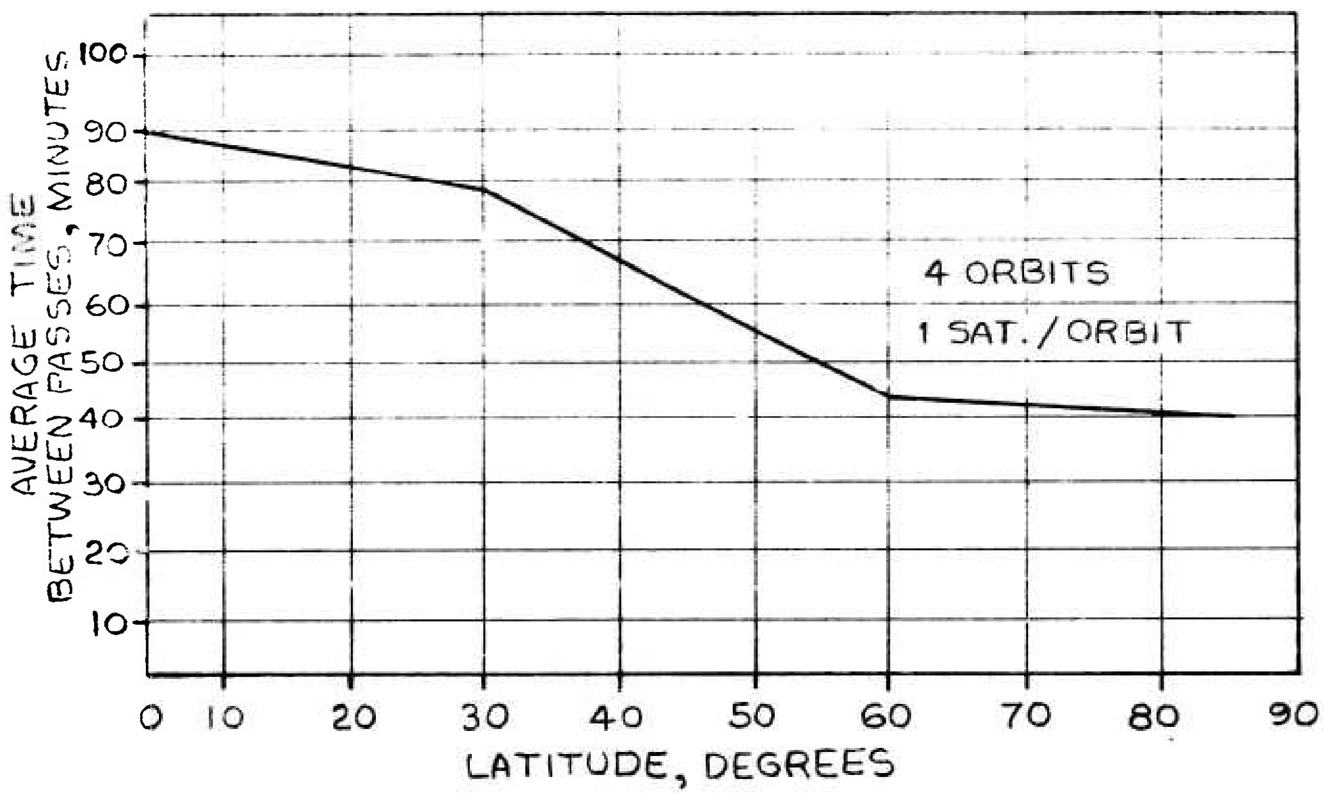
O = UNUSED INTERVAL (23 SEC)

? = USED INTERVAL (ELEVATION BELOW 7.5 DEGREES)

| = USED INTERVAL (ELEVATION ABOVE 7.5 DEGREES)

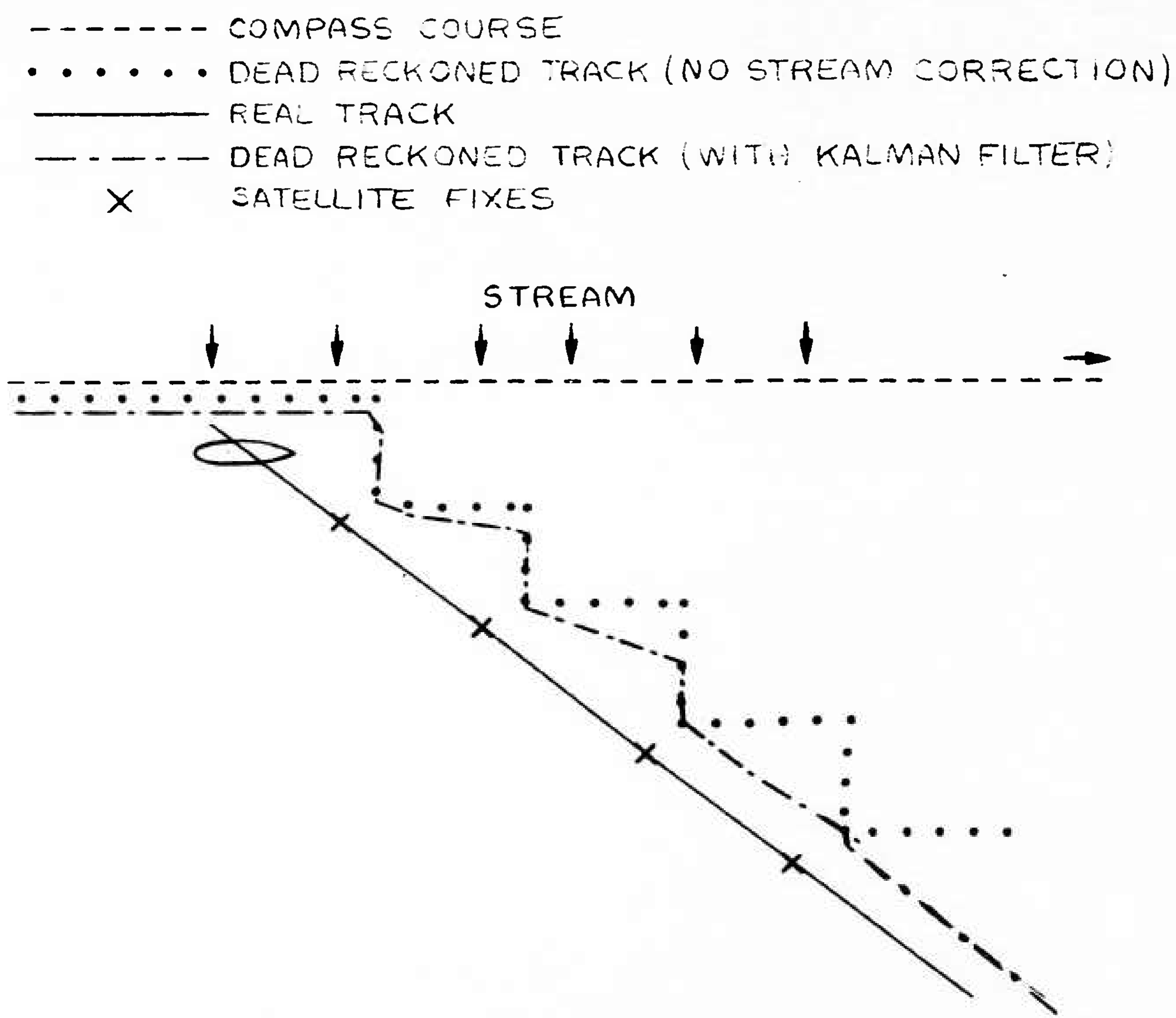
FIGURE 11

EXAMPLES OF SATELLITE DATA OUTPUT



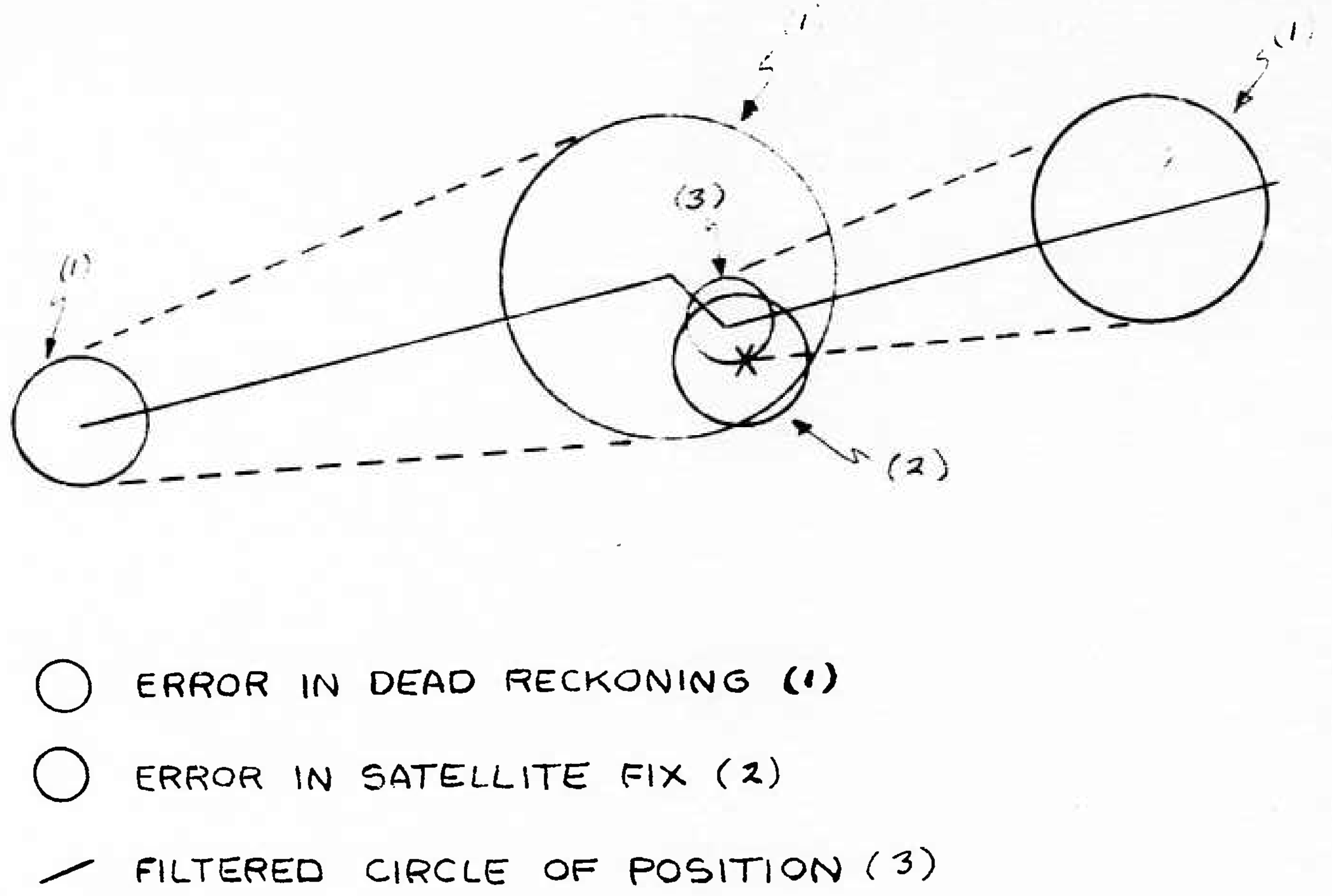
SATELLITE AVAILABILITY CHART

FIGURE 12



DEAD RECKONING DIAGRAM

FIGURE 13



CORRECTION OF DEAD RECKONED POSITION BY SATELLITE FIX

FIGURE 14

CHAPTER 4

T/T SEA SERPENT UNMANNED ENGINE ROOM SYSTEM

GENERAL

Operation of SEA SERPENT's automated engineering plant was observed over a three-week period (18 May to 7 June). One week of this time (18 May to 21 May) the ship was at anchor at Point a Pierre, Trinidad, discharging oil to the Texaco Refinery, and the remaining two weeks the ship was at sea enroute from Trinidad to Cape Town, South Africa.

Plant operation during the one week the ship was at anchor involved the provision of high pressure superheated steam to operate the turbo-generator set for electrical service; high pressure desuperheated steam for operation of cargo oil pumps to discharge cargo; and low pressure auxiliary steam to support various auxiliary machinery items and for operation of deck winches. This level of operation was accommodated with both main boilers on the line using one of the three burners available in each boiler. Provision of auxiliary low pressure steam was via the LP steam generator.

Enroute to Cape Town, South Africa, SEA SERPENT steamed 5415 miles over a period of almost exactly 14 days at an average speed of 16.1 knots. Except for a few hours when in restricted waters on leaving Trinidad and on arrival at Cape Town harbor, the engineering plant was operated at full power, 32,000-32,500 SHP at 80 to 85 shaft RPM.

Engineering plant operation during the in-port period, the at-sea enroute period, and while maneuvering on entering and leaving port, was at all times under the control of the plant's automatic systems with what essentially could be called an unmanned engine room. It was obvious from direct and frequent observations of the Engineering Control Center and all parts of the engine room that SEA SERPENT engineering personnel had developed a strong reliance and a high level of confidence in the automatic control of their main propulsion plant and auxiliary equipment. At no time was an engineering watch maintained for the purpose of monitoring gauge boards, logging data, making routine checks of machinery spaces, etc. Engine room personnel were utilized almost totally in a plant maintenance capacity which involved routine maintenance of equipment, undertaking alarm and safety circuit tests, painting and cleaning, the general administrative functions of preparing engineering reports, personnel time records, etc., and,when required,correction of faults and making repairs. Except during an "alarm" situation or when making routine alarm and safety circuit tests, the Engineering Control Center was unmanned, and outside of normal working hours (8 to 5 Monday through Friday and a half-day on Saturday) the engine room was totally devoid of personnel.

ENGINEERING PLANT CHARACTERISTICS

The principal features and operating characteristics of SEA SERPENT's engineering plant are summarized below:

Main Propulsion

Two water tube boilers with superheaters, designed by Combustion Engineering and manufactured by Kockum Shipbuilding are installed, each having a maximum steam generating capacity of 156,000 lbs/hr. Steam leaves the superheater outlet with a pressure of 866 psia and at a temperature of 950°F.

Main propulsion turbines are of Stal-Laval design and manufacture. They consist of a high pressure unit with 9 impulse stages operating at a maximum steam inlet pressure of 863 psia and a temperature of 945°F. The high pressure unit exhaust steam drives a low pressure turbine having 8 impulse-reaction stages with inlet steam conditions of 54 psia and 378°F. Enclosed in the same casing with the L. P. ahead turbine is an astern turbine having 2 Curtis impulse stages that operate with an inlet steam pressure of 863 psia and a temperature of 945°F.

The main condenser at maximum power utilized 29,000 gallons/min of saltwater cooling through a single pass and has 19,698 square feet of cooling surface. The circulating water inlet and outlet diameter is one meter. The exhaust steam inlet from the low pressure turbine is 2.77 meters in diameter.

The turbines drive a Stal-Laval main reduction gear. Both the H.P. and L.P. turbines drive through planetary gear trains to a bull gear that turns at a full power speed of 85 RPM producing 32,000 SHP.

The power is transmitted through a thrust shaft (740/680 mm dia.), an intermediate shaft (650 mm dia.) and a propeller shaft (867 mm dia.). All three shafts are solid. The main thrust bearing is manufactured by Kockums using one thrust collar (1540 mm dia.) and 20 thrust pads. The propeller shaft passes through a stern tube seal that utilizes two seals with an oil filled chamber between the seals.

The propeller is 890 mm diameter, 5 blades, right hand turning.

Auxiliary Systems

Electric power of 440V, 3 phase, 60 Hz is generated by one turbo alternator rated at 1250 KVA. The driving turbine uses high pressure superheated system (869 psia, 947°F). A standby diesel generator is capable of producing 1250 KVA at 440V, 3 phase, 60 Hz.

Auxiliary steam is provided from two sources:

1. Desuperheaters incorporated in the two main boilers produce (per boiler) 92,700 lbs/hr of steam at a temperature of 626°F.

2. A low pressure steam generator, which utilizes steam from the main boilers as a source of heat, produces 99,000 lbs per hour of steam at a pressure of 150 psig and a temperature of 365°F.

GENERAL DESCRIPTION OF AUTOMATIC CONTROL SYSTEMS

The engineering plant automatic control system fitted in SEA SERPENT does not utilize a single computer with an integrated process control for all major propulsion plant systems and components. Automation to the point that the engine room is unmanned is achieved instead by a series of independent process control units with communication links between the control units to improve the response, the safety and the reliability of the total machinery plant when performing its designed mission.

The major control systems installed which provide the necessary automatic control of the engineering plant can be identified and described in brief terms as follows:

1. Combustion Control System - The function of which is to govern the supply of fuel and air to the boiler to match closely the steam demand required for ship propulsion and support of certain auxiliary power loads. While matching the demand the system design is aimed at optimizing combustion efficiency through close control of the fuel-air mixture. Varying steam demand requires a sensitive and safe control of the feed water supply to the boiler. For this function boiler drum water level, and the total boiler water mass is sensed, and this information is utilized to compute and control the required

flow of water to the boiler. Control of excess steam generated during periods of low power is provided by means of a steam dump system.

2. Main Engine Control System - Is designed to permit a simple selection of engine RPM and direction of rotation of the main shaft from the bridge using the engine order telegraph circuit, or from a console in the Engineering Control Center. The engine order command is provided to a process control computer which in accordance with a program matched to the main engine characteristics directs steam flow to the ahead (or astern) main turbines, via a throttle control loop, until the desired RPM is reached. The system constantly monitors critical system parameters and compares them to standard set points. When a limit is exceeded, the computer will reduce power or prevent increasing power beyond an established safe limit for the particular situation involved. Under certain circumstances, such as excessive engine vibration, if corrective action is not taken the computer will provide a signal to trip the main engine advising by warning and trip light in the Engineering Control Center the reason for the main engine shutdown. Either the bridge or the engine room can, by positioning a selector switch, indicate who is to have control of the main

engine; however, the bridge cannot override the mode selected by the engine room. The bridge engine control console is also provided with a "Crash Stop" switch which when activated turns the task over to the computer to bring the ship to dead in the water through a predetermined maneuvering program that takes the plant safely through a full ahead to full astern evolution.

3. Burner Control System - The system is designed to safely and reliably control the sensitive task of lighting off and shutting down the burners in each boiler. The boiler's readiness for light off is checked using an analog process control system that sequentially checks pre-light off boiler air purge, the adequacy of air flow, fuel oil pressure, that the burner is inserted and that the burner air register is open before energizing the ignition system and finally opening burner fuel valves. Boiler shut down is similarly controlled in a series of timed sequential steps that insures adequate air purge following shut down. Quick and consistent burner light offs and shut downs were observed, both under test and in unscheduled loss of power situations. This system also includes a control panel at each boiler, immediately adjacent to the burners, where local activation of the

control system can be used when needed. Quick and positive shut down of one or all burners is possible from either this local control panel or the Engineering Control Center boiler control panel.

4. Flame Guard System - This system is designed to provide continuous supervision of each burner in the boiler once boiler light off has been achieved and the boiler is in operation under the control of the Combustion Control System. Two photo transistors are installed adjacent to each burner which monitor light emission from the flame and via electrical amplification circuits provide a failure indication when one burner scanner shows a weak signal as compared to a reference level setting. A flame failure indication automatically shuts down the fuel oil supply to the affected burner and initiates an alarm signal.

5. Boiler Safety System - The system receives inputs from the Combustion Control System, boiler level control, forced draft pressure sensors, and air heaters sensors. These inputs are monitored and compared to program set points and allowable limits. Where out of tolerance conditions are seen by the system, alarms are initiated and if corrective action is not taken then, depending on the fault,

feed water valves or the boilers are tripped off the line. This system also serves an important function of providing a test simulation capability that allows simulation of high and low boiler levels such that the operability of the alarms associated with these out of tolerance conditions can be observed.

A more detailed description and discussion of the above control systems, together with supporting and auxiliary systems is provided in the following sections.

DETAILED DESCRIPTION OF ENGINE ROOM AUTOMATIC CONTROL SYSTEMS

A. KOCKUMS COMBUSTION CONTROL SYSTEM MK 3TF

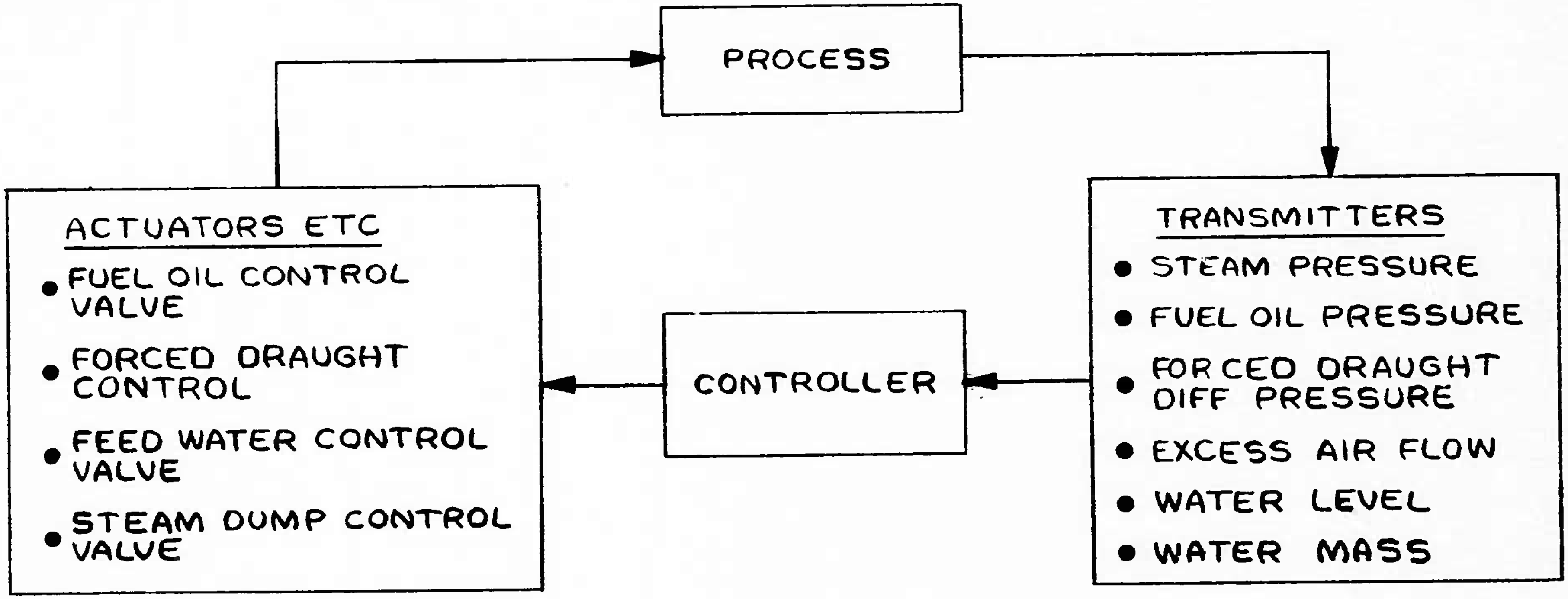
SEA SERPENT was fitted with a Kockums Combustion Control System MK 3TF. This system is adequately described with accompanying diagrams and photographs of equipment in Kockums descriptive literature which is included in this report as Appendix I-1. The combustion control panel is a part of the main engineering plant control console, which console is located in the Engineering Control Center.

The controller functions to:

- Govern the supply of air to the boiler
- Maintain the proper ratio of air to fuel at any level of steam demand
- Govern steam pressure
- Govern the feed water supply to the boiler
- Control steam dumping to the condenser

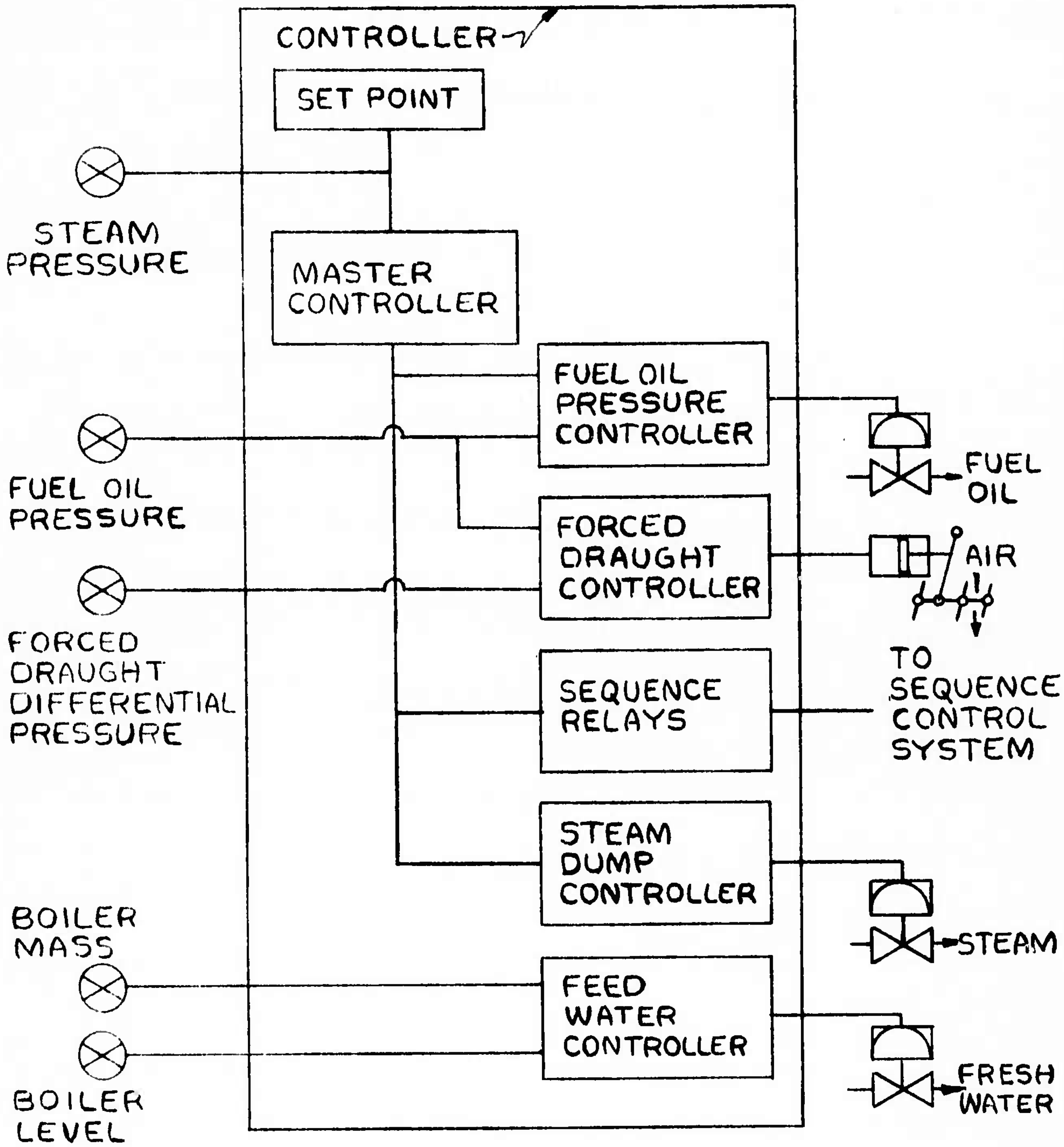
A general system diagram of the combustion controller is shown in Figure 15. Controller inputs and outputs are shown in the block diagram, Figure 16, and a further detailed description of the computer networks involved for each function shown in the block diagrams in Appendix I-1.

Alarm supervisory circuits are provided which detect controller circuit failures or faults in the external



COMBUSTION CONTROL-
GENERAL SYSTEM
LAYOUT

FIGURE 15



COMBUSTION CONTROL BLOCK DIAGRAM

FIGURE 16

connections, transmitters or actuators. If a fault occurs, an alarm indicator light is energized, and the operation of the system can be shifted to manual. Built-in test circuits are incorporated in the panel which permit checking the various circuits against known set points to identify the fault.

Change over from automatic to manual combustion control or vice versa was demonstrated on a number of occasions during this trip. The change overs were accomplished quickly without introducing major disturbances to plant operation. Control knobs on the panel are shifted from the "Automatic" position to a null or so-called "Blue Dot" position which then, by the use of panel controls, permits matching of pointers on feed water, forced draft and fuel pressure gauges to correspond to a "Blue Dot" position marked on these indicators. This adjustment means that the output signals from both the manual and automatic control circuits are identical, thereby allowing a smooth shift of the plant to manual when the control knobs are rotated from the "Blue Dot" position to "Manual." The panel is then manned and feed water, air and fuel are varied as required using controls on the panel. During the tests of manual operation of the system, it was found that adjustments to feed water supply to the boilers was necessary on a continuous basis, but little adjustment was required for forced draft air and fuel oil supply while running in a steady state condition.

Two separate 220 volt power supplies are fitted to the Combustion Control System. One supports automatic operation; the other supports manual operation, thus insuring independent operation for each mode.

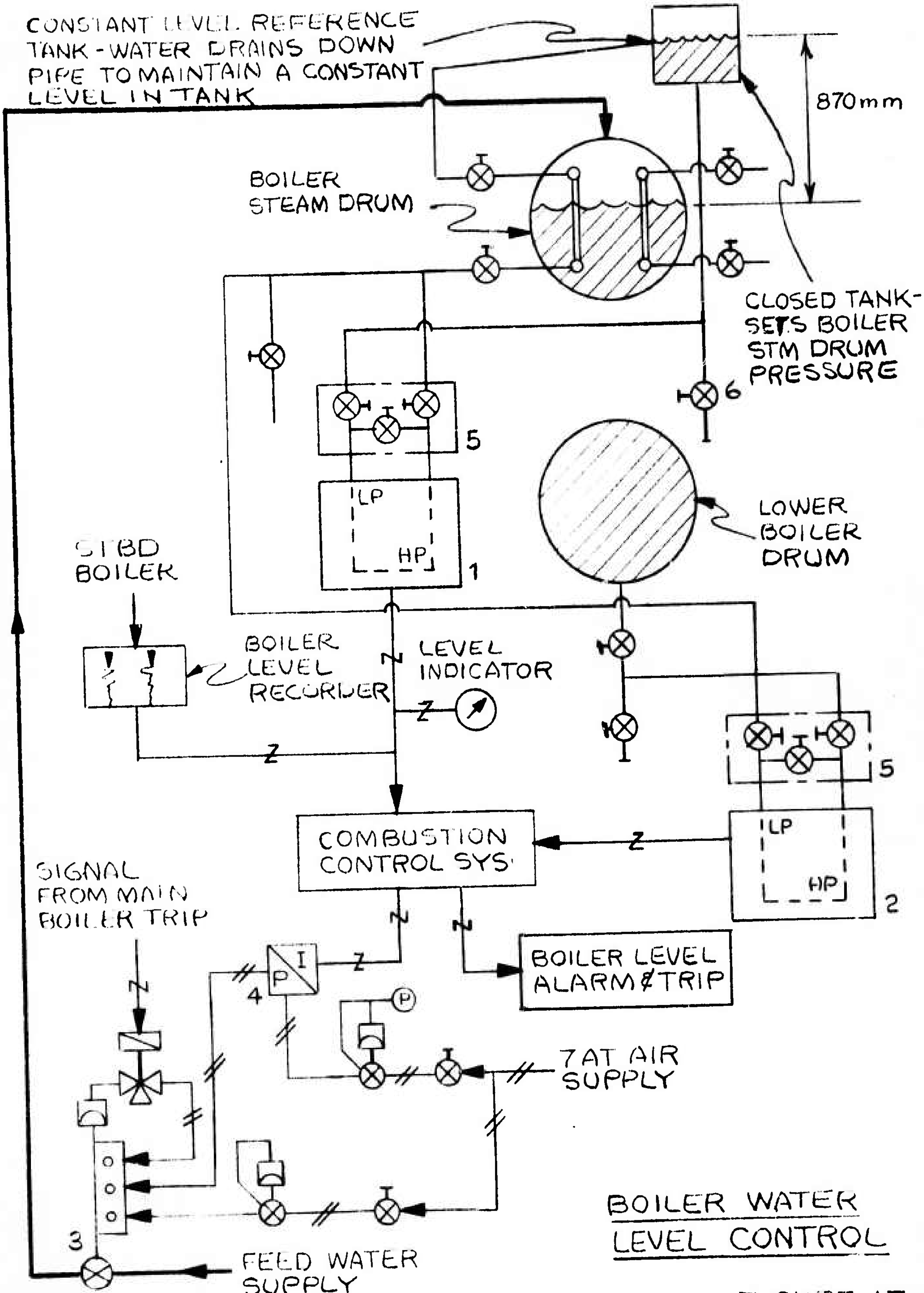
Supporting systems to the Combustion Control System are briefly described below:

Boiler Fuel Oil Supply and Trip System

Based on plant steam demand, the Combustion Control System directs an electrical signal to an I/P transducer which regulates the flow of control air to an air actuated fuel oil control valve. This valve, one per boiler, regulates the flow of fuel oil from the main fuel oil pumps to each boiler. Down stream of this control valve is an air actuated fuel oil stop valve which is normally open and closes on signal from the boiler safety system, interrupting the oil flow to all burners for the boiler served. This signal from the boiler safety system also directs the fuel oil control valves previously mentioned, to go to the fully closed position and provides double valve closure in the fuel oil supply line to each boiler for casualty or fault control. The metered flow of fuel oil to each boiler as determined by the Combustion Control System can be directed to from one to three burners per boiler utilizing air actuated fuel oil stop valves located at each burner housing. These local burner stop valves will close at the direction of the Flame Guard System. Then, if the fuel oil supply to a boiler is shut down by the fuel oil safety stop valve and fuel oil control valve, the Flame Guard System will see no flame or a reduced flame at each burner and will signal the local burner stop valves to close, thereby providing three valve protection against fuel oil being introduced to a hot boiler fireside with no burner flame present.

Boiler Water Level Control (See Figure 17)

The water flow to the boilers is controlled by one air actuated control valve for each boiler (Item 3). Both boiler water density and steam drum water level is sensed and the overall boiler level sensing system is referred to as the "Mass Level Compensated Control System." A mass level transmitter (pressure differential transmitter, Item 2) senses the variation in boiler water density and signals this information to the level controller network in the combustion control system. The level controller also receives an input from the steam drum level transmitter (Item 1). The influence of both signals determines the output directed to the I/P transducer (Item 4) which meters the flow of control air used to position the feed water control valve, (Item 3). Items 5 are three valve manifolds that are used to equalize pressure across the transmitter diaphragms when the transmitters must be removed for servicing. The system is blown down once a month by actuating the stop valve (Item 6).



BOILER WATER LEVEL CONTROL

FIGURE 17

Additional boiler level transmitters are fitted to the steam drum to serve the boiler safety system. The function of these transmitters is discussed elsewhere in this report.

Main Boiler Dump Steam System (See Figure 18)

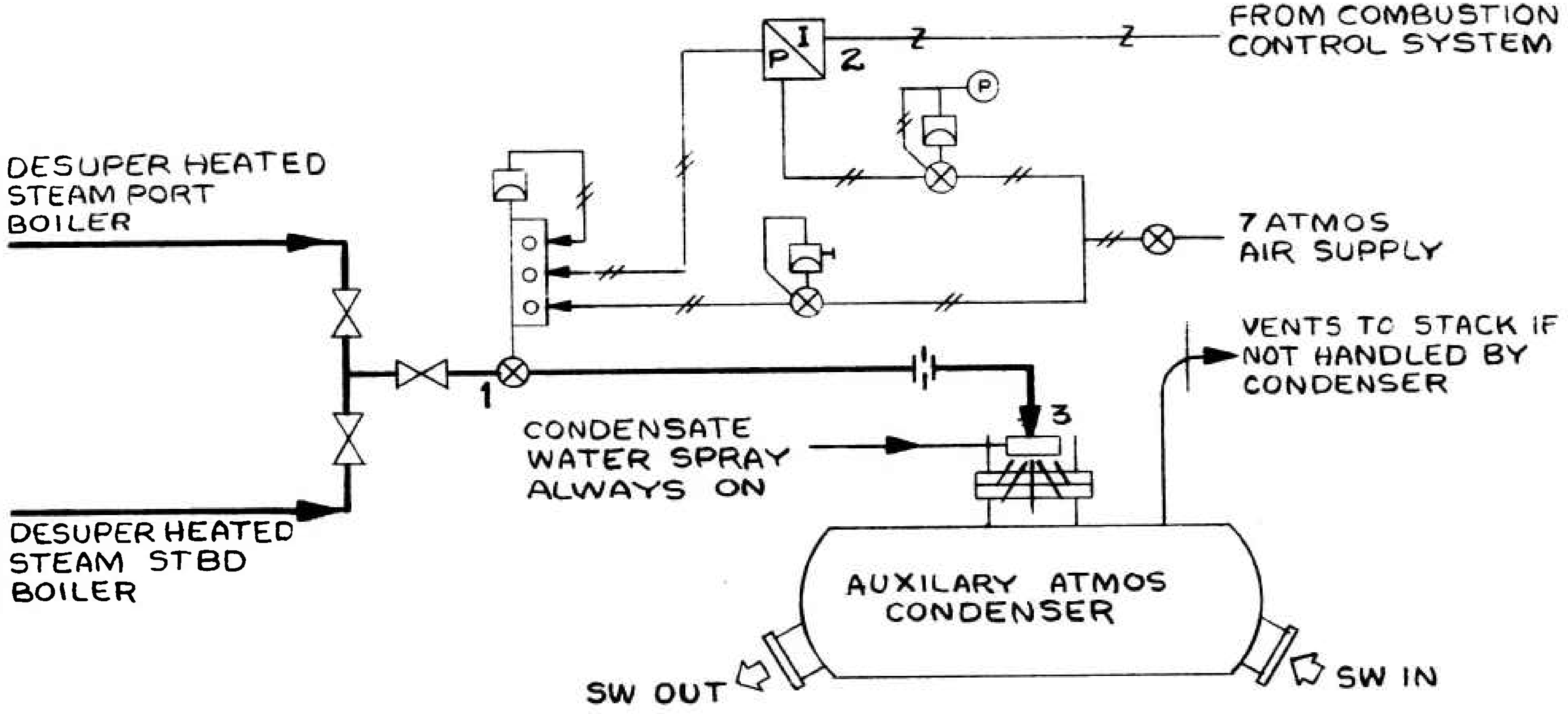
The purpose of this system is to facilitate operation of the main propulsion plant at low boiler load. The steam dump valve (Item 1) is an air controlled valve that regulates the dumping of desuperheater steam from both the port and starboard boilers to the auxiliary atmospheric condenser. The Combustion Control System provides a signal to the I/P transducer (Item 2) which regulates the flow of control air positioning the steam dump valve.

The steam dump closes or remains in the closed position on loss of control air. Condensation of dumped steam is facilitated by a spray nozzle (Item 3) in way of the steam entry to the condenser. Condensate water from the main condenser is continuously fed to this spray head.

Flue Gas Oxygen Indicating and Recording System

Each boiler is provided with one complete oxygen analyzing system. The major components of the system are:

- Electrically heated flu gas probe
- Gas cooler
- Gas filter using paper membranes that are periodically renewed



MAIN BOILER STEAM DUMP SYSTEM

FIGURE 18

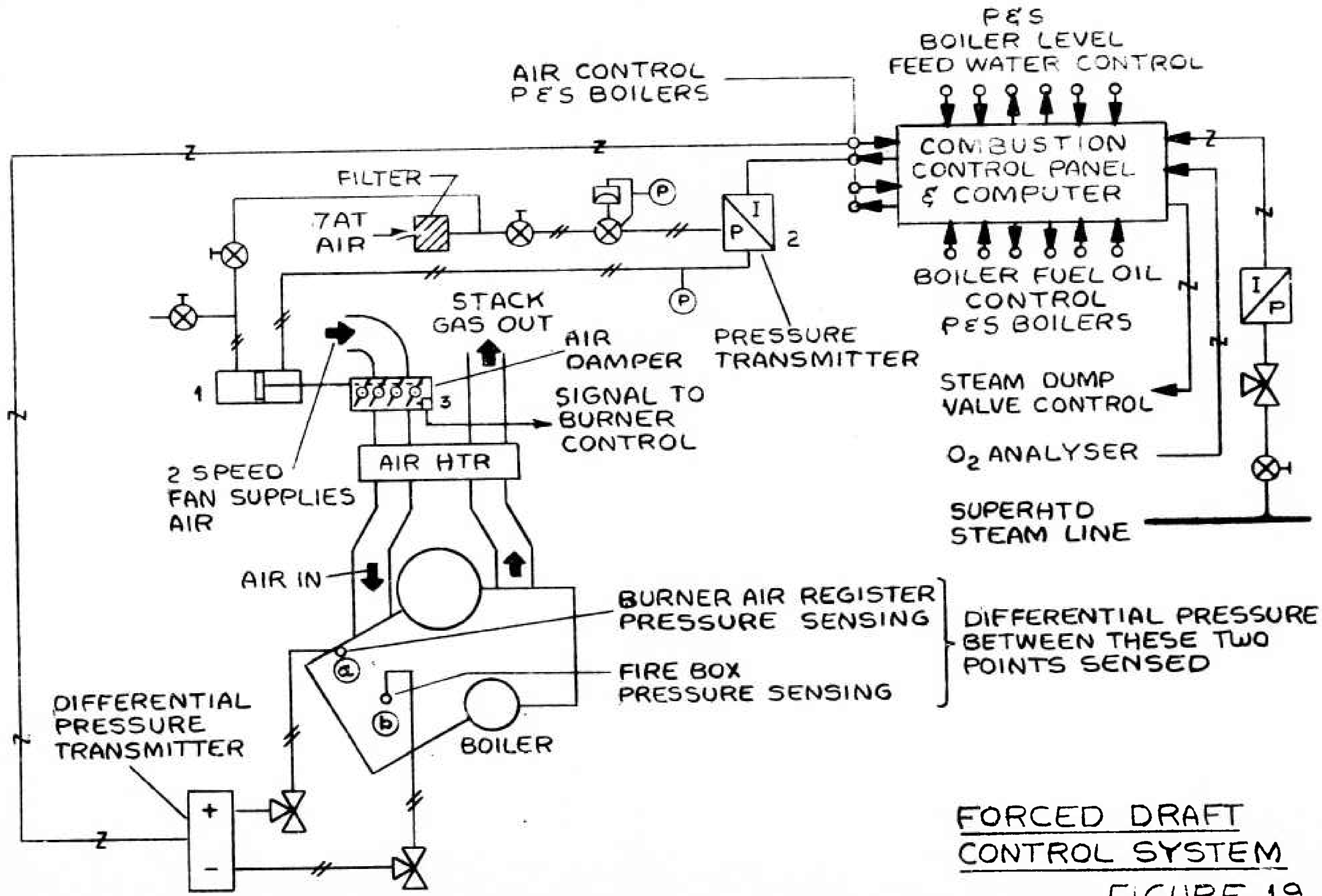
- Membrane pump
- Flow indicator/controller used to adjust flow to 50 liters/hour
- O_2 analyzer with a range of 0-5% oxygen

The system can provide inputs to the Combustion Control System for the purpose of controlling the boiler fuel-air mixture. The ship considered that the reliability of this system was not such that its input should be fed to the Combustion Control System. The ship uses only the forced draft sensing system for control of fuel/air mixture via the Combustion Control System.

The readout of the gas oxygen content is continuously printed out on paper recorders located in the Engineering Control Center. This data is monitored and, if required, periodic adjustments are made to fuel/air ratio settings in the Combustion Control System.

Boiler Forced Draft Air Control (See Figure 19)

Each boiler is served by a two-speed electric motor driven forced draft fan. Continuous regulation of air flow to the boiler is accomplished by adjusting the position of an air damper in the supply ducting using a control-air driven piston/cylinder mechanism (Item 1). Air pressure is sensed at the inlet to the boiler (point a) and in the fire box (point b). A differential pressure transmitter provides a pressure difference signal to the Combustion



FORCED DRAFT
CONTROL SYSTEM

FIGURE 19

Control System which in turn controls the air damper position via I/P Transducer (Item 2). Position of the dampers is sensed by a micro switch (Item 3) that provides a signal to the burner control system which is used in the automatic light off or shut down of burners.

Other components or systems having automatic control features which are required for the proper functioning of the Combustion Control System are briefly described below: (The control of these systems is independent and not a part of the Combustion Control System).

Boiler Feed Water Pump Automatic Start

If the running feed pump stops inadvertently, the standby feed pump will start automatically when the feed system pressure drops below 70 AT. At 70 AT a pressure switch activates the auto start of the standby feed pump. A lube oil pressure sensing system prevents start of the feed pump steam turbine if inadequate lube oil pressure is available to serve the turbine.

Fuel Oil Viscosity Control

This is achieved automatically by use of a Kockums designed viscosity controller. The fuel oil is heated in fuel oil heaters, and the correct viscosity is obtained by mixing warm and cold fuel oil using a air controlled three way valve. The actual viscosity of the mixture leaving the three way valve is transmitted to the viscosity controller by means of a Källe viscosity transmitter. High and low viscosity alarms are initiated by pressure switches.

Fuel Oil Service Pumps Automatic Pressure Control

The fuel oil service pumps are fitted with a pressure control system using a bypass loop around the pump in which flow is controlled by an air actuated regulating valve. Pump discharge pressure is sensed and the pressure control system positions the regulating valve as required to provide the necessary pressure to fuel oil discharged by the pumps to the fuel oil heaters.

Burner Atomizing Steam Automatic Pressure Control

A pressure controller senses atomizing steam pressure in a common steam line supplying both boilers, and the controller directs the flow of control air to an air regulated valve in the low pressure steam line which provides the atomizing steam to the boilers. Pressure switches sense the atomizing steam pressure being supplied each boiler and provide an electrical signal to trip a boiler if fuel oil pressure is below 12 kp/cm^2 at the same time that steam atomizing pressure is below one kp/cm^2. If fuel oil pressure is above 12 kp/cm^2, then fuel oil atomization continues without the help of atomizing steam.

Fuel Oil Heater Automatic Temperature Control

Fuel oil temperature is monitored at the discharge side of each of two fuel oil heaters and temperature information is transmitted to a controller. The controller, fitted with an adjustable temperature set point, positions an air regulated steam valve that controls the flow of steam to the heaters. The set point of the temperature controller can be adjusted manually to allow for changes in fuel oil quality.

Fuel Oil Filter Automatic Cleaning

Rotary disc type fuel oil filters are fitted, two units on the suction side of the fuel oil pumps and two units on the discharge side. The differential pressure across each set of filters is continually monitored, and when the differential pressure reaches a preset limit, a signal is transmitted to pressure switches which start filter cleaner motors. The motors rotate the center filter discs past fixed fins attached to the shell causing a scraping cleaning action. The residue is collected in a sump in the base of the filter which can be drained off (or blown out using low pressure steam) to the waste oil collecting tank. The cleaning motor rotates the filter for one minute. If after that time a high differential pressure still exists, an alarm is given in the Engineering Control Center.

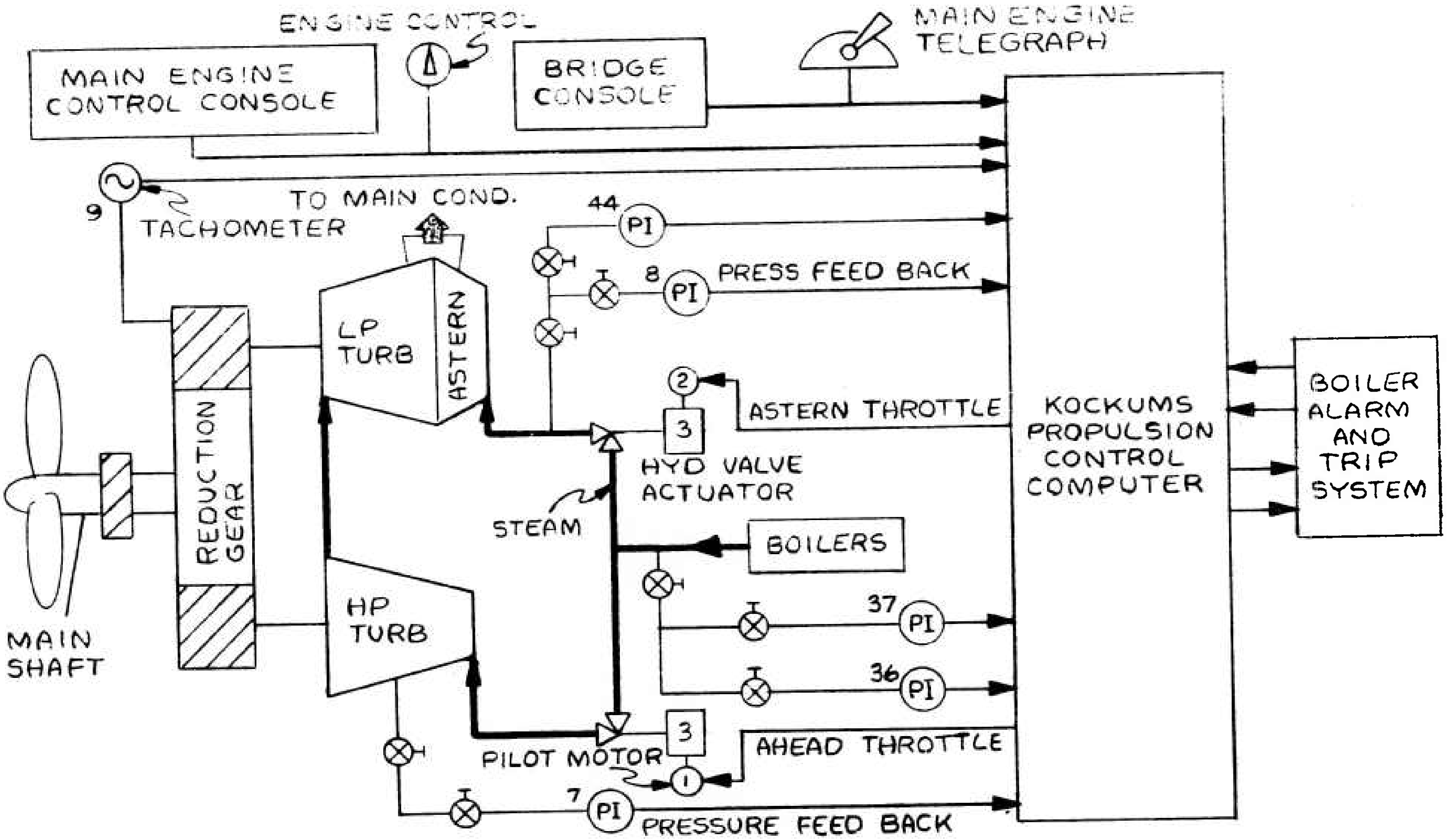
Main Feed Pump Automatic Pressure Control

The feed pump discharge pressure is transmitted to a Kockums pressure controller. The output signal from the controller is directed to an I/P transducer and the pneumatic output from the transducer positions a Woodward Speed Regulator controlling the feed pump turbine speed.

B. MAIN ENGINE AUTOMATIC CONTROL SYSTEM

The principal function of this system is to permit a simple selection of main propulsion shaft RPM and direction either from the bridge or from the Engineering Control Center. Command of the engine function, once selected from either of these locations, is directed by the central computer in accordance with a predetermined timed cycle (see Figure 10) compatible with the main propulsion plant's characteristics and capabilities. The propulsion plant can be remotely controlled by the system over the full range of ahead and astern operation. The control system performs the additional function of imposing constraints on the range of operation of the plant under certain engine casualty conditions.

The mechanical system diagram (Figure 20) for automatic control of the main engine from either the bridge or Engineering Control Center indicates the relatively low inputs/outputs from the main computer required to control shaft RPM and direction. Ordered shaft speed is transmitted to a pilot motor (Item 1 for ahead operation and Item 2 for astern operation) which drives a hydraulic valve actuator (Item 3) opening and closing, as required, the turbine throttle valves. Pressure transmitters (Items 7 and 8) provide the computer with inlet steam pressure readings at the ahead and astern turbines, and a tachometer-generator (Item 9) provides the computer feedback as to actual shaft RPM.



MAIN ENGINE AUTOMATIC CONTROL SYSTEM DIAGRAM

FIGURE 20

While operating on automatic control, if the boilers safety system senses an out of limit boiler level or low boiler pressure situation, or if certain input failures related to engine function should occur, the computer time program will be blocked. When this occurs, a red "Auto-Blocking" warning light appears on the main engine control consoles located on the bridge and in the Engineering Control Center. The following is a brief summary listing the causes of an "Auto-Blocking" situation and the limits on plant operation that the computer will impose under each circumstance:

1. Low Boiler Level Alarm
   - Power limited to 12,000 SHP

2. High or Low Boiler Level Trip
   - Power reduced and limited to 12,000 SHP

3. Low Main Steam Pressure
   - No further increase in power. (Pressure transmitter (Item 36, Figure 20) is set at 57 atmos. to control this function).

4. Low Main Steam Pressure Trip
   - Power reduced and limited to 12,000 SHP. (Pressure transmitter (Item 37, Figure 20) is set at 55 atmos. to control this function).

5. Shaft RPM Transmission Failure
   - Hold present power level, however, if a requested increase is not greater than 5 RPM, allow increase.

6. Engine Order Telegraph Transmission Failure

7. Ahead Turbine Pressure Transmission Failure

8. Astern Turbine Pressure Transmission Failure

9. Engine Order Telegraph Micro Switch Failure

10. Hydraulic Converter Pressure Switch Failure
    - For 6 through 10, hold present power level

In addition to the above, during an emergency backing maneuver, the computer will prevent a further increase in steam supply to the astern turbine when the limiting pressure of 15 atmos. is sensed by the pressure transmitted (Item 44, Figure 20). Also, for all situations except failure of engine order telegraph, the computer system will permit a reduction in engine RPM.

C. BURNER AUTOMATIC CONTROL SYSTEM

The function of lighting off and shutting down burners in high performance oil fired boilers must be undertaken with considerable care. Attention to the required timing and sequencing of events is essential if the task is to be successfully completed in a safe fashion. It is the type of function that a computer process control system is particularly suited to perform. The computer system can provide the repeatability, sequencing and timing required. Burner light off and shut down on SEA SERPENT using the automatic burner control system was observed on numerous occasions during the three weeks the authors were on board. On each occasion the task was completed successfully in exact accordance with the programmer's sequencing and timing. The total extent to which the human was involved in the process was the need to select the burner to be ignited and then to push a button marked "Start." The automatic system then carried the sequence through to the green light - "Flame On" without further human help or interference. It was obvious that all engineering officers on board had a high level of confidence in this system, and all officers initiated light off or shut down whenever required.

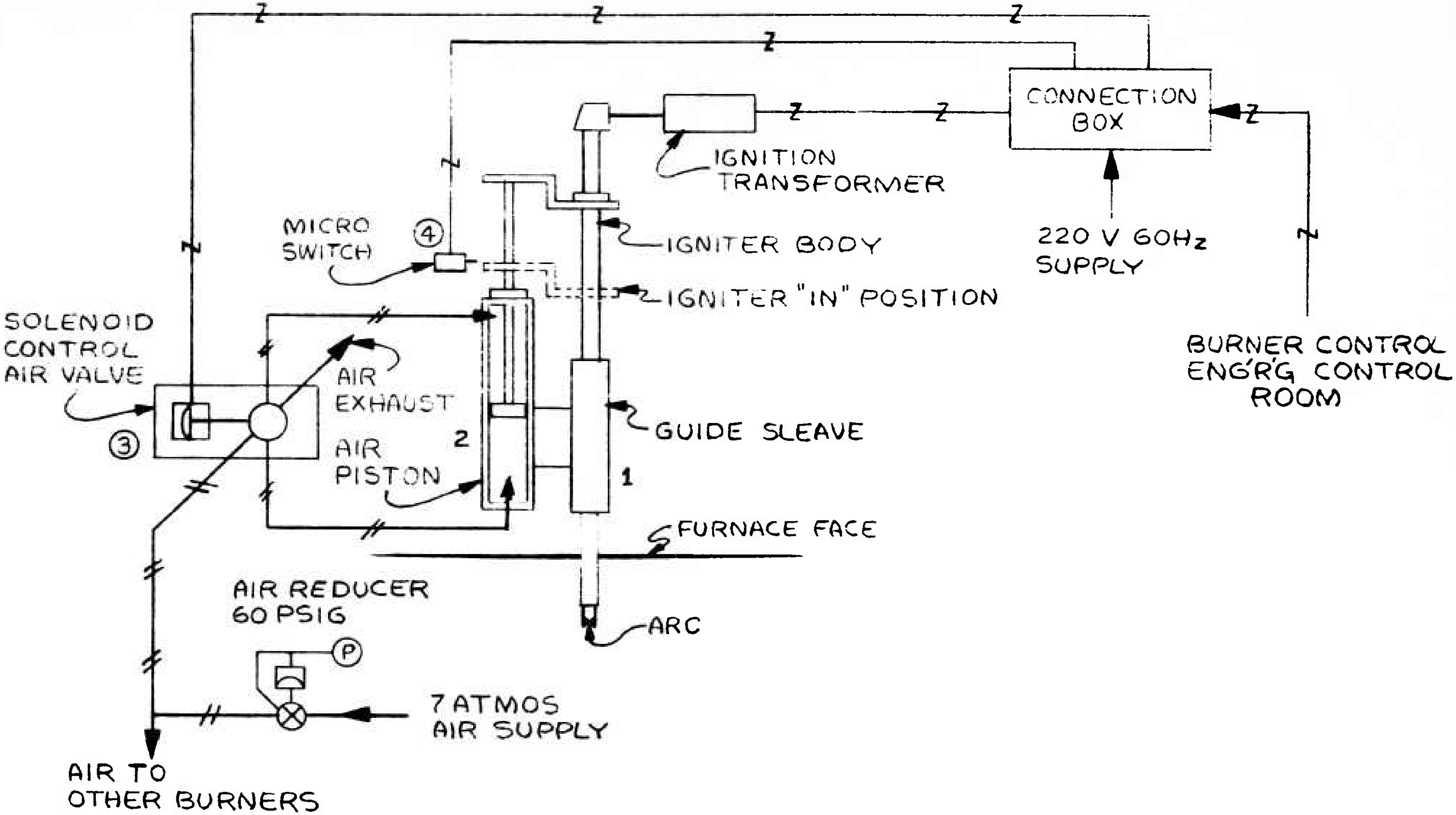
A relatively complete description of this system and the method of operation is contained in Appendix I-2.

For cold iron no-steam start the SEA SERPENT uses the local boiler front controls immediately adjacent to the burners to open the air register, observe the furnace purge, open the fuel oil valves, and ignite and observe burner flame. A small electric-driven diesel oil pump is used to supply diesel oil to the burner. Power for the pump is supplied from the diesel generator set. A carbon arc torch is available for initial light-off using diesel oil. The ship indicated that at any time trouble was experienced with the installed system igniters, the electric arc torch had been used successfully.

Supporting systems to the boiler burner control system are described briefly below.

Power Arc Burner Ignition System (See Figure 21)

Burner igniter systems are installed adjacent to two of the three burners in each boiler. The third burner is ignited using flashover from burners one and two. The burner igniters (Item 1) are inserted for ignition and withdrawn from the boiler fire box following ignition by means of an air driven piston (Item 2). The burner control system provides an electrical signal to energize the solenoid controlled air valve (Item 3) which puts air to the air piston to drive the igniter in or out. Ignition will take place by means of the ignition transformer only when the micro switch (Item 4) indicates the igniter fully inserted. Igniter travel is approximately 12 inches.

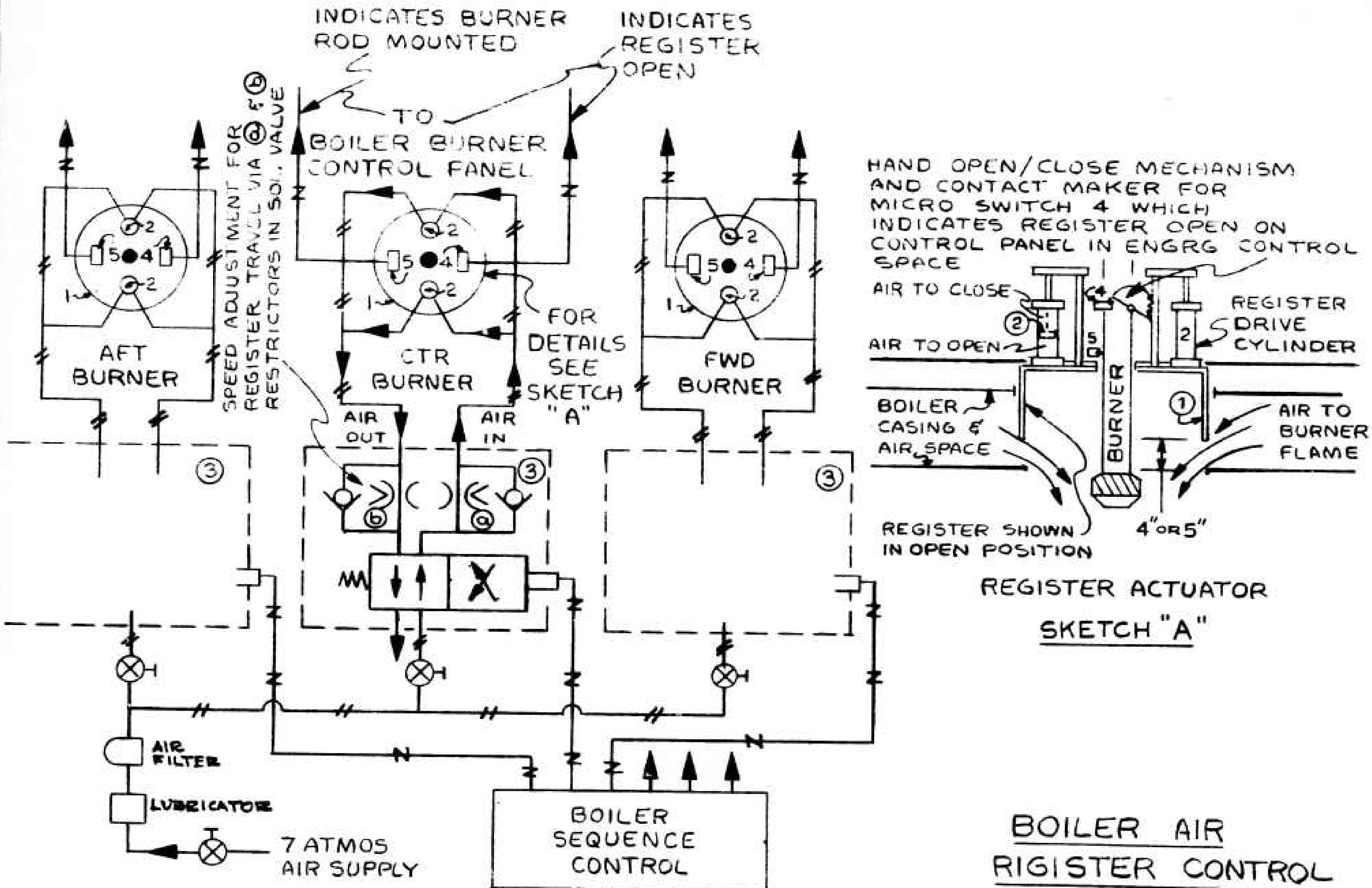


POWER ARC
BURNER IGNITION
SYSTEM

FIGURE 21

Air Register Automatic Operation (See Figure 22)

Air supply to each burner is controlled by an air register which is withdrawn from the boiler casing to the extent that a 4 or 5 inch wide annulus is created in way of the burner tip. This annulus admits air from the boiler casing air space to the burner. The register (Item 1) is raised and lowered by means of two air pistons (Item 2) that are actuated by solenoid controlled air valves. Electrical signals from the burner control system energize or de-energize the solenoid air valves (Item 3) to properly sequence the positioning of the register. Micro switches (Items 4 and 5) provide signals to the burner control console that the register is in the open position and that the burner rod is seated in position.



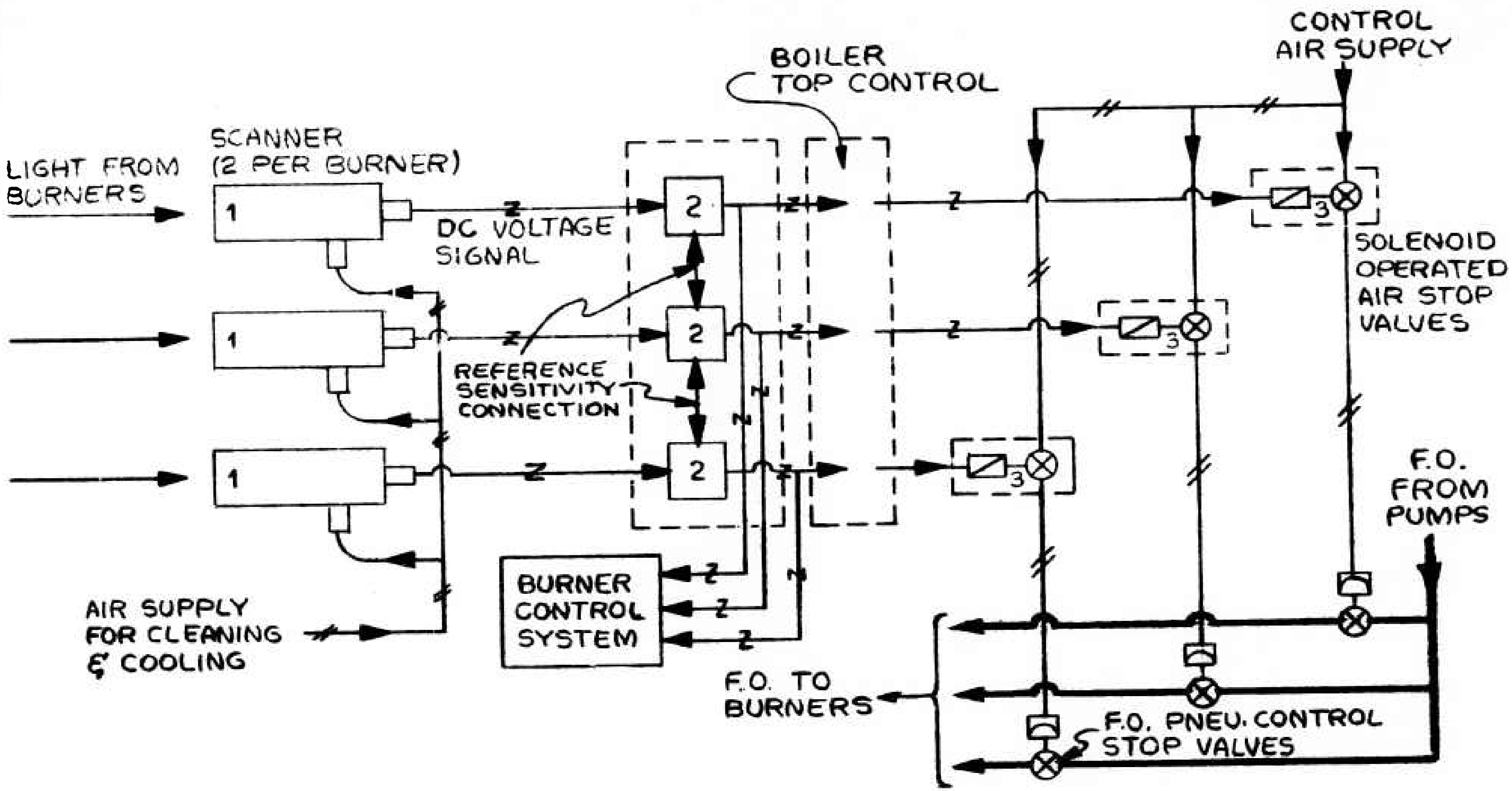
BOILER AIR RIGISTER CONTROL SYSTEM

FIGURE 22

D. FLAME GUARD SYSTEM

When ignited, each burner flame is continuously supervised by a flame guard system to insure that the burner is in fact ignited; or, if the burner flame fails, then it is the function of the flame guard unit to initiate "Flame-Off" warning alarms and through the burner control system shut down fuel oil valves to the burner. Appendix I-3 provides a detailed description of the flame guard components and a general description of the operation of the system.

System diagram, Figure 23, shows the flame guard circuits for one boiler. Two photo transistors with noise suppressors (Item 1) are fitted to the boiler top adjacent to each of 3 burners. Light emission from the burner flame generates a DC voltage signal output from the photo cells which is directed to the central control units located in the Engineering Control Center. The control units (Item 2) amplify the DC signal and via relays provide a "Flame-On" lighted indication on the panel. If no flame appears, then a signal is provided to the boiler top control panel (a part of the burner control system) which system directs an electrical signal to solenoid control valves (Item 3) porting air to close the fuel oil stop valve serving the burner showing no flame. The flame guard system provides electrical signals to the burner control panel indicating via panel lights which burners have "Flame-Off."



FLAME GUARD CONTROL SYSTEM

FIGURE 23

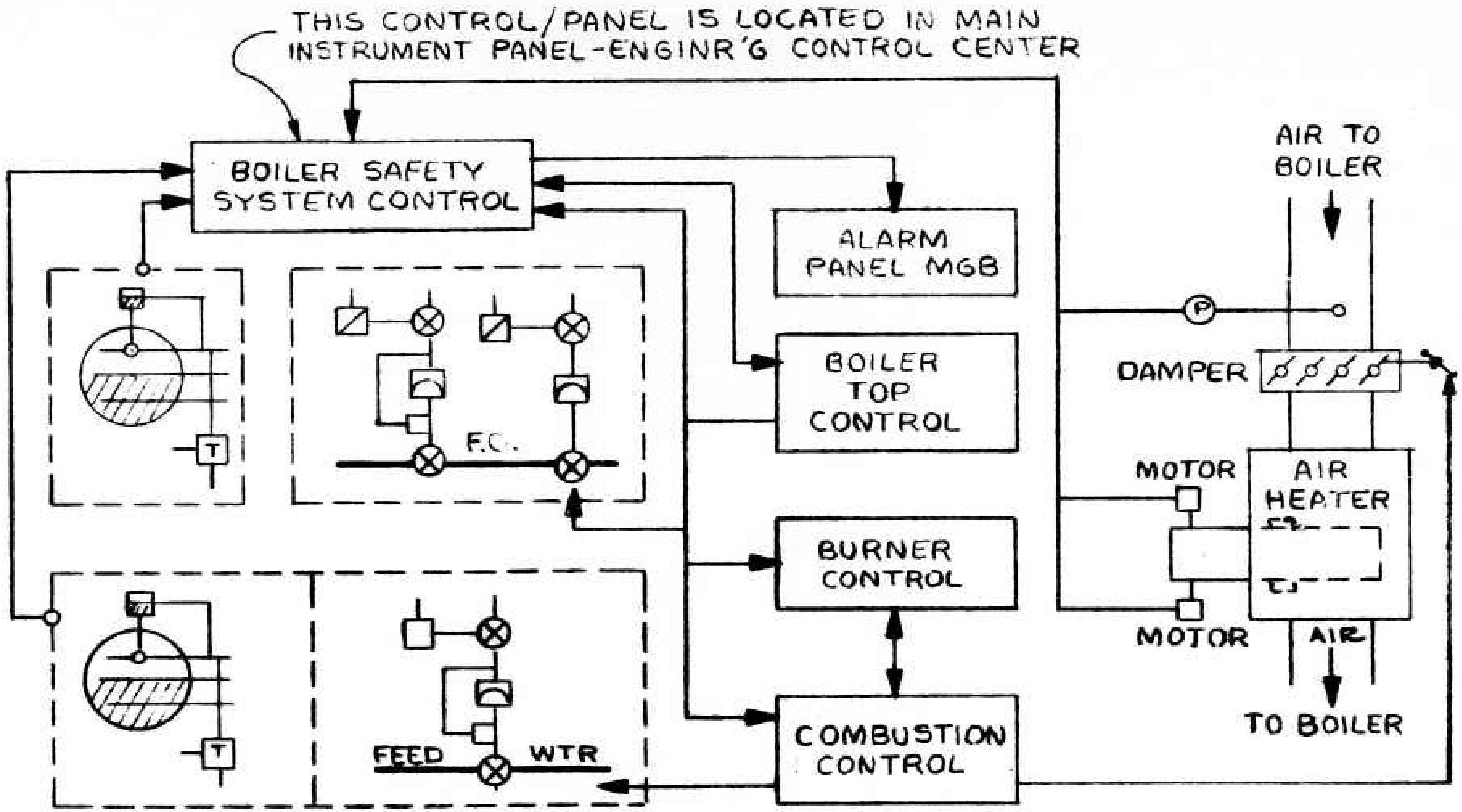
A sensitivity adjustment control is provided on the face of each flame guard panel that enables the adjustment of sensitivity of each scanner. A manual adjustment of sensitivity is made when lighting off a burner to insure an adequate level of sensitivity to recognize a flame. If the sensitivity setting is too low, even though flame is in fact present, the scanner will not provide a signal to the "Flame-On" light on the burner control panel, and the burner control system will direct the fuel oil valve to shut down to cut off the flow of oil to what appears to be an unlighted burner.

E. BOILER SAFETY SYSTEM

This system oversees and monitors all critical system and component parameters that could, through a malfunction or out of tolerance operation, cause serious damage to a boiler. The system first initiates alarms and, after certain time delays depending on the conditions involved, will, if corrective action is not taken, initiate shut down of feed water valves or of the boiler. The systems and components served by the boiler safety system are shown in Figure 24.

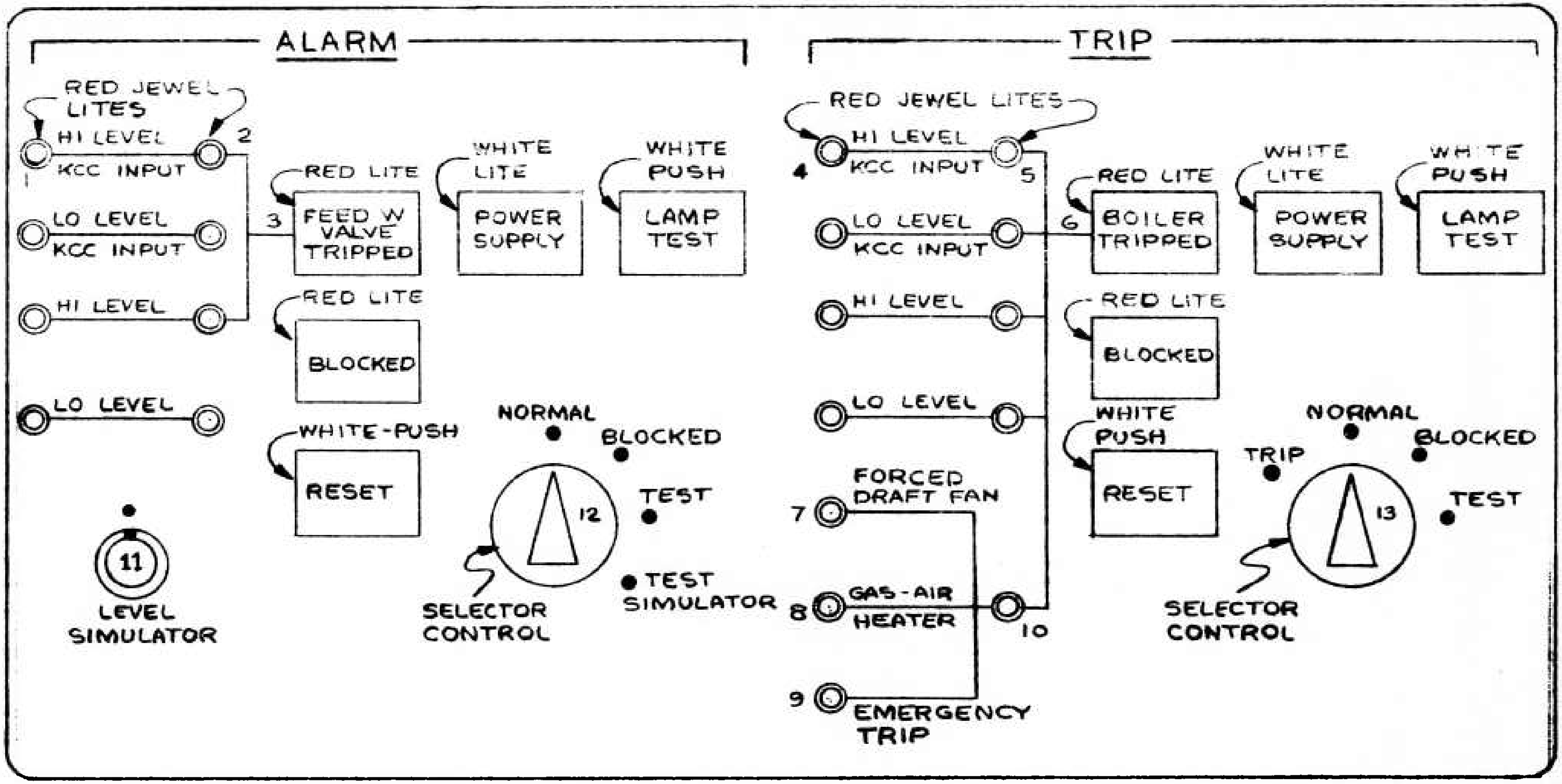
The boiler safety system indicator and control console is located on the main gauge board in the Engineering Control Center. Figure 25 shows the console arrangement for one boiler. Referring to Figure 25, examples of the function of the system are described below:

- If the boiler served has a high water level, reaching the alarm level of 100 mm above normal, the level transmitters will energize jewel light-1 (JL-1), and after 10 seconds JL-2 will light, sounding a horn energizing an alarm light for high boiler level at the main engine control console alarm panel. If no corrective action is taken within 10 seconds after sounding the alarm, the feed water valve will be tripped through the action of the Combustion Control System and red alarm light No. 3 will be energized.



BOILER SAFETY SYSTEM

FIGURE 24



BOILER SAFETY CONSOLE

FIGURE 25

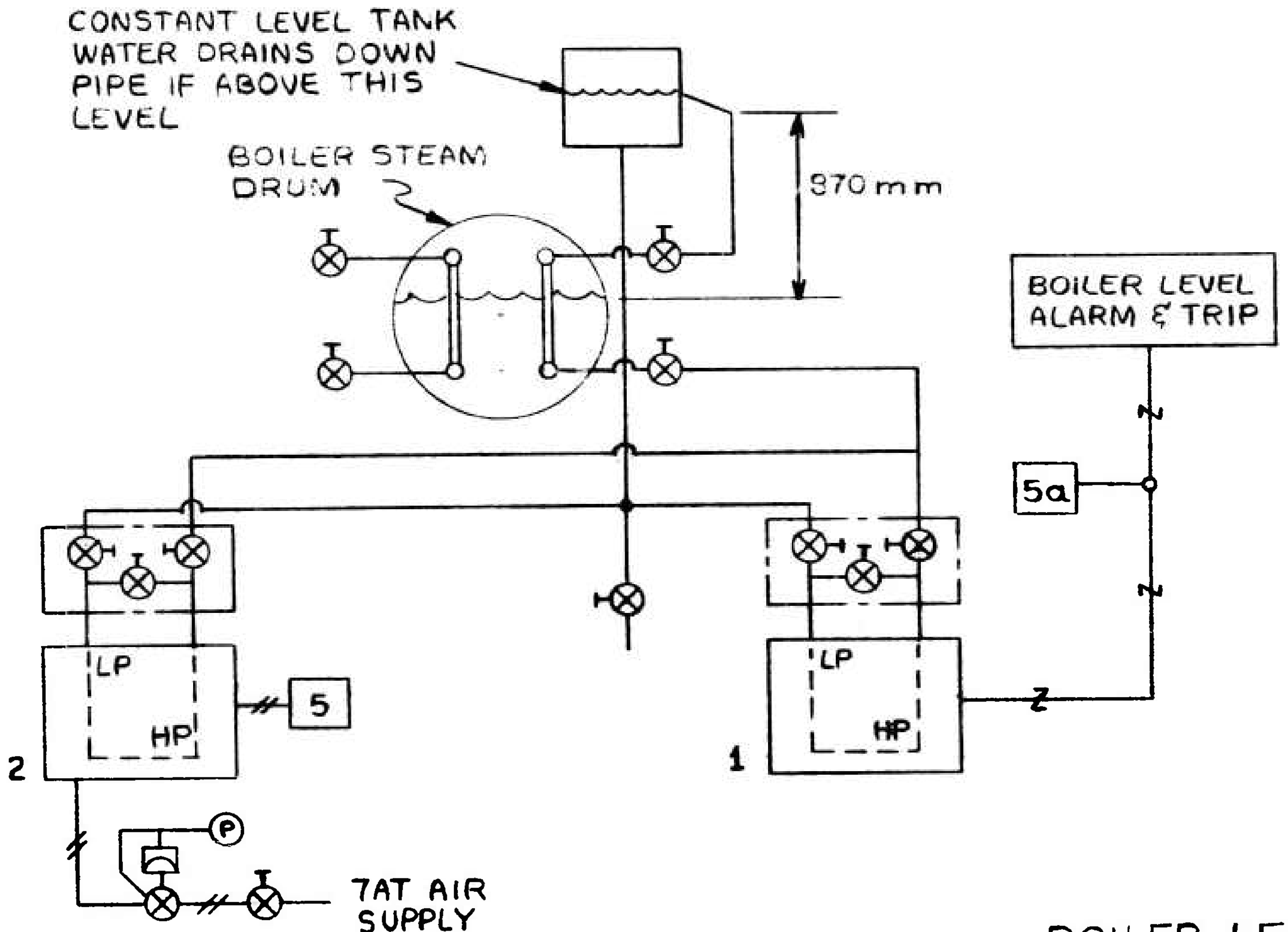
- If the boiler level continues to rise and reaches the "Trip" range (100 to 200 mm above normal), then JL-4 will be energized. After a 10 second delay JL-5 will light sounding a horn and energizing the boiler trip alarm light on the alarm panel of the main engine control console. If no corrective action is taken, the boiler will trip off the line by closing fuel oil valves through the action of the boiler safety control and burner control system. When this occurs, "Boiler-Trip" red alarm (No. 6) on the boiler safety console and "Boiler-Trip" alarm light and horn on the alarm panel of the main engine control console are energized.

- Other high and low level boiler level alarms shown on the panel operate in a sequence similar to that described above. Signals are received by the system from two sets of boiler level sensors; one set serves the Combustion Control System (these are indicated by the marking, "KCC Input," on Figure 25), the second serves the boiler safety system and is described later in this section.

- If forced draft fan air pressure output falls below a set limit, or if the gas air heater rotation stops, JL-7 or JL-8 is energized. JL-10 is energized after a time delay, sounding horn and energizing alarm lights, as described for the boiler level sequence. If no corrective action is taken, the boiler will be tripped and alarm light No. 6 will be energized.

- Turning selector switch No. 13 to the "Trip" position will trip the boiler immediately, and JL-9 and 10, and alarm light No. 6 are energized simultaneously.

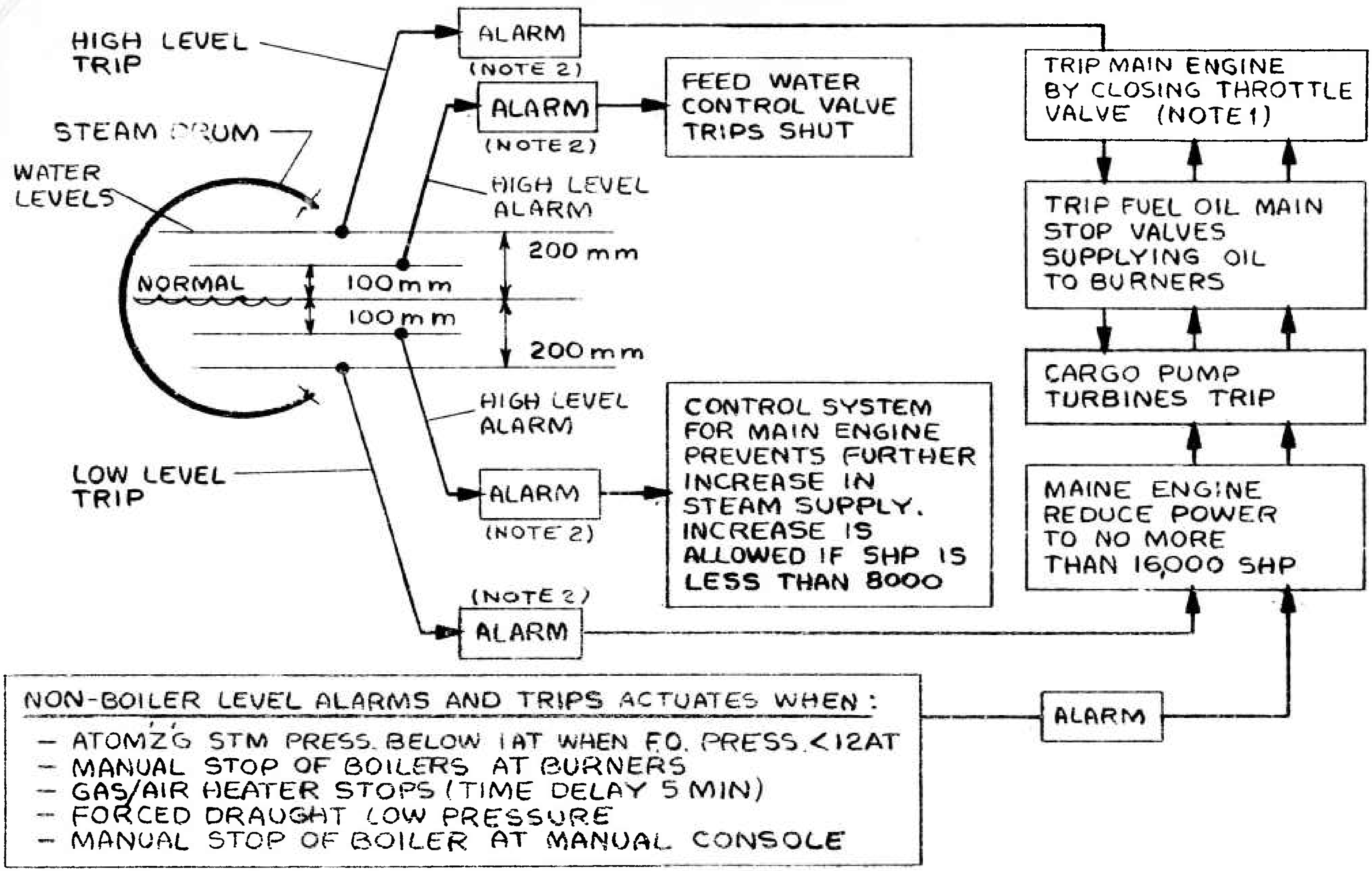
- The boiler safety system is supported by the boiler level alarm and trip transmitter system, in addition to the boiler mass level compensated control system, which includes a constant level tank and two level transmitters and was discussed under the Combustion Control System. A separate level transmitter system is provided that serves only the boiler safety system. The operation of the constant level tank and level transmitters serving the boiler safety system is similar to that discussed under the Combustion Control System. Figure 26 is a diagrammatic of the system. Level transmitter (Item 1) provides a signal to a level gauge (Item 5A) located on the main gauge board in the Engineering Control Center. Level transmitter (Item 2) provides a signal to a large boiler level gauge (Item 5) located on a gauge board at the boiler front which is visible from the Engineering Control Center through the viewing windows in the aft bulkhead of the Center.



BOILER LEVEL
ALARM AND
TRIP SYSTEM

FIGURE 26

- Boiler alarm and trip functions are shown in the schematic diagram, Figure 27. The diagram indicates the high and low water levels that initiate boiler alarms and trips. Also indicated are the actions that will be imposed by the automatic systems if correction of a fault is not completed within preset time delay periods.



NOTE:

1 – EVENT WILL OCCUR ONLY AT SIGNAL FROM BOTH BOILERS THAT "HI" OR "LO" LEVEL TRIP HAS OCCURRED.

2 – HI & LO LEVEL ALARMS HAVE 10 SEC DELAY AFTER ALARM LEVEL REACHED AND BEFORE ALARM SOUNDS – HI-LO LEVEL TRIPS HAVE 10 SEC DELAY AFTER ALARM SOUNDS & BEFORE RECOVERY EVENTS OCCURS.

BOILER LEVEL ALARM AND TRIP FUNCTIONS

FIGURE 27

F. CONTROLLER SYSTEM

A controller system is provided on SEA SERPENT as an adjunct to the major automatic control systems discussed above. The "System" is in reality a grouping of independent control loops in a single panel which is located in the main gauge board complex in the Engineering Control Center. The control loops serve various functions such as the control of temperatures, water levels and pressures in connection with the operation of the main propulsion plant and auxiliary steam systems. Kockum's description of the system is contained in Appendix I-4.

A diagrammatic of the controller system panel is shown in Figure 28. The number of panels required is dependent upon the number of systems served. Two panels were fitted on SEA SERPENT, and the systems served by each panel are listed below:

Panel 1

A. Superheated Steam Temperature - Port Boiler

B. Superheated Steam Temperature - Starboard Boiler

C. Main Feed Pump Pressure - Fwd Unit

D. Main Feed Pump Pressure - Aft Unit

E. Deaerator Level Control - Spillover

F. Deaerator Level Control - Makeup

G. Recirc Gland Condenser Temperature Control

H. High Pressure Drain Tank Level

Panel 2

A. Low Pressure Steam Generator Pressure Control

B. Low Pressure Steam Generator Drain Level Control

C. Low Pressure Steam Generator Feed Water Control

D. Low Pressure Drain Tank Level Control

E. Fuel Oil Viscosity Control

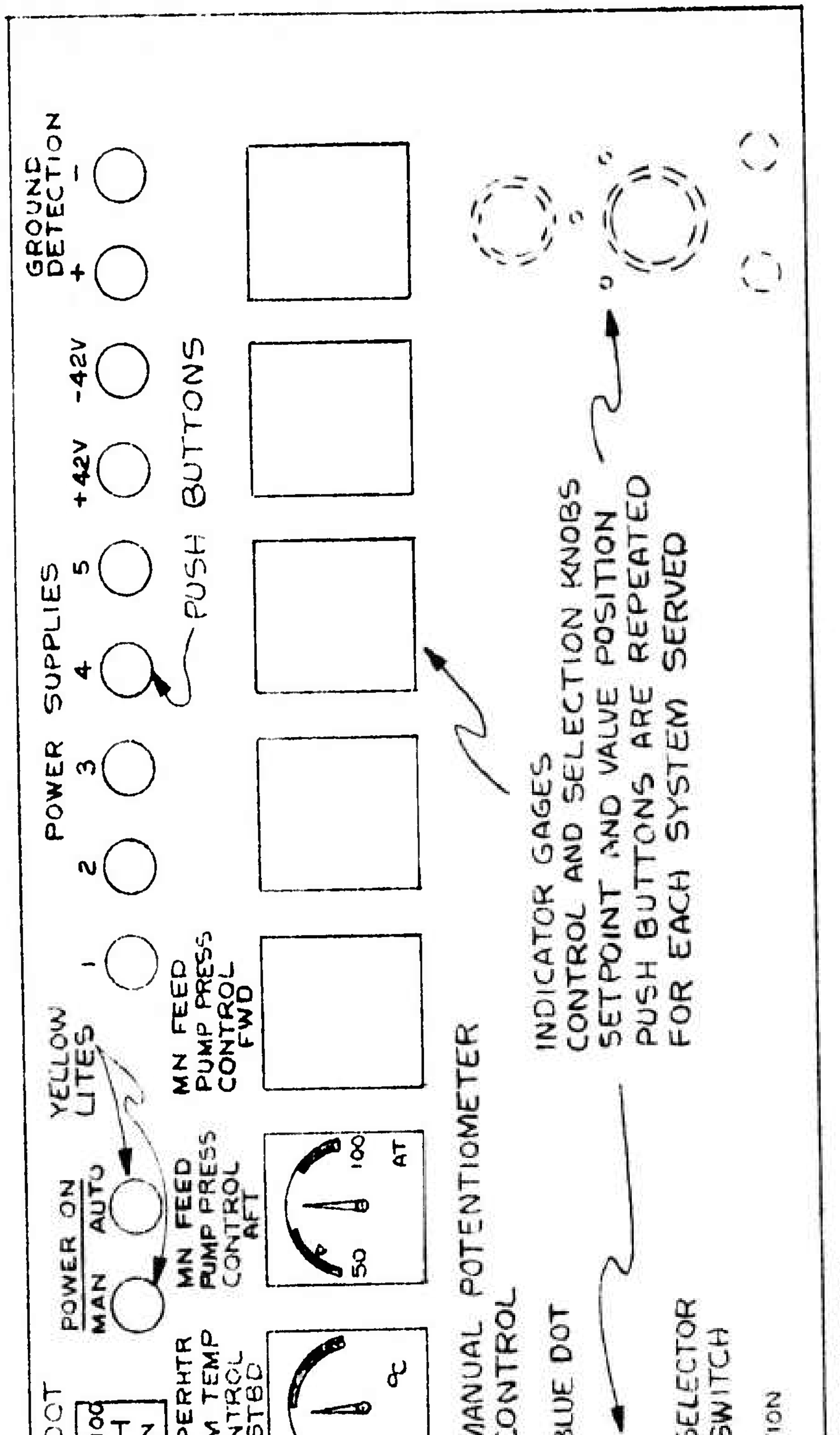
F. Fuel Oil Service Pump Pressure Control

G. Exhaust Steam System Pressure Control

H. Deaerator Makeup Pressure Control

Each of the above listed functions is served by a separate control loop, and an indicator (Item 6) for the function is mounted in the panel as shown in Figure 28.

The profile instrument read out (Item 1) indicates process set point or provides valve position information in percent open/closed when control buttons (Items 2 and 3) are held in. Selection switch (Item 4) is used to shift a system from automatic control to manual control. To make the shift from automatic to manual, the switch is first placed in the "Blue Dot" position, and the manual potentiometer control (Item 5) is adjusted to bring the pointer on the profile instrument (Item 1) to midscale or to the "Blue Dot" position. This equates the manual and automatic inputs into the system and allows the shift to be made without a major disturbance to the system.



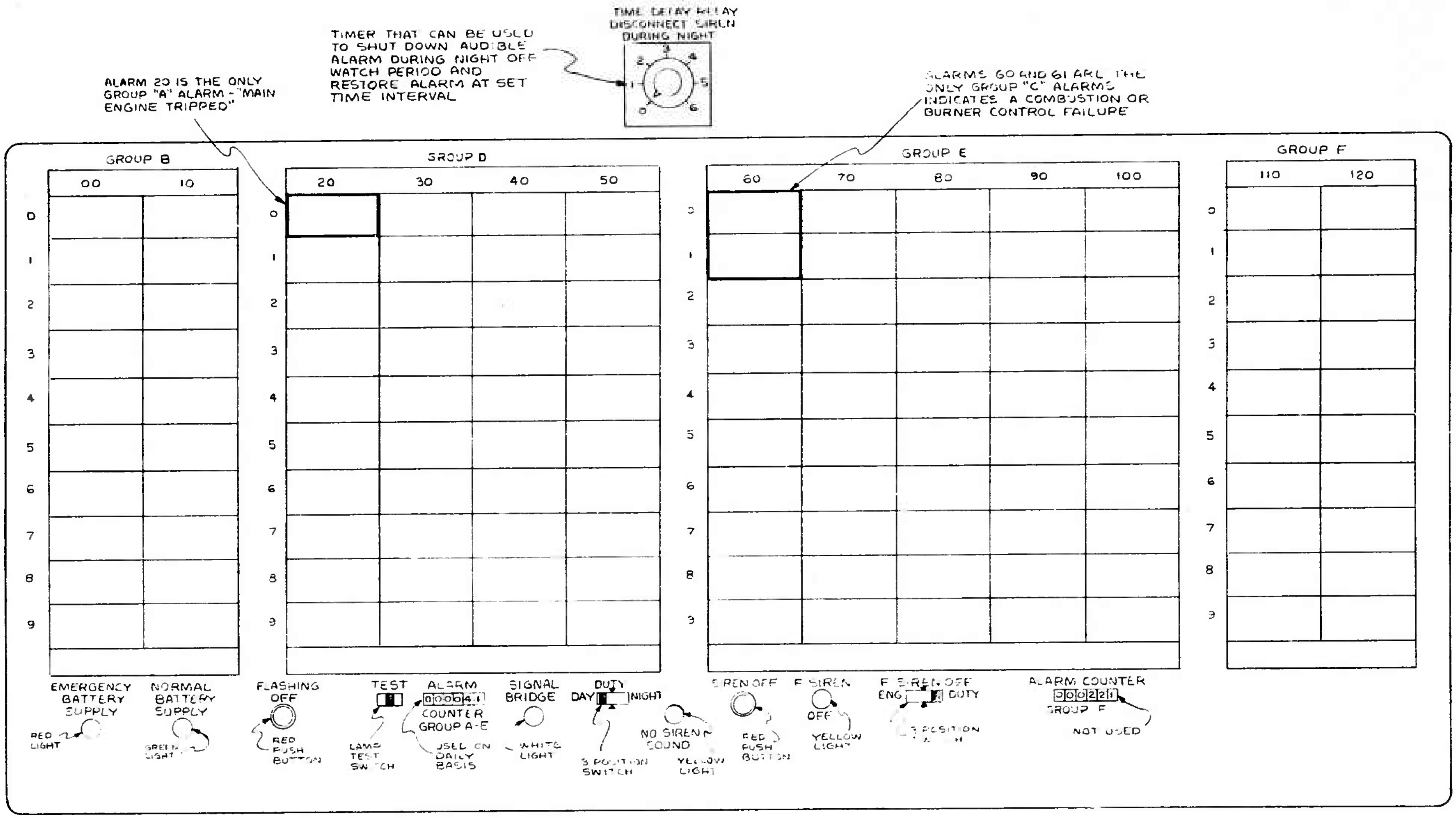
CONTROLLER SYSTEM PANEL

FIGURE 28

G. CONSOLIDATED ALARM SYSTEM

A consolidated alarm system panel forms a major part of the main engine control console located in the Engineering Control Center. Alarm warning lights are located in various panels in the Engineering Control Center; however, parallel circuits insure that for each of these alarms an indicator light and siren on the main alarm panel will also be energized. Figure 29 shows a general arrangement of the main alarm panel. In normal operation all alarm points are extinct. When a fault occurs, the corresponding alarm name plate flashes and a siren sounds. The acoustic siren can be shut off by pressing the "Siren Off" button. The flashing light can be set to a steady light by pushing the "Flashing Off" button. The alarm light will then remain on until the fault is corrected.

From the alarm panel in the Engineering Control Center the six different groups of alarms, A through F, can be transmitted to various locales throughout the ship; the importance of the alarms to the operability of the main power plant have been grouped in grades of descending importance, with A being the most important, and F group the least critical. The groupings and the specific alarms are shown, with the alarm set points indicated in parentheses in Figures 29a through 29d.



GENERAL ARRANGEMENT
MAIN ALARM PANEL

FIGURE 29

GROUP B

	00	10
0	STEAM BEFORE MAIN ENGINE LOW PRESSURE (57 AT)	LUBE OIL TO MAIN ENGINE LOW PRESSURE
1	LUBE OIL TO MAIN ENGINE HIGH TEMP (50°C)	ASTERN TURBINE EXHAUST HIGH TEMP (350°C)
2	MAIN CONDENSER CONDENSATE HIGH LEVEL (800 MM)	MAIN CONDENSER VACUUM FAILURE (579 MM Hg)
3	STBD BOILER HIGH-LOW LEVEL (±100MM)	PORT BOILER HIGH-LOW LEVEL (±100MM)
4	STBD SUPERHEATER HIGH TEMP (520°C)	PORT SUPERHEATER HIGH TEMP (520°C)
5	STBD GAS AIR HEATER STOPPED	PORT GAS AIR HEATER STOPPED
6	STBD FORCED DRAUGHT FAN FAILURE	PORT FORCED DRAUGHT FAN FAILURE
7	DEAERATOR HIGH-LOW LEVEL (300 MM LOW)	FEED WATER LOW PRESSURE (60 AT)
8	MAIN CIRCULATING PUMP STOPPED	TEMP RECORDER 3 HIGH TEMP 1-18=70°C MAIN ENG 19-24=60°C
9	LIMITS pa TEST TEST	WATCHMAN NO CHECK ON BRIDGE
	ALARM GROUP B REDUCE ENGINE RPM	

*±10 LIMITS
L.P. PLANET — 1.8 AT
1a H.P. PLANET — 1.8 AT
2a H.P. PLANET — 1.6 AT

ALARM GROUP B
MAIN ALARM PANEL
FIGURE 29a

GROUP D

	20	30	40	50
0	MAIN ENGINE STOPPED [GROUP "A" ALARM]	MAIN ENGINE L O SUMP TANK LOW LEVEL (700MM HIGH)	CONTROL OIL LOW PRESSURE LOW LEVEL (3 AT 500 MM)	EXHAUST STEAM TO MAIN ENGINE VALVE NOT CLOSED
1	BRIDGE CONTROL SYSTEM TRANSM FAILURE	STERN TUBE OIL-SEA WATER HIGH-LOW DIFF (0.1 -1.0 AT)	STERN TUBE FWD SEALING LOW OIL LEVEL (100 MM)	STERN TUBE LUBE OIL TANKS LOW LEVEL (100 MM LOW)
2	STBD BOILER STACK GAS HIGH TEMP (270°C)	PORT BOILER STACK GAS HIGH TEMP (270°C)	FUEL OIL AFTER HEATERS HIGH-LOW TEMP (80-130°C)	FUEL OIL AFTER VISC CONTROLLER HIGH TEMP (142°C)
3	GAS AIR HEATERS LUBE OIL LOW PRESSURE (2.4AT)	LP STEAM GEN HIGH-LOW PRESS HIGH-LOW LEVEL (*)	TURBO GENERATOR L O SUMP TANK LOW LEVEL (115 MM LOW)	TURBO GENERATOR LOW OIL PRESSURE HIGH OIL TEMP (1AT, 50°C)
4	SPARE DIESEL GENERATOR FAILURE	SPARE DIESEL GEN TRIPPED (**)	GENERATOR VOLT-FREQUENCY FAILURE (440±.13V 57 HZ)	GENERATOR WINDINGS (TURB 100°C) HIGH TEMP (DIESEL 115°C)
5	FWD FEED PUMP LUBE OIL LOW PRESSURE (0.9 AT)	AFT FEED PUMP LUBE OIL LOW PRESSURE (0.9AT)	FWD FEED PUMP WRONG WAY ROTATION (-60 MM Hg)	AFT FEED PUMP WRONG WAY ROTATION (-60 MM Hg)
6	STBD FUEL OIL O SERVICE PUMP STOPPED	PORT FUEL OIL O SERVICE PUMP STOPPED	AUX CIRCULATING O PUMP STOPPED	SEA WATER VALVES FAILURE
7	HIGH SALINITY (0.25 GRAINS PER U.S. GAL)	FEED WATER SERVICE TANK LOW LEVEL 9 m^3 (14 m^3)	COMPRESSED AIR LOW PRESSURE (5AT)	CONTROL AIR LOW PRESSURE (5AT)
8	STEERING GEAR LOW OIL LEVEL (50MM LOW)	SALT WATER SERVICE SYSTEM LOW PRESSURE (2.5AT)	EXHAUST STEAM SYSTEM HIGH-LOW PRESS (3.2-4.1AT)	FUEL OIL HIGH-LOW VISCOSITY (6-14 PSIG)
9	MAIN ENGINE EMERG. STOP FROM BRIDGE	GLAND FAN STOPPED	CO_2 EQUIPMENT FAILURE (19AT)	TEMP RECORDER HIGH TEMP (70°C)
	ALARM GROUP D AUXILIARIES MAIN FAILURE			

*33 LIMITS:-
8-10.6AT
100 MM LOW - 500 MM HIGH

**34 LIMITS:-
LOW L.O. PRESS 2AT
" C.W. " 1.5AT
" C.W. TEMP 95°C

ALARM GROUP A&D
MAIN ALARM PANEL
FIGURE 29b

GROUP E

	60	70	80	90	100
0	COMBUSTION CONTROL [GROUP FAILURE "C" ALARM]	HIGH FUEL-RATE 400 GAL(KWH)	BRIDGE CONTROL SYSTEM NO VOLTAGE	SMOKE DETECTOR STBD BOILER HIGH DENSITY (0.7 Ma)	SMOKE DETECTOR PORT BOILER HIGH DENSITY (0.7 Ma)
1	BURNER CONTROL FAILURE [GROUP "C" ALARM]	FLAME GUARD SYSTEM FAILURE	MAIN CONDENSER COOLING WATER LOW LEVEL (0.41 AT)	COND AFTER GLAND CONDENSER HIGH TEMP (70°C)	MAKE UP TO MAIN CONDENSER VALVE NOT CLOSED
2	STBD EVAPORATOR FAILURE	PORT EVAPORATOR FAILURE	MAIN CONDENSER COOL WATER OUTL HIGH TEMP (50°C)	ATM CONDENSER COOL WATER OUTL HIGH TEMP (75°C)	GENERATOR OVERLOAD (110% RATE I)
3	LOW PR. AIR TANK EMERG. [illegible] PUMP ROOM VENT. (6 ATMOS)	GAS AIR HEATERS FWD L.O. PUMP STOPPED	GAS AIR HEATERS AFT L.O. PUMP STOPPED	STBD CONDENSATE PUMP STOPPED	PORT CONDENSATE PUMP STOPPED
4	FUEL OIL AFTER PUMPS LOW PRESSURE (35 ATMOS)	STBD LUBE OIL PUMP STOPPED	PORT LUBE OIL PUMP STOPPED	RUDDER BEARING LUBE OIL PUMP STOPPED	HP DRAIN TANK HIGH-LOW LEVEL (250 MM LO) (520 MM HI)
5	BILGE WELL STBD HIGH LEVEL (200 MM HIGH)	BILGE WELL PORT HIGH LEVEL (200 MM HIGH)	FEED WATER SERVICE TANK LOW LEVEL (25 M3)	FUEL OIL SETTLING TANK HIGH/LOW LEVEL 950 MM HI-500 MM LO	FUEL OIL SETTLING TANK HIGH TEMP (65°C)
6	FUEL OIL STBD BUNKER TANK HIGH TEMP (65°C)	FUEL OIL CENT BUNKER TANK HIGH TEMP (65°C)	FUEL OIL PORT BUNKER TANK HIGH TEMP (65°C)	FUEL OIL DISCHARGE FILTER HIGH DIFF PRESS (1.4 ATMOS)	FUEL OIL SUCTION FILTER HIGH DIFF PRESS (0.7 ATMOS)
7	STBD LUBE OIL PURIFIER FAILURE	PORT LUBE OIL PURIFIER FAILURE	LUBE OIL DISCHARGE FILTER HIGH DIFF PRESS (0.6-1.2 ATMOS)	CARGO VALVES POWER PACK UNIT FAILURE SUCT-15AT DISC-90AT LO LEVEL	SUPERH STEAM PORT OR STBD HIGH TEMP (520°C)
8	COMPUTER FAILURE	EMERGENCY SIGNAL PERSONAL LIFT	FWD CONTROL OIL PUMP STOPPED	AFT CONTROL OIL PUMP STOPPED	CONTROL OIL TANK LOW TEMP (40°C)
9	MAIN ENGINE EMERG L.O PUMP FAILURE	MAIN ENGINE TRIP SYSTEM LOCALLY BLOCKED	MAIN ENGINE TRIP SYSTEM EARTH FAILURE	BOILER SAFETY SYSTEM FAILURE	PUMP ROOM BILGE HIGH LEVEL

ALARM GROUP E
AUXILIARIES FAILURE

ALARM GROUP C/E
MAIN ALARM PANEL
FIGURE 29[illegible]

GROUP F

	110	120
0	GLAND STEAM TO MAIN ENGINE FAILURE (60°C)	AUTOMATIC BLOCKING (LOW OR HIGH BOILER LEVEL)
1	STBD BOILER STACK GAS LOW TEMP (125°C)	PORT BOILER STACK GAS LOW TEMP (125°C)
2	STBD BOILER FUEL OIL TRIP	PORT BOILER FUEL OIL TRIP
3	STBD BOILER SOOTBLOWING FAILURE (MUST COMPLETE	PORT BOILER SOOTBLOWING FAILURE SEQUENCE IN 8 MIN)
4	TURNING GEAR STOPPED O	OIL LEAKAGE AT BURNERS (200 MM LOW)
5	SALT WATER SERVICE PUMP STOPPED O	GENERAL SERVICE PUMP STOPPED O
6	FUEL OIL SLUDGE TANK HIGH LEVEL (150 MM HIGH)	WASTE OIL TANK HIGH LEVEL (200 MM HI)
7	LUBE OIL AFTER SEPARATOR HEATER HIGH/LOW TEMP (60-80°C)	NO ENGINEER'S ACKNOWLEDGE
8	ENGINE TELEGRAPH NO VOLTAGE	AIR CONDITIONER PLANT FANS TRIPPED
9	WASTE LUBE OIL TANK HIGH LEVEL (200 MM HIGH)	(SPARE)

ALARM GROUP F

ALARM GROUP F
MAIN ALARM PANEL
FIGURE 29d

Group A through C alarms are transmitted to the Chief Engineer's bedroom, and a reset button is provided to secure the alarm following determination of the cause.

All six groups are transmitted to the bridge and to the engineer's passageway on B deck. The display in the engineer's passageway and on the bridge indicates by light the alarm group that has been triggered and also provides a selector switch to permit transmission of alarms to the duty engineer's stateroom. The nomenclature used for each of the six groups in this display is as follows:

Group		Function
A	-	Main Engine Stopped
B	-	Reduce Engine RPM to 55
C	-	Combustion Failure
D	-	Main Auxiliaries Failure
E	-	Auxiliaries Failure
F	-	Miscellaneous Alarms

Any alarm in the six groups will energize one of the above alarm lights and sound a bell in the following locations:

- Duty Engineers Stateroom
- Mess Room A Deck
- Day Room B Deck
- Swimming Pool
- Navigation Bridge

The duty engineer must then proceed to the Engineering Control Center to determine the specific alarm that has been triggered and take action to correct the cause. The acoustic alarm for Group F is switched off in the engine room during non-working hours.

H. ENGINEERING CONTROL CENTER

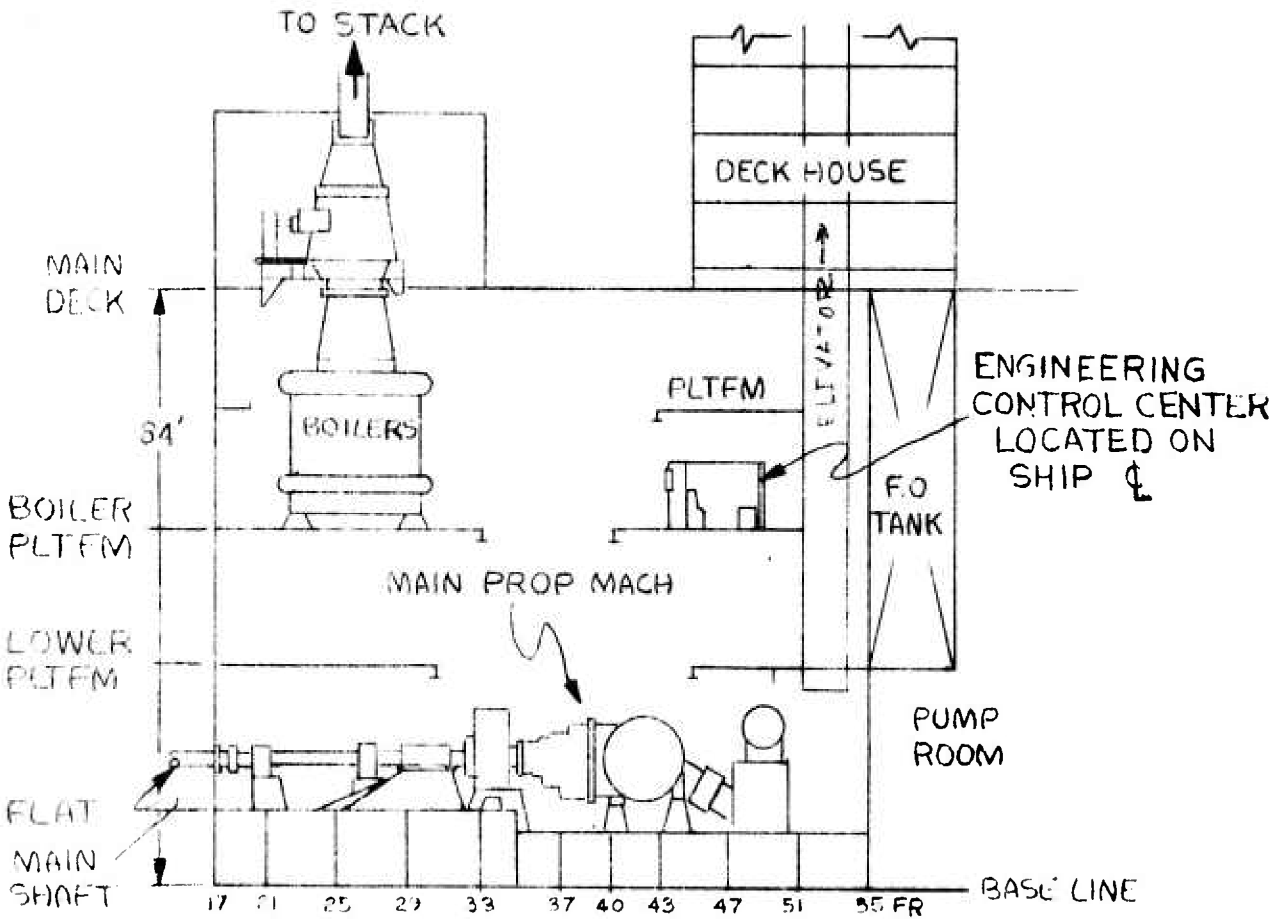
The nerve center of all automatic control systems for SEA SERPENT's engineering plant is the Engineering Control Center. This space is relatively small, located in the main engine room, and is air conditioned and sound insulated to provide a comfortable and quiet environment. The general arrangement of the Center and its location in the main engine room are shown in Figure 30.

The Center contains two major consoles which are discussed below:

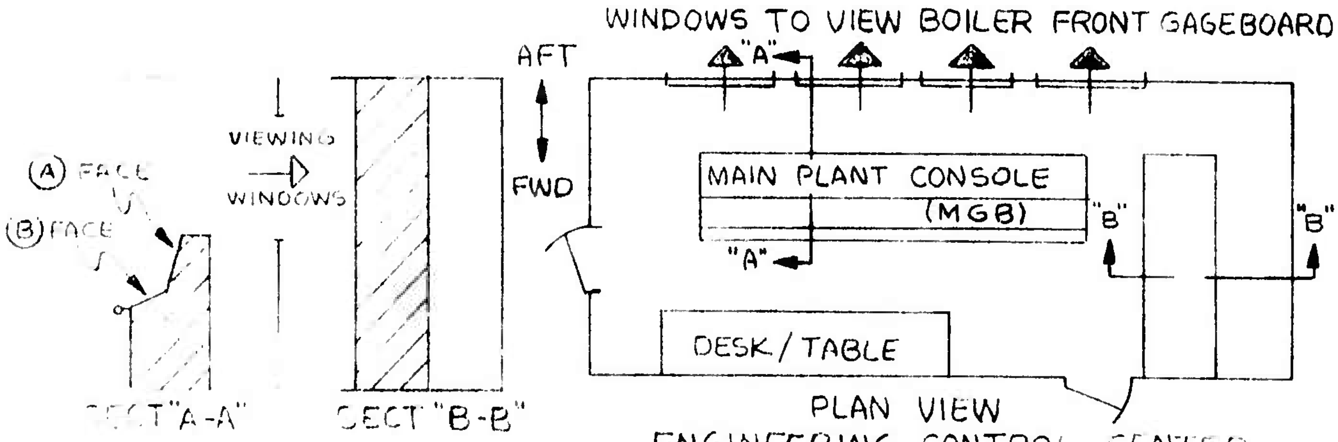
1. The Main Engineering Plant Control Console

The main engineering plant control console contains the principal controls, instruments and alarms required for operation of the main propulsion plant and supporting auxiliaries. Observation of the panel during maneuvering and full power operation showed the console to be convenient in layout, and with few exceptions, the human engineering details were excellent.

Most important, adequate space was provided on all sides of the panel, permitting clear observation of the entire console face. Access to each control or instrument group for maintenance or checking of test points was convenient, using hinged fronts on the



MAIN ENGINE ROOM
ELEVATION LOOKING TO PORT



SECT "A-A"
MAIN ENGRG PLANT CONTROL CONSOLE LOOKING TO STBD

SECT "B-B"
MAIN INSTRUMENT BOARD LOOKING AFT

PLAN VIEW
ENGINEERING CONTROL CENTER

GENERAL ARRANGEMENT-
ENGINEERING
CONTROL CENTER
FIGURE 30

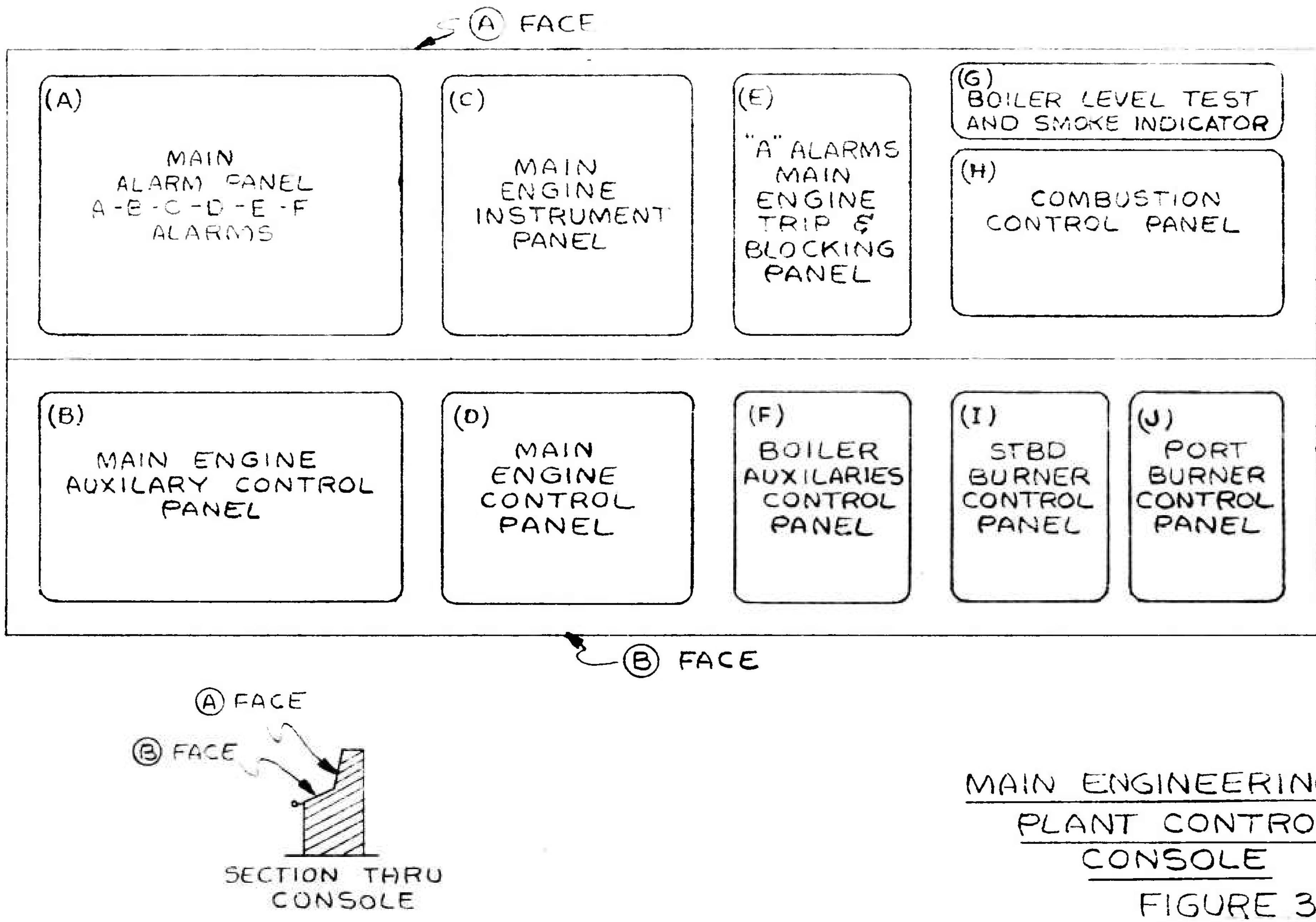
units in combination with large doors that allowed access to the rear of the entire console. The layout of the main engineering plant control console is shown in Figure 31.

As shown in Figure 31, the console contains ten control or instrument groups. Each group is identified and briefly described below:

a. Main Alarm Panel - For the engineering plant. This panel was previously described on page 4-49 of this report, and a detailed layout of the panel is provided in Figure 29 with details of each alarm group shown in Figures 29a through 29d.

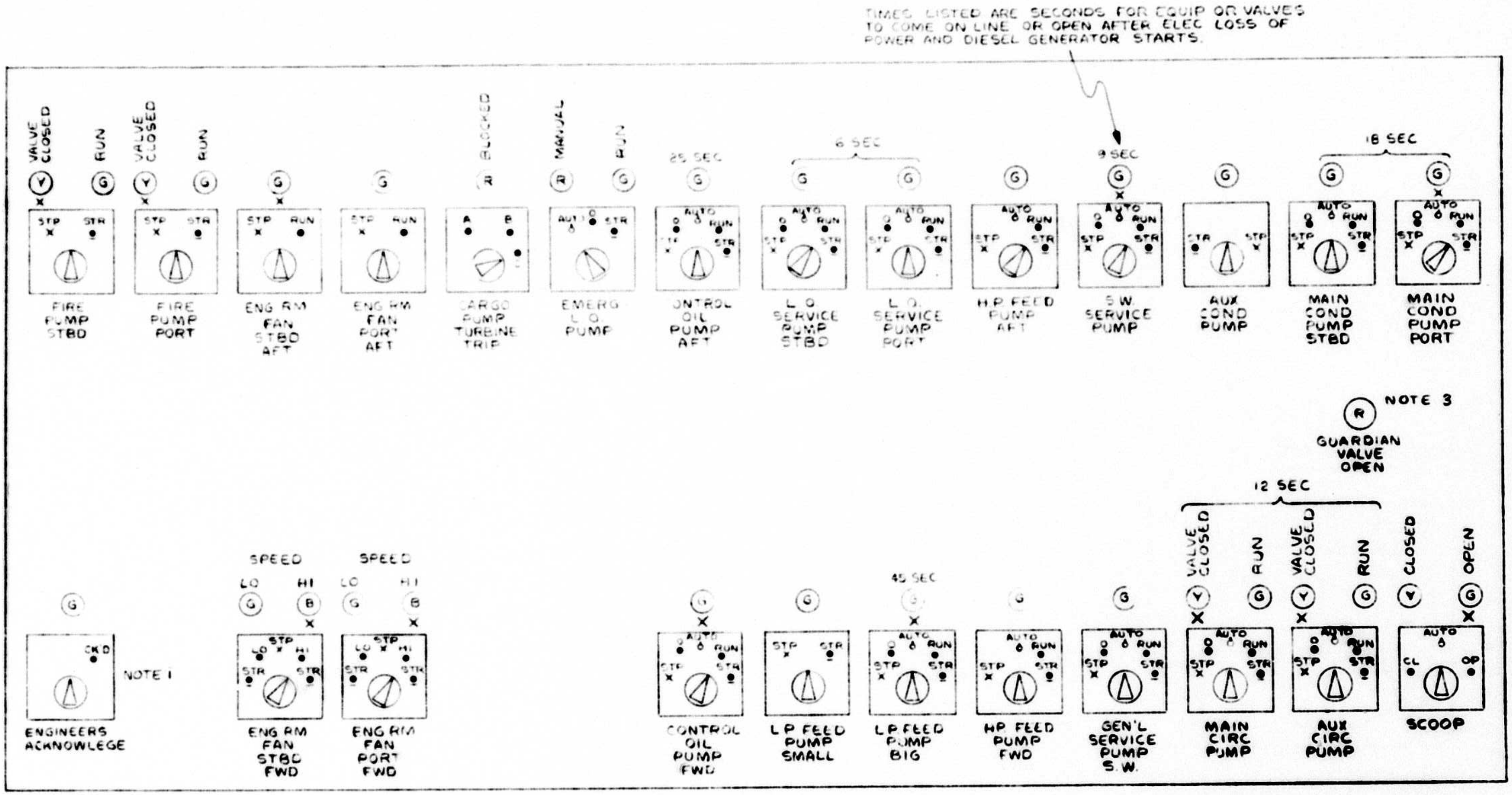
b. Main Engine Auxiliary Control Panel - This panel contains the controls and indicators for operation of all principal auxiliaries that support the operation of the main propulsion plant. The components controlled from this panel are shown in Figure 31a.

c. Main Engine Instrument Panel - The primary instruments relating to the operation of the turbines, gears, and main propulsion shaft are grouped on the panel. The arrangement of instruments on the panel is shown in Figure 31b.



MAIN ENGINEERING
PLANT CONTROL
CONSOLE

FIGURE 31



NOTES
1. WHEN ON MANUAL CONTROL IN ENGRG CONTROL CTR ONE MAN ON WATCH MUST SIGNAL BRIDGE EVERY 1/2 HOUR TO INDICATE ALL OK - "DEAD MAN CONTROL" LIGHT STAYS ON - GOES OFF EVERY 1/2 HR THEN ENG RM HAS 30 SECONDS TO ANSWER TO RESTORE LIGHT."
2. STOP AND START POSITIONS ARE SPRING LOADED TO RETURN SWITCH TO "O" OR "RUN" WHEN RELEASED.
3. WHEN LIGHTED INDICATES STOP VALVE ON MN STM TO ASTERN TURBINE OPEN - NORMALLY VALVE CLOSED TO GUARD AGAINST STM LEAK BY ASTERN THROTTLE VALVE

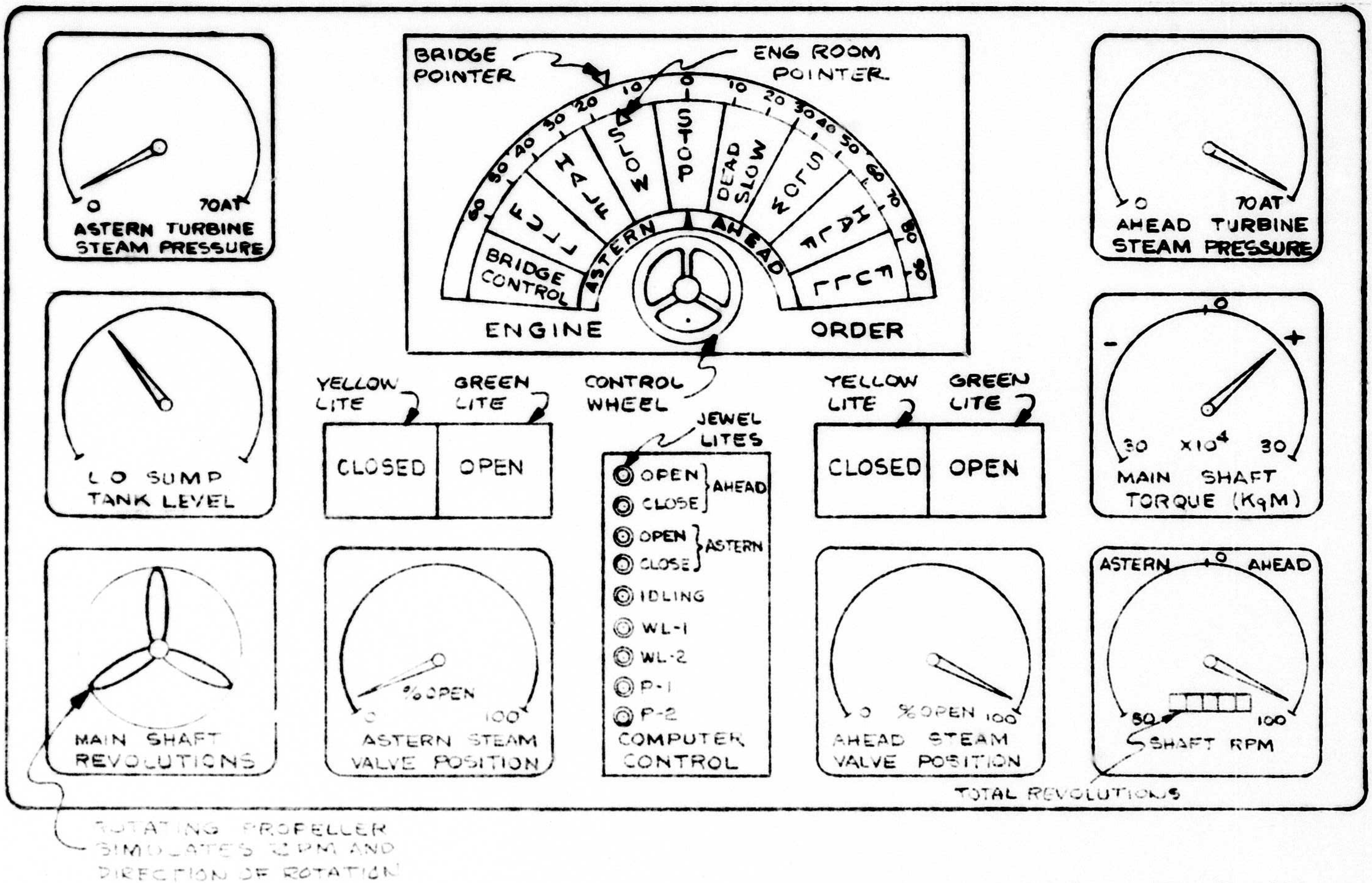
(Y) = YELLOW LIGHT
(G) = GREEN LIGHT
(R) = RED LIGHT
(B) = BLUE LIGHT

( ), X } INDICATE LIGHT ON AT FULL POWER 85 RPM CONDITION

INDICATES POSITION OF SWITCH AT NORMAL FULL POWER 85 RPM CONDITION

STP = STOP
O = ZERO POINT
AUTO = AUTOMATIC CONTROL
RUN = RUN POSITION
STR = START

MAIN ENGINE AUXILARY CONTROL PANEL
FIGURE 31a



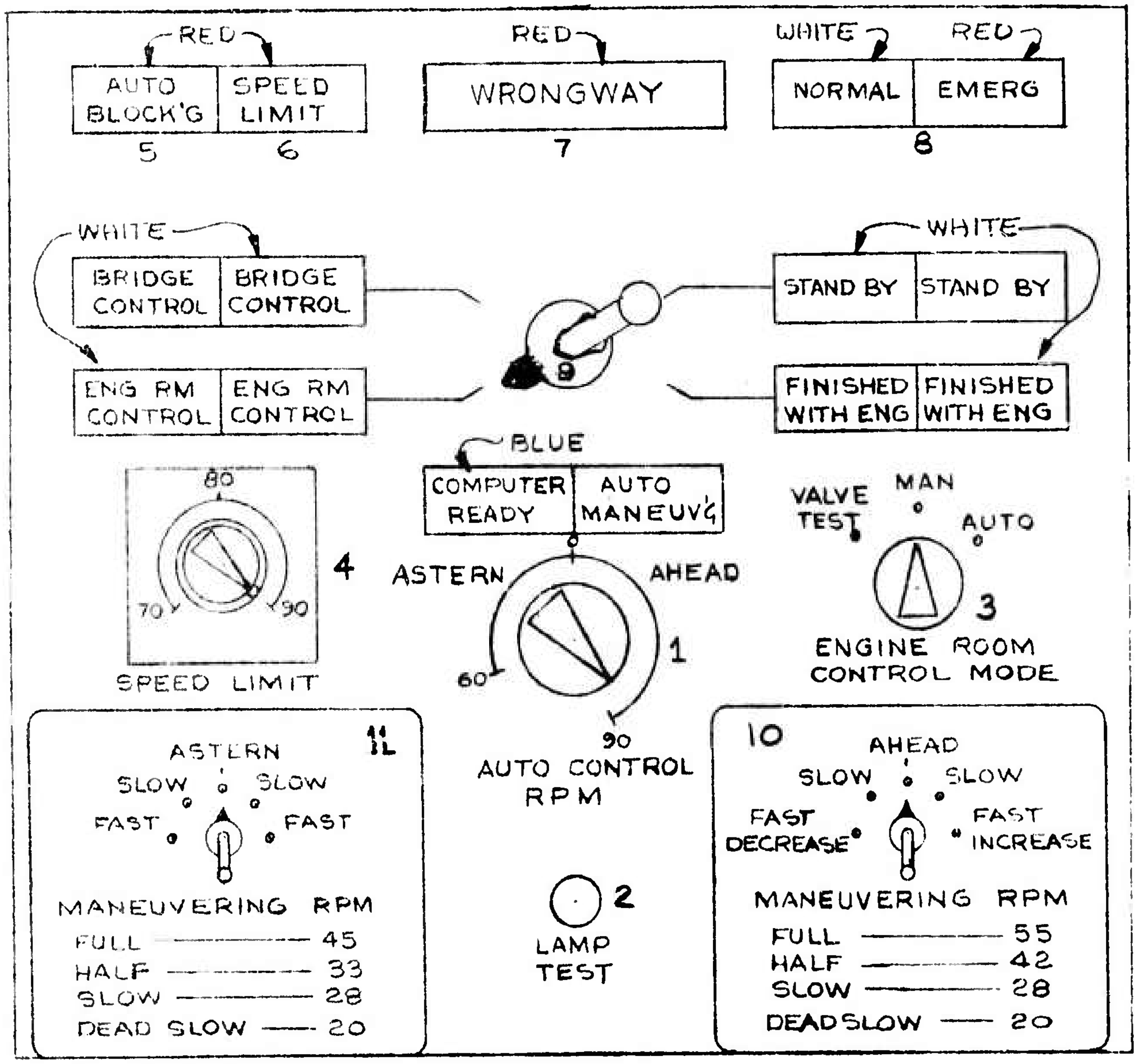
MAIN ENGINE INSTRUMENT PANEL

FIGURE 31b

The "Computer Control" indicator located in the bottom center of the panel shows by red jewel lights: When the computer is opening or closing the ahead or astern main turbine throttle valves; when the turbine is idling (steam injected periodically to keep turbine slowly rotating when maneuvering at 0 shaft RPM); WL-1 indicates turbine limited (12,000 SHP) due to low or high boiler level alarm; WL-2 indicates turbine limited (12,000 SHP) due to high or low boiler level trip; P-1 indicates low main steam pressure alarm limiting turbine; and P-2 indicates low main steam pressure trip has occurred.

d. Main Engine Control Panel - This panel contains the engine room controls for the main propulsion plant, plus certain critical indicator and warning lights. Since the function of the controls on this panel is not evident from an examination of the panel diagram, Figure 31c, the following is a brief description of each control or indicator (numbers refer to diagram):

(1) Shaft RPM Control - Allows engine room to select shaft RPM and direction of



MAIN ENGINE CONTROL PANEL

FIGURE 31c

rotation using automatic computer control of the plant.

(2) Lamp Test - Push button permits a check of all lamps on panel.

(3) Control Mode Selector Switch - For use by engine room to select automatic or manual control of main propulsion plant. "Valve Test" position of switch permits actual motion of turbine throttle valves while main plant is in "Bridge Control" mode. Insures valve motion possible when needed.

(4) Speed Limiter Control - Allows engine room to set limiting RPM for main shaft which is observed by the computer for control of main steam throttle valve. This control might be used with a casualty condition such as shaft vibration or shaft seal problem.

(5) Automatic Blocking - Red indicator light is energized when computer has sensed an engine or boiler alarm and will set certain limiting conditions for plant operation. Details of this

function are discussed under Main Engine Automatic Control, page 4-28.

(6) Speed Limit Reached - Red indicator light advises when limit on shaft RPM set by control No. 4 has been reached.

(7) Wrongway - Red indicator light and horn alarm are energized if engine room activates turbine valves or shaft RPM control in direction opposite to bridge command.

(8) Normal/Emergency - White/red indicator light. White "Normal" light remains on with a shift to red "Emergency" light when the bridge activates the emergency stop computer control function.

(9) Propulsion Control Selection Switch - Allows bridge or engine room to indicate locale for control of the main propulsion plant. Both lights in a pair are energized when bridge and engine room selector handles are placed in same position. Horn alarm sounds when handle position is changed. The engine room can override the bridge selection

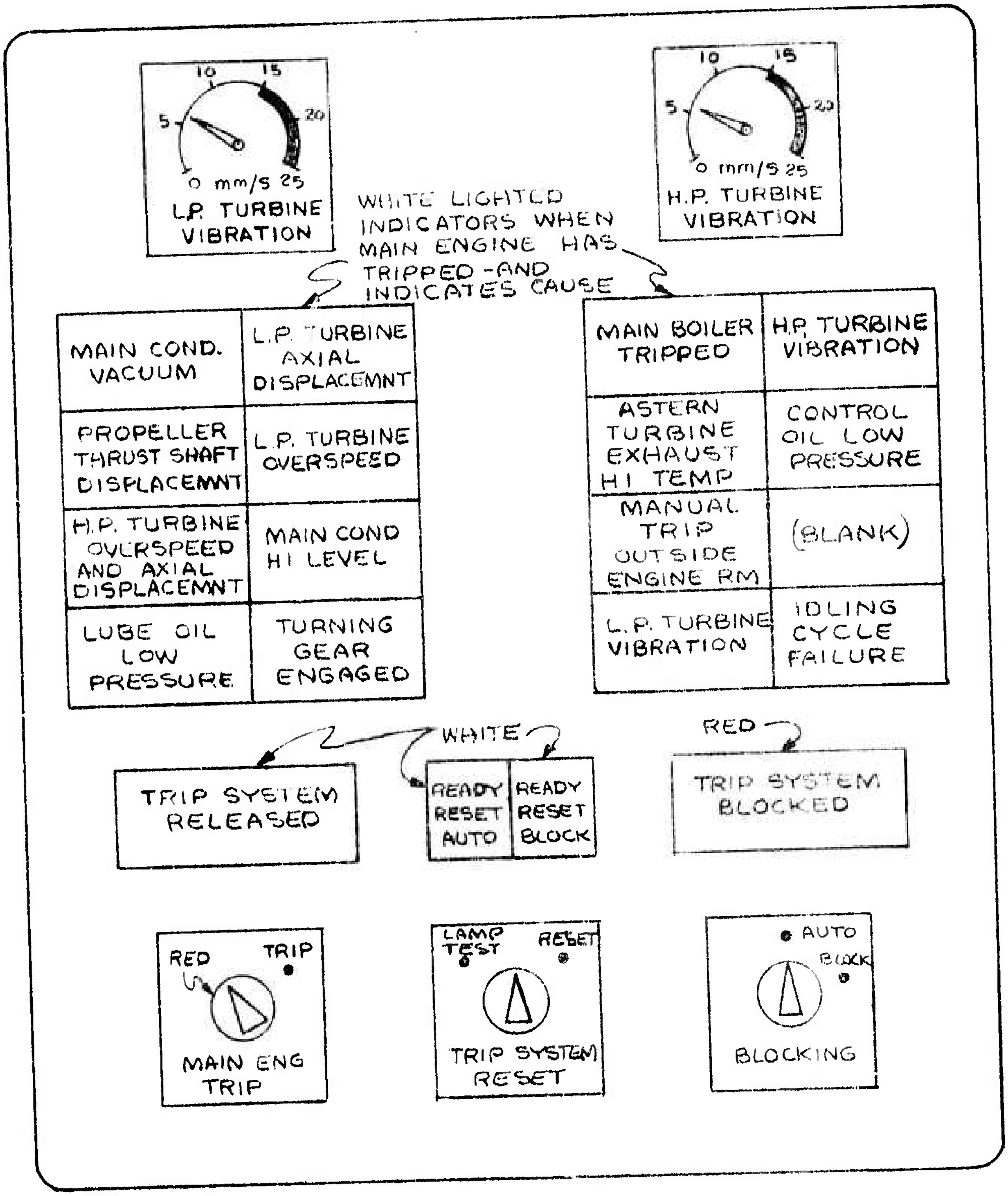
of control which is necessary for engine casualty recovery action.

(10) and (11) Ahead and Astern Main Steam Throttle Valve Control - This control is used for direct activation of turbine valve position with the plant in the manual mode.

e. Main Engine Trip and Blocking Panel - This panel, Figure 31d, contains all the alarm lights, with the light clearly labeled as to the cause of the main engine tripping off the line. When any one of the alarm lights on this panel is energized, the main alarm panel (A) will show a "Main Engine Tripped" light (alarm No. 20, Figure 29b).

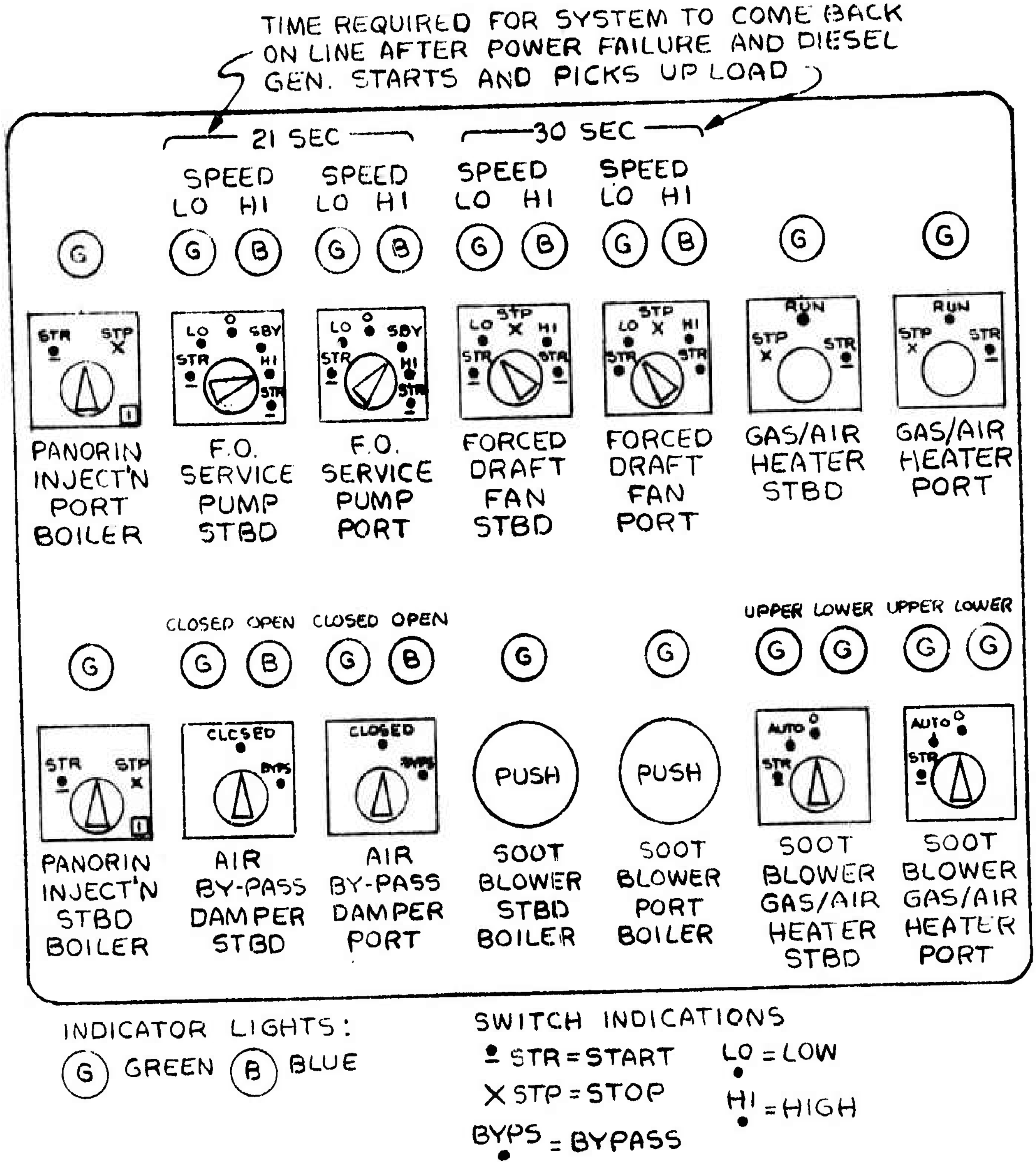
f. Boiler Auxiliaries Control Panel - Controls and indicators for the major boiler auxiliary systems are included in this panel (see Figure 31e).

g. Boiler Level Test and Smoke Indicator Panel - This panel, Figure 31f, includes boiler level simulator controls for testing boiler level indicators and alarm circuits that are a part of the automatic Combustion Control System.



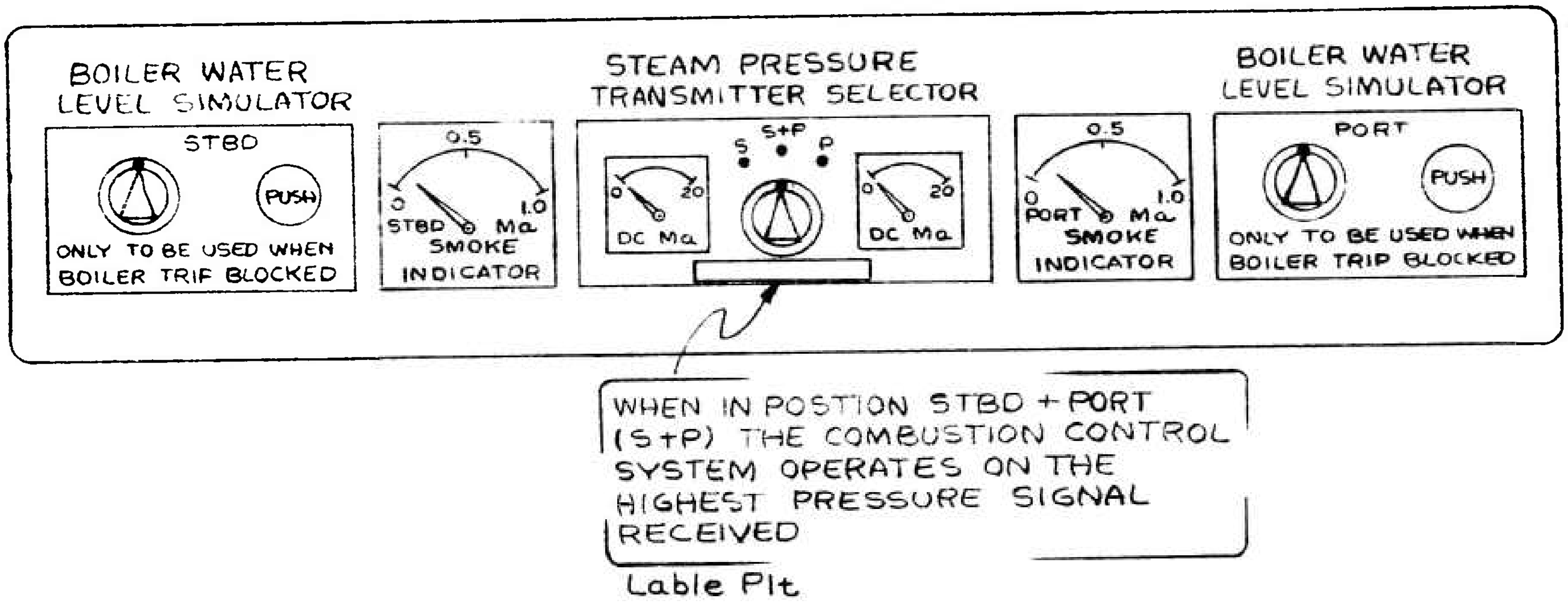
MAIN ENGINE TRIP AND BLOCKING PANEL

FIGURE 31d



BOILER AUXILIARIES CONTROL PANEL

FIGURE 31e



BOILER LEVEL TEST

AND

SMOKE INDICATOR PANEL

FIGURE 31f

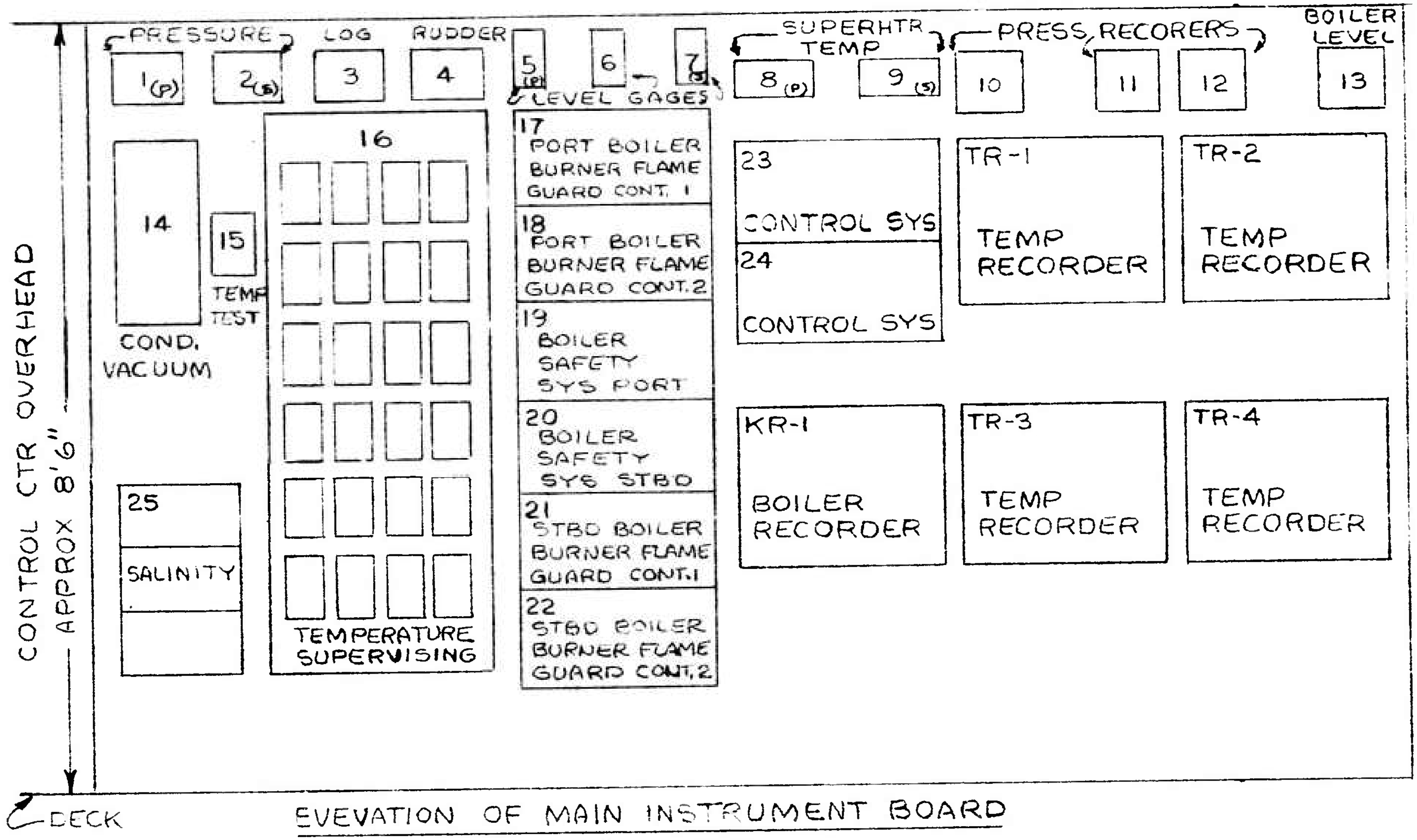
In addition, selection of the steam pressure transmitter to be used is accomplished from this panel. Smoke indicators provide alarms at 0.7ma reading on the gauge.

h. Combustion Control Panel - The details of instruments and controls included in this panel are discussed on page 4-11 of this report and in Appendix I-1.

i. and j. Starboard and Port Boiler Burner Control Panel - The details of indicators and controls included on these panels are discussed on page 4-30 of this report and in Appendix I-2.

2. Main Instrument Panel

The main instrument panel is primarily devoted to gauges and controls supporting the main and auxiliary machinery systems. The general layout of the board is shown in Figure 32. As with the main engineering plant control console, adequate space has been provided for maintenance of main instrument panel units, either by front hinged or pullout access, or from the back of the panel using hinged cover plates. Referring to Figure 32, the following is a brief listing of instrument and controls contained in this panel (numbers refer to those shown on Figure 32):



EVEVATION OF MAIN INSTRUMENT BOARD

LOOKING TO PORT

MAIN INSTRUMENT BOARD ARRANGEMENT

FIGURE 32

(1) and (2) Pressure (kp/cm^2) indicators for the following port and starboard units, respectively:

(a) Desuperheater outlet

(b) Boiler drum

(c) Soot blowing steam

A selector switch is used to indicate pressure for any one of the three systems listed.

(3) Log indicates ship's speed (kts)

(4) Rudder angle indicator (degrees)

(5) and (7) Boiler level indicators (mm) for port and starboard boilers

(6) Deaerator level indicator (mm)

(8) and (9) Superheater steam temperature (°C) for port and starboard boilers

(10) Pressure recorder (continuous paper using ink pen - kp/cm^2) for main steam and turbine control stage

(11) Pressure recorder (same as 10) for crossover steam pressure and exhaust steam pressure

(12) Pressure recorder (same as 10) for H.P. bleeder steam

(13) Boiler level recorder and gauge (mm above and below normal level - continuous paper using ink pen) for port and starboard boilers

(14) Main condenser vacuum gauge (mercury manometer calibrated in mm)

(15) Temperature test unit. "MINIMITE" thermo-electric temperature supervisor used to check temperature gauges in temperature indicator unit (16). Temporary test plug-in wires are run between units (15) and (16) to check balancing circuits and zero settings for each unit in (16).

(16) Temperature supervising unit (°C). 24 separate plant temperature indicators provide a profile temperature readout with a green light to indicate when gauge is in operation and temperature monitored is within limits. A red alarm light is energized when temperature is out of limits.

(17), (18), (21) and (22)	Flame guard control and indicator units. For discussion of operation, see page 4-35 of this report and Appendix I-3.
(19) and (20)	Boiler safety system control and indicator units. For discussion of operation, see page 4-38 of this report.
(23) and (24)	Controller system units. For discussion of operation, see page 4-45 of this report and Appendix I-4.
(25)	Evaporator and feed water salinity indicator
(TR-1)	Temperature recorder (continuous paper and ink printout - °C). Records:

- Superheater steam (P and S)
- Desuperheater steam (P and S)
- H.P. bleeder
- Superheater steam at main engine
- Crossover line
- Astern nozzles
- Astern turbine outlet
- Diesel alternator exhaust fwd blower in

- Diesel alternator exhaust aft blower in
- Diesel alternator exhaust fwd blower out
- Diesel alternator exhaust aft blower out

(TR-2) Temperature recorder (same as TR-1).

Records:

- Main cond cooling water (inlet and outlet)
- Main cond pumps outlet
- First feed htr condensate (inlet and outlet)
- Deaerator condensate outlet
- HP feed htr feed water outlet
- Main turbine bleed to evaporators
- Main turbine bleed to evaporators first feed heaters
- LP turbine exhaust
- Exhaust steam after dump valve

(TR-3) Temperature recorder (same as TR-1).

Records:

- Lube oil to main engine
- HP turbine L.O. (thrust brg, fwd and aft journal brg)
- LP turbine L.O. (thrust brg, fwd and aft journal brg)

- Reduction gear L.O. (9 points recorded)
- Main thrust brg L.O.
- Main shaft bearing L.O. (fwd and aft)
- Stern tube
- Stern tube fwd sealing oil

(TR-4) Temperature recorder (Same as TR-1).

Records:

- Lube oil turbo generator (to and from)
- Turbo gen turbine brgs L.O. (fwd and aft)
- Turbo gen reduction gear brgs L.O. (4 points)
- Turbo gen generator brgs L.O. (fwd and aft)
- Fwd feed pump brg L.O. (turbine and pump)
- Aft feed pump brg L.O. (turbine and pump)
- Steering gear hydraulic oil (P and S)
- Gas air heater L.O. (P and S)
- Feed pump L.O. after cooler (fwd and aft units)

(KR-1) Boiler recorder (continuous paper and ink printouts - various units recorded).

Records:

- Boiler smoke density (P and S)
- Flue gas O^2 content (P and S)
- Air temperature before air heaters
- Air temperature after air heater (P and S)
- Flue gas temperature to air heater (P and S)
- Flue gas temperature leaving air heater (P and S)

CHAPTER 5

OPERATION OF THE VESSEL UNDER COMPUTERIZED AUTOMATION AND CREW REACTIONS

DIGITAL COMPUTER IMPACT ON THE CREW

Table X presents the manning list for the T/T SEA SERPENT during the trip of May 24 - June 7, 1973 from Point-a-Pierre, Trinidad to Cape Town, South Africa. Of these, however, only five and possibly six are in any way specifically influenced in their jobs by the digital bridge computer system as applied on the T/T SEA SERPENT. These include the Captain, the three Watch Officers, the Electrical Technician (one of the Engineering Officers) and possibly the Chief Engineer.

The life and work routines of the engineering personnel are, of course, vitally affected by the fact that the T/T SEA SERPENT operates with an unmanned engine room at night, on weekends, and on holidays. The computer is indeed used to effect bridge control of the engine room and make the unmanned engine room possible. However, the engineering personnel have no contact with the computer itself, and the task performed by it in the bridge command function is a relatively easy one which could be readily taken over by analog devices as it is on many other Scandinavian ships.

TABLE X

CREW LIST

T/T SEA SERPENT

VOYAGE FROM TRINIDAD TO CAPE TOWN

MAY 24 - JUNE 7, 1973

	Name	Position	Nation-ality	Birth Date
Officers				
1.	Svensson, Bengt	Master	Swed	25 03 21
2.	Jönsson, Ivar	Chief Off	Swed	33 03 25
3.	Wennberg, Lars	2nd Off	Swed	43 08 21
4.	Olsson, Olaf	2nd Off,Jr	Swed	45 07 24
5.	Johansson, Bruno	Radio Off	Swed	23 08 17
6.	Sjölund, Evald	Chief Eng	Swed	31 08 26
7.	Simonides, Johann	1st Eng	W.Germ	32 04 17
8.	Jönsson, Sten Ove	2nd Eng	Swed	44 07 25
9.	Wigren, Bo	3rd Eng	Swed	40 01 02
10.	Lehtonen, Bertel	El Techn	Finnish	45 04 06
11.	Krussel, Bertil	3rd Eng (Storekeeper)	Swed	28 08 15
12.	Strom, Martin	Chief Stew	Swed	25 02 22
Crew				
13.	Helfer, Rolf	Chief Cook	Swiss	31 04 09
14.	Malmström, Göran	2nd Cook	Swed	49 06 24

TABLE X (Cont.)

	Name	Position	Nation-ality	Birth Date
Crew (Cont.)				
15.	Persira, Jöse	Mess Man	Port	38 09 05
16.	Van Dyk, Frans	Mess Man	Belg	14 04 27
17.	Gualdino, Luis Frances	Mess Man	Port	37 08 13
18.	Du Guet, Laila	Mess Man	Swed	27 03 25
19.	Häkansson, Leif	Boatswain	Swed	43 08 20
20.	Mäsabacka, Helmer	ab	Finnish	32 04 07
21.	Johansen, Björn	ab	Norw	47 03 25
22.	Sanchez, Fernando	ab	Span	20 11 22
23.	Brandt, Rüdiger	ab	W.Germ	39 09 11
24.	Karlsson, Jan	ab	Swed	50 04 04
25.	Conde-Lorenzo, Antonio	ab	Span	37 06 24
26.	Vasquez-Chenlo, Caferino	ab	Span	44 03 08
27.	Mayo-Anton, Andres	os	Span	45 08 28
28.	Eriksson, Sune	ab	Swed	44 10 24
29.	Vandenbossche, Noel	os	Belg	44 08 11
30.	Seifert, Gerhard	Pump Man	W.Germ	32 02 17
31.	Du Guet, Jöse	Repair Man	Swed	29 09 01
32.	Granudd, Villy	Greaser	Swed	47 07 13
33.	Karlsson, Sven	Greaser	Swed	42 02 15
34.	Brito, Haimundo	Greaser	Port	33 02 17
35.	Fettig, Manfred	Greaser	W.Germ	34 06 22
36.	Jonsson, Bo	Ex Pump Man	Swed	37 08 16

None of the seamen, engine or deck, have any contact whatever with the computer system.

All Bridge Officers had access to the logging functions of the computer during their watch period. It was used mainly for satellite ALERT functions or destination readouts. Logging of other ship parameters was seldom, if ever, done. None of the Watch Officers except the Captain had any experience at programming or with any computer functions except those carried out through the typewriter. The Chief Engineer used the computer once a day to log out and read selected engine room values.

Bridge Operation Under Computer Control

When underway at sea, the bridge of the T/T SEA SERPENT is manned by two men, a Watch Officer and an Able Seaman. Since the computer handles all steering, engine room contact, and navigation functions, the watch crew's main remaining task is that of an anticollision watch and as an emergency standby unit. The Watch Officer occupies part of his time as follows:

1. First Officer - Cargo manifests, tank venting and cleaning, cargo transfers, upkeep of log book, etc.
2. Second Officer - Upkeep of medical records, maintenance of inventory of charts and their corrections, determination of future tracks, ship position reports, etc.

3. Third Officer - Upkeep of crew's work records because of complex Swedish overtime rules, etc.

The seaman spent approximately half his time in clean up and painting tasks, and the remainder on active lookout from the bridge or bridge wings. No other lookout was maintained.

Except during periods of heavy rain, all lookout was visual. During rain the radar was used. Otherwise, it was switched off to conserve it for more critical periods. Except as noted in Chapter 6, the crew accepted the work of the computer system completely and trusted it implicitly. During the period of the voyage only five celestial sightings were taken--two sun speed lines, two three-star fixes, and one five-star fix. One sun line was used to check the position along the course after one of the watch officers misplotted a noon fix from the computer. The other line and one three star fix were taken during one eight hour period when the satellite receiver was out. The remaining star fixes were taken the evening prior to arrival off Cape Town. No checks were made on navigation satellite position readings under normal operation.

During the period when the ship was being maneuvered out of the Trinidad port area and in preparation for stopping off Cape Town, South Africa, the bridge of SEA SERPENT was under the command of the Captain. He was assisted by a watch officer who plotted positions using the radar as a primary plotting input. The helm was manned and responded to changes in course or rudder angles ordered by the Captain. An alert watch was maintained on the bridge wings (one man). Control of the engine during maneuvering was via the computer automatic system. The captain personally initiated the changes using the engine order telegraph.

Except for the six bridge watch personnel and the Captain, who operated on a staggered schedule to cover all watches, every other member of the crew worked a regular five-day, 8-5 half-day Saturday, Sundays and holidays off, schedule. Mess personnel obviously had their own somewhat different schedule. During port periods of loading and unloading, much longer and more arduous schedules were kept, of course.

The bridge contains a read-out meter for engine RPM and a set of the major engine alarm signals. There is also a pair of television cameras which can be used for inspection of the engine room areas. However, these latter had deteriorated since being installed and were never used. Other than this, there was no bridge contact for engine-room conditions, no logging of engine room variables, indicators of engine and boiler conditions, etc.

All personnel were happy with the existing systems as regards engine information. They felt that any extra information supplied them would be worthless paper and useless activity.

Engine Room Operation Under Automation

Engineering officers had, beyond question, developed a high level of confidence in the engineering plant automatic control systems and in the casualty alerting capability of the alarm system. Observation of the engineers during working and nonworking hours clearly demonstrated a relaxed attitude toward plant operation. Except to respond to alarms they considered their prime function was plant maintenance and faithful checking of automatic alarm circuits to insure that these circuits were operating properly. Administrative paper work appeared to consume only a small percentage of their time.

The engine room worked a standard industrial 45 hour week. Weekday work hours were from 0800 to 1700 with one hour off for lunch. Saturday work hours were from 0630 to 1200 with a half hour off for breakfast. The remainder of week and holidays were completely free time to be spent as they desired except for engineering officer duty assignments.

During non-working hours the engine room was completely unmanned. No requirement existed for any officer or crew members to be present in the engine room spaces during off hours, and repeated observations by the authors of the spaces during these periods verified the zero manning concept. During working hours the engineering control center was not manned and no requirement existed to maintain a watch in the center during working hours. Officers were present in the space on occasion to use the log desk to maintain records, to discuss maintenance problems, to consult engineering manuals and for their coffee breaks since the space was air conditioned, sound insulated, and housed their coffee mess. The consoles and gauge boards in the center were observed or used only to respond to an alarm, make changes in the mode of operation of components of systems, light off burners, or test alarm circuits. Engine control was strictly "by exception" responding to alarms that identified the exceptions.

One engineering officer was assigned to standby duty during non-working hours. The watch was rotated on daily basis between the first, second, and third engineer. The chief engineer, electrical technician, third engineer store-keeper, and engineer room crew members stood no watches but were on call if their services were required. During the three week period the authors were on board it was noted that nearly all corrective action required during an off-hour alarm was handled by the watch officer. On a few occasions it was necessary to call on the service of the electrical technician where the fault involved an electrical component or circuit.

Each engineer's cabin was equipped with a set of engine alarms. The engineering watch officer on taking the watch set the alarm to ring in his room only so as to be awakened should something go amiss. Other locations on the ship were equipped with alarms to alert the duty engineer, and the Chief

Engineer's cabin contained a set of major alarms. A detailed description of the alarm circuits and their locations is contained in Chapter 4 of this report.

No engine room crew member stood watches outside of regular working hours and other than the repairman who performs routine welding, grinding, machine work, etc., the engine crew was only used for painting and cleaning. Actual equipment maintenance and repairs was carried out by the officers with the assistance of the repairman.

The officers and crew members listed in Table X who were directly associated with engine room operation and support are listed below:-

- Chief Engineer
- 1st Engineer
- 2nd Engineer
- 3rd Engineer
- Electrical Technician
- 3rd Engineer storekeeper *

Total - 6 Officers

- Repairman *
- 4 Greasers

Total - 5 Crew

* The Storekeeper and Repairman also served other departments and areas of the ship when required.

As previously noted the prime function of the engineering officers involved conducting plant maintenance and test work. The Chief Engineer offered the following estimate of how the engineer's work time was spent:-

- Chief Engineer	
Supervising/Adminstrative	100%
- 1st Engineer	
Supervising in Engine Room	90%
Routine Maintenance	10%
- 2nd Engineer	
Safety Circuits and Alarm Tests	50%
Administrative Record Keeping	50%
- 3rd Engineer	
Routine Maintenance	60%
Safety Circuits and Alarm Tests	40%
- Electrical Technician	
Routine Maintenance of Elec. Equipment	75%
Electrical Record Keeping	25%

TRAINING, MAINTENANCE AND OTHER FACTORS

Computer Training and Experience of Ship's Personnel

A major effort had been made to give thorough computer training to the first crew of the T/T SEA SOVEREIGN, Sweden's and Salen's first computerized ship. However, most of these personnel quickly left the sea for more lucrative and stable jobs on land. As a result only a minimum amount of training was given the first crews of later ships. In most cases replacement personnel got no formal training whatever.

First crews now receive three or four hours of lectures on computer fundamentals and descriptions of the functions to be carried out by the computer. They receive no programming training.

Details of the program content, actual algorithms used, programming changes instituted, etc., are retained by Kockums personnel who carry out such changes. Little or no information is volunteered to the crew of the effect of the changes being made.

A detailed instruction book in Swedish written by Kockums personnel explained the operation of the teletype to obtain all data of Tables V and VI.

The Captain had been First Officer and Captain of the SEA SOVEREIGN, Sweden's first computerized ship. He had also served on the yard crews during construction of both the SEA SOVEREIGN and SEA SERPENT.

The First Officer had been on the SEA SERPENT yard crew and had served three periods at sea on the SEA SERPENT. The Second Officer had been on the SEA SOVEREIGN, the yard crew, and one period on the SEA SOLDIER, a sister ship to the SEA SERPENT, and was on his second tour on the SEA SERPENT. The Third Officer was on his first tour on any vessel as an officer. He had had no computer instruction except what he picked up on board the T/T SEA SERPENT.

The Chief Engineer, 1st Engineer and 2nd Engineer received their basic engineer officers training at the Swedish Merchant Marine "Sea Officer's School" which involved 2 or 3 years of studies with practical at-sea training or shipyard work interspersed during summer months. The 3rd Engineer's basic training was received during three years in the Navy which included Navy technical training that was accepted by the Swedish Merchant Marine.

The Electrical Technican had received a two months course in the fundamentals of electronics, on computer and peripheral maintenance, and on assembly language programming. However, he had no experience with the program used on the T/T SEA SERPENT and carried out programming functions only as directed by Kockums personnel. All program updates, reloading of the program, etc., were carried out by the Captain, who had by far the most experience of any personnel on board with the ship's computer system.

Specific training in computer technology and associated control systems to equip the engineering officer to serve on an automated ship was minimal. Only the Chief Engineer had received the benefit of Salen's original effort to provide the crews of these new ships with a thorough understanding of computers and the automated system. The companies current training program apparently relies almost entirely on an "on-the-job training" approach with the more senior engineers who have had relatively long experience at sea on automated ships training the junior engineers as they are brought aboard from the "Sea Officer's School" or the Swedish Navy.

The period of time that engineers are now permitted to be in a shipyard when assigned to a new automated ship under construction has been drastically reduced from the original periods of 6 or 7 months to 2 or 3 months during recent ship deliveries. This reduction is due both to the shipping companies desire to reduce this training period and also to the fact that the ship construction periods at Kockum's Shipyard has been markedly shortened.

The Chief Engineer's first automated Ship Assignment was SEA SPRAY where he spent 6-7 months at Kockum's during construction and 8 months at sea on the ship. He was then assigned to SEVEN SEAS with a 4-5 month construction period of training and 3 years at sea. Next he was assigned to SEA SERPENT where he spent only 3 months at Kockum's during construction and was, at the time we were on board completing his third tour at sea on the ship (tour being 3 or 4 months).

The 1st Engineer had acquired long experience as an engineer on nonautomated ships with the German Merchant Marine Service (at sea experience commenced in 1955). Following 3 years at the Swedish Sea Officer's School, which included a 2 month summer tour on the automated ship SEA SPIRIT, he was assigned to SEA SERPENT shortly after the ship was delivered.

The 2nd Engineer had 7 months experience in automated machinery controls while assigned to SEVEN SEAS as an Engineer-in-Training. He spent 5 months on SEA SWAN as the 3rd Engineer and had just came aboard SEA SERPENT in Trinidad, as the 2nd Engineer, when the authors came aboard.

The 3rd Engineer had a 5-month tour at sea on SEA SWAN as a greaser which qualified him, based on his previous Navy service and training, for assignment to SEA SPIRIT as a 3rd Engineer. Following a 5-months at-sea tour on SEA SPIRIT he had been assigned to SEA SERPENT as 3rd Engineer and was now completing his 4th month at sea on that ship.

It must be said that the on-board, on-the-job training of the Company's operating engineers, although not a formal documented program, was undertaken by the ship's engineering officers as a serious and very important effort. Close observation of the process clearly showed that each officer felt a real responsibility to train the man next junior to him, and each man willingly and eagerly accepted the training being offered him as he went about his day-to-day duties.

Computer Maintenance

The Computer system in the T/T SEA SERPENT had three failures during its first five months of operation. Two were programming errors which were corrected by Kockums' personnel. The third was a crack in a printed circuit card. There have been no further failures during the year that has passed since that time. The computer was given a thorough check in October 1972 by Kockums' personnel while the shop was in dry dock. No problems were found.

Should a problem arise, the ship carries tapes of several diagnostic programs. These are run by the Electrical Technician. The results are sent to Kockums in Malmo, Sweden. Should the problem be in the input-output equipment, they then wire back suggested card changes, etc., to try for repair. Should these be unsuccessful, the system is shut down, and Kockums' personnel meet the ship at its next port to effect repairs. No spare cards or other parts are carried for the computer itself. Should it fail, the system must be shut down until it can be repaired by Kockums. So far this has not occurred.

Maintenance manuals and wiring lists for all peripheral units and for all computer related inputs, outputs, etc., were available for the use of the Electrical Technician.

Kockums personnel told us later that the four existing systems of the T/T SEA SERPENT type have now run 46,000 hours with only 100 hours out of service for repairs. This is an availability of 99.76%, remarkable considering the fact that repairs are effected at the next port of call.

Crew Reaction to the Computer

All Watch Officers were very happy with the operation of the computer system. They very much appreciated the relief from the drudgery of navigation and steering. They looked forward eagerly to further computer functions such as anti collision systems, automatic cargo handling, and eventual unmanned bridges. All expected the latter to come eventually. They envied the free evenings, weekends and holidays of their engine room compatriots and longed for the same privileges. The problem is adequate sensors and permissable rules, not computer system capabilities, in their unanimous opinions.

The Officers felt that they should be provided more of the details of the program content and of the many program changes carried out by Kockums' personnel. They were concerned with their helplessness in the face of any problems or errors which might occur in the system in the future. This latter did not diminish their use and faith in the computer itself or its functions.

CHAPTER 6

ENGINE ROOM MAINTENANCE

AUTOMATIC CONTROL SYSTEMS - TESTS AND CHECKS

The high degree of reliability enjoyed by the SEA SERPENT's automated engineering plant, and level of confidence that the ship's engineering officers very clearly placed in these systems is due in large measure to the very thorough and extensive tests and checks that were carried out to insure the operability of the safety alarm and test circuits.

A "Routine Book" was maintained in the Engineering Control Center that specifically listed all safety and alarm circuit tests and checks to be carried out, the scheduled interval for these tests and the records to be maintained to certify their proper accomplishment. It was the duty of the 2nd Engineer to insure the proper completion of such tests and to maintain the administrative record required.

Three categories of safety and alarm system checks or tests were required, the categories are:

1. Check of alarm circuit using test simulators or special equipment to avoid disruption of plant operation.

2. Test of automatic functions and their safety circuits (i.e. check operability turbine throttle valve control to insure valve motion and shutdown given a simulated plant casualty)

3. Test of backup safety functions (i.e., Diesel Alternator starts automatically when turbo generator shutsdown.)

For each category of test the component or system is specifically listed and the frequency of check/test is listed. Intervals vary from 14 days to 1 year. The applicable instruction for accomplishing the test or check is identified. The instructions are included as an Appendix to the "Routine Book". The instructions are very specific, step by step, providing valve numbers, set points, tolerances, etc.

Also included in the "Routine Book" were requirements for routine observation of operating equipment, the date to be logged when making the observation, and the frequency with which the operation was to be observed. Examples of these requirements are:

- Main engine lube oil flow and the temperature of the oil at the bearing - to check against the automatic temperature recording equipment.

- The need to change or clean a unit - such as oil burner tips will be cleaned and replaced once each week.

The "Routine Book" also lists the specific system and component checks or tests to be made under certain special circumstances, such as, prior to entering port; prior to entering drydock; prior to leaving drydock, etc.

ROUTINE MAINTENANCE AND OVERHAUL WORK

The prime aim of keeping the engine room personnel almost wholly engaged in routine maintenance, tests, and repair work was to minimize shipyard overhaul costs and the time that ship was out of operation while in the shipyard for overhaul. The Chief Engineer expressed the opinion that a significant reduction in the size of the engine room force could be made insofar as plant operation was concerned but felt that for conducting the maintenance and test work assigned to the crew and handling the unscheduled repairs, the number of personnel currently on board were needed. Assuming the crew handled the engineering plant maintenance and test work, and took care of the stitch-in-time repairs and painting, then it was intended that the ship enter the shipyard for a one-week period once a year, the prime purpose of this week being to accomplish underwater hull painting and repairs and complete inspections that can only be done while in dry dock. In view of the cost of shipyard work, the lost revenue and fixed costs while a ship of this size is kept off the line, it appears that the approach that the company has taken (i.e. engine room crew size) regarding maintenance requirements, and shipyard overhaul time appears reasonable. Obviously, whether the proper balance of these factors, together with the other ancillary inputs which can impact the results, has been reached requires an indepth economic tradeoff study which was beyond the scope of our investigation.

Routine maintenance and overhaul work undertaken by the engine room force is controlled by the Chief Engineer utilizing a "Routine Maintenance System" that was developed by a private consulting firm for Salen Shipping Co. The requirements are specifically tailored to SEA SERPENT's components and systems.

The Chief Engineer retains in his office a series of "Routine Maintenance Books" which contain a series of loose leaf indexed cards showing each item to be routinely maintained and the time interval for work on the item. The card also indicates the applicable instruction to be used in carrying out the routine. Cards are indexed with tabs such that it is relatively easy to determine the items of work which are scheduled to be undertaken each month. A copy of the cards that are used is shown in Figure 33. The back of the card is lined with a date column and is used to record any special comments or findings relative to the item.

When an item is due for routine maintenance, the Chief Engineer prepares a work order using a standard form that is a part of the routine maintenance system. This work order is delivered to the 1st Engineer who then obtains a lamenated plastic maintenance instruction sheet that lists in detail the work to be accomplished. The 1st Engineer then makes a work assignment to one of the engineering officers, providing the work order and instruction sheet for the man's guidance. When the work is completed the man accomplishing the work signs the work order, making any

	Jan.	Febr.	Mars	April	Maj	Juni	Juli	Aug.	Sept.	Okt.	Nov.	Dec.
19......												
Utfört den												
19......												
Utfört den												
19......												
Utfört den												
19......												
Utfört den												
19......												
Utfört den												
19......												
Utfört den												

MARK IN THESE SPACES TEST OR INSTRUCTION NUMBER THAT WAS USED IN ACCOMPLISHING WORK

DATE THAT WORK IS COMPLETED IS MARKED IN THESE SPACES

Arbetsinstruktion nr: spec. instr. — REFERENCE MAINTENANCE INSTRUCTION LISTED HERE

Underhållsintervaller: — THIS SPACE USED TO INDICATE DUE DATE FOR WORK ON ITEM

	Jan.	Febr.	Mars	April	Maj	Juni	Juli	Aug.	Sept.	Okt.	Nov.	Dec.
Djupgåendemätare (ITEM OR COMPONENT NAME LISTED HERE)												

11 E-14

IKO-408 71941

ROUTINE MAINTENANCE CARD

FIGURE 33

needed special comments, and the card is then returned to the Chief Engineer via the 1st Engineer. The Chief Engineer logs the necessary data regarding completion of the work in the "Routine Maintenance Book" and marks the next due date for work on the item. A copy of the "work order" card is shown in Figure 34.

ARBETSORDER (WORK ORDER)	Instruktion nr: (LIST NO. OF MAINTENANCE INSTRUCTION TO BE USED IN OVERHAUL OF ITEM.)	Uppslag: (APPLICABLE PAGE IN MAINTENANCE MANUAL)	
Utföres vid/i (WHERE WORK IS TO BE DONE)	Arbetsställe: (DESCRIPTION OF WORK)		Mån./vecka (MON/WK)
Hamn (IN PORT)			Ansl. tid (ESTIMATE REQD)
Sjön (AT SEA)			Bemanning (WHO DID WORK)
Verkstad (IN YARD)			Utf. datum (DATE)
Stopp (STOPPED AT SEA)			Använd tid (TIME USED ON WORK)
Gångtid: (RUNNING HRS)			Signatur
Använda reservdelar (SPARE PARTS USED)			Infört (CHECK WHEN LOGGED)
Typ/Nr: (TYPE & NO. OF PART)			

SANDSTRÖMS, TUMBA 711825

ROUTINE MAINTENANCE WORK ORDER

FIGURE 34

DISCUSSION OF CASUALTIES AND ALARMS

A review of available records of casualties and alarms that had occurred in connection with the operation of SEA SERPENT's automated engineering plant indicated that the plant had enjoyed an outstanding performance record during the 1-1/2 years of operation subsequent to delivery by the shipbuilder.

The ship is required to record, as part of a permanent log, only alarms or casualties that are significant. A report of these must be made to the company once each month. Review of the reports submitted are summarized below:

Period	Approximate Number of Alarms or Casualties Reported per Month
Nov. '71 to Apr. '72	25 Minimum to 45 Maximum
May '72 to Oct. '72	15 Minimum to 25 Maximum
Nov. '72 to Apr. '73	10 Minimum to 15 Maximum

A review of the specific alarms reported showed that in many instances they initially were minor rather than significant, or they were repetitive in nature, i.e. salinity alarms due to hydrozene injections to boiler feed systems, bilge alarms requiring pumping of bilges. It was apparent also that there was a tendency to record only those alarms that occurred during off-work hours unless the item was significant. As time progressed the recording of repetitive and minor alarms was eliminated and more attention was given to matters having significance.

The Chief Engineer felt strongly that the steady reduction in the incidence of alarms/casualties recorded over the 18 months the ship has operated was also due to improved performance of the plant since many bad actors, such as defective micro switches had been weeded out. He also pointed out in the record where the incidence of alarms had increased sharply following the overhaul period but had decreased to a normal incidence rate once the systems were properly groomed and shaken down at sea.

CHAPTER 7

SOME COMMENTS CONCERNING THE COMPUTERIZED BRIDGE CONTROL AND NAVIGATION SYSTEM ON BOARD THE T/T SEA SERPENT

COMPUTER CENTER OPERATION

Table XI presents several points noted by the present authors concerning the use and operation of the present Kockums Bridge Control and Navigation Computer System. These can be considered criticisms of the present system and recommendations for changes which would enhance its value to the crew. Acceptance is already complete, so this factor is not presently at stake.

TABLE XI

SOME NOTES CONCERNING COMPUTER CENTER OPERATION

1. An operator's error made in changing memory locations cannot be recovered. The memory tape must be reloaded.

2. A memory map has not been supplied with the system. An erroneous memory value can only be corrected with a memory reload.

3. It is not possible to carry out simulated navigation or operational problems on the computer system since speed values cannot by entered at the TTY.

4. The dead reckoning position determination has priority in establishing the vessel's actual position. Dead reckoning positions determined at the time of the satellite fixes are corrected toward the satellite determined value according to a formula which develops a correction whose size is in inverse proportion to the error between the two determinations. Thus, a large error is uncorrected.

5. It is not possible to enter data applicable to time periods earlier than the present moment, i.e., past speed errors cannot be corrected. Also, actual position fixes from celestial sightings or pilotage must be run ahead to present time before entering.

TABLE XI (Cont.)

6. It would be quite helpful if the high speed paper tape reader, operators panel and teletype were in the same location on the ship. At present the teletype is on the bridge and the tape reader and operators panel in the electrical apparatus room on E deck. A second teletype in the computer room could also serve as a spare.

7. Paper tapes for memory read-in are punched on paper rather than Mylar. A torn tape would make the system inoperative. Several other tapes are available but are older versions of the program. Corrections would thus have to be made in several memory locations.

8. Because of the lack of a memory list, it is not possible for operators to determine presently listed settings of any of the system parameters which are set through the teletype.

9. Only one system variable can be logged at any one time. It is not possible to make variable comparison logs.

10. When the computer corrects the DR position to conform to a satellite position, the amount of correction is not included in the logged distance travelled for the

TABLE XI (Cont.)

watch report. The same is true of new positions inserted as star fixes, pilotage, etc.

11. The computer prints a midnight distance travelled, etc., report. The Navigation Officer requires corresponding information concerning the noon position. This is not available to him from the computer.

12. It should be quite easy to use the error between the DR and satellite fix to determine a correction for set, drift and log calibration error to give a more accurate DR position later on. This is only partially done by the present Course Correction parameter.

13. The crew should have a set of the equations used by the computer so that they can rationalize any apparent anomalies in the computer presentation of data to them versus what they get from other sources.

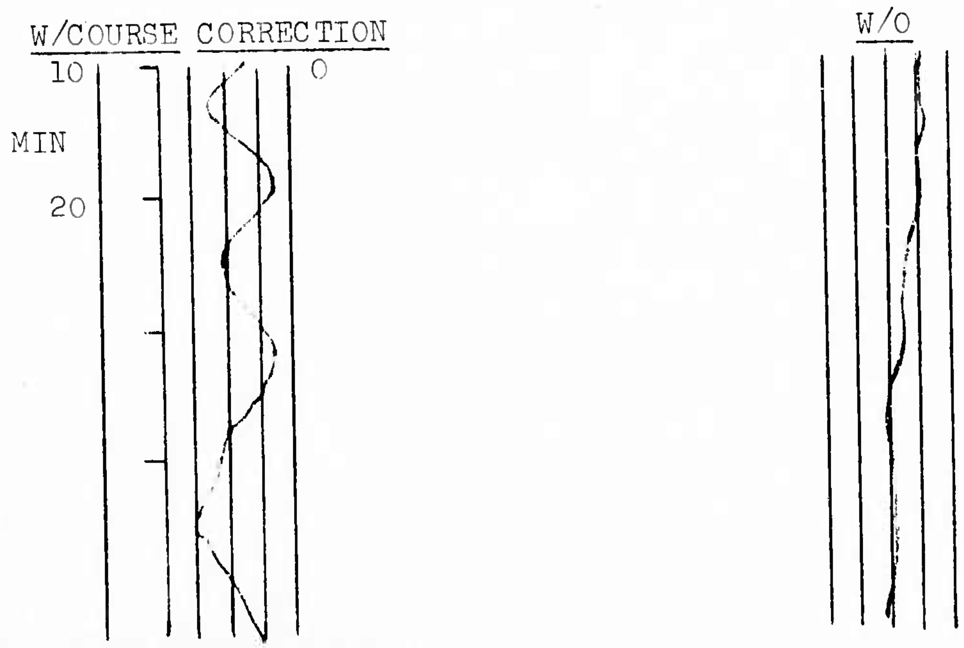
14. The Kockums Position Indicator should present true course, speed, distance during the last watch, and time as well as present position. This would be extremely convenient for the navigator.

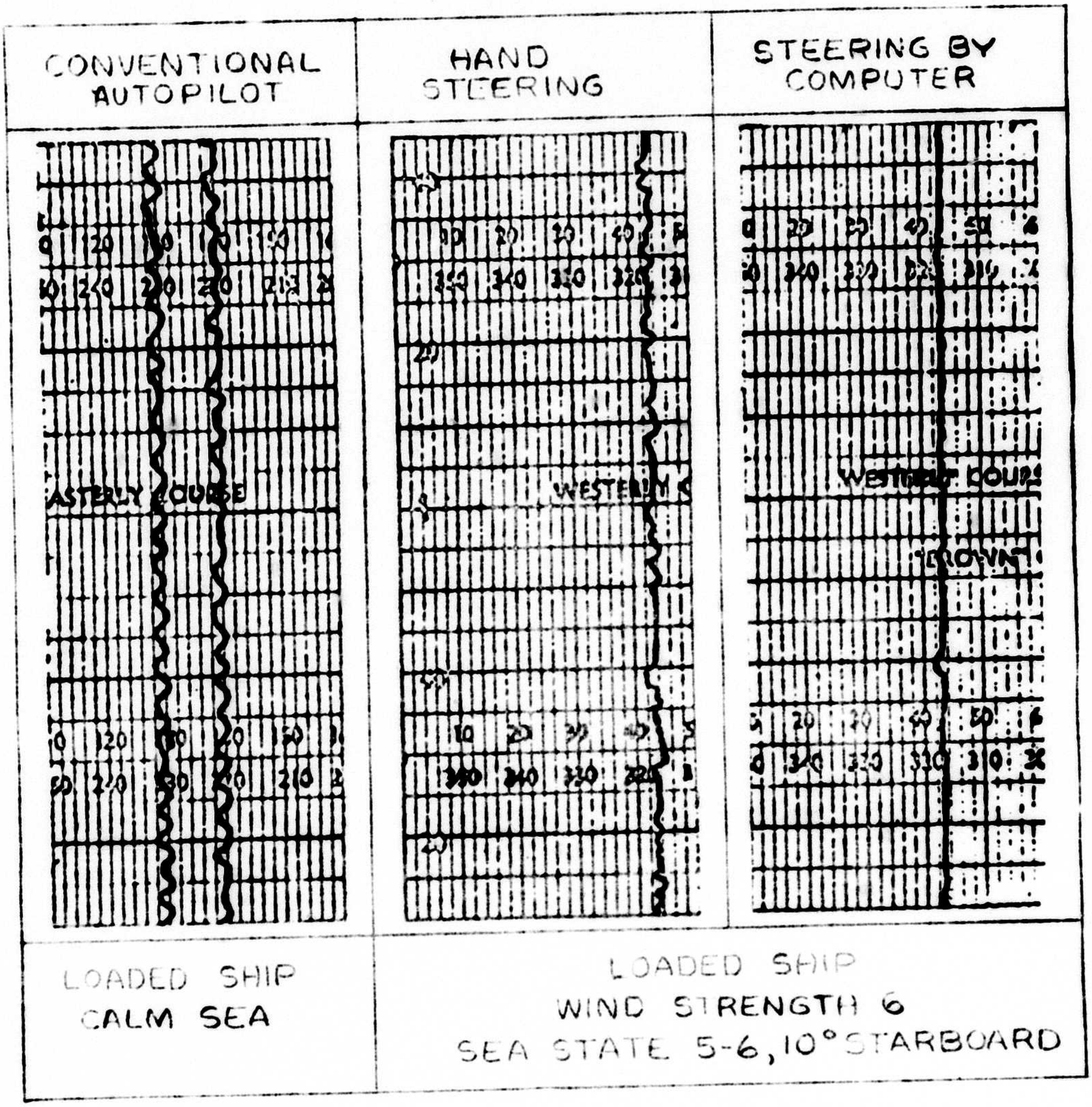
AUTOMATED STEERING

Figure 35 presents a diagram prepared by Kockums as a result of tests carried out on the SEA SOVEREIGN purporting to show the effect of computerized steering on all of the Kockums systems.

The crew maintains that this diagram is not correct for the SEA SERPENT. The new Sperry Autopilot is much better than the one for the SEA SOVEREIGN which was the basis of the chart presented. Thus on the SEA SERPENT the autopilot would be much better than the computer-based gyro rate correction steering.

There is a correction to the autopilot called "weather adjust" which puts a dead band in the rate correction. When the COURSE CORRECTION is on, this dead band is cancelled. This is a very questionable practice. In addition the course correction system is apparently adjusted to match SAL Log variation. This latter correction is apparently causing an over-correction of the system. The sketches record the response of the present system.





EFFECT OF COMPUTERIZED STEERING

FIGURE 35

CALIBRATION OF BRIDGE CONTROL SYSTEM

When bridge control is used without propeller speed control being exercised, the telegraph lever is normally pushed full forward, Point 4 logs this position at 95.5 RPM. Normal maximum engine speed is 84 RPM, but can be lowered at will by the engine room crew without an alarm sounding from this cause. The bridge crew must check log speed or the RPM indicator rather than by the telegraph or its calibration.

The SAL Log indicator presents a value which is about 0.25 knots slower than that recorded by the computer. This latter appears to be approximately 0.5 knots slower than actual speed made good through the water by the ship. Lack of a Doppler Sonar made an accurate check of the above impossible since currents were not known to any accuracy.

The admiralty constant gave a value consistently low by about 1.5 knots from speed actually made good by the ship. The parameters of the equation for this function need review.

BRIDGE CONTROL SYSTEM

EQUIPMENT PERFORMANCE

The Doppler Log was inoperative on the SEA SERPENT throughout the time we were on board. It has given a very poor operational history in the past. The Second Officer stated that the same was true for the SEA SOLDIER while he was on board that vessel.

The 10 cm radar transmitter was inoperative for unknown reasons during the voyage. The 3 cm radar was used only sparingly to conserve it for emergencies. The crew stated that the life of the Selenia radars was much poorer than the corresponding Raytheon systems made in America. The average time between repairs is only two or three months. The crew was quite critical of the design of the two radar scopes installed on the bridge. Although made by the same company and interchangeable in use, they have entirely different control consoles without clear distinction of knob function by shape or size. They can easily be incorrectly operated in the dark or at times of emergency when control knob positions are confused between the two sets.

CHAPTER 8

FUTURE PLANS FOR AUTOMATED SYSTEMS

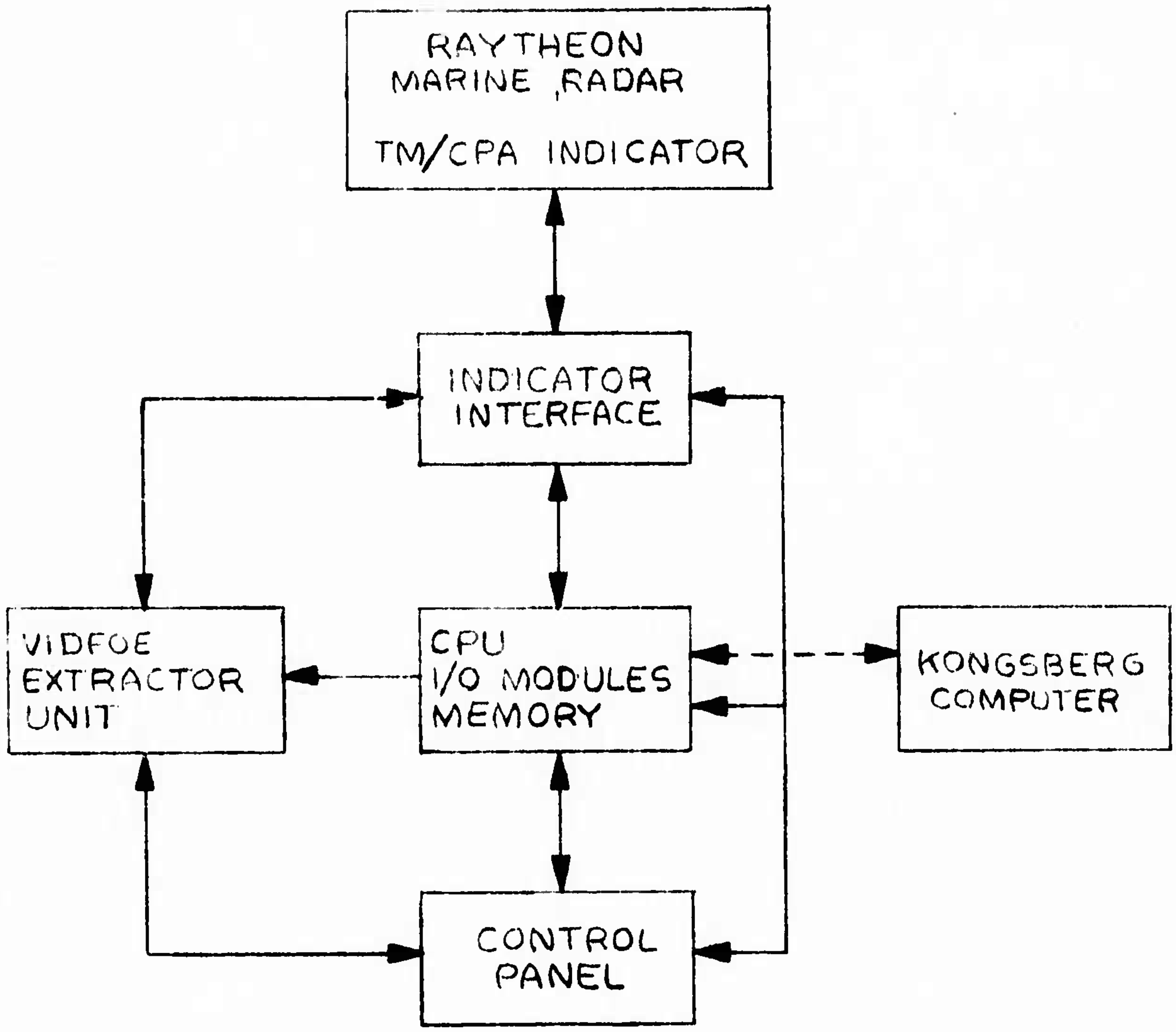
RADAR, ANTICOLLISION SYSTEM

The T/T SEA SOLDIER, a sister ship to the T/T SEA SERPENT, is equipped with an anticollision radar system. The SEA SERPENT is scheduled to receive such a system also, probably during the dry docking period this coming fall. The system selected is built by Raytheon through their Italian Division, Selenia, s.p.A., in Rome, which produced the present radars on the ship.

Figure 36 presents a block diagram of the proposed radar-based, anticollision system. Please note that it contains its own built-in computer system which has an interface to the Kongsberg computer of the main ship system. The computer, NDC16, is an 8K, 16 bit machine, especially built by Selenia for this task. It has interfaces only to the radar, the PPI indicator, the Kongsberg computer, and a paper tape reader.

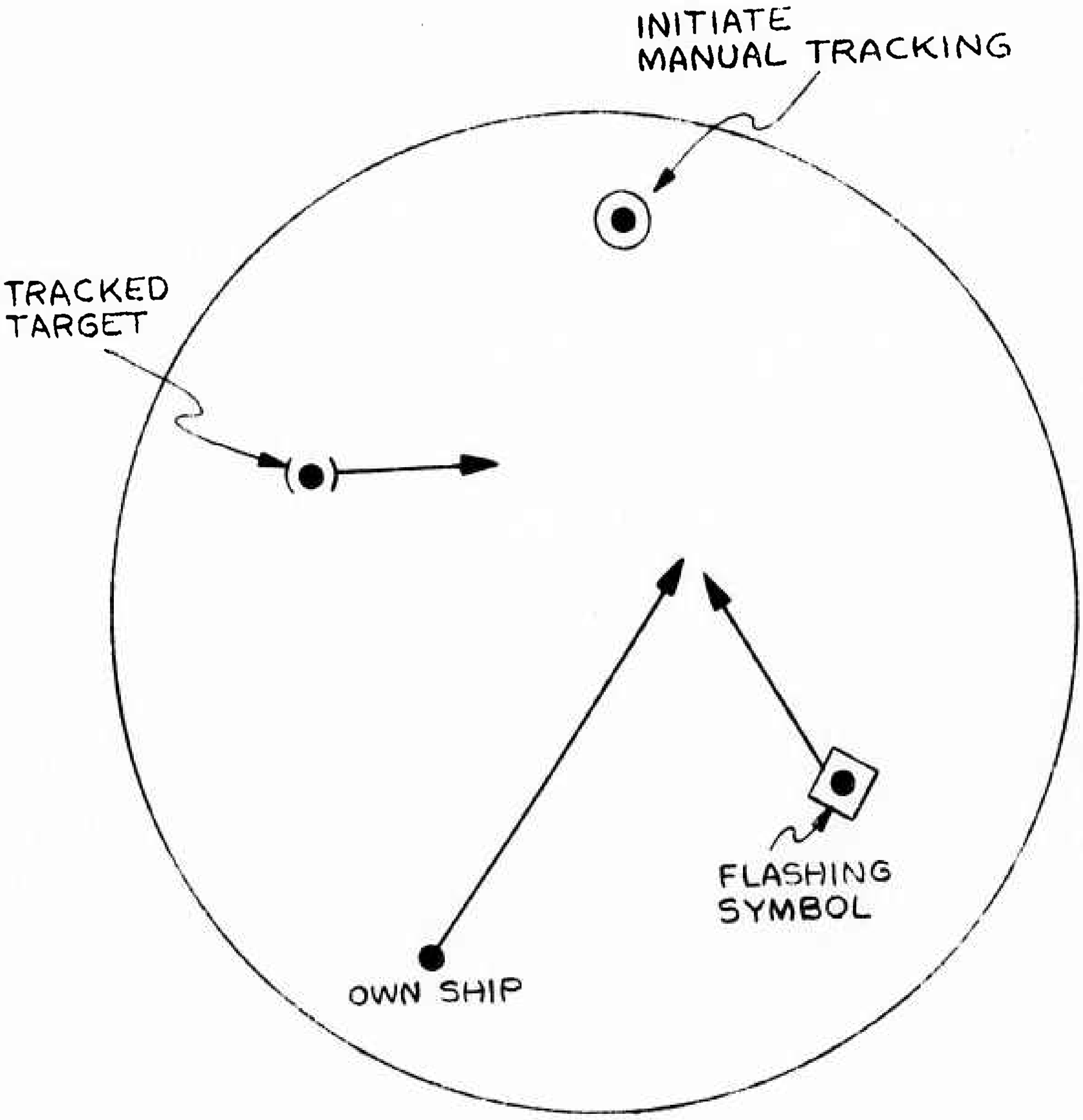
This system performs the functions listed in Table XII. An example of the scope presentation is shown in Figure 37.

Figure 38 presents a view of the control panel designed by Kockums for this system which is different from that normally marketed by Selenia. Figure 39 presents a sketch



RADAR ANTICOLLISION
SYSTEM COMPOSITION

FIGURE 36



PPI PRESENTATION: TRUE MOTION
VECTOR PRESENTATION: TRUE MOTION

RADAR ANTI
COLLISION SYSTEM
SCOPE PRESENTATIONS
FIGURE 37

TABLE XII

LIST OF FUNCTIONS OF THE RAYTHEON-SELENIA ANTICOLLISION RADAR SYSTEM

1. Auto-tracking of up to 40 targets after manually acquired for the computer system.

2. Display of heading vectors of targets being tracked showing true or relative course and speed. Presentation on radar scope.

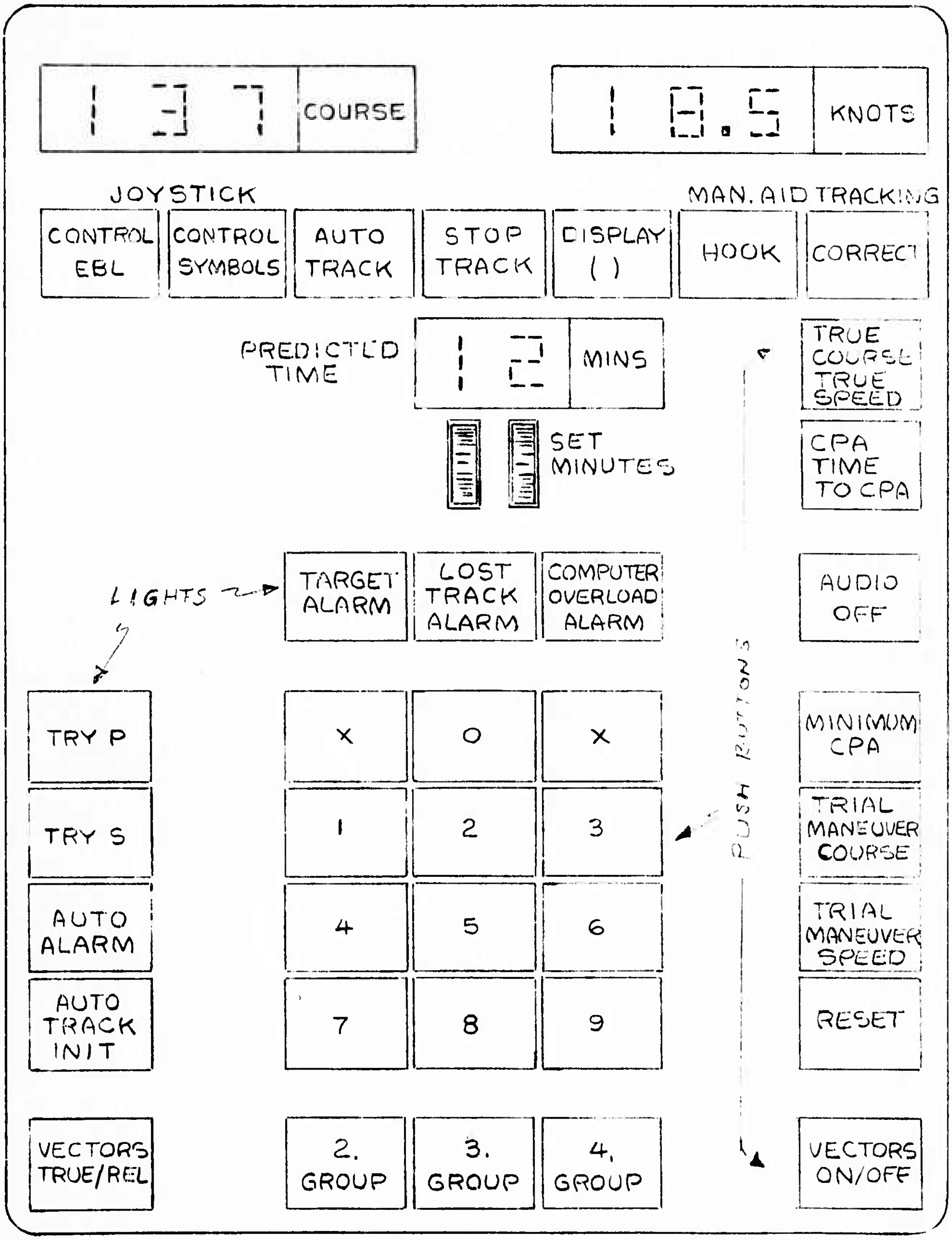
3. Calculation and readout of closest point of approach, CPA, and time to closest approach, TCA, for all targets being tracked. If target is within minimum CPA (selected by operator) an alarm sounds.

4. After operator selects direction of change of course, system calculates recommended safe course and speed to avoid penetration of selected CPA by target in question.

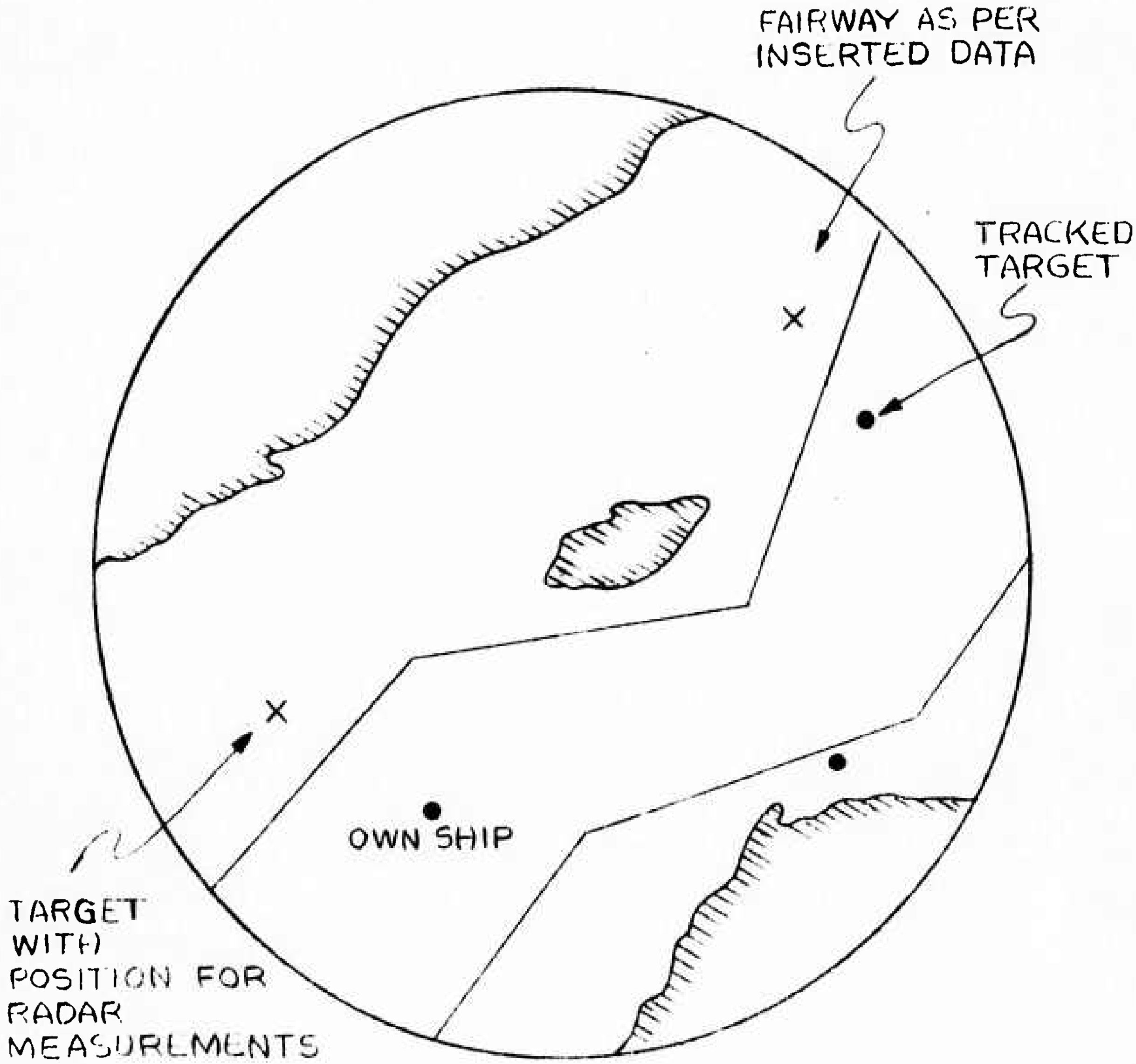
5. Calculation and readout of selected target course/speed and bearing/range.

6. Automatic alarm in case of loss of tracking of any acquired target.

7. Automatic acquisition of close-in targets as an alternate to Item 1 above.



CONTROL PANEL
RAYTHEON ANTI-COLLISION SYSTEM
FIGURE 38



RADAR FAIRWAY NAVIGATION (PROPOSED)

FIGURE 39

of the scope presentation possible if a future proposal, Fairway Navigation, is incorporated by Kockums in the anti-collision system. In this case coordinates of safe channels through various harbors would be stored in the computer and projected on the anticollision radar screen to keep the ship within safe operating distances from obstructions and low water.

The crew is anxious to have the Anticollision Radar System installed. However, they are somewhat concerned about its probable reliability in view of the operational history of their present radars.

CARGO HANDLING SYSTEM

Appendix V presents a short description by L. Sten of Kockums of the Cargo Handling System now being developed on the T/T SEA SOVERIGN for possible use on the next series of Kockums ships (350,000 TDW). There are no present plans for retrofitting such a system to the SEA SERPENT class of ships.

The crew of the SEA SERPENT would like very much to see such systems developed, particularly one which could handle several different products simultaneously. It should also be able to print out cargo manifests and all other types of reports required of the ship which at present are quite extensive.

There is also a very great need on tankers for a reliable, long-life, level measurement system in place of the present float and chain system which is inaccurate and subject to breakage in heavy seas. Even more important is the need for a reliable, permanently installed, combustible gas analyzer, for use in empty tank monitoring and in tank cleaning operations. Both of these latter items should be incorporated into the cargo handling computer system.

ENGINE ROOM COMPUTER SYSTEM

Despite the fact that the T/T SEA SOVEREIGN experiment was primarily an engine room computer system, there are no plans for changing the present analog-based unmanned engine room system for a digital computer-based one. Likewise, the same engine room system as on the SEA SERPENT will probably be used for the next series of ships. A final decision has not yet been made on this point, however.

APPENDIX I-1

KOCKUMS COMBUSTION CONTROL MK3

Kockums Combustion Control MK3

1. GENERAL

KOCKUMS COMBUSTION CONTROL MK 3 is a modern, Swedish-built solid-state control system, specially designed to meet the demands imposed by modern steam plants. Kockums' extensive experience in turbine ships has successfully been combined with modern process control engineering to produce a sensitive, reliable control which has been simplified to permit operation and maintenance by relatively unskilled personnel. While accessory equipment is readily obtainable in most countries, only the KOCKUMS MK 3 offers a truly compact, simple, easy-to-maintain solid state combustion controller which can be operated by plant personnel where extensive instrument and electrical training is not feasible.

Principle of Operation

The purpose of the controller is to govern the supply of air and of fuel to the boiler furnace in the proper ratio and in close accordance with steam demand, to facilitate fast and efficient firing changes to follow plant loads. The control characteristics is proportional and integrating, so that the steam pressure is maintained at a set value independent of the plant load. The control accuracy is high to hold the steam pressure within close limits.

Arrangement

The controller usually contains all the electronic control circuitry required for two identical boilers. However, single boiler arrangements are available, as well as two dissimilar boilers, such as main and auxiliary. Special firing arrangements, such as simultaneous firing of oil and gas, are also available.

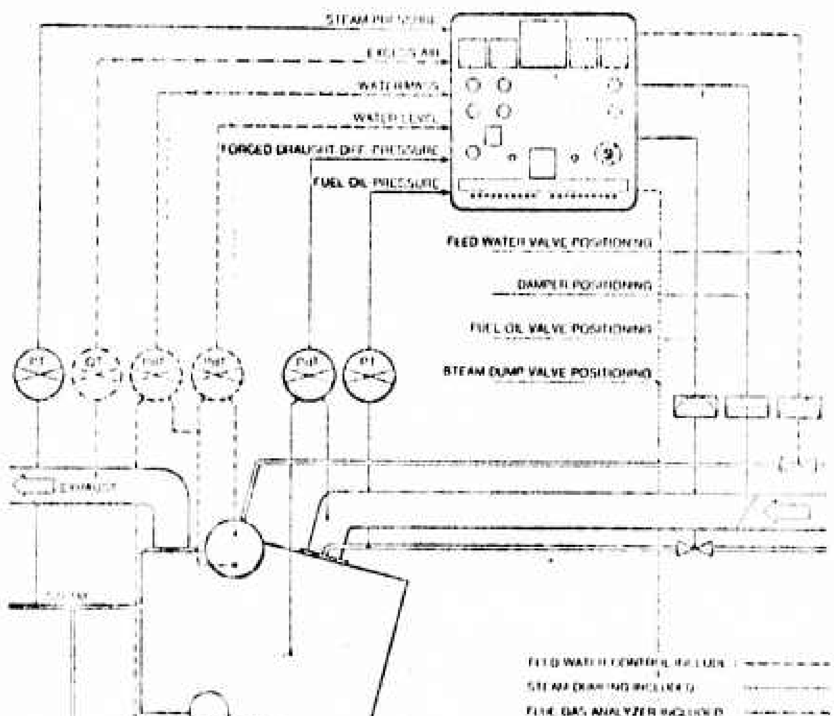


Fig. 1

Construction

All main parts and electronic circuitry are factory assembled into a small cabinet whose swing-front is intended for flush-mounting in a central boiler control panel. Integrated circuits are used throughout for maximum accuracy and reliability. Components are all high quality rated for long life and accuracy. The cabinet door, switches, etc. are gasketed so that the controller can be used in normal fireroom environments without further protection or cooling. Normal vibration found in fireroom equipment either afloat or ashore will not harm the components or the operation. Circuit boards are easy to remove and replace. Indicating instruments and control switches are easy to read and operate, mounted on the controller door.

Testing and Automatic Supervision

Built-in electronic supervision is provided which performs a continuous checking of all transducers and positioners and provides immediate alarm, should any of these fail. Automatic turndown to low fire can be incorporated. The unit also contains a process simulator by means of which the electronic circuitry can be tested by simulating a change in steam load and observing the indicating instruments. If internal or external failures are suspected, a built-in sensitive instrument can be connected to a number of test points in accordance with a simple trouble-shooting table in order to locate the faulty component.

Computer Program Design

Kockums has developed a computer program for designing every controller to optimal efficiency. The electronic component values are calculated for every new application. This decreases the need for initial adjustments, increases reliability and simplifies operation.

Safety and Reliability

To obtain high reliability, components of proven quality and methods of modern engineering technique have been used throughout. The equipment has been temperature and vibration tested and meets the requirements of Lloyd's Register and Det Norske Veritas. Operation should, therefore, be highly reliable, without nuisance shutdowns.

2. SYSTEM ARRANGEMENT

The accessory equipment to be used in a Kockums Combustion Control System can be of any well-known make. As Kockums assume responsibility of the complete system, this can be purchased in two ways: —

1 By the ship-yard direct from manufacturer but in accordance with a specification agreed on by Kockums.
2 By Kockums, and re-sold to the ship-yard as a part of the total delivery.

The number and types of the items included in a complete system will depend upon model of electronic controller, number of controlled boilers and parameters controlled.
Generally speaking, however, the following items are needed: —

Per system: —	Kockums Electronic Controller
Per steam output to be controlled: —	One pressure transmitter
Per boiler: —	1 One pressure transmitter (including separating chamber) for fuel oil pressure 2 One differential pressure transmitter for forced draft pressure 3 One diaphragm actuated control valve with electro-pneumatic valve positioner, for controlling fuel oil 4 One pneumatic cylinder with electropneumatic positioner, for controlling air dampers or inlet vanes
Per boiler, if steam dumping included: —	One diaphragm actuated control valve with electro-pneumatic valve positioner.
Per boiler, if feed water control included: —	One differential pressure transmitter for water level measurement. *and one for water mass*

A typical system lay-out for one boiler is shown in Figure 1.

3. TECHNICAL DESCRIPTION

1. Steam pressure indicator.

2. Summing point giving the difference between required and actual steam pressures. (Set point potentiometer located inside the cabinet.)

3. Proportional and integrating regulator

4. Transforming network from main engine trip signal to provide instantaneous fast boiler turn down.

5. Summing point giving the power demand as the sum of regulator (3) output, trip turn down and ordered steam power from the bridge.

6. As two boilers are never identical, a manual adjustment of relative evaporation of steam is provided on the front panel.

7. Summing point.

8. Limiting network to ensure a low stable flame when the power demand decreases below zero.

9. Proportional regulator for the fuel oil valve to give a fuel oil pressure proportional to the power demand.

10. Proportional regulator primarily intended to govern the air dampers to maintain a constant ratio between fuel oil pressure and air pressure.

11. Derivating network to ensure air increase before fuel increase.

12. Gate which passes only positive signals in order to prevent air decrease before fuel decrease.

13. A limited gate which decreases fuel oil supply if air supply is insufficient, e.g. due to low fan r.p.m.

14. Proportional regulator to open the steam dump valve at negative power demands signals.

15. If a steam dump valve is not fitted, burner sequencing is initiated from sub-unit 15.

17. Fuel oil pressure indicator.

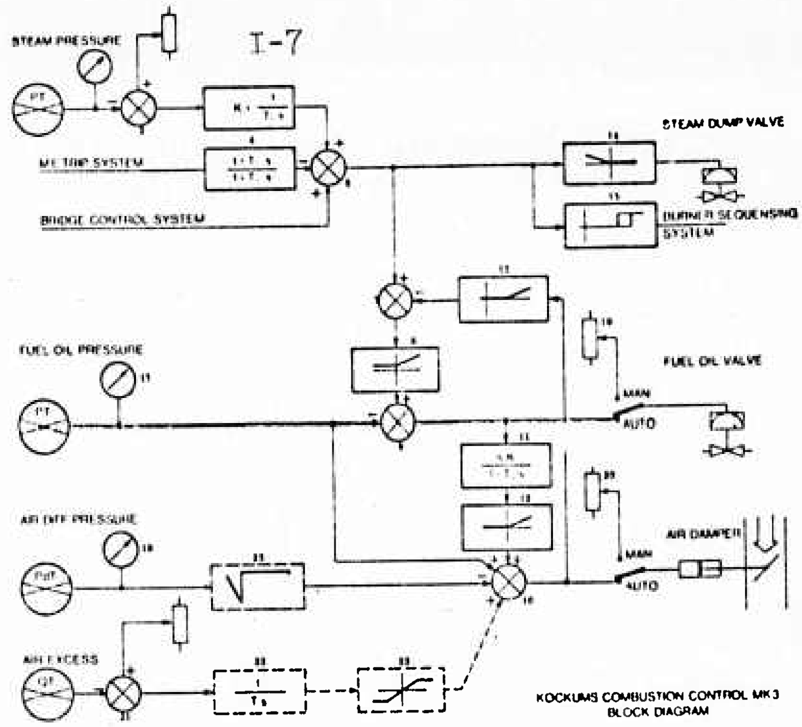
18. Forced draught indicator.

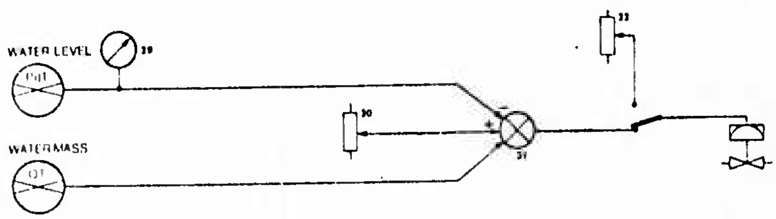
19. & 20. Manual remote controls for fuel and air.

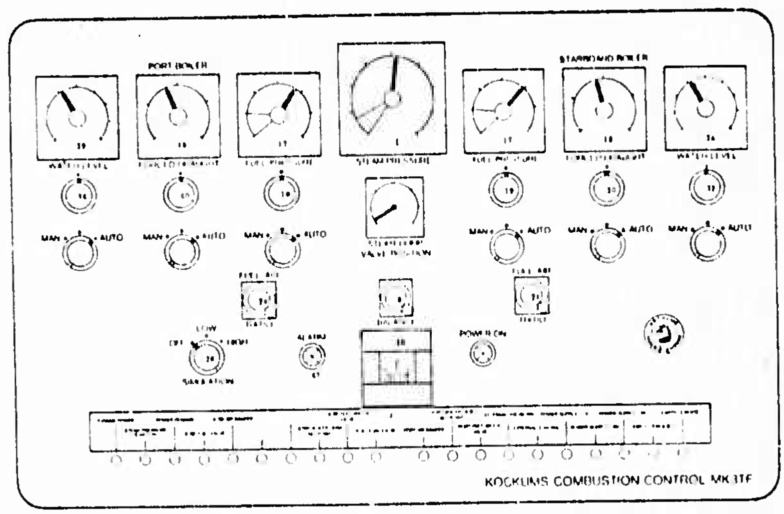
21, 22 & 23. If a reliable flue gas analyser is installed, excess air control can be provided by sub-units 21, 22 and 23. (Used for very low excess air firing system).

24. Fuel/air ratio adjustment.

25. If the burners have linear characteristics, sub-unit 25 produces the square root of the draught value.







26. Process simulator for testing of the internal electronic circuitry. It can only be used at full manual control. By turning a switch to position "High", high steam load is simulated and fuel and air indicators will show high values. By turning the switch to position "Low", low steam load is simulated and the dynamic response of the steam pressure can be observed on the indicator as well as the reduction of fuel and air pressures.

27. Alarm supervisory circuits. These will detect any short circuits or open circuits in the external connections to the transmitters and the actuators.

28. Test instrument. If information from items 26 or 27 indicates a failure, this can be analysed by connecting the test instrument to a number of test points.

29. Boiler water level indicator.

30. Boiler water level set point.

31. Proportional regulator controlling the feed water control valve position.

32. Manual remote control for feed water

4. NORMAL OPERATION

A. Automatic Operation

During normal conditions Kockums Combustion Control governs the production of steam by regulating the supplies of air and fuel to the boiler furnaces without human assistance. (In F-models even feed water is governed by the Controller.) The control is executed in such a way that the actual steam demand is effectively and economical fulfilled.

Resetting may be required if:

1 The steam pressure has changed appreciably (0.5 atmospheres or 7 p.s.i. or more) from the nominal value. The steam pressure set point is adjusted by a small potentiometer mounted on the connector base board inside the cabinet. Clockwise turning decreases the steam pressure set point.

2 The smoke from the furnaces has changed, e.g. according to changes in fuel quality, input air temperature or burner tip performance. The potentiometer marked "Fuel/Air ratio" on the front panel governs the amount of excess air to the boiler. In position 0 on the dial the air supply is low and in position 10 the air supply is maximum. The setting is a relative measure of the amount of excess air.

Action is also necessary If:

3 The "Power On" lamp is off.

4 The "Failure" lamp is on. See FAULT-FINDING.

B. Switching Auto to Manual or Manual to Auto

Smooth transfer between Auto and Manual or vice versa is carried out in the following way: —

1 Turn the actual switch to the intermediate position indicated by a blue dot. The indicating instrument is now connected as a null instrument showing the difference between actual Auto and Manual output signals.

2 Turn the manual control knob until the pointer reaches the blue dot on the dial. The output signals are now identical and the switching-over can be completed.

N.B. Switch air to auto before fuel and fuel to manual before air.

C. Manual Operation

Fuel Oil Pressure and Forced Draught are controlled by means of the knobs below respective instruments.

N.B. Never operate the system with Fuel Oil in Auto and Forced Draught in Manual. If, in that case, the power demand Increases, the fuel oil supply, but not the air, is increased.

D. Long time steady state operation

If two different 220 V supplies are connected to the controller, manual and automatic operation are completely independent. At loss of 220 V auto supply, automatic switching to manual control is obtained though the switches are still In position auto. During long time steady state operation it is therefore recommended that all manual control knobs are positioned according to the actual load.

5. ALARM SYSTEM

An alarm supervision system is included in the circultry. The most likely failures to be encountered are open circuits or short circuits in the accessories (transmitters, positioners or associated wiring) and power supply failure. At any of those occasions the supervision system deenergizes a relay and lights a red lamp on the front panel. The relay contacts are intended for connection to an engine room alarm system or can be used for automatic turn-down.

Alarm Points

1 Power Supply.
Open circuit or short circuit in ±15 V supplies or −50 V supply. The −50 V supply is used when Källo differential pressure transmitters are used.

2 Positioners.
Open circuit or short circuit in positioners.

3 Transmitters.
Too high or too small signal from the transmitters. This can be due to faults in the Controller or in the transmitter.

N.B. If the number of burners in operation is insufficient an alarm will be obtained when the output to the fuel valve gets higher than "full open".

6. TEST POINTS

By means of push-buttons a test instrument can be connected to various test points in the Controller.
The test points available on a certain Controller depends on model and are specified in App. B.
The test voltages are also available at numbered connectors inside the cabinet.

Turbine Power

The instrument measures the output voltage from one of the operational amplifiers. The signal should be linearly proportional to the turbine power, provided that the ship has a Bridge Control System for the main turbines which is connected to the Combustion Controller. Maximum reading corresponds to maximum turbine power. Five scale divisions equals one volt.

Steam Pressure Deviation

The output voltage from this test point is proportional to the deviation of the steam pressure from the set value. A deviation of 1 atmosphere changes the reading by ten divisions. Too high steam pressure gives a positive and too low a negative reading. (In some controllers one division equals one p.s.i.)

Definition: — The reading is **positive** when the dial zero is to the left of the index.

Power Demand

This signal is proportional to the demand of fuel, when positive, and to the position of the steam dump valve (if included), when negative. The steam dump valve starts to open at −10 divisions (−2 V) and is fully open at −50 divisions (−10 V).

Fuel Valve

This test point gives the output voltage to the fuel valve. The valve is closed at −10 divisions (−2 V) and fully open at −50 divisions.

Air Damper

This test point gives the output voltage to the air damper. The damper is closed at −10 divisions and fully open at −50 divisions.

O_2 Analyzer

This test point gives the output from a smoke or oxygen analyzer. The analyzer is not necessary for combustion control.

O_2 Control

If smoke or oxygen analyzer is connected to the Combustion Controller this signal provides an even more adjustment of the fuel/air ratio.

WATER MASS TRANSMISSON
NO BOILER LOAD = −10 DIV MAX BOILER LOAD = −50 TO −40 DIV

Feed Water Valve Position

The valve starts to open at − 10 divisions (−2 V) and is fully open at −50 divisions (−10 V).

Supply 1. +15 V

This test point gives the output voltage from the left-hand power supply. The instrument shall read +15 divisions (+15 V).

Supply 2. −15 V

This test point gives the output voltage from power supply No 2. Normal value −15 V corresponding to −15 divisions.

Supply 3. −15 V

This test point gives the output voltage from power supply No 3. Normal value −15 V corresponding to −15 divisions.

Supply 4. −50 V Supply 5 −42V (Honeywell transm.)

If a Källe difference pressure transmitter is used for forced draught measurement, this test point is included. The instrument shall read about −50 divisions (−50 V).

Eart Leakage+and Earth Leakage −

These test points are intended for earth leakage detection. The instrument gives the following reading for different types of earth leakage.

Earth Leakage	Positive	Negative
−15 V line	No deflexion	+ 44 divisions
+ 15 V ,,	−44 divisions	No DEFLECTION
− 50 V ,,	NO DEFLECTION	+ full scale (to be avoided)
0 V ,,	−22 ,,	+ 22 divisions

7. SIMULATOR

An electronic process simulator is included for testing the electronic circuits. The function can be seen from the simulator block diagram. The power supplied to the boiler furnace is proportional to the fuel oil flow q_F. The power removed from the boiler is proportional to the steam flow q_S. The difference is proportional to the rate of change of the stored heat content in the boiler, which can be approximated by the rate of change of boiler drum pressure (p_B). Thus: −

$$c_1 q_F - c_2 q_S = \frac{dp_B}{dt}$$

The pressure drop in the superheater is dependent on the steam flow.

$$p_B - p_S = f(q_S)$$

If p_B is eliminated the steam pressure dynamic dependence on steam and fuel flow is obtained. This can be simulated by a special circuit provided that all controls are set to "Manual". By turning a change-over-switch, high or low steam consumption is simulated. The resulting dynamic change in steam pressure, fuel oil pressure and air pressure can be observed on the instruments which are disconnected from the transmitters during the test.

As can be understood from the figure all actions of the Controller can be tried and an internal failure will show up immediately.

The simulator is used to test the working of the controller.

Turn the knob to "Low Simulation" to simulate a low steam demand. The Forced Draught and Fuel Oil Pressure readings should both change to low values and the Steam Pressure reading should slowly approach the pre-set steam pressure value.

Now turn the knob to "High Simulation" to simulate a high steam demand.

The Forced Draught and Fuel Oil Pressure readings should now both change to high values and the Steam Pressure reading should again slowly reach the pre-set steam pressure value.

The exact readings will be found in Appendix A.

in Appendix A is a diagram for the steam pressure deviation when simulated. Press the button for test point "Steam Pressure Deviation" and compare the reading with the diagram.
The actual diagram for low simulation and high simulation could now be plotted. To obtain an accurate simulation a well-defined starting value is required. This, too, can be obtained by simulation. Turn the knob to position "Low" and wait until the instruments are showing a steady reading (3—4 min). Then quickly switch to "High". This is zero time.
Plot the instrument reading every 5 second until the "steam pressure deviation" shows a steady reading near zero. We now have a well-defined starting value again and the "Low" simulation can be performed direct.
The plotted readings should not differ more than 10 % from the diagram figures in Appendix A.

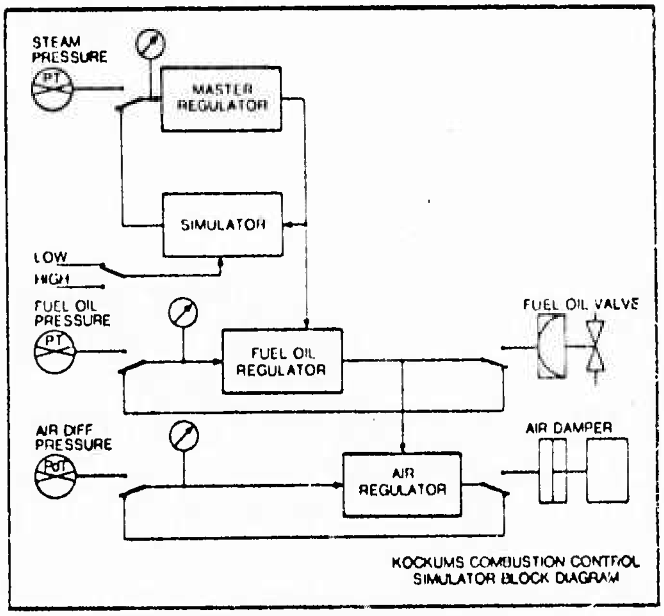


Fig. 3

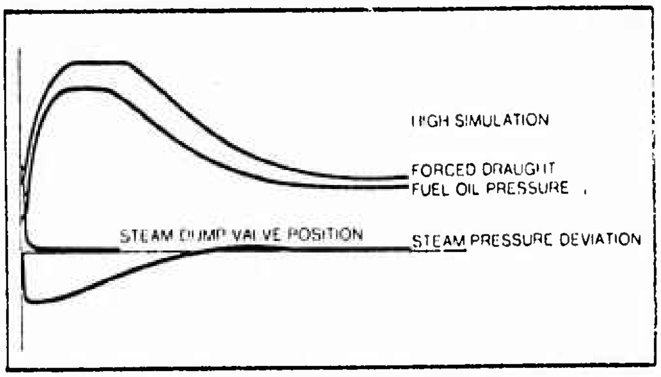


Fig. 4

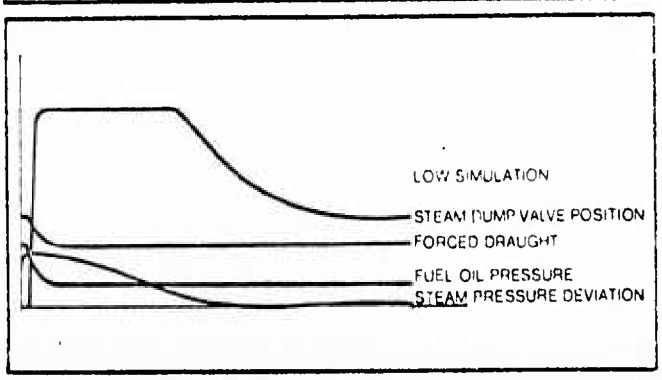


Fig. 5

8. FUNCTIONAL CHECK

Before lighting the boiler all parts of the Combustion Control System should be checked.
The transducer signals can be checked by the test instrument according to Section 6. The test instrument readings should correspond to actual pressures.
To check the working of positioners, the Controller is set to "Manual" and the knobs for Forced Draught and Oil Pressure turned. The positioners should now move in the correct manner.
Internal checking of the electronic Controller is performed by means of the Simulator. See Section 7.

9. FAULT-FINDING

Kockums Combustion Control has three different means for combating a fault. The Alarm Supervision immediately signals a fault. Then the simulator and the test instrument aids the operator in tracing it.
The first step when the Combustion Control fails is to switch over to manual operation and try to operate the Combustion System manually.
The next step is to distinguish between external and internal faults.

External faults

Upon an alarm, one or more of the faults described in Section 5 will be the cause and can be traced with the test instrument.

a Check the four supply voltages with the test instrument. If any of these test points shows to small or no voltage, the controller cannot work correctly. The power supply is built on three printed circuit boards. If any of the ±15 V supplies fails, the three printed circuit boards can be interchanged. The faulty board shall be removed and the correct boards shall be placed in Positions 1 and 3 from the left.
The toggle switch between Nos 2 and 3 shall be thrown to the left. Then the two remaining boards (Nos 1 and 3) will supply all the ± 15 V power.

b Check TURBINE POWER. An incorrect reading here probably depends on a failure in the input signals from the Bridge Control. Check these.

c Check STEAM PRESSURE DEVIATION. The reading should be near zero provided that the actual steam pressure is roughly correct.

d Check POWER DEMAND. The reading should be approximately proportional to the fuel oil pressure or the steam dump valve position.

e A fault according to b, c and d can depend on a fault in the Master Controller Card. Change to a spare one, if available.

f Check AIR DAMPER. If the instrument shows zero, there is probably a short circuit. An open circuit can also cause the "Failure" lamp to go on. Then the instrument reading is maximum.

g Check FUEL VALVE. See the preceding point.

h At Mk 3 T the SB Fuel and Air controller PC-board can be interchanged with the Port Fuel and Air controller PC-board. If, when changed, a failure moves from one boiler to the other the failure is in one of these cards. The malfunctioning card should be, replaced by a sparecard.

i At Mk 3 T the Hand/Auto Relay PC-boards can also be interchanged. THIS MUST NOT BE DONE IF BOTH BOILERS ARE NOT ON LOCAL MANUAL CONTROL OR SHUT OFF.

j If one of the output relays fails, use the spare relay in the cabinet.

Internal Faults

The simulator gives an excellent possibility to trace an internal fault. See Section 6.

N.B. Vibrations in the ship can cause screws in the terminal strips to loosen. Check them some weeks after the installation and whenever necessary. If the controller does not work properly the soldering of the internal cable connections should be checked.
Also check that the circuit boards are secure and in their correct position.
If a serious fault or malfunction is discovered in the system and the attempts to repair are unsuccessfull, a complete and detailed description of the fault should be forwarded to Kockums.

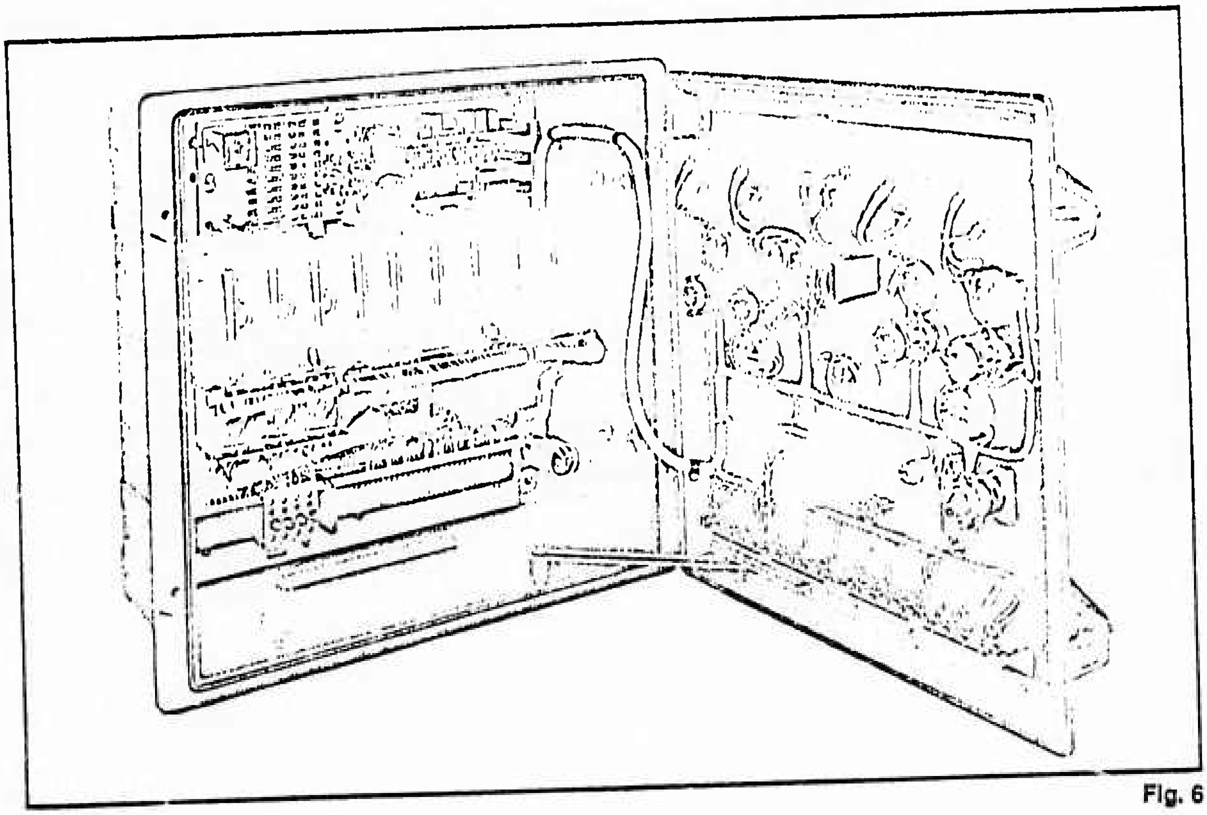


Fig. 6

KOCKUMS COMBUSTION CONTROL MK3TF

SPECIFICATION

General

KCC Mk3TF is intended for governing the supplies of fuel oil, air and feed water to two identical boilers with common steam line.

Inputs, Common

Steam pressure
Bridge control
Main engine trip
O_2-analyzer

Inputs, Port and Starboard

Fuel oil pressure
Forced draught differential pressure
Boiler level differential pressure

Output, Common

Failure alarm

Outputs, Port and Starboard

Fuel oil control valve position
Inlet vane position or air damper position
Feed pump r.p.m. control or feed water control valve position
Relay output to burner sequencing system
Steam dump valve position

Simulator

By a built-in simulator the correct working of the regulator can be checked.

Internal Test Points

The following signals will be available for connection to the test instrument:

Turbine power	
Steam pressure deviation	
Power demand	
Fuel valve position	
Vane or damper position	port and starboard
O_2-transmitter	
O_2-control	
Boiler level set point	
Feed water valve position	
Power Supplies	+15, −15 and −15 V (3 testpoints)
Earth leakage plus and minus	(2 test points)

Mains Supply

110-220-440 V/50-60 Hertz
Voltage and frequency to be specified, when ordering.

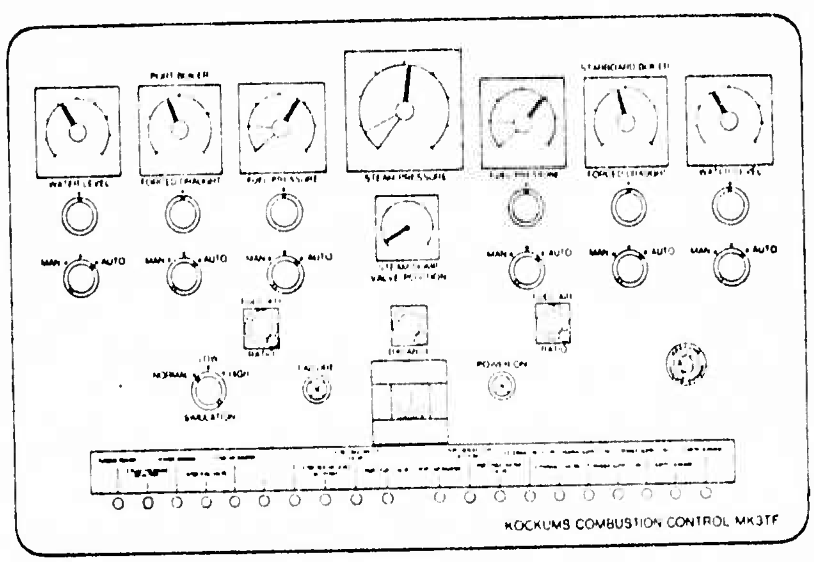
Notes

1 Burner sequencing system is not included but two relays, operating at separately set fuel oil pressures can deliver input signals to a burner sequencing system.
Some ships use steam dumping instead of burner sequencing for low power operation. An analogue signal output to a steam dump valve is available.
Depending upon low power operation mode, a steam dump valve position instrument or signal lamps for the burner sequencing relays are mounted in the front panel.

2 Fan motor speed control is not included.

3 At mains power supply loss during automatic operation, the Kockums Combustion Control System automatically switches over to manual control for which a separate mains supply shall be connected.
When switching over, the positioners move to the positions indicated by the manual control knobs.

4 The feed water control operates in the following manner: —
At constant pressure and temperature the steam flow is proportional to the power demand. The feed water flow is equal to the steam flow.
Hence, the power demand signal, originally assigned to control the fuel oil flow, also serves as a dynamic input signal to the feed water regulator.
A differential pressure transmitter on tho boiler gives a level input signal for stationary level control.
The feed water control circuitry is housed in the same cabinet as the Combustion Controller.



C SPARES

The following spares are mounted inside the cabinet and included in the normal delivery: —

1 off	Power supply
1 off	Output relay for alarm or burner sequencing
6 off	Bulbs
24 off	Fuses
4 off	Mounting frames for spare printed circuit boards

The extra power supply is connected to the manual/remote controls so that manual control is immediately available, should there be a fault in any of the two power supplies for the automatic control. When a faulty supply is removed, the remaining two can be connected to supply all the required power. The supplies are short-circuit protected.

Fuses

The Combustion Control is protected by 5 fuses placed in the cabinet. F1 and F2 protects the input to the transformer. F3 and F4 protects the output from the Källe differential pressure transmitters. F5 protects the output from the —50 V power supply.

Fuse Ratings

F1, F2: 2 × 1 A
F3, F4: 2 × 0.35 A
F5 : 1 A

Spare Fuses

12 × 1 A
12 × 0.35 A

Bulb Changing

Bulbs for Power on, Failure, Burner 2 and Burner 3 can easily be changed by unscrewing the caps on the front panel. Spare bulbs are mounted inside the electronic cabinet.
Be sure that lamps of correct voltage is used as the lamps may be different.

Values:		
	Power on	24 V, 1,2 W
	Failure	24 V, 1,2 W
	Burner 2	18 V, 0.1 A
	Burner 3	18 V, 0.1 A

N.B. In the normal delivery no spare cards are included. However, space is provided on the spare parts console.

APPENDIX I-2

KOCKUMS BURNER CONTROL

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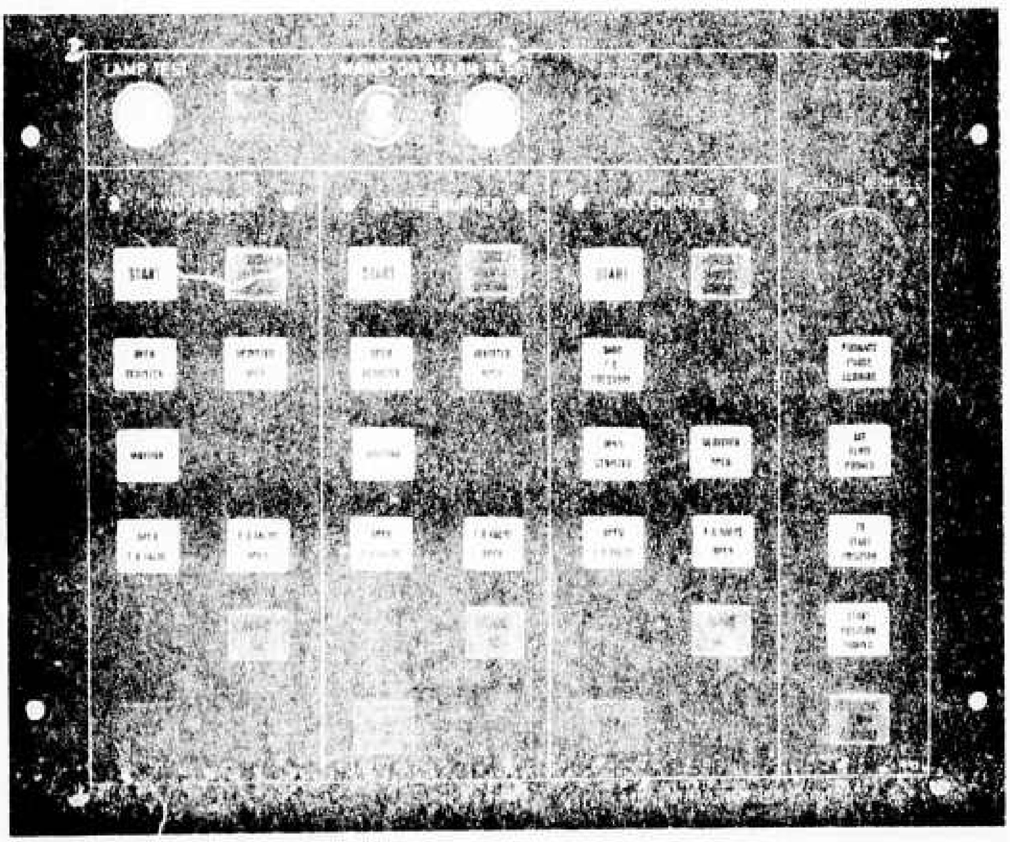
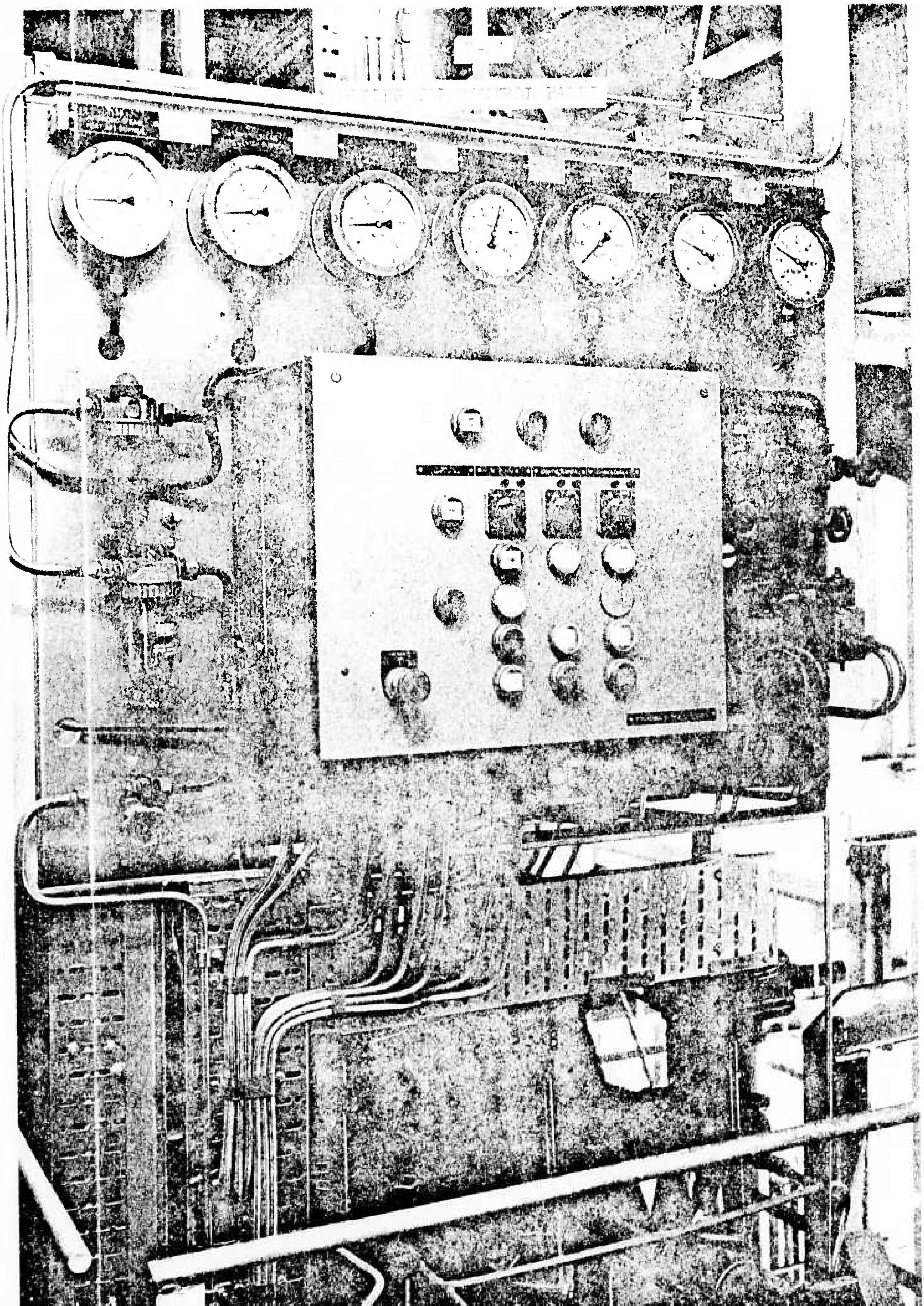
Kockums Burner Control

An automatic, all-electronic, push-button management system for safe, simple burner light up and shut down. In these sensitive phases of boiler operation, the risk of human error is eliminated by Kockums Burner Control.





Lighting up and shutting down burners in oil-fired boilers on modern ships is a sensitive task: a vast number of functions must be executed in the proper sequence. Timing and method must be faultless. As if the job weren't complicated enough, it usually has to be performed under difficult working conditions. Errors are costly: the slightest mistake can create serious problems for the man who is manoeuvring the ship. Explosions on board are all too common.

The Kockums Burner Control system eliminates the source of error: safe, sure electronic equipment executes all operations and check-outs in a programmed sequence that can be initiated at the Engine-room Control Console. The necessary precautions are built into the system, so that every step is timed exactly and carried out properly.

A variety of control layouts is available, and the functions incorporated in the system can be exactly suited to the user's specifications.

When a Kockums Burner Control System is installed on board your ship you'll have:

- ☐ An Operation Panel layout that provides easy and exact supervision of all inputs and outputs. There's one rack for each boiler; push-buttons and indicators are arranged in logical order on each rack.
- ☐ Solid-state electronics for maximum reliability.
- ☐ Input signals that are electrically isolated from each other and from the internal circuitry.
- ☐ System outputs that operate via plug-in relays for easy replacement.
- ☐ Inputs that can be blocked one by one, allowing the operator to run the system in case of failure of, for example, a micro-switch.

In the event of complete break-down of the Operation Unit or the Central Unit, the boiler can still be operated from the Boiler Top Control Panel by separate, manually operated control circuitry.

The Kockums Burner Control System (KBC) complements the Kockums Combustion Control System (KCC). KBC gets the boiler going and shuts it down again when power is no longer required. KCC keeps it going in between times.

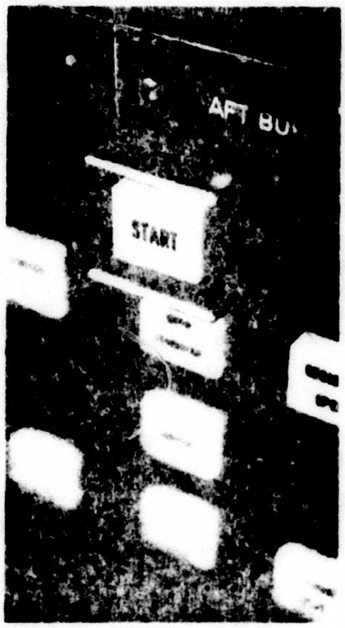
KBC System layout

The Kockums Burner Control management system includes a separate system for each boiler. Kockums delivers and installs complete systems, consisting of:
- ☐ Central Electronic Unit
- ☐ Operating Panel
- ☐ Boiler Top Control Panel
- ☐ Cables
- ☐ Circuit Diagrams and Instructions

The Central Electronic Unit is installed in the engine control-room. It's built in 19" standard and contains the electronic computing system together with blocking switches for all inputs. These are located inside the front panel. The electronic computing system is divided between two different types of PC-boards:
- ☐ the Master PC-board contains the electronic components needed to prepare the boiler for lighting of the first burner.
- ☐ the Burner PC-board — one for each burner — includes the electronic components needed for one burner.

The PC-boards and the relays in the electronic unit are of the plug-in type. Replacement is swift and easy.
An outstanding feature of the KBC system is that the Operating Panel can be mounted either as an integrated part of the Central Electronic Unit, or installed separately and connected to the Central Electronic Unit by two multiwire cables.

The panel contains signal lamps indicating all inputs and outputs, buttons for Start, Stop, Lamp Test and Alarm Reset, and a switch for blocking the atomizing steam requirement when starting up a cold boiler with diesel oil.



The Boiler Top Control Panel is installed at the boiler. This panel contains push-buttons for Start, Stop and Lamp Test, indicating lamps for flame scanners, boiler trip and atomizing pressure, and control mode switches. The panel also contains two push buttons and a lamp that may be employed for the boiler safety system.

Data

Input:
Contact closures operate on internal low voltage DC.
Microswitches for position indications. Pressure switches for sensing FO and air-pressure.

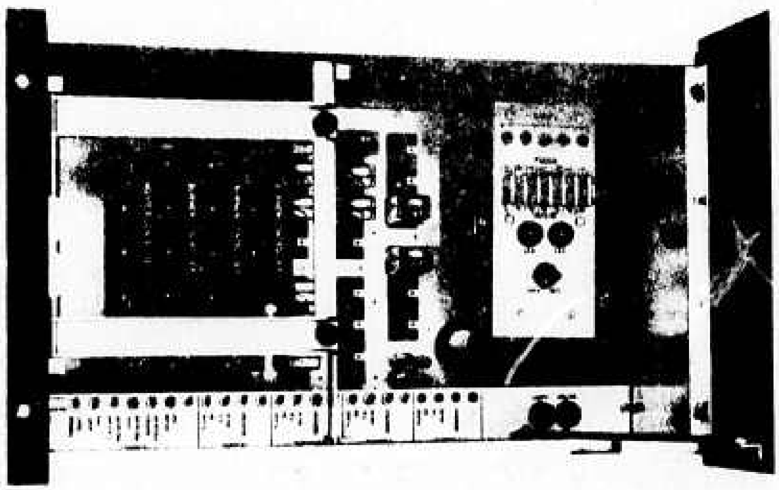
Output:
Contact closures or voltages equal to supply voltage. These signals normally control solenoid valves that operate pneumatic actuators.

Power Supply:
110/220 V AC 24 V AC 45-65 Hz
Cabling: no shielded cables necessary.

Ambient Temperature: 70° C. maximum.

Mounting Angle:
No limit for any unit.

Roll and Pitch permitted: no limit.



Dimensions
Central Electronic Unit: width 482 mm, height 276 mm, depth 537 mm (including cable connectors)
Operating Panel: width 349 mm (3 burners), 433 mm (4 burners) height 268 mm, depth 220 mm (including cable connectors)
Boiler Top Control Panel: width 400 mm, height 500 mm, depth 250 mm

Connections
Multi-core cables are used for unit-to-unit and unit-to-external connections.
The system as delivered by Kockums includes cables between the Central Electronic Unit and the Control Panel, and between the Central Unit and terminal blocks in the control room. Multi-core connectors are mounted on the cables delivered by Kockums; this ensures easy, trouble-free installation.

Alarm system
The alarm system included in the circuitry is designed to be connected to the engine-room alarm system.
The alarm is activated by
- ☐ flame failure
- ☐ failure of pre-purge to begin on order
- ☐ low atomizing pressure
- ☐ failure to obtain start position on order
- ☐ failure of register to open on order
- ☐ FO valve remaining open on order to close

When the alarm system is activated the appropriate indicator lamp begins to flash and a signal is given to the alarm system on board.
When the Alarm Reset button is pressed the indicator lamp glows steadily. At the same time the signal to the alarm system is cancelled, so that the alarm is ready for operation again if necessary.

Fault finding
A Lamp Test push-button is mounted on the Operating Panel. The built-in alarm system is the principal means for locating faults.

Spare parts
The system is delivered with the following spare parts mounted inside the Operating Panel cabinet:
Bulbs
Fuses
Relays
We also recommend that one master PC-board and one burner PC-board are kept on board as spares.

Installation
The Kockums Burner Control is compact and easy to install. All main parts and electronic circuitry are factory-assembled in cabinets, or encased for wall or bulkhead mounting. The Boiler Top Control Panel is constructed as a waterproof steel cabinet. Doors, switches, etc. are mounted with gaskets, so that the equipment may be used in normal boiler-room environments: no further protection or cooling is necessary.

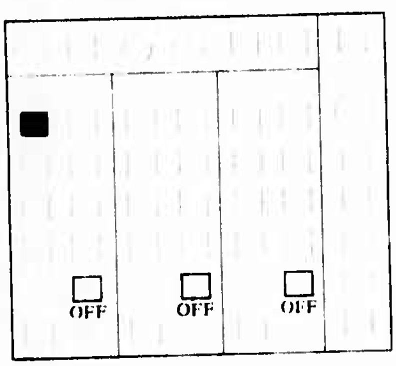
Operation
Lamps and control switches are easy to read and operate. The Kockums Burner Control can be operated by engine-room personnel without extensive instrument and electrical training.

High Quality
All components are of professional quality, ensuring long life as well as maximum accuracy and reliability. The system employs conventional external equipment.

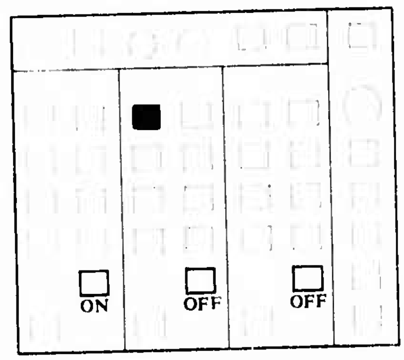
Tested for working environment
Vibrations normal to the shipboard environment will not damage components or affect operation. All units are also tested for service in tropical climates.

Normal Operation of KBC

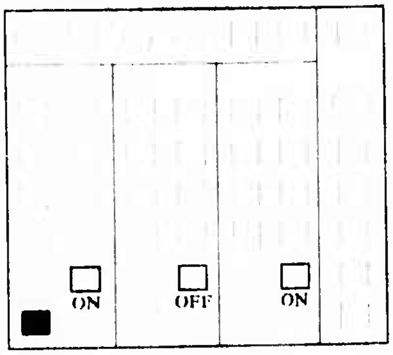
Purging and shut down sequences are automatic, each controlled by a single button. The starting order can be selected at will, i.e. burners equipped with igniters can be started in any sequence desired.
A special feature is the override, which permits internal blocking of normally required external functions.
Here's a brief description of some of the variations available under normal KBC operation.



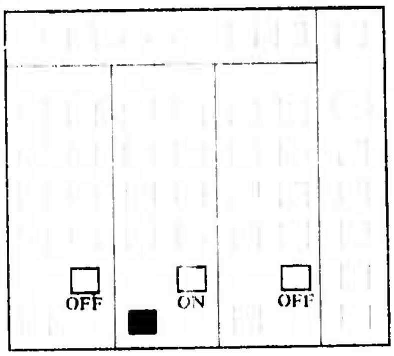
Starting the first burner
In order to begin the starting sequence, the following conditions must be proved: no boiler trip, high atomizing pressure (if starting burner is used this condition is blocked), high FO pump-pressure, no flame indicated by flame scanner for the first burner. The selector on the Boiler Top Control Panel must be set at Normal and the Stop button released.
When the Start button is pressed the following sequence is activated: Opening order is given to all air-registers and to the air-damper. The register opening is checked by limit switches. The pressure switch checks the damper indicating high air-pressure, and then checks the air-damper opening. On completion of these checks, the furnace purge continues for approximately 60 seconds.
At the end of this time, the order to close is given to the other burner registers, and the FO control valve and air-damper are ordered to start position. When the start position has been checked, the igniter receives the ignition order. Five seconds later the FO shut-off valve is ordered to open, and it remains open for ten seconds. If flame is indicated within 10 seconds, the FO shut-off valve remains open, as long as the flame scanner indicates flame. If no flame is indicated, the FO shut-off valve closes after 10 seconds; after-purge of the furnace, similar to pre-purge, is then carried out.
No additional pre-purge is required if a new starting sequence is begun during the after-purge, or within two minutes subsequent to the after-purge.



Lighting of other burners
In order to begin the starting sequence, the following conditions must be proved: high atomizing pressure, high FO pump-pressure, no flame indicated by flame scanner for the burner to be lit, one other burner already in operation with flame indicated, selector switch on Boiler Top Control Panel set at Normal and Stop button released.
When the Start button is pressed the igniter goes in and the FO shut-off valve opens. Ignition begins after the igniter is checked at the in position. Following an ignition period of 10 seconds, the FO shut-off valve closes if no flame is indicated by the flame scanner. If flame is indicated the FO shut-off valve remains open. The igniter goes out when flame is indicated.

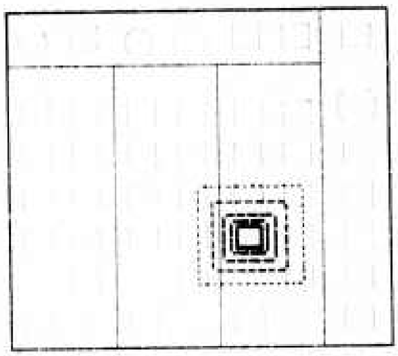


Stopping a burner while at least one other burner remains lit
When the Stop button is pressed, the FO shut-off valve and the registers close. Steam purge for a predetermined length of time can then be ordered (optional).



Stopping the last burner
Pushing the Stop button closes the registers and the FO shut-off valve. The after-purge starts a few seconds later. All three registers and the damper then open: when this has been checked, the furnace purge continues for approximately 60 seconds. The boiler can be re-ignited without pre-purge if the starting sequence is begun within three minutes of the start of the after-purge. (The last three phases are optional.)

Automatic burner shut down
In case of flame failure, the burner in question is automatically shut down.
All burners are automatically stopped at:
a) trip-signal from the boiler safety system
b) low atomizing pressure, when FO pressure at burners is low.



Abnormal conditions
If abnormal conditions should obtain during the start or shut-off sequences, the signal lamp for the next step in the sequence starts to flash, and alarm is given to the alarm system.

Boiler Top Control
At any point in time the boilers can be controlled from the boiler top. When the control mode selector is at Normal, control is effected through the central unit. In an emergency, the boiler top station can serve as a manually operated electric control box. In such a case the central unit is disconnected from the control process. During these circumstances it is also possible to run a burner without having the flame scanner engaged.

APPENDIX I-3

KOCKUMS FLAME GUARD SYSTEM 300

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Kockums Flame Guard System 300

Here it is. The alarm you want.
Regardless of stray-light from neighbouring flames,
regardless of background emission.
The problem of descrimination is solved
when you install Kockums Flame Guard.

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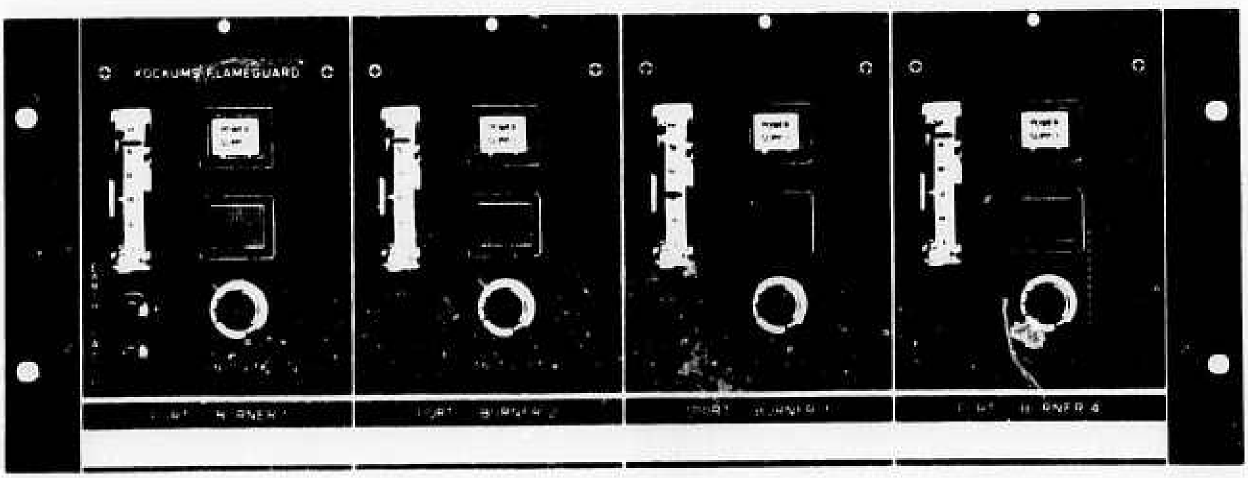


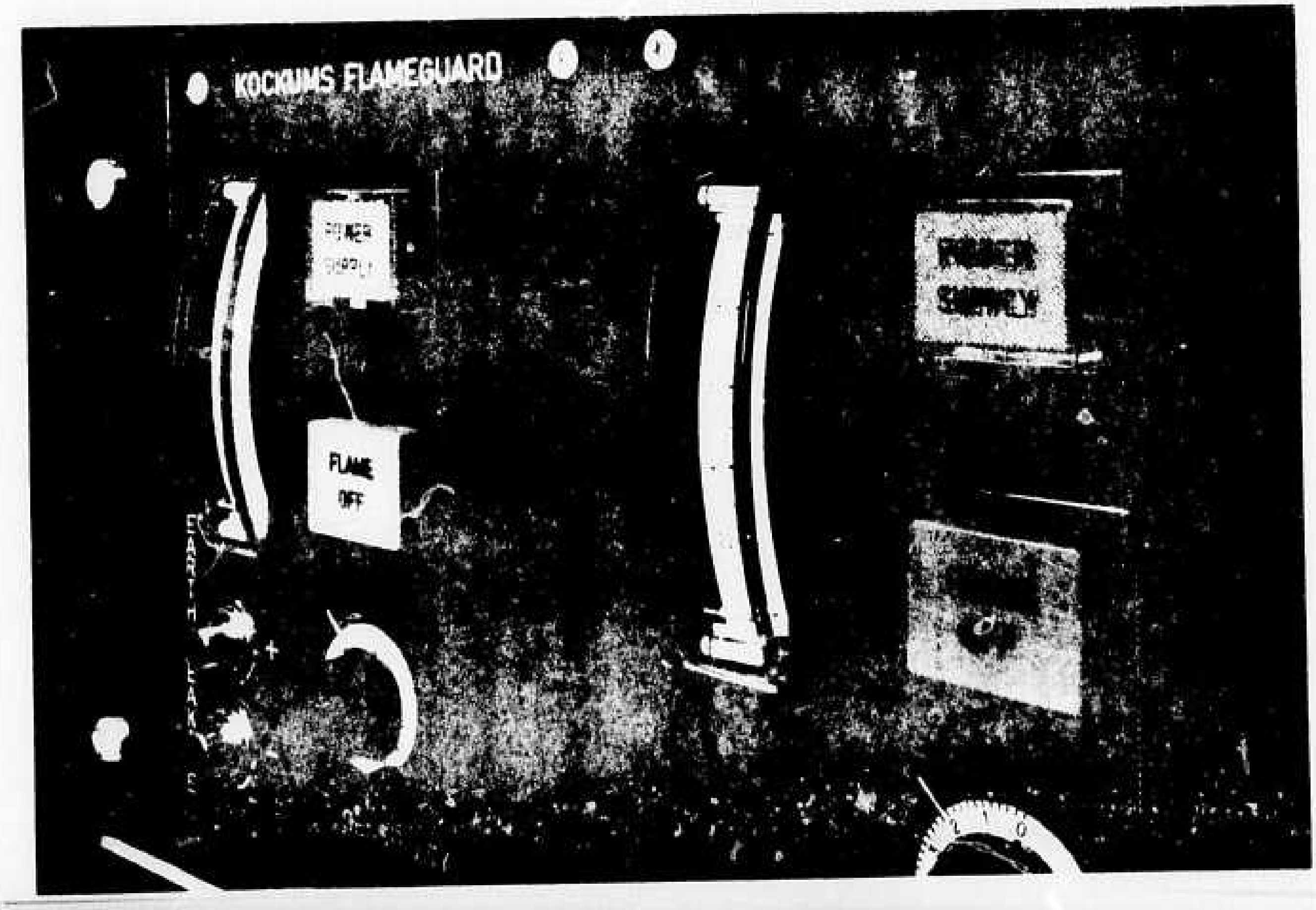
The problem of monitoring burner flames has greatly increased over recent years, due to the wider range of burner turn-down obtained. Two apparently opposed requirements have to be fulfilled simultaneously. On one hand, the sensitivity must be high in order to ensure indication of very small flames; on the other hand, the sensitivity must be low to prevent stray light or background emission being indicated as flame.

Previous attempts to solve this problem have included the use of UV-cells, frequency-selective amplifiers and even, on occasion, the use of two flame scanners per burner to ensure flame indication at all load conditions. Extreme care has also been a prerequisite of these installations.

KOCKUMS FLAME GUARD offers a revolutionary new method of solving these problems. This solution, which is fully patented, very simply separates the two demands, i.e. low sensitivity and high sensitivity. The basic sensitivity of each scanner is very high to ensure indication of even the very smallest flame.

As soon as two or more of the scanners in a system indicate flame, the strongest scanner signal is automatically selected as a reference and is distributed to all parts of the signal system. The strength of the reference scanner is directly proportional to the strongest flame emission, i.e. 'floating reference.' Since all signals from other flames must have a minimum value relative to the reference signal, the sensitivity of the system to reflected radiation from walls or stray light from neighbouring flames possibly causing a false flame indication is eliminated.

- The floating reference — an entirely new solution to the problem of flame discrimination.
- Modern solid state electronics designed for simple installation and operation.
- Complete systems for 2, 3 and 4 burner installations available.
- All parts are of plug-in type to simplify trouble-shooting and service.
- No special cooling fan or compressor required — ordinary forced draught air is enough.
- Sensor of semiconductor type — no problems with ageing.
- Many systems already in operation with excellent result.



Systems

KFG is produced in four different versions for installations with 2—4 burners. Kockums deliver complete systems, each consisting of

— central unit
— connection cables
— scanners
— documentation

The central unit is built up in 19" standard. Here are power supplies, electronic circuitry, indicators etc. installed as plug-in units, easily accessable for trouble shooting and service.

Two basic plug-in unit models are produced. Type 342 is the standard model mounted on the front of which are the potentiometer for sensitivity adjustment, analogue indicator for scanner signal and signal lamps for Power on and Flame off.

Type 341 also gives a possibility to check for earth leakage by means of two push buttons. Therefore, one unit 341 is included in each system.

The 19" rack is connected via prefabricated cables. The rack end of each cable has a factory mounted multi-connector. the other end is intended for conventional connection to central terminal blocks in the engine room. Cable length 4 meters.

The scanners, delivered with adjusting tubes, mainly consist of light-sensitive photo transistors in air cooled houses. The cooling air, which also serves as sealing to protect the sensor from dust, can be taken from the forced draught fan.

The four system versions are

302 2-scanner system

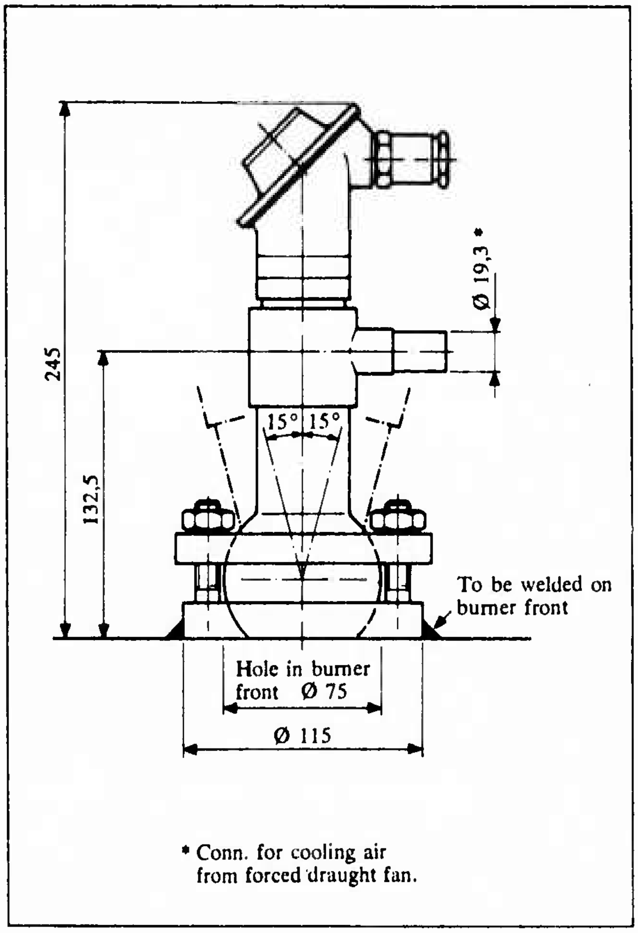
303 3-scanner system

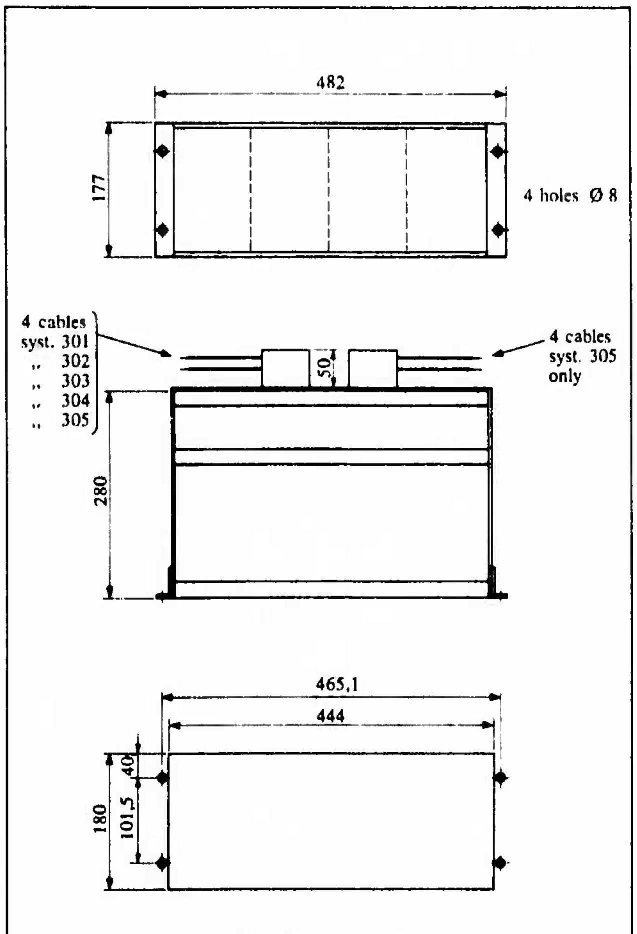
304 4-scanner system

305 2 delete independent 2-scanner systems

Data

Input	Visible light from burner flame
Output	3 changing relay contacts 220 V AC 1 A
	Contacts changing over when scanner signal is higher than a certain limit and equal to or almost as strong as the strongest scanner signal in the system.
	Time delay, standard, on 2 s, off 2,5 s
Power Supply	110 or 220 V AC +10 −15 % 45—65 Hz. Transients ±20 %, max 2 s. Voltage to be stated at ordering.
Ambient Temperature	Sensor 0—90° C
	Central unit 0—70° C
Cooling Air	Required to the scanners.
Mounting Angle	Sensor: any, adjustable ±15° Central unit: front vertical, ±15°
Permitted roll and pitch	No limitation
Cabling	No shielded cables necessary.
Shipping Weight	Appr. 20 kg for a complete system incl packing.





Panel cutout (one rack)

Sign Plates

On plug in units and external analogue indicators, space is provided for sign-plates. The text can vary due to the application. Standard texts are included in the price and defined by this list:

0	no text	no text	no text
1	PORT BOILER	BURNER 1	SCANNER 1
2	STBD BOILER	BURNER 2	SCANNER 2
3	BOILER 1	BURNER 3	
4	BOILER 2	BURNER 4	
5	MAIN BOILER	FWD BURNER	
6	AUX BOILER	CENTER BURNER	
7		AFT BURNER	
8		SPARE	

Spare parts

The following spare parts are recommended to be kept in stock on board:

Unit	Ordering no.	Recommended no. of units	
		per ship	per KFG system on board
Plug-in unit	KFG 341	1	
PC board, plug-in unit	KFG 351	1	
Sensor, for scanner	KFG 369		1
Fuse F1, F2			6
Fuse F3, F4			6
Bulb for signal lamp			6
O-ring			8
Relay			1

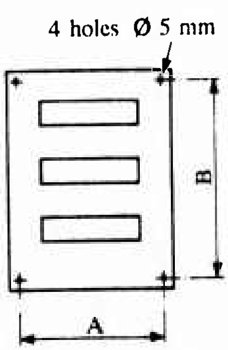
External indicators

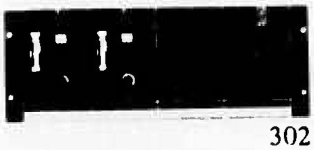
External analogue indicators are used for remote indication of scanner signals. They are connected to the scanners via the central unit. The indicators are mounted on a plate for panel installation.

Permitted angle: horisontal to vertical

		External indicator, type		
		392	393	394
For KFG system type		302	303	304, 305
Front plate:				
heigth	mm	125	165	205
width	mm	115	115	115
depth behind panel	mm	90	90	90
Panel cut out:				
heigth	mm	95	135	175
width	mm	85	85	85
Distance A	mm	100	100	100
Distance B	mm	110	150	190

When ordering external indicators, also give code figures for sign plates.

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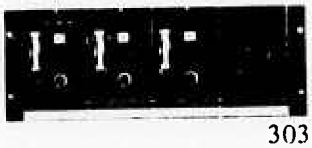

303


304


305

Installation, commissioning

The installation and commissioning, which are both very simple, are thoroughly described in the instruction manual.

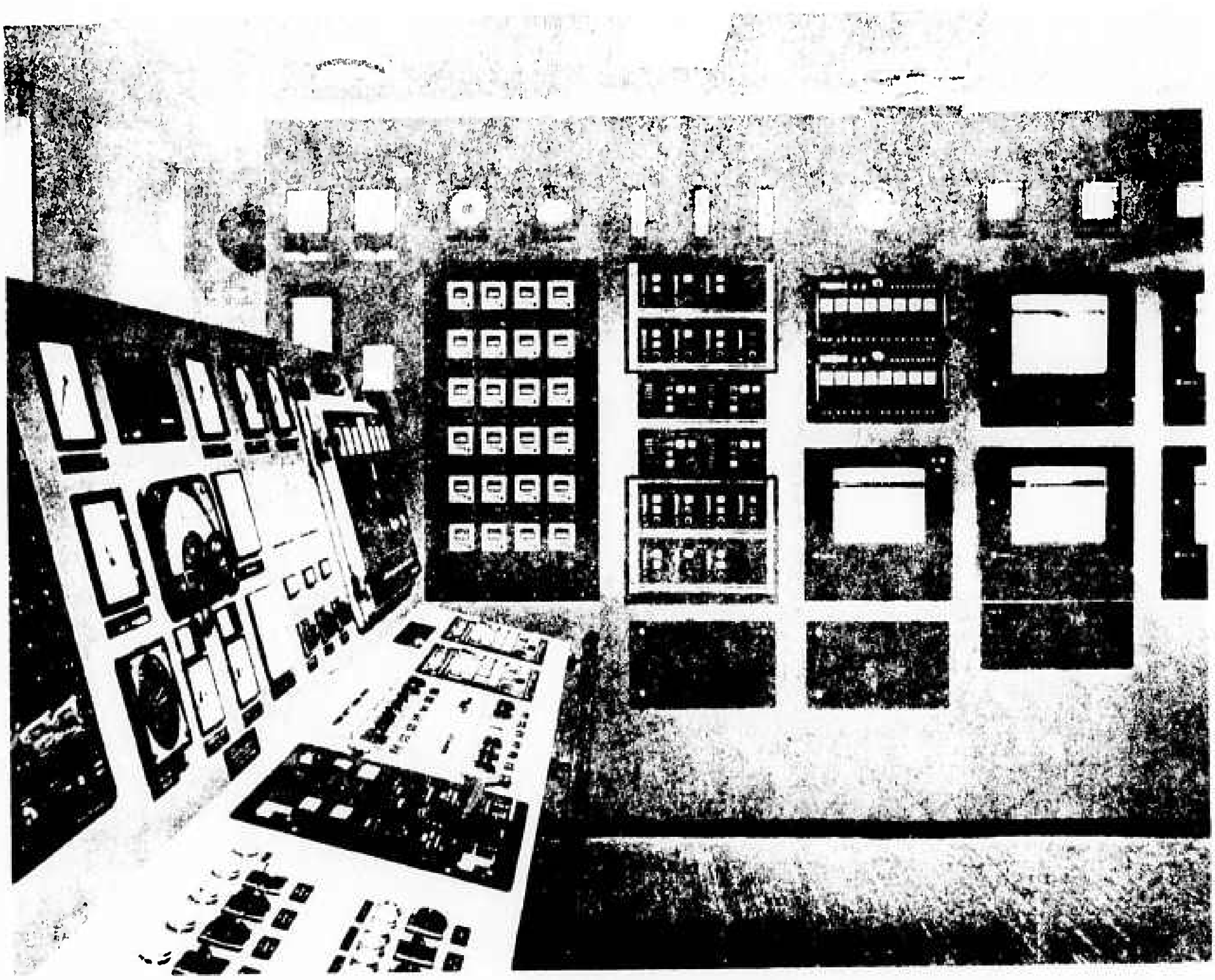
Yard personnel or members of the ship's crew are assumed to be capable of doing this in accordance to the step by step instructions. Of course our service engineers will assist if wanted.

Operation

The entire system is of solid state type, and no moving parts require regular service.

By the crew only two actions are to be taken with regular intervals.

First, scanner cleaning. This is done for example in conjunction with burner tip service.
Second, the analogue indicators are to be watched. These indicators will give an early warning not only of KFG scanner contamination, but also bad boiler tips and similar failure causes are recognized.



APPENDIX I-4

KOCKUMS CONTROLLER SYSTEM

Kockums Controller System (KCS)

is the name given to a comprehensive range of electronic control modules that can be put together as desired to provide

– central fingertip regulation of functions other than those governed by Kockums Combustion Control

– central readout of system status in computer-run boiler plants.

The prototype of the KCS was built to special order for installation aboard the 210 550 tdw Kockum-built tanker Sea Sovereign to serve as a backup controller of propulsion plant functions normally run by the on-board computer. The system proved so practical, however, that Kockums decided to put it on a production basis. Controller Systems of this kind are now on order for several ships.

CONSTRUCTION. The Kockums Controller System is built up of module racks, with the interior consisting of solid-state circuitry and the front forming a simple control panel. The layout of the module panels is largely standardized, but variable according to need. Typical components are a dial instrument, a manual/auto selector switch, a twist knob for manual operation and push-buttons for test purposes. If the system is installed as a backup to a digital computer, a computer on/off switch is also included.

The transmitters that supply information to the system are electric, as are all input and output signal links. The user is free to choose any suitable type of mechanism for execution of the command signals.

OPERATION. The Controller System can be operated in parallel with a computer or by itself as a master control station. It presents the engineer with a concentrated display of information and enables him to make any necessary adjustments simply by turning the appropriate knob.

Practically any desired number of control functions can be grouped in this way. Typical examples are

– fuel oil viscosity
– boiler water level
– superheater steam temperature
– exhaust steam pressure
– gland sealing steam pressure
– HP drain tank level
– de-aerator level
– LP steam generator pressure
– LP steam generator drain level
– LP steam generator feed water supply
– feed water pressure.

Parallel modules can of course be provided for multiple boiler installations.

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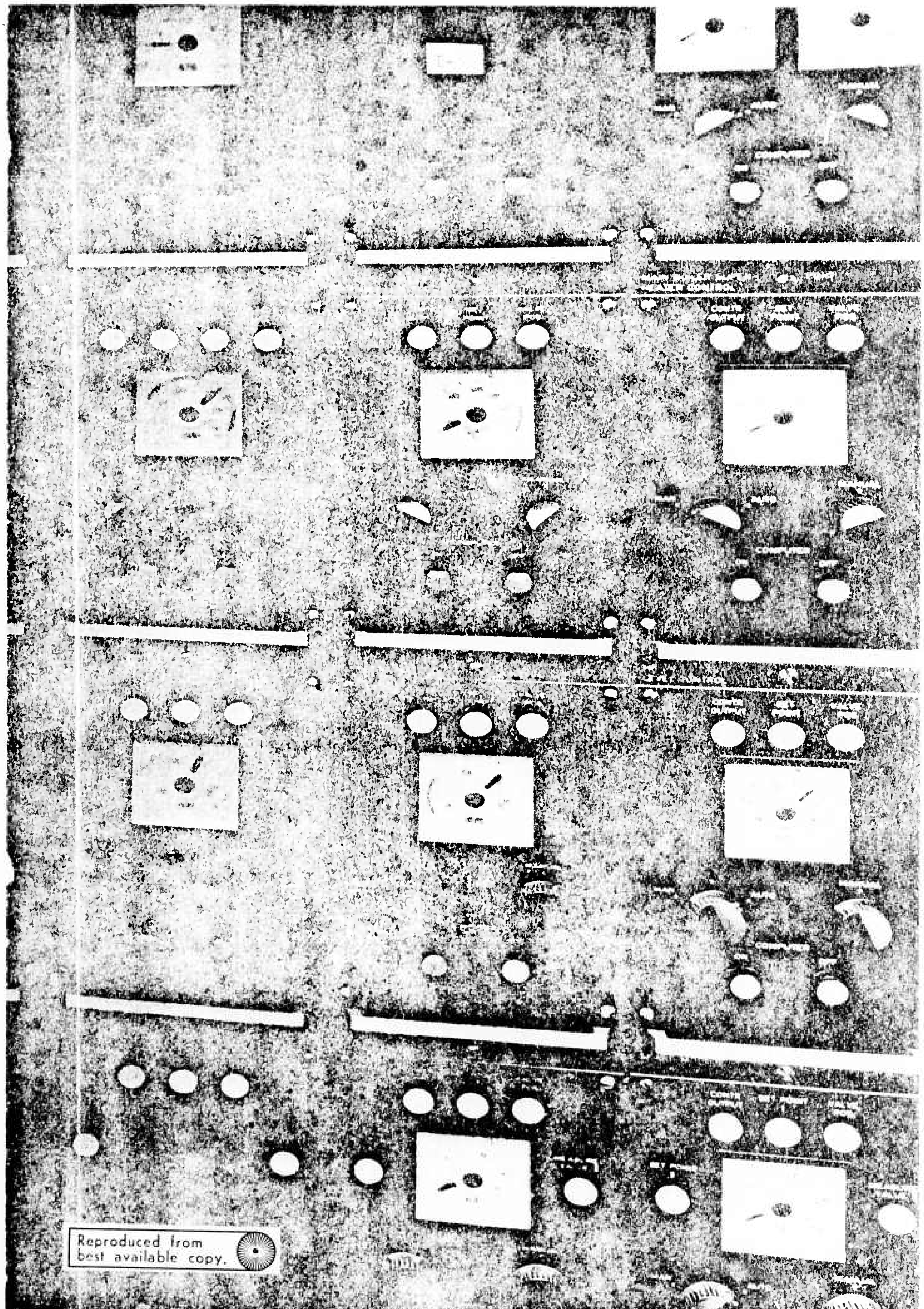

APPENDIX I-5

AUTOMATION OF CARGO HANDLING IN OIL AND LIQUIDS TRANSPORTATION

AUTOMATION IN CARGO HANDLING OIL AND LIQUIDS TRANSPORTATION

L. Sten, M.El.Eng.
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ABSTRACT

The aim of automating any activity on board a ship is to improve her possibility to transport cargo safely and economically. Automation in the engine room, on the bridge, and of the cargo handling system have the same purpose - to make the ship transport cargo safely and economically.

During the cargo handling the ship cannot be regarded as an autonomic unit. Thus, the complete automation of the cargo handling is difficult.

Computers have been used to automate cargo handling-- mainly on board ships where the computer is used for navigation or engine room control. In these cases it has been natural to use available computer capability also for automation of cargo handling.

The use of a computer in the automation of cargo handling usually assigns to one of the below mentioned categories:

1. Off line cargo calculation
2. Data logging

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3. On line control
4. Ship-shore integrated cargo handling

Categories 1 and 2 are often used. A few ships are known with Category 3, on line control. Ship-shore integrated cargo handling has not yet been tried.

This paper describes the computerized cargo handling system on board the SEA SOVEREIGN, an example of on line control of cargo handling. The automation is a result of a ship-born process computer project work sponsored by the Swedish Ship Research Foundation (SSF).

The development work has been carried out by Kockums Mekaniska Verkstads AB in Malmoe.

The cargo handling system includes:

Process input acquisition

Direct digital control of pumps and gas seperators

Valve control

Stress calculations

Capacity calculations

Automatic loading

Automatic discharging

The programs are running in real time on-line with the process.

The system has been in successful use since September 1970.

No unscheduled normal intervention has been necessary during loading and discharging of the ship. The operations have been directed entirely from the cargo control room, with no one on deck. Even topping up and stripping, the two most critical phases, have been entirely automatically controlled.

INTRODUCTION

The transportation of oil and other liquids has grown rapidly during the last years due to the increasing need of energy in the industrialized countries. The units for transportation have grown continuously. Today, the worlds leading shipyards are producing very large crude oil carriers (VLCC) with transport capacities exceeding a quarter of a million tons. The trend is pointing towards vessels with transport capacities of up to one million ton deadweight.

Ships of this size become difficult and tricky to handle. Every precaution must be taken to prevent disasters such as oil pollution.

The aim of automating any activity on board a ship is to improve her capability to transport cargo safely and economically. Automation in the engine room, on the bridge, and of the cargo handling proper all have this aim.

The automation of the cargo handling is specific for each ship. The type of cargo, the type of ship, and the type of harbor affect distinctly the automation equipment design.

During the cargo handling the ship cannot be regarded as an autonomic unit--the ship is dependent on harbor facilities and jurisdiction. These seem to be the main reasons for the present focussing on automation in the engine room and at the bridge.

There are, however, outstanding advantages to be gained by automation of cargo handling activities. Some important features are:

1. Improved safety for ship, crew, cargo and environment.
2. Time savings in port
3. Less personnel involved in the cargo handling

Centralized control and monitoring from a cargo control room conducted and supervised by operators are well known. Remote level readings, remote cargo valve control, and remote cargo pump control are implemented in most of the modern VLCC's built today.

This paper discusses computerized cargo handling and the benefits of such an installation.

DIFFERENT STAGES OF AUTOMATION

The computer can be integrated in the system to various degrees. The different stages are:

1. Off Line Computer Cargo Calculations - The computer is used for optimization of cargo distribution, stress calculation, etc.

2. Data Logging - Collection and print-out of different valve settings, tank levels, pump speeds, volumes, deadweight, etc. The computer assists the operator in decision-making.

3. On-Line Computer Control - The computer operates the process on-line, controlling valves, pumps and gas ejectors in the ship. Orders and questions affecting equipment outside the ship are transmitted to the operator via a general communication unit.

4. Fully Computerized Cargo Handling - Cargo handling is completely controlled by the computer with no human activities. The ship-borne computer is working on-line with a shore-based computer controlling several ships.

Off Line Methods

Off-line calculations of hull stresses and optimization of load distribution are extensively used on many of todays ships. For stress calculations special purpose computers are often used which predict shear forces, banding moments, deadweight, draft and trim.

Optimization of loading and discharging sequences can be performed as a background calculation in a real time ship-borne computer or in a land-based computer. The problem is tackled using a straightforward analytic approach. A number of variables have to be taken into account if the results shall be useful. Such a program is very memory-consuming and includes extensive calculations.

Applying certain conditions could mean that the calculation time and memory requirements are decreased.

If the optimized strategy cannot be followed, for instance, due to a damaged pump, the result will be wrong, and possibilities to change the control strategy on-line must be included.

Data Logging

Data logging methods have not been widely used in automation of cargo handling. The system can be used for data reduction, printing out reports on capacity, stresses, etc. The method can also be used to check level-gauging and pump flow.

On-Line Cargo Handling

Automatic on-line cargo handling has been used in some cases with successful results. At first automatic cargo handling by computer will be carried out, sharing the computer with a bridge or an engine room system.

The complexity of a modern liquid carrier with increasing number of tanks requires a computer for the automation of cargo handling.

Ship-Shore Integrated Cargo Handling

The method needs a land-based computer which can communicate with the ship-borne system. In this manner it would be possible to load and discharge several ships simultaneously and completely automatically.

COMPUTERIZED CARGO HANDLING IN THE SEA SOVEREIGN

The system to be described below is part of a shipborne process computer project work sponsored by the Swedish Ship Research Foundation (SSF). The development work was carried out by Kockums Mekaniska Verkstads AB in Malmoe, and the computer was installed in the turbine tanker, SEA SOVEREIGN, of 210,000 tons deadweight built by Kockums for the Salen Shipping Company in Stockholm. The computer is a Control Data 1700 with 24k of core memory.

The automation is an example of on-line computer-governed cargo handling.

The system has been successfully in use since 1970.

System Description

The computer reads the levels from 25 cargo, ballast and bunker tanks (Figure 1). It can automatically control 52 hydraulic valves and senses the position of further 86 manually operated valves. New positions of these valves can be ordered via the typewriter or by the program. Four cargo pumps are controlled, and the pumping is optimized by the computer.

The cargo handling system in the SEA SOVEREIGN is based on a sequence for the automatic loading and discharging of one type of cargo. During the cargo handling the computer controls the levels in each individual tank. When the set

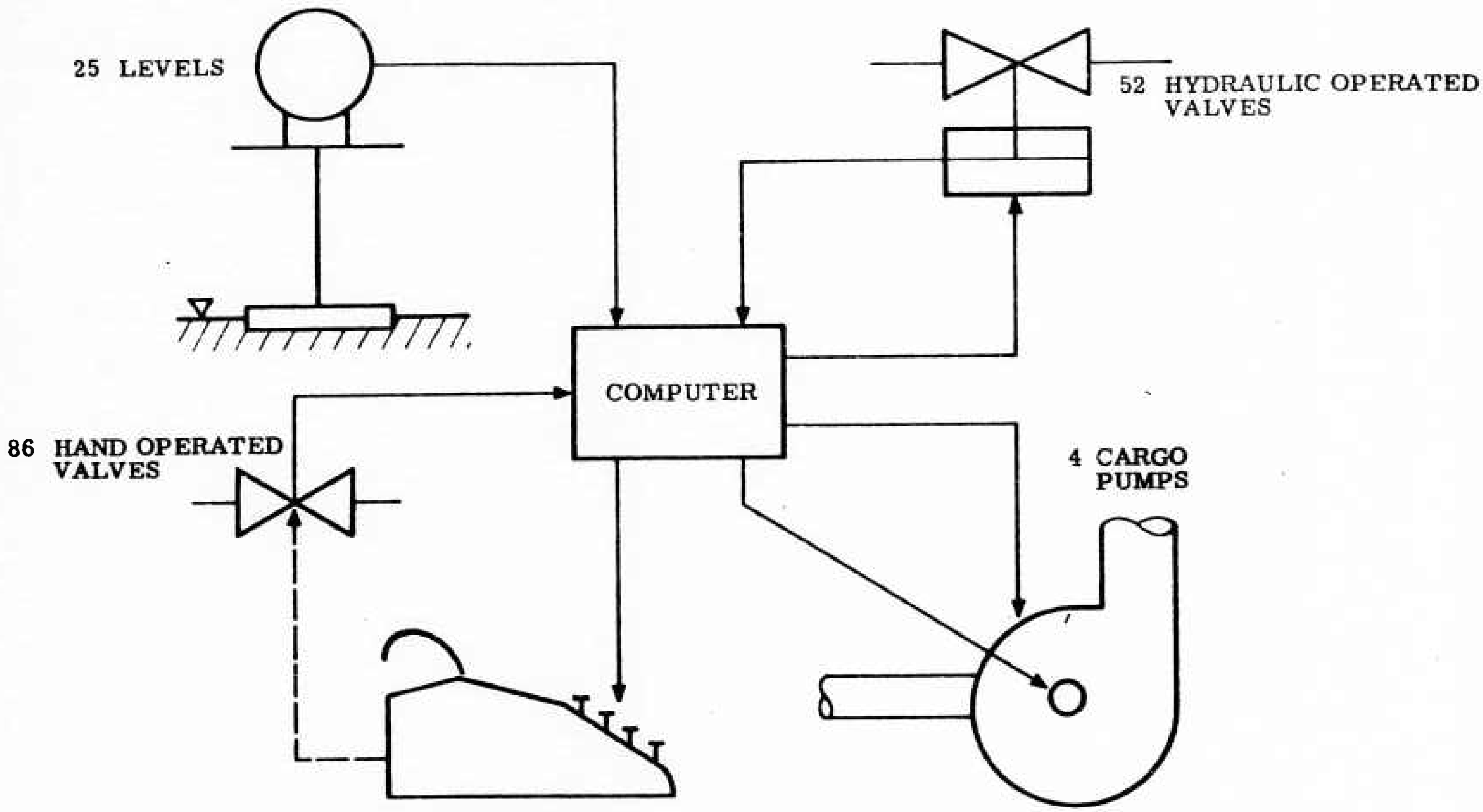

FIGURE 1

TT SEA SOVEREIGN

CARGO HANDLING SYSTEM

ullage value in a tank is reached, the valve to this tank is closed automatically.

The cargo handling software system is built up in modules (see Figure 2). Every module works independent of the other programs.

There are possibilities to degrade the influence of the computer and perform parts of the cargo handling manually. If, for example, a certain item (for instance, a valve) does not work satisfactorily, the operator can control this item manually.

The status is supervised by a specific program. This program controls to which extent every tank shall be discharged or loaded. The supervision program can order changes of valve positions and of pump speeds.

It should be strongly emphasized that the computer is a device which assists the crew in loading and discharging the ship. The Master is still responsible for the cargo handling. The computer assists in doing it rapidly and safely.

Cargo Pump Control

Each of the four cargo pumps on board the SEA SOVEREIGN can supply 4,500 cubic meters/hour. This figure applies only if the pumps are operated on the top of the pump characteristic without cavitation.

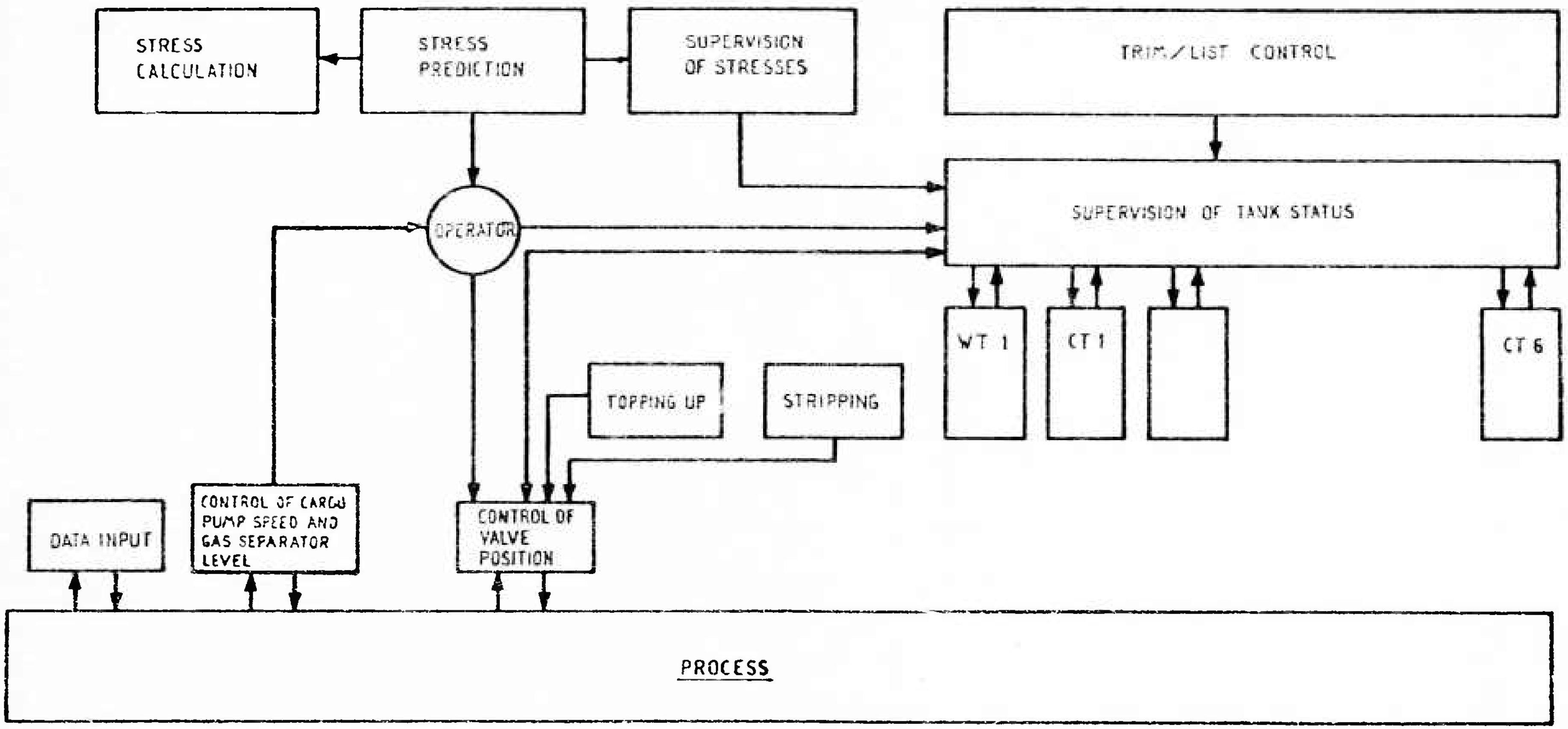

FIGURE 2

BLOCK DIAGRAM

COMPUTERISED CARGO HANDLING WITH DIFFERENTIATED CARGO

The computer controls the speed of the pumps through a programmed proportional and integrating regulator. Appropriate pump speeds can be set either by the program or by the operator.

The computer also controls the discharge valves on the pressure side of the pumps, thus decreasing the risk of cavitation.

The most dangerous period of time for the pumps is when stripping. Air may enter the pipe system and ruin the pumps. To prevent this, a separator is installed ahead of the pump. Input signals from the separator level are used to govern the position of the discharge valve.

Trim and List Control

During loading and discharging the trim must be kept at certain values. When the tanks are being emptied, the ship shall normally be trimmed by the stern because the suction pipes are placed in the aft ends of the cargo tanks. The loaded ship shall often be trimmed at even keel and normally not have a list.

The computer program can be designed to take care of these cases.

Topping-Up

As a rule the most difficult program to solve is level gauging. The levels in critical tanks shall be measured with:

1. Good accuracy (better than 1 cm)
2. Good reliability

The accuracy is most essential when topping-up. Errors of the order of one centimeter might be tolerated. The level gauging system must also be highly reliable, An independent top level alarm is strongly recommended.

In critical places the level gauging system should be redundant.

Stress Calculations

Improper cargo distribution may damage the vessel seriously. Stresses are most severe in bad weather and high seas such that the distance between the wave-crests is about equal to the ship's length. If the ship is unhomogenously loaded, exceptional stresses can lead to cracks in the hull. In extreme cases the ship may break in two. Improper loading will, in any case, shorten the life of the ship.

Hence, it is most essential to correctly calculate shear forces and bending moments in the hull.

The stresses can be continuously and automatically calculated by the cargo handling computer.

The specific particulars of the ship are programmed into the computer. Levels which change during the cargo handling can be read through the process input acquisition program.

The levels are transformed to volume and by multiplication of the specific gravity at the actual temperature, the weight in each tank is obtained.

Weight of stores, fresh water, lubrication oil, etc., which do not change during the cargo handling, can be fed in by means of the general communication unit.

Using this information, buoyance and trim is calculated.

The measured draft and trim is compared with the theoretical figures and an unacceptable difference causes alarm.

The shear forces are obtained by integrating the load distribution, and the bending moments are obtained from an integration of the shear forces.

An unpermittable shear force or bending moment causes also an alarm and action may be taken by the operator.

The stresses can be displayed on instruments showing the operator, for instance, if any of the stresses is increasing rapidly, thus enabling him to take the necessary action.

EXPERIENCES

The cargo handling system on board the SEA SOVEREIGN has been in use since 1970. The ship has been loaded and discharged by the computer approximately 15 times.

The average saving of time has been two hours per loading and discharging compared to conventional centralized cargo handling.

The saving of time is due to quick topping-up of tanks and fast and efficient pumping.

At the end of the loading virtually all tanks will be full simultaneously. The First Officer will, therefore, slow down the rate of oil from ahore in order to be able to top-up one tank at a time. The computer can top-up all the tanks simultaneously.

At topping-up, the First Officer normally has at least two men working on deck, checking the tanks just being filled. The computer performs the topping-up with no man on deck. The set ullage value has been reached with an accuracy of $\pm$ 1 centimeter.

Another benefit of the system is also that time loss during decision-making has been minimized.

The saving of time when discharging depends mainly on optimized cargo-pump control and more efficient stripping of the tanks.

Topping-up accuracy, continuous control of critical valves, and continuous stress calculations all aim towards improved safety for ship and environment.